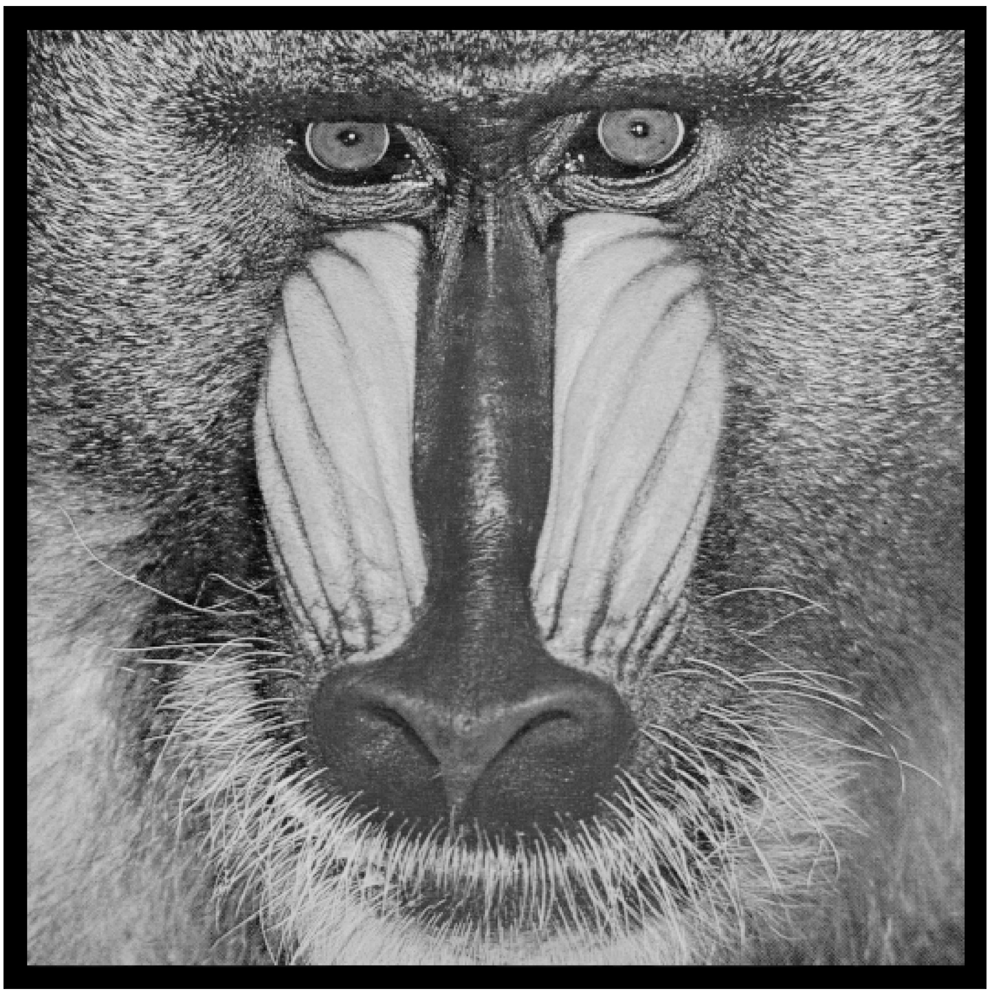
# AIPS COOKBOOK

31-December-2011 and earlier



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# ACKNOWLEDGMENTS

The *CookBook* cover design is by Pat Smiley of the NRAO Graphic Arts Department. It is based on a design suggested by John Bally of Bell Labs.

The image on the title page was converted from the *AIPS* television-like display to Encapsulated PostScript by the *AIPS* task TVCPS. It was then included in this TeX document and plotted on a Hewlett Packard PostScript printer. It is the green portion of the digitized image of a Mandrill which has become a standard in the image-processing field. PostScript is a registered trademark of Adobe Systems Incorporated.

The plot in Chapter 4 was generated with TVCPS in a similar manner. The plots at the ends of Chapters 6, 7, 8, and 9 were generated by various *AIPS* plotting tasks with task LWPLA used to convert the device-independent plot files into PostScript. The data displayed in Chapters 6 and 7 were provided by Bill Cotton for use with the *AIPS* VLAC test suite and by Alan Bridle for use with the *AIPS* DDT test suite, while the data in Chapter 8 were provided by Don Wells for use in testing spectral-line software. The color plots in Chapter 6 are of data provided by Greg Taylor and by Eric Greisen, Kristine Spekkens, and Gustaaf van Moorsel. The editors thank these people for providing their data for our use.

This *CookBook* itself is based on an early users guide written by Alan Bridle. In 1983, it was typeset and edited by Eric Greisen using the TeX program, initially developed by Donald E. Knuth (*The TeXbook*, 1984, Addison-Wesley Publishing Company, Reading, Massachusetts). There were two editions of the *CookBook* in 1983, one in 1985, and one in 1986. The 1990 edition edition was edited by Bill Junor. For recent editions, Eric Greisen has resumed his rôle as editor, while numerous individuals have contributed to the text. In particular, Glen Langston, Andrea Cox, and Lorant Sjouwerman have submitted outline guides to VLA continuum, spectral-line, and high-frequency data reduction which appear as Appendices A. B, and D, respectively. The output of TeX is now converted to PostScript by `dvips` (from Radical Eye Software) and printed on a Hewlett Packard printer. The editors are grateful to Knuth for this program and, especially, for his decision to place it in the public domain.

This *CookBook* is now available on the Internet via the World-Wide Web. The current Table of Contents together with a revision history for the full `31DEC09` *CookBook* is available at URL

`http://www.aips.nrao.edu/cook.html`.

You should review this Web page occasionally to see if chapters important to you have been altered and, if so, why. You may use your favorite Web browser to click on any chapter you wish to receive and the PostScript version will (eventually) appear on your workstation.

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# 1 INTRODUCTION

## 1.1 The NRAO *AIPS* Project — A Summary

The NRAO Astronomical Image Processing System (*AIPS*) is a software package for interactive (and, optionally, batch) calibration and editing of radio interferometric data and for the calibration, construction, display and analysis of astronomical images made from those data using Fourier synthesis methods. Design and development of the package began in Charlottesville, Virginia in 1978. It presently consists of over 1,383,000 lines of code, 146,000 lines of on-line documentation, and 352,000 lines of other documentation.[1] It contains over 467 distinct applications "tasks," representing very approximately 75 man-years of effort since 1978. The *AIPS* group, now solely in Socorro, has two full-time and one quarter-time scientist/programmers, and a few other computing and scientific staff with some low-level responsibility to the *AIPS* effort. The group is responsible for the code design and maintenance, for documentation aimed at users and programmers, and for exporting the code to hundreds [2] non-NRAO sites that have requested copies of *AIPS*. It currently offers *AIPS* installation kits for a variety of UNIX systems (mostly Linux, Solaris, and Mac OS/X), with updates available annually.[3]

In 1983, when *AIPS* was selected as the primary data reduction package for the Very Long Baseline Array (VLBA), the scope of the *AIPS* effort was expanded to embrace all stages of radio interferometric calibration, both continuum and spectral line. The *AIPS* package contains a full suite of calibration and editing functions for both VLA and VLBI data, including interactive and batch methods for editing visibility data. For VLBI, it reads data in MkII, MkIII and VLBA formats, performs global fringe-fitting by two alternative methods, offers special phase-referencing and polarization calibration, and performs geometric corrections, in addition to the standard calibrations done for connected-element interferometers. The calibration methods for both domains encourage the use of realistic models for the calibration sources and iterated models using self-calibration for the program sources.

*AIPS* has been the principal tool for display and analysis of both two- and three-dimensional radio images (*i.e.*, continuum "maps" and spectral-line "cubes") from the NRAO's Very Large Array (VLA) since early in 1981. It has also provided the main route for self-calibration and imaging of VLA continuum and spectral-line data. It contains facilities for display and editing of data in the aperture, or u-v, plane; for image construction by Fourier inversion; for deconvolution of the point source response by Clean and by maximum entropy methods; for image combination, filtering, and parameter estimation; and for a wide variety of TV and graphical displays. It records all user-generated operations and parameters that affect the quality of the derived images, as "history" files that are appended to the data sets and can be exported with them from *AIPS* in the IAU-standard FITS (Flexible Image Transport System) format. *AIPS* implements a simple command language which is used to run "tasks" (*i.e.*, separate programs) and to interact with text, graphics and image displays. A batch mode is also available. The package contains nearly 11.4 Mbytes of "help" text that provides on-line documentation for users. There is also a suite of printed manuals (available on-line) for users and for programmers wishing to code their own applications "tasks" within *AIPS*.

An important aspect of *AIPS* is its portability. It has been designed to run, with minimal modifications, in a wide variety of computing environments. This has been accomplished by the use of generic FORTRAN wherever possible and by the isolation of system-dependent code into well-defined groups of routines. *AIPS* tries to present as nearly the same interface to the user as possible when implemented in different computer

[1] Counted on 24-November-2009 and omitting the GNU copyrights, PostScript and PDF files, and obsolete areas.

[2] The `15JAN96` release alone was shipped to 225 sites and installed on well over 800 computers. The `15APR99` release was shipped to 344 non-NRAO sites. In 2009, more than 2400 different IP addresses installed or updated copies of *AIPS*.

[3] The `TST` version, currently `31DEC10`, will be available continuously. It remains under development and sites may update their copies at will. Binary versions are available for Linux (32- and 64-bit), Solaris, and Max OS/X PPC and Intel and text versions for these and other operating systems.

architectures and under different operating systems. The NRAO has sought this level of hardware and operating system independence in AIPS for two main reasons. The first is to ensure a growth path by allowing AIPS to exploit computer manufacturers' advances in hardware and in compiler technology relatively quickly, without major recoding. (AIPS was developed in ModComp and Vax/VMS environments with Floating Point Systems array processors, but was migrated to vector pipeline machines in 1985. Its portability allowed it to take prompt advantage of the new generation of vector and vector/parallel optimizing compilers offered in 1986 by manufacturers such as Convex and Alliant. It was extended in simple ways in 1992 to take full advantage of the current, highly-networked workstation environment). The second is to service the needs of NRAO users in their home institutes, where available hardware and operating systems may differ substantially from NRAO's. By doing this, the NRAO supports data reduction at its users' own locations, where they can work without the deadlines and other constraints implicit in a brief visit to an NRAO telescope site. The exportability of AIPS is now well exploited in the astronomical community; the package is known to have been installed at some time on a large number of different computers, and is currently in active use for astronomical research at way more than 140[4] sites worldwide. AIPS has been run on Cray and Fujitsu supercomputers, on Convex and Alliant "mini-supercomputers," on the full variety of Vaxen and MicroVaxen, and on a wide range of UNIX workstations and laptops including Apollo, Data General, Hewlett Packard, IBM, MassComp, Nord, Silicon Graphics, Stellar and SUN products. It is available for use on personal computers under the public-domain Linux operating system and, since 2003, On MacIntosh OS/X computers. In late 1990[1], the total computer power used for AIPS was the equivalent of about 6.5 Cray X-MP processors running full-time.

Similarly, a wide range of digital TV devices and printer/plotters has been supported through AIPS's "virtual device interfaces". Support for such peripherals is contained in well-isolated subroutines coded and distributed by the AIPS group or by AIPS users elsewhere. Television-like interactive display is now provided directly on workstations using an AIPS television emulator and X-Windows. Hardware TV devices are no longer common, but those used at AIPS sites have included IIS Model 70 and 75, IVAS, AED, Apollo, Aydin, Comtal, DeAnza, Graphica, Graphics Strategies, Grinnell, Image Analytics, Jupiter, Lexidata, Ramtek, RCI Trapix, Sigma ARGS, Vaxstation/GPX and Vicom. Printer/plotters include Versatec, QMS/Talaris, Apple, Benson, CalComp, Canon, Digital Equipment, Facom, Hewlett-Packard, Imagen, C.Itoh, Printek, Printronix and Zeta products. Generic and color encapsulated PostScript is produced by AIPS for a wide variety of printers. The standard interactive graphics interface in AIPS is the Tektronix 4012, now normally emulated on workstations using an AIPS program and X-Windows.

The principal users of AIPS are VLA, VLBA, and VLBI Network observers. A survey of AIPS sites carried out in late 1990[1] showed that 61% of all AIPS data processing worldwide was devoted to VLA data reduction. Outside the NRAO, AIPS is extensively used for other astronomical imaging applications, however. 56% of all AIPS processing done outside the U.S. involved data from instruments other than the VLA. The astronomical applications of AIPS that do not involve radio interferometry include the display and analysis of line and continuum data from large single-dish radio surveys, and the processing of image data at infrared, visible, ultraviolet and X-ray wavelengths. About 7% of all AIPS processing involved astronomical data at these shorter wavelengths, with 7% of the computers in the survey using AIPS more for such work than for radio and *another* 7% of the computers using AIPS exclusively for non-radio work.

Some AIPS use occurs outside observational astronomy, *e.g.*, in visualization of numerical simulations of fluid processes, and in medical imaging. The distinctive features of AIPS that have attracted users from outside the community of radio interferometrists are its ability to handle many relevant coordinate geometries precisely, its emphasis on display and analysis of the data in complementary Fourier domains, the NRAO's support for exporting the package to different computer architectures, and its extensive documentation.

As well as producing user- and programmer-oriented manuals for AIPS, the group publishes a newsletter semi-annually that is sent to subscribing libraries and is available on the Web. There is also a mechanism whereby users can report software bugs or suggestions to the AIPS programmers and receive written responses from them; this provides a formal route for user feedback to the AIPS programmers and for the programmers to document difficult points directly to individual users. Much of the AIPS documentation

[4] "The 1990 AIPS Site Survey", AIPS Memo No. 70, Alan Bridle and Joanne Nance, April 1991

is now available to the "World-Wide Web" so that it may be examined over the Internet (start with "URL" `http://info.aips.nrao.edu/`). The NRAO knows of over 230 *AIPS* "tasks," or programs, that have been coded within the package outside, and not distributed by, the observatory.

The *AIPS* group has developed a package of benchmarking and certification tests that process standard data sets through the dozen most critical stages of interferometric data reduction, and compare the results with those obtained on the NRAO's own computers. The "Y2K" package is used to verify the correctness of the results produced by *AIPS* installations at new user sites or on new types of computer, as well as to obtain comparative timing information for different computer architectures and configurations. It has been extensively used as a benchmarking package to guide computer procurements at the NRAO and elsewhere. Two other packages, "VLAC" and "VLAL", are less widely used to verify the continued correctness of calibration and spectral-line reductions.

In 1992, the NRAO joined a consortium of institutions seeking to replace all of the functionality of *AIPS* using modern coding techniques and languages. The "`aips++`" project, now named "`casa`," is expected to provide the main software platform supporting radio-astronomical data processing sometime in the future. Further development of the original ("Classic") *AIPS* will therefore be limited mostly to calibration of VLBI data, general code maintenance with minor enhancements, and improvements in the user documentation.

Further information on *AIPS* can be obtained by writing by electronic mail to `daip@nrao.edu` or by paper mail to the AIPS Group, National Radio Astronomy Observatory, P. O. Box O, Socorro, NM, 87801-0387, U.S.A.

## 1.2 The *CookBook*

This *CookBook* is intended to help beginning users of the NRAO *A*stronomical *I*mage *P*rocessing *S*ystem (*AIPS*) by providing a recipe approach to the most basic *AIPS* operations. While it illustrates some aspects of *AIPS*, it does not pretend to be complete. However, it does include detailed instructions for running many important items of *AIPS* software. With these as a model, the user should be able to run other *AIPS* software aided by the `EXPLAIN`, `HELP` and `INPUTS` files and the complete index of software given in Chapter 13 of the *CookBook*. In this edition, some of the chapters have matured into something more like a users' manual, than a beginners' cookbook. These sections provide an overview of a few less basic, but nonetheless interesting, programs which often seem to be forgotten even by experienced *AIPS* users. To assist the beginning and infrequent user, appendices have been added to provide outlines of continuum, spectral-line, and high-frequency calibration procedures, primarily geared to users of the VLA, and a simplified outline of VLBA data reduction. A guide to reduction of early data from the EVLA is planned, but not yet ready. To assist in finding information in this now large document, an index has been added.

*AIPS* software is changing and growing continually. This edition of the *CookBook* describes the `31DEC09` (aka "*AIPS* for the Ages (Aged), version 10") release of *AIPS*. Some chapters have information only from earlier releases. When something only applies to fairly recent versions of *AIPS*, a comment to that effect is made. Features remain in later releases even if the particular comment does not say as much. There were many changes in *AIPS* software between the seventh (`15JAN94`) and the sixth (`15JUL90`) edition of the *CookBook*. The chapter on the *AIPS* calibration package for continuum, spectral-line, solar and VLBI data (Chapter 4) was revised with the assistance of Rick Perley and Alan Bridle. It now has new material for improved editing and spectral-line calibration. The list of current *AIPS* tasks (Chapter 13) has been updated and reflects the extensive improvement and expansion of *AIPS* software in the 90's. The chapters on imaging and improving images were merged as were the chapters on interactive and hard-copy displays. These mergers reflect in part the mergers of these operations. The chapter on spectral-line imaging (Chapter 8) has been revised with the assistance of Elias Brinks. Phil Diamond, John Conway, Athol Kemball, and Ketan Desai have rewritten the chapter on VLBI calibration and imaging (Chapter 9). Appendix Z contains instructions and advice peculiar to the individual *AIPS* sites of the NRAO. This has been revised extensively to reflect the migration of much of the data reduction at NRAO sites away from VAXes and Convex computers to Sun and Linux workstations. The ninth edition has an Index which is current and updates concerning editing, calibration, imaging and single-dish processing in the `15APR98` and later versions of *AIPS*. This edition still contains, essentially unchanged, the helpful glossary of astronomical and computing terms written by Fred Schwab.

Paper copies of recent editions of the *CookBook* are no longer available from NRAO. However, much of the *AIPS* documentation, including the *CookBook*, is now available on the "World-Wide Web" so that it may be examined and retrieved over the Internet (start with "URL" `http://www.aips.nrao.edu`). This edition of the *CookBook* is issued in a ring-binder format with a chapter-based page numbering system. This allows us to update individual chapters without altering the pagination of others and to make each chapter available individually over the Internet. The documentation is also included with every copy of *AIPS* shipped.

Additional written documentation on *AIPS* is available in several forms. A programmers' reference manual called *Going AIPS* is available in two volumes. This was revised completely for the `15APR90` release due to the upgrading of the *AIPS* code to FORTRAN-77 and to reflect the extensive additions and improvements to the software. Unfortunately, it has not been revised since but it continues to be quite useful. The first volume is intended for applications programmers, while the second volume is needed by programmers developing *AIPS* for new peripheral devices or computers. *Going AIPS* may be obtained from the *AIPS* web site.

*AIPS* provides run-time documentation in the form of `HELP` and `EXPLAIN` files which may be viewed at the terminal or printed. (See § 3.8 for explicit instructions.) Should these not suffice, consult your local *AIPS* Manager and then, if needed, call the *AIPS* programmers in Charlottesville or Socorro. Although individual *AIPS* programs have often been written, and are best understood, by a single programmer, the *AIPS* group as a whole assumes responsibility for all released software. Anyone in the group will attempt to help you or, at least, to identify another member of the group better able to help you.

Finally, users are encouraged to recommend new and better analysis and display tools and to help debug the existing software by entering "Gripes" (see § 11.1). Please note that examples of bugs that are documented by printouts of inputs, message logs, *etc.* are most useful to the programmers. Also note that written bug reports are *much* more effective than verbal reports. E-mail to `daip@nrao.edu` reaches everyone in the group.

## 1.3 Organization of the *CookBook*

### 1.3.1 Contents

Chapter 2 of the *CookBook* describes in general terms how to get started in *AIPS* — signing up, logging in, mounting tapes, *etc.* Appendix Z gives details of these operations specific to NRAO's *AIPS* sites. Your local *AIPS* Manager may be able to provide a version of this appendix appropriate to your system. Chapter 3 introduces the basic *AIPS* utilities. Chapter 4 leads you through the basics of reading in and calibrating your *uv* data. Chapter 5 explains the basic operations required to make and improve images. Appendices A, B, and C provide simpler recipe-like approaches to calibration and imaging which beginning users may wish to try. Chapter 6 introduces the basic *AIPS* tools for making interactive and hard-copy displays of images and other data and Chapter 7 describes tools for analyzing them. Chapter 8 and Appendix B contain hints and further *AIPS* tools of particular interest, but not restricted, to spectral-line users and other observers who have images of more than 2 dimensions. Appendix E is designed for users of the new and still changing EVLA. Similarly, Chapter 9 and Appendix C are aimed primarily at users of VLB interferometers. Chapter 10 deals with single-dish data reduction with *AIPS*. Chapter 11 describes how to help the *AIPS* programmers, to backup your data, and to exit from *AIPS*. It also suggests some cures for common hang-ups and miscellaneous "disasters" which seem to afflict *AIPS* users. No such list can be made comprehensive or sufficiently general to cover all the computer systems now running *AIPS*. You will need to consult with your local *AIPS* Manager or other users if you encounter an unlisted problem.

Chapter 12 is intended for the "mature" *AIPS* user who wishes to learn about data formats, procedures, RUN files, and various subtleties of AIPS syntax. We recommend that you read this after becoming familiar with the operations described in Chapters 3 through 7. Chapter 13 contains lists of all available routines broken down by categories. Appendix G presents Fred Schwab's Glossary of radio astronomy data processing terminology. Appendix F gives some useful recipes for estimating disk files sizes and for saving data and images on tape. Appendix I contains the index.

### 1.3.2 Minimum match

In this *CookBook*, we use the minimum-matching capability of *AIPS* to abbreviate the instructions needed to run the programs. This speeds up your activity at the terminal while working in *AIPS*. However, the full names of some of the AIPS instructions may be easier to learn and to remember. They are given in Chapter 13.

### 1.3.3 Fonts and what they signify

Throughout this *CookBook*, RESPONSES TO BE TYPED BY THE USER APPEAR IN THE PRESENT FONT. Prompts provided by the operating or *AIPS* systems are left-justified on the same line, *e.g.*, system prompts $ on VAXes or % on UNIX systems , AIPS prompt >. THIS IS THE FONT USED FOR SAMPLE OUTPUTS FROM THE COMPUTER and for program names such as PRTUV. A lower-case italic font, *such as this,* is used for numeric and character parameter values which must be supplied by the user. The symbol AIPS refers to the program which you will use to communicate with the computer. The symbol *AIPS* refers to the full system, made up of the AIPS program, numerous other programs which may be run from AIPS, and the hardware configuration. The symbol C_R means "hit the RETURN or Enter key on the terminal."

The symbol § means Section and refers to the various chapters and sub-chapters of this *CookBook*. Except in the values assigned to character string variables, *AIPS* is case insensitive. We use upper-case letters in this *CookBook* to differentiate *AIPS* symbols from ordinary words visually. This usage also allows us to generate html and pdf capable versions of the *CookBook* from the basic TeX files automatically.

## 1.4 General structure of *AIPS*

The diagram on the next page is an attempt to show the general structure of the *AIPS* software package. You may wish to refer to it as you read the remaining chapters. Input to *AIPS* is either interactive or batch via the main AIPS program. It uses the *POPS* language processor and symbol table to set "adverb" values and cause application "verbs" to be executed. Chief among these, the verb GO causes independent programs called "tasks" to run. Sequences of commands may be run in batch by SUBMITting them to a batch "checker" and running them using the batch version of AIPS. All programs access and modify disk data files, and interactive ones may access tapes and TV- and Tektronix-like display devices.

## 1.5 Additional recipe

### 1.5.1 Banana daiquiri

1. Combine in an electric blender: 2 ounce **light rum**, 0.5 ounce **banana liqueur**, 0.5 ounce **lime juice**, 1/2 small **banana** peeled and coarsely chopped, and 1/2 cup crushed **ice**.
2. Blend at high speed until smooth.
3. Pour into large saucer champagne (or similar) glass. Serves one.

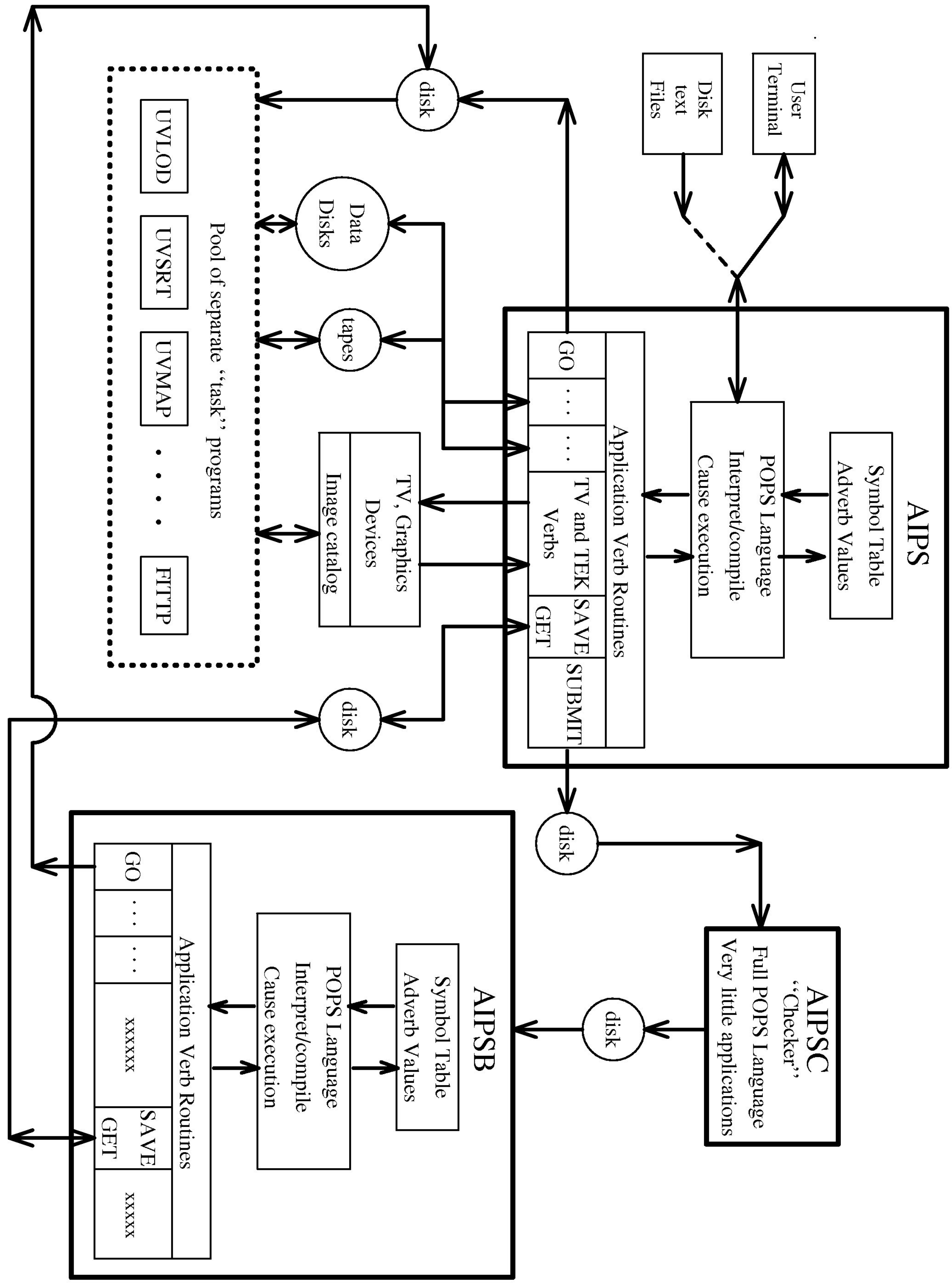



Figure 1.1: Basic *AIPS* flow diagram

# 2 STARTING UP *AIPS*

This chapter contains general information concerning the steps needed to obtain access to, and use, an *AIPS* system. It attempts (as does the design and coding of *AIPS* itself) to avoid specific references to particular computer devices and to the peculiarities of any one *AIPS* installation. We will assume, for the most part, that you will be running *AIPS* on a Unix workstation although *AIPS* should still work in more classical environments. Even for workstations of the "same" operating system, some installation-specific practicalities remain. For the NRAO installations, these are described in Appendix Z.

## 2.1 Obtaining access to an *AIPS* computer

Most *AIPS* sites now possess a number of computers which are networked together and are each individually capable of running *AIPS* while sharing both disk and tape resources. Most such computers cannot support more than a few simultaneous users (or simultaneous incarnations of the same user) of *AIPS*. Thus, most locations are obliged to institute a mechanism for distributing the available *AIPS* time to the people desiring it. At NRAO, some of the computers are assigned to individual staff members and are normally used only by them. Other computers, including all of the most powerful ones, are for "public" use, but are mostly still on an assigned basis. You should arrange to have a workstation assigned to you for your *AIPS* processing. A few of the computers are available on a first-come, first-served basis, and are often used remotely. There may be sign-up sheets and rules for their use posted in or near the principal "*AIPS* Caige" (user-terminal room). To promote fair and efficient use of the system, there are often restrictions on the amounts of time that any one user or user group may reserve.

*AIPS* can support several simultaneous users which it calls `AIPS1`, `AIPS2`, *etc.* In the workstation environment, this is used primarily to allow one user to have separate simultaneous *AIPS* sessions using multiple windows. This also allows users to log in to remote computers (*e.g.*, with the Unix tool `slogin`) and run *AIPS* while remaining comfortably ensconced in their offices in front of their own (presumably lesser) workstations. You should not do this, of course, without permission.

## 2.2 Using the workstation

The way that a workstation behaves is a function of the type of workstation, the computer operating system, the window manager program, and the set-up files for the specific computer account being used. Given all these variables, it is hard to give detailed usage instructions. Nonetheless, it is important for beginning users to master the foibles of the workstation(s) they will be using.

### 2.2.1 Logging in to the workstation

Find your assigned computer in the appropriate *AIPS* caige or office, or an available one intended for general use (checking any sign-up sheets for it). Typing $C_R$ on the keyboard will reveal the current state of the workstation. If you see a message prompting you to log in (*e.g.*, `AOC RedHat Linux, [monkey] login` on a Socorro Linux workstation named monkey), then the computer is ready for you to log on. Type the account name you are supposed to use for *AIPS* followed by a $C_R$ (use `Tab` in forms) and then type the password (it will not be visible on the screen) followed by another $C_R$. See your *AIPS* Manager for the account to use and its password (which should change with time). Many sites will assign an account to you personally, while some use a more generic AIPS account. The login scripts should start the window system automatically and produce one or more `xterm` or `aixterm` windows that you can use for starting `AIPS`.

If the initial C_R produces instead a set of windows (and/or icons), the computer is already being used. If these windows include the AIPS TV and possibly the TEKSRV and MSGSRV server windows, it is being used for AIPS. Check with other possible users before proceeding. If it's okay to use the system, you should log the previous user out and log in for yourself, restarting the window system. If you are patient, you can open each iconified window (by clicking on it once or twice), see what it's doing and finish up and/or exit. If the prompt is > in any text window, AIPS is running there and you should type:

> KLEENEX C_R

which will get out of AIPS and kill the servers. Then once at the system prompt (Unix), you can type exit C_R (lowercase!) to make the window go away. If the XAS *AIPS* TV server is still running, just press the escape key while the cursor is in the TV window. For the MSGSRV message server, move the cursor into the window and press CTRL C. Finally for the tek server, hold the control key down while you press the left mouse button, and choose the QUIT option.

The procedure for exiting from the windowing system will depend on what window manager you use. If your system uses KDE, there will be an icon on the icon bar with a large K superimposed on a globe. If the system uses Gnome, then the magic icon is an image of a foot. Move the mouse to the icon and hold down the left button. A pull-down menu will appear; select the Logout function.

### 2.2.2 Control characters on the workstation

To correct characters which you have typed, you may have to press either the BackSpace key or the Delete (or DEL) key. Unfortunately, which is required varies with the application you are using and how the AIPS account (or your personal account) has been set up. For details, see the manual page on stty with particular note of the erase function.

A control character is produced by holding down the CTRL (or Control) key while hitting another key. Some control characters under Unix have characteristics that may confuse users more used to other environments (VMS, MS-DOS). In particular, CTRL D, CTRL T, CTRL Y and CTRL Z behave much differently under Unix than under VMS. CTRL D is used in Unix as a signal to logout, unless otherwise inhibited. If you use the AIPS accounts at either Charlottesville or the AOC, this feature is automatically disabled. While in AIPS, CTRL Ds are interpreted from the > prompt as an EXIT command. CTRL T (under GNU readline) transposes two characters, while CTRL Y inserts characters previously saved in the "kill" buffer. CTRL Z suspends the current process, printing Stopped on your window and leaving you at the Unix prompt level. The Stopped message does *not* mean that the process has been terminated. It simply means the process has been suspended and placed in the background. For *AIPS* users, the suspended process is normally AIPS$n$. Users who do not understand this state often start up another *AIPS* session. In doing so, they are tying up a second *AIPS* number. If a user does this enough times, s/he can eventually tie up all available AIPS$n$'s. If you are unfamiliar with the use of CTRL Z (suspend) in Unix systems, it's best not to use them from *AIPS*, unless expert advice is close at hand. With an X-Window display, it is preferable to pop up a new xterm or other window and do whatever you want in it, leaving the *AIPS* session undisturbed. (You can get a new xterm, usually, by moving the cursor into the root (background) window, pressing the right mouse button, and selecting the appropriate option.) If you have suspended the current process (usually AIPS) with CTRL Z to get to monitor level (for instance, to edit a RUN file), then you can bring the suspended process back into the foreground with the command fg C_R.

To abort any execution in your window, type CTRL C. Using CTRL C while in AIPS will unceremoniously eject you to the Unix prompt. You will have to restart AIPS with all the input parameters having been lost. In some cases, any *AIPS* tasks running in the background, and maybe even the TV and other servers, will also be "killed" and will disappear from the screen. Aborting *AIPS* "tasks" (sub-processes) is usually done from within AIPS with the command ABORT *taskname* C_R (see § 3.1.2) rather than with CTRL C's or Unix-level system commands. Not only does this avoid killing AIPS, but it even allows for orderly deletion of scratch files.

During execution, scrolling of output lines out of the window can be halted by typing `CTRL S` and resumed by typing `CTRL Q`. If you are using an `xterm` (or `cmdtool` or `aixterm`) window with a scroll bar, you probably won't have to worry too much about doing this; use the scroll bar to review lines which have rolled off the visible part of the window. You can specify how many lines these terminal emulator windows remember, *e.g.*, for `xterm` with the `-ls` option or with the X resource `xterm*saveLines` (in your `.Xdefaults` file).

### 2.2.3 Starting the AIPS program

As you enter the commands needed to log in to your system and start AIPS, please read all messages which appear. They are often important and relate to current system, disk, and *AIPS* problems which may affect your reductions.

To begin AIPS, enter

% aips CR          with no options initially

You will then be shown a list of printer devices and be prompted to `Enter your choice:`. You will then be told about the assigned printer queue, data disks, and tape devices. If all is going well it will then tell you

`You seem to be at a workstation called` *monkey*

`Starting local TV servers on` *monkey*

where *monkey* is the name of your workstation. Any news messages about your *AIPS* installation will then appear. Read them; they might be important. Finally, you should see the messages:

`Starting up 31DEC10 AIPS with normal priority`

`BEGIN THE ONE TRUE AIPS NUMBER` *n* (release of 31DEC10) at priority 0

where 31DEC10 identifies the release of *AIPS* and $n$ is a number between 1 and 6 (typically). If this is the only *AIPS* session on the computer, you should be assigned $n = 1$, with higher numbers used for additional sessions. If you start with $n > 1$, someone else may be using your computer remotely. AIPS will then tell which TV and graphics devices have been assigned to you:

`AIPS` *n*`:  You are assigned TV device` *nn*

`AIPS` *n*`:  You are assigned graphics device` *mm*

where *nn* and *mm* are numbers assigned to your workstation (or, rarely now, to real TV and graphics devices). AIPS will now ask you for your user number and provide a `?` prompt:

`AIPS` *n*`:  Enter user ID number`

`?` *uuuu* CR

where *uuuu* is the number assigned to you for the local *AIPS* system (in decimal form). The AIPS prompt `>` should now appear.

There is more. Notice the line above that says "`starting local TV servers on monkey`"? At that point, the process of figuring out what computer you're running on and what display you're sitting at (they may be different) is shed in an asynchronous way while the main process of starting the AIPS program proceeds. Then, sometime later, you will see the following messages appear in the same window:

```
XASERVERS: Start TV LOCK daemon TVSERV on monkey
TVSERVER: Starting AIPS TV locking, Inet domain
XASERVERS: Start XAS on monkey, DISPLAY monkey:0
XAS: ** TrueColor FOUND!!!
XAS: *** Using shared memory option for speed ***
XAS: Using screen width height 1270 924
     max grey level 8191 in 16 grey-scale memories
XASERVERS: Start graphics server TEKSRV on monkey, DISPLAY monkey:0
XASERVERS: Start message server MSGSRV on monkey, DISPLAY monkey:0
```

Each of the first four messages should announce the starting of one of the servers. The Tek server will appear in iconified form somewhere on the screen, while the message server will appear opened (not iconified) somewhere else. Finally, the XAS TV server appears in iconified form. If your X-Windows supports 24-bit TrueColor, then XAS will use it. Otherwise, XAS will use 8-bit PseudoColor which is faster but less flexible. In this case, if you have a lot of colors in your X11 display (*e.g.*, an image on the root window displayed with xv), you may also get the message:

```
XAS: Using screen width height 1142 800, max grey level 189
XAS: Warning -- creating virtual colormap
```

which means XAS wasn't able to find enough free colors in the main colormap (189 in the above example) and had to create its own. In this case, the colors of every other window will "flash" when you move the mouse cursor into the opened XAS TV window, and vice versa. You can use `xsetroot -solid navy` command (or other legal X colors) to blank out whatever is on the root window; then restarting AIPS will restart the TV server, hopefully without a virtual colormap. There are a number of X-Window parameters which may be specified in your `.Xdefaults` file for these three windows. After AIPS begins, type HELP XAS C_R, HELP MSGSRV C_R, and HELP TEKSRV C_R for details. Among these is a parameter controlling how many colors XAS tries to use in PseudoColor and whether it tries to use TrueColor or not. See § 2.3.2 for more information about XAS.

There are several options you can use in starting up AIPS. To see them, just enter `man aips` at the Unix command prompt, or if you are already in AIPS, type HELP AIPS C_R. This information is reproduced in part below:

```
       aips [OLD, NEW, or TST]
            [TV=[disp][:][host]]
         or [TV=local[:n]]
         or [NOTV]
            [TVOK]
            [DA=host[,host,...]]
         or [DA=default]
         or [DA=all]
            [TP=tphost[,tphost,...]]
         or [TPOK]
            [PR=#]
            [REMOTE or REM or TEK]
            [DEBUG[=prog][:aips]]
            [LOCAL] [NORL] [NOEX]

DESCRIPTION
       The  aips  command  starts up the AIPS command interpreter and associated AIPS
       server processes.

OPTIONS
       All command line options are case insensitive.

       AIPS allows up to three versions to co-exist (disk space  permitting)  in  one
       installation.  They are identified either by date (e.g. 15OCT98) or name (OLD,
       NEW, or TST).  On most installations, these will all be the same.

       old     Start the OLD version of AIPS.  For NRAO  this  is  a  frozen  version
               which has been distributed worldwide.

       new     Start  the  NEW  version  of AIPS.  For NRAO this is the most recently
               released version and is frozen right at the  time  of  initial  public
               release.
```

```
tst     Start  the  TST  version  of  AIPS.   For NRAO this is the unreleased,
        development version.  This is the default.

TV=[tvdisp][:][tvhost] or TV=local[:n]
        TV display server to use instead of the  default.   The  AIPS  startup
        script  tries  to  deduce  which  host the user is sitting in front of
        (this may not work; it is often difficult or impossible  to  determine
        this  information).   This may not be the same as the machine on which
        AIPS is to be run if, for example, the user has remotely logged in  to
        another machine within a terminal emulator window.

        The  "TV=local" option allows use of Unix based sockets for the TV and
        other servers.  If you choose this option, you MUST run the XAS server
        and  any  AIPS  sessions that will use it on the same host, though the
        DISPLAYs can be the same or different.  Also, no remote AIPS  sessions
        will be able to talk to this local TV.

        If  you  instead  use  "TV=local:0",  it  will  attempt to start a new
        instance of the TV and ancillary servers.  This can be  used  to  have
        multiple  TV's  on  the  same  host, and is useful in a compute server
        environment with X terminals.  If you have multiple Unix-socket  based
        TV's already started, you can choose which one a new AIPS session will
        use by, e.g. "TV=local:2" to choose the second one.

        NOTE: The default TV behavior is to use  INET or Internet based  sock-
        ets,  as  the  scripts  have  been doing since 1992.  The "local" Unix
        socket based functionality does not change this.

        For the default use of internet sockets, the full syntax  of  the  TV=
        option is TV=tvdisp:tvhost, where tvhost is the name of the machine on
        which the TV display server (usually XAS), Tektronix  graphics  server
        (TEKSRV),  message server (MSGSRV), and TV Lock server (TVSERV) are to
        run, and tvdisp indicates the machine to which the DISPLAY environment
        variable  should point for XAS.  Do NOT specify TV=hostname:0.0!  Both
        TVHOST and TVDISP can be different from the machine that  AIPS  itself
        is  running  on.  See the section on X Window System servers below for
        more information on how to control the servers.

        The default behavior of this option  if only one of tvdisp and  tvhost
        is specified is

        TV=tvhost   tvdisp defaults to tvhost.

        TV=tvdisp:  tvhost defaults to the host AIPS is running on.

        TV=:tvhost  tvdisp defaults to the host AIPS is running on.

        For  the remote TV options to work, you must be able to use the rsh or
        remsh command; see the notes on it under the tp= heading below.   Also
        see  the notes on environment variable AIPSREMOTE.  By default, if you
        do not specify any tv= option, you will only get a TV if your  current
        TERM  environment  variable matches sun*, *xterm*, *hpterm, dtterm, or
```

```
        iris*.  The DISPLAY environment variable is used if set, otherwise the
        who  am  i  (on  HP-UX, with the -R option) is used to make a guess at
        "where" you really are.

NOTV    Prevents automatic activation of the  TV  servers  if  no  display  is
        wanted.   This option also disables the Tektronix graphics server, the
        message server and the TV lock server.  See the section  on  X  Window
        System  servers  below for information on how to control the Tektronix
        and message servers.

TVOK    Assume that the TV display servers are already running;  the  particu-
        lars  (display, host) are still worked out -- from the TV=... argument
        (see above) if necessary -- but no servers will be started.

DA=host[,host,...] or DA=default or DA=all
        Select user data areas (directories, or "disks" in AIPSpeak) that  are
        local  to  the  (comma  separated)  list of machines.  Data areas from
        "required" hosts and those on the  local  machine  are  always  added,
        regardless of the list of hosts.

        All disks from each named host will be assigned.  Use the FREE command
        within AIPS to see the disk assignments you end  up  with.   They  are
        also shown on startup.

        AIPS  has  a  limit  of 35 disks in any one session.  The limit on the
        number of disks that can be defined for any given site is 512.  Disk 1
        is special in that it stores the AIPS message and save/get files.  The
        system is designed so that one particular required  disk  will  almost
        always  be  assigned  as disk 1.  For performance reasons, this may be
        undesirable if the filesystem in question is mounted via NFS.  See the
        description of personal .dadevs files below, as it can be used to cus-
        tomize the list of possible user data areas.

        Selecting DA=ALL will try to include every area defined in the startup
        file, up to the session limit.  Bear in mind that most AIPS tasks only
        have 10 slots for  "BADDISK".   Selecting  DA=DEFAULT  will completely
        bypass the configurable data areas  and  choose only  those data areas
        preconfigured by the AIPS manager; THIS IS NOT NORMALLY ENABLED, CHECK
        WITH YOUR AIPS MANAGER BEFORE USING DA=DEFAULT.

        There  is  a hierarchy of data area "lists" that AIPS will look for on
        startup.  These are:

        $HOME/.dadevs       This would be in your  private  login  area  (what
                            $HOME  points  to).   It  need  not  exist.  If it
                            doesn't, AIPS looks for the next file:

        $DA00/DADEVS.LIST   This is a host-specific file possibly  set  up  by
                            the  AIPS  manager.   If  it  doesn't  exist, AIPS
                            finally looks for:

        $NET0/DADEVS.LIST   which is the  site-wide  data  area  configuration
                            file.
```

The normal state of affairs is to have just one place for disks to be defined, namely $NET0/DADEVS.LIST. Your AIPS manager can choose to install host-specific list files, and you can choose (if you run AIPS from your own private account) to override both of these two with your own private version. This allows for considerable flexibility but moves the onus of maintenance of these files to the user. In other words, if you have your own .dadevs file, you have to keep track of your site's disk configuration!

If your AIPS installation supports multiple sites, e.g. to support both little-endian (Intel, Alpha) and big-endian (Sparc) systems, you can have any of these files refer to one or the othe site by appending the site name, e.g. $HOME/.dadevs.VCOARN for SITE=VCOARN.

The format for these files is all the same: a list of directory names preceded by a "+" for required or a "-" for optional. There should be two (2) spaces between the "+" or "-" (in the leftmost column) and the directory name.

In addition to all of the above, you may define a list of data areas in an optional $HOME/.dadevs.always file. This is used in addition to whichever of the DADEVS files have been selected by the rules above. The data areas that you will be assigned start with any required data areas in the $HOME/.dadevs.always file followed by any required data areas in the selected DADEVS file regardless of name. The 3rd group of data areas are those optional ones in the selected DADEVS file containing a string matching the user's host name. Then come the optional data areas in the $HOME/.dadevs.always file regardless of name. Finally, the optional data areas in the selected DADEVS file with strings matching the names of any hosts given in the DA=host[,host,...] command-line option. The order of data areas within each group, i.e. which is disk 1, etc., is determined by the order in the files.

There is also a $NET0/NETSP file that is maintained by the AIPS manager and controls aips user-number access to the disks. You will get error messages if your private .dadevs file includes AIPS data areas ("disks") that are not in the NETSP file. Regardless of the number of sites in your installation, there is only one NETSP file.

TP=host[,host,...]
: Make sure tape daemons (TPMON) are running on the comma separated list of machines. While the AIPS account is usually set up so that it can perform remote shell (rsh or remsh) commands, your personal account may not. Check with your system administrator or network guru for details. Also check the Unix manual pages on rsh (remsh on HP-UX), rhosts, and hosts.equiv. The tp= option uses rsh to issue commands to remote hosts.

TPOK
: Do NOT check or launch the TPMON tape daemons on the local host. The default is to check if they are running and to launch them if not found.

```
PR=#    Select  printer number (e.g., pr=2).  If this option is not specified,
        the user will be presented with  a  menu  of  available  printers  and
        prompted  to enter a choice.  If there is only one printer configured,
        no menu will be presented.  You may change the selected printer within
        AIPS via the PRINTER adverb.

REMOTE or REM or TEK
        Any  one  of  these indicates that the user is running from a terminal
        with Tektronix display  capability.   Graphics  output  will  be  sent
        directly  to  this  terminal.  NOTE: AIPS will not switch from text to
        graphics mode on terminals with a separate graphics "screen".

DEBUG[=prog][:aips]
        Start AIPS in debug  mode.   With  no  arguments,  the  user  will  be
        prompted  for  the name of the debugger (e.g. gdb, dbx, adb, csd, xde,
        dbxtool, debugger, xxgdb) and also whether to run  AIPS  itself  under
        the  debugger.  If you answer no, only AIPS tasks will be run in debug
        mode.  If =prog is specified, this suppresses the prompt for the  name
        of  the  debugger program.  If :aips is specified, this suppresses the
        prompt for whether to run AIPS itself in debug  mode  and  assumes  it
        will.   Use of both these options is useful in speeding up the startup
        of the system when debugging a program or AIPS itself.

LOCAL   Start a local copy of AIPS.EXE  residing  in  the  current  directory.
        Usually used by programmers for debugging purposes.

NORL    Disable  GNU  readline library and command-line editing.  This is pri-
        marily useful for running backgrounded  AIPS  sessions,  running  AIPS
        from "here-document" shell-scripts, and for debugging.

NOEX    This defers AIPS execution and is not normally used directly by users.


X WINDOW SYSTEM SERVERS
       If  you are running under the X Window System, AIPS will open up to three win-
       dows: a TV window (normally XAS), a message window  (MSGSRV)  and  a  graphics
       window  (TEKSRV).  If you specify the notv option on the command line, none of
       these will be started.

       MSGSRV and TEKSRV are actually simple programs running inside a terminal  emu-
       lator.   You  may use any terminal emulator that you would normally use on the
       machine on which you are running AIPS for the MSGSRV window.  Examples include
       xterm  (the  sample  vt100/Tektronix emulator that comes with the MIT X Window
       System code); cmdtool and shelltool (the standard terminal emulators for Open-
       Windows)  and  AIXterm  (the standard terminal emulator on RS/6000s).  You can
       choose which one to use by setting the environment variable  AIPS_MSG_EMULATOR
       to  the  name  of  the terminal emulator you wish to use.  For example, if you
       want to use cmdtool you would type

       setenv AIPS_MSG_EMULATOR cmdtool

       if you use the C or TC Shell, or
```

```
        AIPS_MSG_EMULATOR=cmdtool; export AIPS_MSG_EMULATOR

        if you use Korn, BASH, or Bourne shells before you start up AIPS.   You  could
        also   add   these  commands  to  your  .login  file  (C  Shell)  or  .profile
        (Korn/BASH/Bourne Shells) to make the assignment more permanent.  You can also
        give AIPS_MSG_EMULATOR the special value of "none" which will disable the mes-
        sage  window  without  affecting  the  Tektronix  window  or   the   TV.    If
        AIPS_MSG_EMULATOR is not set, the default is xterm.

        You  may  choose the terminal emulator used for the Tektronix window using the
        environment  variable  AIPS_TEK_EMULATOR  in  the  same  way  that   you   use
        AIPS_MSG_EMULATOR  to  choose  the terminal emulator, but it must support Tek-
        tronix graphics codes.  On most machines the only values of  AIPS_TEK_EMULATOR
        that  make any sense are xterm and none.  If AIPS_TEK_EMULATOR is not set AIPS
        will behave as if it were set to xterm.  (Note: dxterm, aixterm,  and  cmdtool
        are not "xterm"; they cannot display tek graphics).

        You  can set preferences for positions and  colors for all three servers using
        the standard X Window System mechanisms.   Further  information  is  available
        through the AIPS HELP system (subjects MSGSRV, TEKSRV, XAS and XVSS).

        Note  that  AIPS  expects that a terminal emulator can start a program that is
        specified using a -e flag on the command line.  This is true  of  all  of  the
        terminal emulators we know about but if you find one that requires a different
        flag you can specify the flag as AIPS_TEK_EXE_FLAG or AIPS_MSG_EXE_FLAG.

ENVIRONMENT VARIABLES
        In addition to the Message and Tek server customizations, you  may  choose  to
        set a variable AIPSREMOTE to indicate your choice of remote shell command.  It
        is strongly recommended that the secure shell (ssh) be used in  place  of  the
        traditional Berkeley rsh or remsh command:
               setenv AIPSREMOTE "ssh -n"
        for csh or tcsh shells, or
               export AIPSREMOTE="ssh -n"
        for bash, korn, zsh and other bourne-like shells.
```

If you do not specify a printer (by number) on the command line when starting `AIPS`, you will get a menu showing you all the alternative printers available. You should omit the `PR` option until you are familiar with the choices. The OLD version of *AIPS* is likely to be relatively free of bugs (provided the *AIPS* version in NEW does not prescribe format changes which prevent OLD from working), but the NEW version will contain improvements and will be mostly debugged. The TST version is a debugging area recommended for NRAO staff and those few users who may require the most recent software. (Note that this choice affects only the version of the `AIPS` program itself. You may choose TST, NEW or OLD versions of the *AIPS* reduction programs at a later time — see § 3.5.)

### 2.2.4 Typing commands to the AIPS program

As of the 15JUL95 release, *AIPS* is available to users under a GNU-style license. This has numerous benefits, one of which is that it allows us to incorporate other GNU-style code within our system. The first of these is the GNU readline library which provides the user-input interface for AIPS under Unix beginning with the 15JAN96 release. The GNU readline library gives the user the ability to use the cursor-arrow keys, as well as various "control" and "escape" key sequences, to recall previously-entered commands, to edit the current command line (without having to back-space and re-type the entire line), to search the command history for previously-executed commands, to define customized key bindings for executing commands and macros, and much more. The full information may be obtained with the command man readline from the system command line (not inside AIPS). There is even "tab completion" based on the list of *AIPS* help files and on context. At any point, when typing a symbol, you may hit the TAB key. The symbol name will be completed if it is unique or the screen will flash (or the bell sound) is it is not. A second hit on the TAB key will produce a list of the possible completions. Since a task name cannot be the first symbol on a line, tasks are included in the possible completions only after some other symbol appears on the line.

The default key bindings should be very familiar to users of emacs and/or the bash shell; many of them should also be recognizable to users of the Korn and tcsh shells. Hard-core vi users can put AIPS into "vi-mode" and use vi-like key bindings instead. (The basic emacs-like key bindings will be outlined below; it will be assumed that those who are using the non-default vi-like key bindings already know what they are doing.)

Your command-line history is automatically saved between sessions, unique to both the user number and the "*AIPS* number" of the session, and then recovered at the next AIPS startup.

Use of the GNU readline library for input can be disabled on a per-session basis by starting AIPS with the "norl" option. This can prevent problems under some operating systems (most notably HP/UX) with putting AIPS into the background, when running with input "fed" from a script, or when debugging AIPS itself.

The key bindings are given below. Key sequences/bindings using the CONTROL key will be prefixed below with "C-." Those using the ESCAPE key (or "META" key — often available as the ALT key on PC keyboards and as the "diamond" key on Sun keyboards) will be prefixed with "M-." The basic cursor-movement key bindings are:

```
C-b      backward-character       [also: left-arrow]
C-f      forward-character        [also: right-arrow]
C-p      previous-command         [also: up-arrow]
C-n      next-command             [also: down-arrow]
M-b      backward-word
M-f      forward-word
C-a      beginning-of-line
C-e      end-of-line
C-r      incremental-search backward
C-p      previous-history (move backward in history list)
C-n      next-history (move forward in history list)
```

The basic editing key bindings are:

```
C-d      delete-character (under cursor)
M-d      delete-word (to right of cursor)
M-DEL    delete-word (to left of cursor)
C-t      transpose-characters (left with under cursor)
```

DELETE and BACKSPACE work as expected.

## 2.3 Managing windows

Unfortunately, the management of windows on a workstation screen depends heavily on the type of window manager and on the setup files defined for your login. At best, we can only be approximate here and try to describe general characteristics of normal setups.

### 2.3.1 General window management

Most window managers allow multiple windows to be created on the screen at the same time. These windows can either be closed in a small "iconified" form or opened in a larger and more usable form. Windows are normally opened by positioning the cursor on the icon with the mouse and clicking either once or twice with the left button. You can type only into open windows. An open window can be resized usually by "grabbing" (position the cursor with the mouse and then hold down the mouse button) one of its corners with the left mouse button. Windows under `twm` have a widget in the upper right corner which must be grabbed with any of the buttons. Positioning the cursor in the top bar of a window border and holding down a mouse button will do something. Usually, the left button moves the window, the middle button puts the window above or below other windows, and the right button gets you a pull-down menu of all the window manipulation options. Under `Motif` the middle and right buttons are switched. In the upper left corner of the top bar is a special button widget. Under `Openlook` and `twm`, clicking on this widget iconifies the window. Under `Motif` the iconify widget is shown as a dot and is usually in the upper right corner. The widget in the upper left corner under `Motif` offers a pull-down menu of window options, but is dangerous since a double click on that widget with the left button destroys the window (and any programs running in it).

Positioning the cursor in the root window (the background) and holding down a mouse button usually gets a pull-down menu with programs that can be run and various other options including exiting from the system. Well-configured systems offer a separate menu with each button. This is usually the way to get more windows if you need them.

When encountering a system for the first time, you should explore what the various controls have to offer. Position in the background, press each button in turn, and follow up what is offered by the pull-down menus which appear. Many menu items may themselves have a menu which you get by dragging the cursor to the right. Usually there is an arrow at the right of the menu item to indicate this. Then, try to open some icons with a single click or a quick double click. Then try the various mouse buttons in the top bar, the corners, and any special widgets visible in the window. Some windows also have scroll bars along the left or right side. Experiment with the various mouse buttons, clicking or dragging, in the scroll-bar region to see how to scroll back to previous text or forward to the last line. It pays to master all this slight of hand to allow you rapid access to multiple windows, previous text, and the like. It is very painful to click the wrong button and destroy a program that has been running for a few hours already!

### 2.3.2 Managing the *AIPS* TV window called XAS

On workstations, *AIPS* simulates a real TV display with a program called `XAS`. The program starts when you start `AIPS` and comes up in an iconified form. Its icon shows a cute drawing of an ape along with words like `24-BIT` for full-color display and `AIPS98 INET` for Internet-connectivity. In many ways, this is a normal window which can be resized, moved, iconified, and destroyed like any other. However, when the window is open and the cursor positioned inside the window, `XAS` offers some additional features. The cursor changes shape and color in the window to indicate this fact. To get `XAS` to treat the cursor position as a "TV cursor" position, you must hold down the left mouse button. This allows the cursor to fill two rôles at nearly the same time, that of a workstation cursor and of a TV cursor. You do not have to hold the button down for long to register a TV position and, in fact, it is more efficient in interactive TV operations simply to click the left button at the desired locations. When you drag the cursor, numerous intermediate values are read with consequent extra computation. Note that the TV cursor position is read by XAS whenever the cursor is in the XAS window with the left button down. However, that position is only used when some verb or task reads it from XAS and uses it for some purpose, *e.g.*, to select image coordinates or to control image enhancement.

AIPS TV functions refer to "buttons" A, B, C, and D for the purpose of signaling conditions to the software. In the XAS simulation, these buttons are the keys a, A, or F3 for button A, keys b, B, or F4 for button B, keys c, C, or F5 for button C, and keys d, D, or F6 for button D. The F2 and F7 buttons toggle the size of the display from full screen to whatever size you set the window. XAS simulates a TV with a number, usually sixteen, of grey-scale memories and eight one-bit graphics overlays. The x and y dimensions of the memories adapt to the display area of your workstation less some room for window borders and, sometimes, for a few lines of a type-in window as well. XAS has the ability to display full-color (256 levels for each of red, green, and blue) on terminals capable of supporting full "TrueColor visuals." The internal dynamic range of images in XAS is actually 0:8191, but displays are limited to 0:255. You pay for this capability with a small reduction in speed for ordinary enhancements, blinks, and the like. You may select to limit your XAS to a "PseudoColor visual" which is all that is available on some older workstations. In that mode, the higher the number of grey levels the greater the dynamic range is available in the display of images. The maximum allowed maximum grey level is 235, but this will use all 256 levels of a "colormap" and therefore force XAS to use its own colormap. When the cursor enters the XAS window, the computer switches to that special colormap changing all of the other colors in the other windows (often in ways that are very undesirable). The default number of grey levels is 199 which may be small enough to avoid this effect or to manage to leave the colors of your most basic windows unaffected. Type HELP XAS C_R when in AIPS to see how to control the number of levels, the colors of the graphics overlay planes, and numerous other parameters.

## 2.4 Additional recipes

### 2.4.1 Bananes rôties

1. Preheat oven to 375 deg.
2. Place 6 (peeled) **bananas** in a baking dish.
3. Sprinkle bananas with juice of 1/2 **lemon**.
4. Pour 2 tablespoons melted **butter** and 2 tablespoons **dark rum** over the bananas. Sprinkle with 2 tablespoons **brown sugar**.
5. Place in oven for 10 minutes.
6. Pour on 2 more tablespoons **melted butter** and 2 more tablespoons **dark rum** and bake for 5 minutes more.
7. Serve at once, spooning some sauce over each banana.

### 2.4.2 Banana pick-me-up

1. Slice ripe, peeled **bananas** into 3 cm chunks.
2. Wrap each chunk in strip blanched **bacon**.
3. Prepare mixture of **brown sugar** and **cinnamon** to taste.
4. Sprinkle mixture over banana chunks.
5. Bake at 350 deg until the bacon is crisp and the sugar slightly caramelized.

# 3 BASIC *AIPS* UTILITIES

This chapter reviews some basic *AIPS* utilities with which you should be familiar before you start calibrating data or processing images in *AIPS*. Many of these utilities will appear in later chapters on calibration, image making, and so on. However, in those chapters, these utilities will be explained only briefly.

## 3.1 Talking to *AIPS*

### 3.1.1 *POPS* and *AIPS* utilities

When using the *AIPS* system, you talk to your computer through a command processor called *POPS* (for People Oriented Parsing System) that lives in the program AIPS. The steps needed to start this basic program are discussed in § 2.2.3. The copy of this program that you get will be called AIPS$n$ where $n$ is often referred to as the "*POPS* number" of your session.

The *POPS* command processor is not unique to *AIPS*. It has been present in other programs at the NRAO for many years, and will be familiar to users of the NRAO single-dish telescopes. Chapters 4 to 11 of this *CookBook* give explicit examples of most of the *POPS* commands that a new *AIPS* user needs to know, so we will not give a separate *POPS* tutorial here. The command HELP POPSYM C_R will list the major *POPS* language features on your terminal, and Chapter 12 below reviews some advanced features of *POPS*.

As well as providing a command processor, *AIPS* replaces many features of your computer's operating system with its own utilities. This may seem inconvenient at first — you will have to learn the *AIPS* utilities as you go along. You will see the advantage of this approach when you use *AIPS* in a computer that has a different operating system. Your interface to *AIPS* will be almost identical on a VAX, or a Convex C-1, or a Unix-based workstation, or a Cray X-MP. Once learned, your *AIPS* skills will therefore be highly portable.

Lists of the important *AIPS* utilities can be obtained at your terminal by typing ABOUT CATALOG C_R and ABOUT GENERAL C_R. See also Chapter 13 for a relatively recent version of all such category lists.

### 3.1.2 Tasks

*AIPS* provides a way for you to set up the parameters for, and then execute, many applications programs sequentially or in parallel. The more computationally intensive programs may take many minutes, hours (or even days) of CPU time to run to completion. They are therefore embodied in *AIPS* "tasks" — programs that are spawned by the AIPS program to execute independently and asynchronously (unless you choose to synchronize them). This lets you get on with other work in AIPS, while one or more tasks are running. You may spawn, however, only one copy at a time of each task from a given *AIPS* session (*i.e.*, *POPS* number.)

A typical task setup will look like:

| | |
|---|---|
| > TASK '*task_name*' C_R | to make *task_name* the default for later commands; note the quote ' marks. |
| > HELP C_R | to write helpful text on your terminal about the purpose of the task and about its input parameters. |

You will then spend some time setting up parameter values, as in § 3.1.4 below. Then, type

| | |
|---|---|
| > INP C_R | to review the parameter values that you have set and |
| > GO C_R | to send the task into execution. |

You may also specify which task you want to execute by an immediate argument, *e.g.*, GO UVSRT C_R to execute the task UVSRT. After the GO step, you will watch for messages saying that the task has started executing normally, has found your data, etc., while you get on with other work in *AIPS*.

If you discover that you have started a task erroneously, you may stop it abruptly with

| | |
|---|---|
| > ABORT C_R | to kill the task named by TASK, or |
| > ABORT *task_name* C_R | to kill *task_name*. |

This will stop the job quickly and delete any standard scratch files produced by it. However, input data files — and output data files that are probably useless — may be left in a "busy" state in your data catalog. The catalog file is described in § 3.3, including methods to clear the "busy" states and to delete unwanted files.

The current full list of tasks may be obtained on your terminal (or workstation window) by typing ABOUT TASKS C_R. Since this list runs for many pages, you may wish to direct the output to the line printer (with DOCRT = -2 C_R) or to consult the list in Chapter 13 of this *CookBook*.

### 3.1.3 Verbs

Some of the smaller *AIPS* utilities run quickly enough to be run inside the AIPS program rather than being spawned. These "verbs" include simple arithmetic and *POPS* operations, the HELP, ABOUT, INP, and GO commands mentioned already, interactive manipulations of the TV-like display, and many more. Verbs are sent into action simply by setting their input parameters and typing the name of the verb followed by C_R. (The sequence GO *verb_name* C_R will also work, but a bit more slowly since it also saves the input parameters of the verb for you; see § 3.5 for a further discussion of saved parameters. The sequence TASK '*verb_name*' ; GO C_R will not work, however.) While a verb is executing, AIPS will not respond to anything you type on the terminal (but it will remember what you type for later use). Just watch out for messages and do what is called for with the TV cursor or terminal. You may, of course, think about what you will do next.

You can list all the verbs in *AIPS* on your terminal by typing HELP VERBS C_R, but the output lists only the names. To find out more, type ABOUT VERBS C_R which describes what the verbs do. Since this output fills several pages, you may wish to direct it to the line printer (set parameter DOCRT to -2), or to consult the (perhaps dated) list printed in Chapter 13 of this *CookBook*.

### 3.1.4 Adverbs

*AIPS* uses "adverbs" (which may be real numbers or character strings, scalars or arrays) to pass parameters to both "verbs" and "tasks." A significant part of your personal time during an *AIPS* session will be spent setting adverbs to appropriate values, then executing the appropriate verbs or tasks. Examples of adverb-setting commands in *AIPS* are:

| | |
|---|---|
| > CELL 0.5 C_R | to set a single scalar CELL to 0.5 |
| > CELL 1/2 C_R | alternate for above with *POPS* in-line arithmetic |
| > IMSIZE 512,256 C_R | to set a two-element array IMSIZE to IMSIZE(1)=512, IMSIZE(2)=256 |
| > IMSIZE 512 256 C_R | an alternate for the above if both values are positive |
| > IMSIZE 256+256,256 C_R | an alternate for the above using *POPS* in-line arithmetic |
| > UVWTFN 'NA' C_R | to set a string variable UVWTFN to the value NA |
| > LEVS 0 C_R | to set all elements of the 30-element array LEVS to zero |
| > LEVS = -2,-1,1,2,3,4,5 C_R | to set LEVS(1)=-2, LEVS(2)=-1, LEVS(3)=1, etc. The = avoids in-line arithmetic that would otherwise subtract 2 from LEVS(1) |

| | |
|---|---|
| > LEVS = -2,-1 1 2 3 4 5 CR | an alternate for the above; the comma avoids in-line arithmetic that would otherwise set LEVS(1) = -3 |

Many *AIPS* tasks will assume sensible "default" values for adverbs that you choose not to (or forget to) specify. Some adverbs cannot be sensibly defaulted; these should be clearly indicated in the appropriate help information. You may review the current input parameters for any *AIPS* task or verb by typing

| | |
|---|---|
| > INP CR | to review the parameters for task TASK, or |
| > INP *task_name* CR | to review the adverbs for task *task_name*. |

Any adverbs which you have set to *à priori* unusable values will be followed on the next line by a row of asterisks and an informative message. Details of the input parameters used by any *AIPS* verb or task can be obtained on your terminal by typing:

| | |
|---|---|
| > HELP CR | to review the parameters for task TASK, or |
| > HELP *task_name* CR | for task *task_name* |
| > HELP *verb_name* CR | for verb *verb_name* |
| > HELP *adverb_name* CR | for adverb *adverb_name* |

See § 3.8 below for more methods of obtaining on-line help with *AIPS*.

You can list all the adverbs in *AIPS* on your terminal by typing HELP ADVERBS CR, but the output lists only the names. To find out more, type ABOUT ADVERBS CR which describes what the adverbs do. Since this output fills several pages, you may wish to direct it to the line printer (set parameter DOCRT to -2), or to consult the (perhaps dated) list printed in Chapter 13 of this *CookBook*.

## 3.2 Your *AIPS* message file

AIPS and all tasks talk back to you by writing messages to a disk file called the "message file" and/or by sending them to you on the appropriate "message monitor." Simple instructions and progress messages usually go only to the monitor; very few (if any) messages go only to the file. For AIPS itself, the message monitor is always the workstation window or terminal into which you are typing your commands. For the tasks, the monitor can also be a separate terminal (on well-equipped, but old, systems) or a second workstation window under control of the *AIPS* dæmon process MSGSRV. You can control whether or not you get the message server window by the setting of a Unix environment variable (AIPS_MSG_EMULATOR). Enter

| | |
|---|---|
| > HELP MSGSRV CR | for details. |

At most *AIPS* installations, you get a message server by default. You may also control the size and appearance of the message server with parameters in the X-Windows .Xdefaults file. These parameters are also listed in by HELP MSGSRV CR.

You may review the contents of the message file by typing PRTMSG CR at the > prompt at your terminal. PRTMSG is an example of an *AIPS* "verb" — it does not need a GO from you to execute, and it is *not* shed from your terminal. Each message in the file has, associated with the text, the time, task name, *POPS* number, and the priority of the message. The priority codes range from 0 for user input to 2 for "unimportant" messages to 5 for "answers" and other significant normal messages to 8 for serious error messages. The PRTMSG verb has adverbs to let you select either the printer or your window or terminal for the display and to let you control which messages will be displayed. For example, to set the minimum priority level for messages to be displayed, type:

| | |
|---|---|
| > PRIORITY *np* CR | where *np* is the desired minimum level, |

before running PRTMSG; then only messages at this level or above will be listed on the printer or terminal. If *np* is $\leq 5$, then messages at level 0 are also shown. PRTMSG has further adverbs to limit the output by program name (PRTASK, uses minimum match), message age (PRTIME as upper limit to the age), and *AIPS* number

(PRNUM). Note that PRNUM must be your *AIPS*, *i.e.*, *POPS*, session number, not your user identification number. The choice of the output device is made with

> DOCRT -1 C_R — to select the line printer
> DOCRT 1 C_R — to select the terminal at its current width $\geq 72$ characters
> DOCRT *nc* C_R — to select the terminal at width $nc$ characters: $72 \leq nc \leq 132$.

The wider you can make your window display, up to 132 characters, the more information *AIPS* can put on a line. You may change the line printer selection with PRINTER.

PRTMSG does not delete messages from your message file. Use:

> CLRMSG C_R — to delete messages and to compress the message file.

CLRMSG supports adverbs like those of PRTMSG, except that the deletion is of messages older than PRTIME and the printing is of messages younger than PRTIME seconds ago. Old messages are automatically deleted from your message file when you EXIT from AIPS. (The time limit for "old" messages is set by your local *AIPS* Manager. Usually, it is about 3 days.)

## 3.3 Your *AIPS* data catalog files

Your *uv* data sets and images are your largest inputs to, and outputs from, *AIPS*. A summary record of all your disk data sets (*uv* data, images, beams and temporary "scratch" data created by active tasks) is kept in your disk catalog files (one per disk). To interrogate this catalog file, use:

> INDI 0 ; MCAT C_R — to list all images on all disks, or
> INDI 0 ; UCAT C_R — to list all *uv* data sets on all disks.

A complete listing of the catalog file, which may be printed with PRTMSG, can be generated by:

> CLRNAME C_R — to reset INNAME, INCLASS, INSEQ, INTYPE, and INDISK,
> CATALOG C_R — to generate the listing.

which will list all of your disk data sets. To limit the listing to a particular name, class, sequence number, type, and/or disk, use a combination of the adverbs INNAME, INCLASS, INSEQ, INTYPE, and INDISK. The INNAME and INCLASS adverbs allow a rather powerful wild-card grammar; type HELP INNAME C_R for details. Unless you want a hard copy, it is faster to use MCAT and UCAT, although they respond only to the INDISK adverb. A typical listing looks like:

```
CATALOG ON DISK  1
CAT USID MAPNAME      CLASS   SEQ  PT     LAST ACCESS      STAT
 18   76 3C166L5OK   .IIM001.    1 MA 27-OCT-1996 22:30:18
 19   76 3C166L5OK   .IBM001.    1 MA 27-OCT-1996 23:02:14
 22   76 3C166L5OK   .IIM001.    2 MA 28-OCT-1996 15:30:45
CATALOG ON DISK  2
CAT USID MAPNAME      CLASS   SEQ  PT     LAST ACCESS      STAT
 22   76 1200+519    .IIM001.    1 MA 01-NOV-1996 23:50:10
 23   76 1200+519    .IBM001.    1 MA 01-NOV-1996 23:59:58
 24   76 1200+519    .QIM001.    1 MA 28-OCT-1996 00:10:10
 25   76 1200+519    .UIM001.    1 MA 28-OCT-1996 00:19:19
 28   76 1200+519    .ICL001.    1 MA 02-NOV-1996 00:35:20 WRIT
 31   76 SCRATCH FILE.IMAGR1.    1 SC 02-NOV-1996 00:35:37 WRIT
 32   76 SCRATCH FILE.IMAGR1.    2 SC 02-NOV-1996 00:35:39 WRIT
CATALOG ON DISK  3
CAT USID MAPNAME      CLASS   SEQ  PT     LAST ACCESS      STAT
  2   76 3C138 A C   .UVSRT .    1 UV 22-OCT-1996 12:56:50
 36   76 1200+519    .UVXY  .    1 UV 02-NOV-1996 00:32:50 READ
 37   76 1200+519    .IMAGR .    1 UV 02-NOV-1996 00:34:25 WRIT
```

This user (identification number 76) has eight image files, three on disk 1 and six on disk 2. He also has two sorted *uv* data sets and an IMAGR *uv* work file on disk 3. There are two scratch (temporary) files on disk 2 which were created by IMAGR running out of AIPS1 (this determines their IMAGR1 classname). Image data files (images and beams) are distinguished by the type code MA. The *uv* data files are distinguished by the type code UV and scratch files by type SC.

Note that this user has encoded useful information other than the source name into the image file names on disk 1. These images were of 3C166 at L band with 50 kilo-wavelength (*uv*) taper. Such information is also carried in AIPS history files (see § 3.4 below), but it is often useful to place it at a level where CAT can see it. The user also gave the UVSRT file in slot 2 on disk 3 a name that encodes the source name (3C138), the VLA configuration (A), and the observing band (C). Careful choice of AIPS filenames can save much other bookkeeping. The file name can be any valid string up to 12 characters long. Also note how SEQ numbers distinguish different versions of a file with the same name; this and the global variables in AIPS are helpful features when doing iterative computations such as self-calibration.

### 3.3.1 Speedy data file selection

Each catalog entry has an identification number called the "catalog slot number". The CAT column at the left of the listing above shows these catalog numbers. They can be used to set up inputs quickly for AIPS programs that read cataloged disk data sets. Use:

> INDI *n1* ; GETN *ctn1* C<sub>R</sub> where *n1* selects the disk and *ctn1* is the catalog slot number.

The verb GETNAME (abbreviated through minimum match as GETN above) sets the adverbs INNAME, INCLASS, INSEQ, and INTYPE used by many tasks and verbs. Some tasks require a second, a third and even a fourth set of input image name adverbs. For these, use:

> IN2D *n2* ; GET2N *ctn2* C<sub>R</sub> to set the second set, and

> IN3D *n3* ; GET3N *ctn3* C<sub>R</sub> to set the third set.

> IN4D *n4* ; GET4N *ctn4* C<sub>R</sub> to set the fourth set.

The verb GETONAME (GETO for minimum match) sets the adverbs OUTNAME, OUTCLASS and OUTSEQ to those of a pre-existing output file. GETO is particularly useful with calibration tasks that copy extension tables (*e.g.*, CL or FG tables) from one database to another or for restarting an image deconvolution.

### 3.3.2 Catalog entry status

Note that several catalog slots on disks 2 and 3 in our sample catalog listing above do not have blank entries in the STAT column. This listing was made while the user was running a Clean deconvolution with IMAGR on the sorted *uv* data set in slot 36 — this *uv* data file is opened for READing. The Clean image file, ICL001 in slot 28, and the scratch and IMAGR files are opened for WRITing. Procedures that attempt to read files which are opened for writing, or vice versa, will be rejected with appropriate error messages. You must therefore note any non-blank entries in the STAT column carefully. In some situations (mainly involving system crashes or abortion of tasks [§ 3.1.2]) files may be left in READ or WRIT status indefinitely. If this happens, you may reset the file status with CLRSTAT C<sub>R</sub> after issuing the appropriate INDISK and GETNAME. Note that a WRIT status on a file which is not, in fact, being used at present probably indicates that the data in the file have been corrupted. Such files should usually be removed from your catalog by first clearing the file status with GETN *nn*; CLRST C<sub>R</sub> then deleting them with ZAP C<sub>R</sub>.

Before using a data set as input to an AIPS task, check that the data set has a clear status. (It is possible to let two tasks read the same data at the same time, but this is not recommended as it will usually slow execution.) Also note the data set's disk number and its ordinal number in the catalog, as these are useful for GETN, GET2N, etc.

### 3.3.3 Renaming data files

Files may be renamed, after they have been cataloged, using the *AIPS* verb RENAME. Typical inputs might be:

| | |
|---|---|
| > INDI 2 ; INNA '1200+519' C_R | to select disk 2 and set the input (old) name. |
| > INCL 'IIM001' ; INSEQ 1 C_R | to set the rest of the input name adverbs, *i.e.*, to select the file in slot 22 on disk 2 in the example above. |
| > OUTN '1200+51 15K' ; OUTSEQ 2 C_R | to set desired output name and sequence number. |
| > INP RENAME C_R | to review the inputs. |
| > RENAME C_R | to rename the I image to '1200+51 15K' and reset its sequence number to 2. |

Two verbs can be used to alter the catalog numbers of files. RENUMBER moves a file to an empty, user-specified slot; a one-line command to do this would be SLOT $n$; RENUM C_R where $n$ is the new slot number. Note that $n$ may now be higher than any slot numbers currently in use. RECAT compresses the catalog (*i.e.*, it removes gaps in the catalog numbers) without changing the order of the entries in the catalog.

### 3.3.4 Header listings

Every image or *uv* data set in *AIPS* has an associated header file that contains information needed to describe the data set in detail.

The header also contains information on the number of extension files of each type that have been associated with the data set. The most important file extensions that can be associated with *AIPS* image data are the HIstory file described below, the CC or Clean component files (see Chapter 5) and the PLot files and SLice files (see Chapter 6).

Multi-source *uv* data files may have many extensions (see Chapter 4). The most important are the HIstory file, the ANtennas file (subarray geometric data, date, frequency and polarization information, *etc.*), the BP (bandpass) file for bandpass calibration data, the CL (calibration) file for calibration and model information, the FQ (frequency) file for frequency offsets of the different IFs, the FG (flag) file for editing information, the NX (index) file (which assists rapid access to the data), the SN (solution) file for gain solutions from *AIPS* calibration routines, and the SU (source) file with source-specific information such as name, position, and velocity. Chapter 4 describes the use of these extensions in some detail.

You can list the header file of any catalog entry on your terminal by following the GETNAME step above with

| | |
|---|---|
| > IMHEAD C_R | for a detailed listing, or |
| > QHEAD C_R | for a shorter listing. |

The output of IMHEAD and QHEAD can also be printed using PRTMSG (at PRIORITY 2).

Output from IMHEAD on a multi-source *uv* data set might look like:

```
Image=3C345     (UV)         Filename=Z17G1_A     .MULTI .   1
Telescope=SBLNKGYO           Receiver=VLBI
Observer=FAP                 User #= 1353
Observ. date=27-FEB-1991     Map date=13-JUN-1995
# visibilities    112813     Sort order  TB
Rand axes: UU-L  VV-L  WW-L  BASELINE  TIME1  WEIGHT  SCALE
           SOURCE
--------------------------------------------------------------
Type    Pixels   Coord value  at Pixel    Coord incr   Rotat
```

```
COMPLEX      1   1.0000000E+00    1.00 1.0000000E+00    0.00
STOKES       4  -1.0000000E+00    1.00-1.0000000E+00    0.00
FREQ       128   2.2228990E+10   63.50 5.0000000E+05    0.00
RA           1    16 41 17.608    1.00      3600.000    0.00
DEC          1    39 54 10.820    1.00      3600.000    0.00
--------------------------------------------------------------
Maximum version number of extension files of type SU is   1
Maximum version number of extension files of type CL is   3
Maximum version number of extension files of type HI is   1
Maximum version number of extension files of type AN is   1
Maximum version number of extension files of type NX is   1
Maximum version number of extension files of type FG is   1
Maximum version number of extension files of type SN is   1
```

Output from IMHEAD on an image file might look like:

```
Image=3C219     (MA)         Filename=3C219-BC-6  .ICL001.   1
Telescope=VLA                Receiver=
Observer=BRID                User #=   76
Observ. date=06-SEP-1992     Map date=18-APR-1994
Minimum=-1.89720898E-04      Maximum= 5.05501366E-02 JY/BEAM
--------------------------------------------------------------
Type    Pixels   Coord value  at Pixel    Coord incr   Rotat
RA---SIN   510    09 17 50.662  263.00     -0.300000    0.00
DEC--SIN   640    45 51 43.555  294.00      0.300000    0.00
FREQ         1   4.8726000E+09    1.00 2.5000000E+07    0.00
STOKES       1   1.0000000E+00    1.00 1.0000000E+00    0.00
--------------------------------------------------------------
Map type=NORMAL              Number of iterations=   50000
Conv size=   1.40 X   1.40   Position angle=   0.00
Observed RA   09 17 50.600    DEC  45 51 44.00
Maximum version number of extension files of type HI is   1
Maximum version number of extension files of type PL is   5
Maximum version number of extension files of type SL is   1
```

Both QHEAD and IMHEAD list the maximum version numbers of the table extension files associated with a data set. Because you may acquire many versions of such tables during calibration, these verbs are often invoked during calibration in *AIPS*.

## 3.4 Your *AIPS* history files

Every *uv* and image file has an associated "history", or HI, file. This HI "extension" of the data set stores important information about the processing done so far on the data in the file. Every *AIPS* task and verb that alters either the data or the file header will record its key parameters in the history file. The history file is written to tape when you use FITS format, so you can preserve it for reference in later *AIPS* sessions or when sending data to colleagues.

In general, each "card" in the history file begins with the task or verb name. It then gives one or more of the input adverb values it used (*i.e.*, the defaults are filled in). All or parts of the file may be displayed on your terminal or printed on the line printer. For example, use:

| | |
|---|---|
| > INDISK *n* ; GETN *ctn* C_R | to select the file to be displayed. |
| > PRTASK 'UVMAP' C_R | to examine only history information from UVMAP. |

| | |
|---|---|
| > DOCRT 1 C_R | to direct the display to your terminal, using its full width. |
| > PRTHI C_R | to print the UVMAP history. |
| > PRTASK ' ' ; DOCRT FALSE C_R | to select all history cards and direct the output to the line printer. |
| > PRTHI C_R | to print the full history file. |

There are several (legitimate) reasons why you might wish to edit your history files. Repetitive self-calibration cycles, or image combinations, can lead to very long and very repetitive histories which could be substantially shortened with no real loss of information. Also some entries in the history file may become obsolete by, say, the deletion of plot files. The verb STALIN allows you to send a range of history lines to Siberian salt mines (*i.e.*, delete) by number with some selectivity and, optionally, interactive confirmation of each deletion. You may, of course, simply wish to add information to the history file. The verb HINOTE can be used to append one line, given by the adverb COMMENT, or many lines, typed in interactively, to the history file. Even more powerfully, the verb HITEXT allows you to write your history file to an external text file (see § 3.10.1). You may edit that file with your favorite Unix file editor and then read it back, writing your edited file into any *AIPS* history file you want (with verb HINOTE).

## 3.5 Saving and restoring inputs

All input and output parameters ("adverbs") are global throughout AIPS. When an adverb value is specified for, or set by, a task or verb, it remains at that value for any other task or verb that uses an adverb of the same name (until you change it). This global nature of the *AIPS* adverbs is useful in most cases. It can, however, be inconvenient — especially if you are taken by surprise because you have not reviewed the adverb values before running a task. Before running any task or verb, check your current input adverbs carefully with:

| | |
|---|---|
| > INP *name* C_R | where *name* is the program name, or |
| > INPUTS *name* C_R | to write the input values to the message file. |
| > QINP C_R | to resume the previous INP or INPUTS with the page last displayed. |

Some tasks have multiple pages of input parameters. QINP allows you to change a parameter on a page, review that page and then go on to the next page without having to view the first pages over again. Some verbs and a few tasks have *output* adverbs. Unless they are also used on input, they will not appear when you do INP or INPUTS. After running such verbs and tasks, do

| | |
|---|---|
| > OUTPUTS *name* C_R | to view the output values and write them to the message file. |

To reset all adverbs for a particular task or verb to their initial values, without changing any other adverbs or procedures, enter

| | |
|---|---|
| > DEFAULT *name* C_R | to reset the values for *name*. |
| > DEFAULT C_R | to reset the values for the verb or task named in the TASK adverb. |

You can save all adverbs you have specified for *AIPS* to disk at any time by typing:

| | |
|---|---|
| > SAVE *aaaaa* C_R | where *aaaaa* is any string of up to 12 characters. |
| > GET *aaaaa* C_R | will restore these inputs later. |

These commands save or restore your entire AIPS "environment". For this reason, GET must be the only command on the input line; SAVE may appear with other commands, but will be executed before *any* of the other commands on the line. Thus, the sequence INNAME '3C123' C_R INNAME 'BLLAC' ; SAVE BLLAC C_R will save a 3C123 environment, not a BLLAC one. AIPS automatically saves your environment in a disk area called LASTEXIT whenever you use the EXIT, KLEENEX, or RESTART commands. The command GET LASTEXIT is automatically executed whenever you start up the AIPS program again on the same machine. Thus, you retain your own *AIPS* environment from one use of AIPS to the next. To obtain a null version of the adverb values and of the rest of the *AIPS* environment, type:

> RESTORE 0 CR

There is also one temporary area for saving your AIPS environment. To save your inputs temporarily, type:

> STORE 1 CR — to save your inputs in area 1, and

> RESTORE 1 CR — to recover the inputs you previously stored in area 1.

When new verbs and adverbs are created at your site, your old SAVE files will not know about them. Beginning with the 15JAN96 release, you may update the old files with the sequence:

> GET *aaaaa* CR — to recover the old SAVE area.

> COMPRESS CR — to get the new basic vocabularies without losing your adverb values and procedures.

> SAVE *aaaaa* CR — to save the updated area for later; use the full name of the SAVE area here.

The list of SAVE areas may be reviewed with the verb SGINDEX. In 31DEC02, a SAVE area may be written as a RUN file (§ 3.10.2) if you first GET the area and then use SG2RUN.

The input adverb values associated with a task or a verb can be stored by the command:

> TPUT *name* CR — where *name* is the verb or task name.

and retrieved by the command:

> TGET *name* CR

TPUT and TGET allow you to avoid, to some extent, the global nature of the adverb values in AIPS. This is sometimes advantageous. Whenever a task (or a verb, for that matter) is executed by the verb GO, TPUT runs automatically. TGET will therefore recover the last set of input adverbs used to execute the task, unless you deliberately overwrite them with a TPUT of your own. Note that *AIPS* will complain if you try to TGET input adverbs for a task for which no TPUT has previously been run (either manually or automatically). You must "put" before you can "get." TGINDEX will show you what tasks have been TPUT and when. In 31DEC00, VPUT, VGET, and VGINDEX allow you to save, recover, and list task-specific adverbs from up to 35 completely user-controlled storage areas. In 31DEC06, PLGET lets you recover the adverbs used to construct a user-selected plot file.

You can change between versions of *AIPS* software once you are inside AIPS by typing

> VERSION '*version*' CR — where *version* is one of OLD, NEW or TST

Alternatively, you may use this command to access a private version of a program in some other area — see § 12.2.2. Note that toggling between different versions of *AIPS* is possible only when the data formats are the same. Unfortunately, 31DEC09 is not fully compatible with previous versions of *AIPS*. (The antenna file format changed.) Note also, that you are toggling between different versions of tasks, not the verbs within the AIPS program. That version is selected when you start the program (§ 2.2.3) and can be changed only by exiting and start anew.

## 3.6 Monitoring disk space

Since the 15APR92 release of *AIPS*, the availability of data areas via NFS has vastly increased the amount of disk space accessible from a given *AIPS* session. The da= command line option to the aips command allows you to specify "disks" (data areas) from many hosts in addition to the current host, subject to a maximum of 35 disks per session. Note, however, that the BADDISK adverb has a limit of 10 disks. Thus, if more than 10 disks are accessed via NFS, you will not be able to prevent one or more from being used for scratch files. This can be important. Reading data over NFS is relatively efficient, but writing data is not.

Even file creations (under Unix) require the writing of zeros to the whole file in order to guarantee later access to the requested space. Over NFS, this can be a slow process. For example, if user disk 1 is accessed via NFS, then every line of the message file must be written with NFS, a process which has been observed to require about one second of real time per message!

Another aspect of the new disk allocation system is a scheme by which the local *AIPS* Manager may restrict the availability of some disk areas to a set of user numbers, specified on a disk-by-disk basis. Managers usually use this tool to set aside most disks on a staff member's workstation for his/her sole use and to reserve space for visitors or other special projects on "public" workstations on a case-by-case basis. Use the `FREE` verb within `AIPS` to show you the space used and available on all disks for your session and also to show whether or not that space is reserved. The right-most column of `FREE`'s output will show `Alluser` if the space is not reserved, `Resrved` if you are one of the users for which the space is reserved, `Not you` if you are not allowed to use the space, and `Scratch` if the space is to be used only for scratch files. Use `FREE` often to keep track of how much space is available and where the space can be found.

Disk space is still generally at a premium. If more than one user has access to the disk areas you are using, then another useful tool for monitoring disks is the *AIPS* task called `DISKU`. To run it, type

| | |
|---|---|
| > USER 32000 ; INDISK 0 C_R | to get all disks and users. |
| > GO DISKU C_R | to run the *AIPS* disk user task. |

This will (eventually) list on the `AIPS` monitor (and the message file) the amount of data space in use by each user for all *AIPS* disks. Identify the worst disk hogs and apply appropriate peer pressure. If you are, mysteriously, the culprit on some disk, then

| | |
|---|---|
| > USER 0 ; INDISK *n* C_R | where *n* is the mysteriously eaten disk |
| > DOALL 1 ; GO DISKU C_R | to run the job |

will give you the size of every one of your files on the specified disk. Armed with this information, you may be able to take appropriate action upon your own data.

Sometimes the available disk space has been eaten up by *AIPS* scratch files that are no longer in use. Tasks that abort while executing (and other mysterious events) may produce this situation. To delete all your scratch files, except those for tasks which are still running, type:

| | |
|---|---|
| > SPY C_R | to see which tasks are running. |
| > SCRD C_R | to delete the files. |

`SCRDEST` is run automatically whenever `EXIT`, `KLEENEX`, `RESTART`, or `ABORT` *task_name* are executed. Note that the imaging and deconvolution tasks `IMAGR`, `UVMAP`, `APCLN`, and `VTESS`, the data editor `TVFLG` and the sorter `UVSRT` may create large scratch and "work" files, so you should watch for "dead" copies of scratch and work files from these programs in your disk catalog. Both `MCAT` and `UCAT` will show scratch files as well as the requested file type. Note too that, if you are using more than one computer on a given disk area, only those scratch files created by your current computer will be deleted when you run the `SCRD` verb. Work files have to be deleted individually since they can be still of use after the task which created them has finished.

Chapter 11 of this *CookBook* tells you how to backup or delete your own data to relieve disk crowding. At present, all other methods for managing disk space involve system-dependent commands of one sort or another. Since these may have unexpected consequences they are not recommended.

## 3.7 Moving and compressing files

Two *AIPS* tasks are frequently used to move files from one disk to another with options to reduce the file size. They are `SUBIM`, used on images, and `UVCOP`, used on *uv* data sets. `SUBIM` uses the adverbs `BLC` and `TRC` to select a portion of the input image and `XINC` and `YINC` to select a pixel increment through the portion. If these adverbs are defaulted (set to 0), the entire image is copied. Clean component, history, and other table extension files are copied as well, but plot and slice extensions are not. Similarly, UVCOP uses a wide range of adverbs to select which IFs, channels, frequency IDs, times, antennas, and sources are to be copied. If all of these adverbs are defaulted (set to 0 or blank), then all data are copied except (optionally) for completely flagged records. A flag table may also be applied to the data. including flag tables too large to be handled by most tasks. With extensive data editing, UVCOP may produce a rather smaller data set even with no other selection criteria. Antenna, gain, and other table extension files are copied, but plot files are not. The task MOVE may be used to copy all files associated with a catalog number (without modification) to another disk or to another user number.

## 3.8 Finding helpful information in *AIPS*

Much *AIPS* documentation can be displayed on your terminal by typing HELP *word* C_R, where *word* is the name of an *AIPS* verb, task or adverb. The information given will supplement that given in the INPUTS for a verb or task. It is the only source of information on the adverbs. Type XHELP *word* C_R to display the help file in your WWW browser with links to adverbs from task help files.

To print the HELP information on your line printer, set DOCRT = -1 and enter EXPLAIN *word* C_R instead. (Using DOCRT = 1 with EXPLAIN will send the output to your terminal screen.) For the more important verbs and tasks, EXPLAIN will print extra information, not shown by HELP about the use of the program, with detailed explanations, hints, cautions and examples.

HELP may also be used to list the names of all *POPS* symbols known to AIPS by category, an operation helpful when you can't remember the name of something. Type:

| | |
|---|---|
| > HELP ADVERBS C_R | to get a list of all adverbs in the symbol table |
| > HELP ARRAYS C_R | to get a list of all array adverbs in the symbol table |
| > HELP REALS C_R | to get a list of all real adverbs in the symbol table |
| > HELP STRINGS C_R | to get a list of all character string adverbs in the symbol table |
| > HELP VERBS C_R | to get a list of all verbs, pseudoverbs, and procedures in the symbol table |
| > HELP PSEUDOS C_R | to get a list of all pseudo verbs in the symbol table |
| > HELP PROCS C_R | to get a list of all procedures in the symbol table |

In the past, *AIPS* contained a range of general HELP files which purported to list all verbs and tasks in various categories. Since these were maintained by hand, they were essentially never current and complete. That entire system has been replaced by the verbs ABOUT and APROPOS to be discussed below. A few general help files do remain, and they may even be relatively current. A list of these may be found by typing:

| | |
|---|---|
| > HELP HELP C_R | for help on HELP. |

A few general help files remain. They are POPSYM (symbols used in *POPS* interpretive language ), NEWTASK (writing and incorporating a new task into *AIPS*), and PANIC (solutions to common problems).

The HELP verb is very useful, but only if you know that the function you want exists in *AIPS* and know its name. Two functions have appeared in AIPS to assist you in this search. The first of these, APROPOS, searches all of the one-line summaries and keywords of all *AIPS* help files for matches to one or more user-specified words. For example, type

| | |
|---|---|
| > APROPOS CLEAN C_R | to display all keyword and 1-line summaries of help files containing words beginning with "clean" (in upper and/or lower case), and |
| > APROPOS 'UV PLOT' C_R | note the quote marks which are required if there are embedded blanks, or |

| | |
|---|---|
| > APROPOS UV,PLOT C_R | to display all keyword and 1-line summaries of help files containing *both* words beginning with "uv" and words beginning with "plot." |

The text files used by APROPOS are maintained by the AIPS source code maintenance (check-out) system itself. As a result, they should always be current. Of course, the quality of the results depends on the quality of the programmer-typed one-line and keyword descriptions in the help files. These were not regarded as important previously and hence are of variable quality.

The second new method for finding things in AIPS is the verb ABOUT. Type

| | |
|---|---|
| > ABOUT *keyword* C_R | to see a list of all AIPS tasks, verbs, adverbs, etc. which mention *keyword* as one of their "keywords." |

You need only type as many letters of *keyword* as are needed for a unique match. The source-code maintenance system is used to force all help files to use only a limited list of primary and secondary keywords. Software tools to update the list files have also been written, and are used at least once with every AIPS release. The list of categories recognized is as follows (where only the upper-case letters shown in the name are actually used):

```
ADVERB        POPS symbol holding real or character data
ANALYSIS      Image processing, analysis, combination
AP            Tasks using the "array processor"
ASTROMETry    Accurate position and baseline measurements
BATCH         Running AIPS tasks in AIPS batch queues
CALIBRATion   Calibration of interferometer uv data
CATALOG       Dealing with the AIPS catalog file
COORDINAtes   Handling image coordinates, conversions
EDITING       Editing tables, uv and image data.
EXT-APPL      Access to extension files (tables)
FITS          FITS format for data interchange
GENERAL       General AIPS utilities
HARDCOPY      Creating listings and displays on paper
IMAGE-UTil    Utilities for handling images
IMAGE         Transforming of images
IMAGING       Creation of images: FFT, Clean, ...
INFORMATion   General lists and user help functions
INTERACTive   Functions requiring user interaction
MODELING      Model fitting to uv or image data
OBSOLETE      Functions slated for removal
ONED          Functions for one-dimensional image slices
OOP           Tasks coded with object oriented principles
OPTICAL       Functions of interest for optical astronomy data
PARAFORM      Skeleton tasks for use in building new tasks
PLOT          Displays of image and uv data
POLARIZAtion  Calibration, analysis, display of polarization
POPS          Aspects of the AIPS' user language POPS
PROCEDURe     Creation of and available procedures
PSEUDOVErb    Pseudoverbs in the POPS language and AIPS
RUN           Creation of and available RUN files
SINGLEDIsh    Functions of interest for single-disk radio data
SPECTRAL      Functions for spectra-line and other 3D data
TABLE         AIPS table extension files
TAPE          Use of magnetic tapes
TASK          AIPS tasks - available asynchronous functions
TV-APPL       Tasks using the TV display
TV            Basic functions on the TV display
```

```
UTILITY       Basic functions on tables, uv and image data
UV            Functions dealing with interferometer uv data
VERB          Synchronous functions inside the AIPS program
VLA           Functions of particular interest for the VLA
VLBI          Functions of particular interest for very long
              baseline data.
```

A variety of synonyms are also recognized. Besides those that are merely spelling variants, the currently accepted synonyms are

```
FILES       ->  CATALOG          POSITION   ->  COORDINATES
FLAGGING    ->  EDITING          EXTENSION  ->  EXT-APPL
PRINTING    ->  HARDCOPY         PRINTER    ->  HARDCOPY
MAP         ->  IMAGE            MAP-UTIL   ->  IMAGE-UTIL
MAPPING     ->  IMAGING          LANGUAGE   ->  POPS
CUBE        ->  SPECTRAL         LINE       ->  SPECTRAL
VISIBILITY  ->  UV               VLBA       ->  VLBI
PARAMETERS  ->  ADVERB           HELPS      ->  INFORMATION
SLICE       ->  ONED
```

More detailed descriptions of new developments in *AIPS* can be found in the *AIPSLetter* published by the NRAO every six months and tied to each *AIPS* software release. It is available from the web site `http://www.aips.nrao.edu/` and is included with *AIPS* distributions. An *AIPS* Memo series is published by the NRAO with details of various aspects of the implementation of, and planning for, *AIPS*. Advanced users may also wish to receive, and contribute to, the *AIPS* electronic mail forum — `BANANAS`. There is also an electronic news group called `alt.sci.astro.aips` devoted to *AIPS* matters. This *AIPS CookBook*, many of the *AIPS* Memos, and various other publications of the *AIPS* group are available via anonymous `ftp` (at `ftp.aoc.nrao.edu`) and via the Internet and the "World-Wide Web" starting with "URL" (Universal Resource Location) `http://www.aips.nrao.edu/`).

Your local *AIPS* Manager probably receives the *AIPSLetter*, *AIPS* Memos, and `BANANAS` and can make information from them available at your site. He/she should also be aware of the electronic means of information retrieval, and be able to help you use them. If this is not the case, write to the *AIPS* Group (at NRAO, P. O. Box O, Socorro, NM 87801-0387) or send electronic mail to **daip@nrao.edu** for further information about these services.

## 3.9 Magnetic tapes

Large volumes of data are often brought into, and taken away from, *AIPS* using magnetic tape. Disk files are now also used; see § 3.10. The tape drives assigned to you are displayed as you start up `AIPS`, *e.g.*,

```
Tape assignments:
Tape 1 is IBM 9-track model 9348-012 on LEMUR
Tape 2 is HP 9-track model 88780B on LEMUR
Tape 3 is IBM 7208/001 Exabyte 8200 (external) on LEMUR
Tape 4 is ZZYZX 1.3Gb DAT (left, Model# ZW/HT1420T-CC6) on LEMUR
Tape 5 is ZZYZX 1.3Gb DAT (right; both 150mb personality) on LEMUR
Tape 6 is IBM Exabyte 8200 (internal) on LEMUR
Tape 7 is REMOTE
Tape 8 is REMOTE
```

for the heavily loaded, and now obsolete, IBM called `lemur`. The tape numbers you see above correspond to `AIPS` adverb `INTAPE` values of 1, 2, 3, and so on. The description is meant to give you some idea of which box or slot is to receive your tape. Most of the drives will have a label on them identifying their *AIPS* tape number. If in doubt, ask a local guru for help. The last two tape "drives," called REMOTE, will be discussed separately below.

In case you forget this list, the verb TAPES will show it to you. TAPES is even capable of going out on the Internet and asking what devices are available to an *AIPS* user at the computer specified by the REMHOST adverb (if it is running TPMON)!

### 3.9.1 Hardware tape mount

On some *AIPS* systems, tapes are handled by designated operators. Before mounting tapes, read Appendix Z (for NRAO sites) or obtain directions from your local *AIPS* Manager or operators for methods by which tapes are to be handled. Most *AIPS* systems, however, are on the self-service plan. In that case, the simplest thing to do is to find a drive of the required type without a tape in it. There is no way in most Unix systems (certainly not in Linux or Mac OS/X) of reserving a tape drive globally for your exclusive use, though once you have it MOUNTed from within AIPS, no other AIPS user can access it. It is most efficient to use a tape drive directly connected to your computer (and hence listed as you started up AIPS). However, any "AIPSable" drive will do. Mount the tape physically on the drive following the mounting instructions in Appendix Z or those posted at your installation for the particular kind of tape drive. For half-inch (nine-track) tapes, don't forget to insert a write ring if you intend to write on the tape or to remove any write ring if you intend only to read the tape. Exabyte and DAT tapes have a small slide in the edge of the tape which faces out which takes the place of the write ring of 9-track tapes. For 8mm (Exabyte) tapes push the slide to the right (color black shows) for writing and to the left (red or white shows) for reading. With 4mm DAT tapes, the slide also goes to the right for writing (but white or red shows) and to the left for reading (black shows). Note the identification number *m* marked on the drive you are using, as you will need to provide that number to the software for mounting and dismounting the tape and for executing *AIPS* tasks which read or write tape.

### 3.9.2 Software mounting local tapes

*After* you have the tape physically mounted on the tape drive, *AIPS* must also be told that you have done this and which tape drive you have chosen. This step is called a "software tape mount." It is necessary to wait until the mechanism in the drive has "settled down", *i.e.*, when the noises and flashing lights have stopped, before you can do the software mount. This operation is done from inside AIPS by typing:

| | |
|---|---|
| > INTAPE *m* C_R | to specify the drive labeled *m*. |
| > DENSITY *dddd* C_R | to set the density to *dddd* bpi if needed. |
| > MOUNT C_R | to mount the tape in software. |

Read any messages which appear on your terminal carefully since they report the success, failure, and/or limitations of the operation. The meaning of "density" with modern magnetic tape devices is mostly a matter of convention. With half-inch, 9-track tapes, *AIPS* understands the usual 800, 1600, and 6250 bytes per inch densities. A special value for density, 22500, is taken to mean high density (5-Gbyte) mode on 8mm (Exabyte) tapes. You must set the DENSITY adverb to one of these magic values, but in many cases it does not matter which one you use.

Please dismount the tape as soon as you are finished with it, using:

| | |
|---|---|
| > INTAPE *n* ; DISMO C_R | to dismount a tape from the drive labeled *n*. |

The dismount verb should cause the tape to be rewound and, in most cases, ejected from the drive. Please remove the tape from the tape drive promptly so that others may use the drive. Note that exiting AIPS under most circumstances — even with CTRL C — will cause your mounted tapes to be dismounted automatically.

### 3.9.3 Software mounting REMOTE tapes

On all *AIPS* systems, the last two tape drives are indicated as `REMOTE`. This means you can use two additional adverbs in `AIPS` to access tape drives on other computers. It doesn't matter where the computer is, as long as it's connected via Internet and has *AIPS* installed on it in the conventional way. For example, if you wanted to use *AIPS* tape drive 2 on remote host `rhesus`, you would type:

| | |
|---|---|
| > REMHOST 'RHESUS' ; REMTAPE 2 C_R | |
| > DENSITY *dddd* C_R | to set the density to *dddd* bpi if needed. |
| > INTAPE *n* ; MOUNT C_R | set local "tape" number and software mount |

where $n$ is the number of one of the REMOTE tape assignments in the list of tape drives you see on `AIPS` startup. If you know which computers are to provide remote tape services for you, it is a good idea to specify them when you start `AIPS` using the `tp=`*hostname* option (see § 2.2.3). In this way, you make certain that the *AIPS* dæmon tasks `TPMON`$n$ which provide the remote service are running where they are needed.

### 3.9.4 Using tapes in *AIPS*

*AIPS* provides a number of basic tools for managing magnetic tapes. It is very helpful to have a list of the contents of magnetic tapes you intend to read. To list the contents of a tape on the line printer:

| | |
|---|---|
| > TASK 'PRTTP' ; INP C_R | to review the inputs. |
| > NFILES 0 C_R | to list all files on the tape. |
| > PRTLEV 0 C_R | to list the image headers but not the details — both more and less detailed listings are available. |
| > DOCRT FALSE C_R | to print on the line printer. |
| > GO C_R | to run the task. |

It is also a good idea to run `PRTTP` on your data tapes after you have written them, but before you have deleted the data from disk. `PRTTP` reads the the tape record by record to test for tape errors as well as to check the data format.

The `AIPS` program has a number of verbs to position and check magnetic tapes. These include

| | |
|---|---|
| > REWIND C_R | to rewind the tape, *e.g.*, after running `PRTTP`. |
| > NFILES *n* ; AVFILE C_R | to advance the tape $n > 0$ file marks. |
| > NFILES -*n* ; AVFILE C_R | to move the tape backwards to the $n^{\mathrm{th}}$ previous file. |
| > NFILES 0 ; AVFILE C_R | to position the tape at the start of the current file. |
| > AVEOT C_R | to advance the tape to the end of information, usually for the purpose of adding more data at the end. |
| > TPHEAD C_R | to display the contents of the data file at the current tape position. |

Users are encouraged to treat magnetic tapes with some caution. The tapes themselves can have — or develop — errors which render the data in the file unavailable. Furthermore, there are no generally accepted standards governing magnetic tape software in the industry. As a consequence, each Unix operating system handles them differently and each can change over time. This creates great difficulties in *AIPS* and may cause your version not to handle all tape devices in a fully compatible manner.

## 3.10 *AIPS* external disk files

*AIPS* maintains a wide range of disk files for its own use internally. Unless you intend to write programs for *AIPS* you need not be concerned about their formats or, in many cases, even their existence. However, recent versions of *AIPS* also support "external" disk files to be read from and written to disk directories controlled by you. You may read and write from/to binary "FITS-disk" files with TPHEAD, UVLOD, IMLOD, FITLD, FITTP, and FITAB.. AIPS and some tasks also allow text files to be read or written from/to disk. For example, all print tasks can be instructed to append their output to user-specified text files. These can be examined later with an editor or written to tape with standard tape utilities. The two PostScript tasks, LWPLA and TVCPS, can be instructed to write their output plots in user-specified text files for later processing and, for example, inclusion in manuscripts. And AIPS itself can be instructed to take its input commands from user-created text files.

### 3.10.1 Disk text files

The most significant user control over external files is the specification of the file's full name, *i.e.*, its directory path and its name in that path. You specify the directory path by creating an environment variable ("logical name" in *AIPS*peak) *before* starting AIPS. The simplest way is to change directory (cd Unix utility) to the area you wish to use and enter

% setenv MYAREA ‘pwd‘ C_R

where *MYAREA* is a logical name of your choosing (but all in *upper case*). Note that the pwd is surrounded by backward single quote marks. The grammar above is for users of c-shell and tc-shell. Users of korn, bourne, and bash shells would type:

$ MYAREA=‘pwd‘; export MYAREA C_R

also with backward single quote marks. If you are going to read a text file into *AIPS*, its name must also be in upper-case letters. Finally, inside AIPS, you specify the file with, *e.g.*,

> OUTPRINT = 'MYAREA:3C123.PRT' C_R

where 3C123.PRT is any all upper-case file name of your choosing. Note the surrounding quote marks and the colon that separates the logical name and the file name portions. You may put the file anywhere under any name you choose, but we request that you put it an area owned by you, if you have one, or that you use an identifying name and a standard *AIPS* area set aside for the purpose. Files left around in the *AIPS* directories are subject to summary deletion. Be sure that *AIPS* has the privilege to write into your directory; use chmod to allow appropriate write privilege on the directory file (try to avoid world write!). On Unix systems, duplicate file names are not allowed and *AIPS* tasks will usually die when trying to write a file name that already exists. Print tasks will append to pre-existing files, however. In 31DEC09, the verb FILEZAP allows you to delete external files from inside AIPS. The name of the file to be deleted is given as an immediate argument.

In 31DEC02, file names may also be entered as complete path names, so long as they do not require more than 48 characters, the length of the adverb data values. Thus

```
INTEXT = '/home/primate2/egreisen/AIPS/Text.prt
```

Note that the trailing quote mark is left off and this is the last command on the input line so that the case is preserved.

Ordinary text files are used in *AIPS* for a variety of purposes. Every print task offers the option of saving the output in a file specified by OUTPRINT rather than immediately printing and discarding it. Similarly, output PostScript files from LWPLA and TVCPS may be saved in files specified by OUTFILE rather than immediately printing and discarding them. They may be used later in larger displays, or even enclosed as figures in a TEX document such as this *CookBook*. OUTTEXT is used by numerous other tasks, such as SLICE and IMEAN, to write output specific to the tasks which may be of use to other programs. *AIPS* tables may even be written as text files by task TBOUT, edited by the user, and then read back in by task TBIN. History files may be revised in a similar manner. Adverbs INFILE, INTEXT, CALIN, and INLIST may be used by a number of tasks to specify source models, lists of "star" positions, holography data, and the like. Television color tables are read from and written to disk text files specified with the OFMFILE adverb.

### 3.10.2 RUN files

RUN files are ordinary text files containing AIPS commands to be executed in sequence in a batch-like manner. They are often used to define procedures which you save in your own area or in an *AIPS*-provided public area with the logical name $RUNFIL. The name of the file must be all upper case letters, followed by a period, followed by your user number as a three-digit "extended-hexadecimal" number with leading zeros. (To translate between decimal and extended hexadecimal, use the *AIPS* procedures or the AIPS verbs called EHEX and REHEX.) The files are edited from Unix level using emacs, vi, textedit or your other preferred text editor. For example, log in to the aips (or your own) account. From Unix level, type:

% cd $RUNFIL — to change to RUN area.

% emacs MAPIT.03D C_R

to edit with emacs a file called MAPIT for user 121. You may now also use any area of your choosing instead of the public $RUNFIL area. For instructions on the individual editors, consult the appropriate Unix Manuals. Instruction manuals for the GNU emacs editor are available from local computer staff. In 31DEC02, a SAVE area (§ 3.5) may be written as a RUN file if you first GET the area and then use SG2RUN.

To use the RUN file, define a logical name as in the previous Section. Then start up AIPS under your user number and enter

> VERSION = 'MYAREA' C_R — where MYAREA is your disk area, or

> VERSION = ' ' C_R — if $RUNFIL is to be used

> RUN *FILE* C_R — to execute the file named *FILE.uuu*

where *uuu* is your user number if extended hexadecimal with leading zeros to make three digits.

### 3.10.3 FITS-disk files

FITS is an IAU-endorsed binary format standard for astronomical data heavily used by *AIPS* for almost all of its data on disk and magnetic tape. In fact, it is the only format written by *AIPS* except for simple tape copying. The basic FITS paper (by Wells, Greisen, and Harten) appeared in *Astronomy & Astrophysics Supplement Series*, Volume 44, pages 363–374, 1981. The newsgroup sci.astro.fits is devoted to discussion of FITS. World-wide web users can access the FITS home page at

http://fits.gsfc.nasa.gov/fits_home.html

*AIPS* also supports the FITS format written to disk in exactly the same form as it is written to magnetic tape. The tasks FITTP and FITAB may be instructed to write their output files on disk rather than on tape. Likewise, TPHEAD, FITLD, UVLOD, IMLOD, and PRTTP can read from disk. To write to a FITS-disk file, specify:

> DATAOUT '*filename*' C_R — where *filename* is the name of the desired output file.

and to read from a FITS-disk file, you specify:

> DATAIN '*filename*' C_R

where you must specify *filename* with environment variables ("logical names" in *AIPS*peak), *e.g.*,

> DATAOUT = 'MYDATA:3C123.FIT' C_R

in exactly the same way as described for text files in § 3.10.1. There is a standard public area, called logically FITS, which you may use for reading and writing FITS-disk files. FITTP will use this area if you do not specify a logical name. Be aware that older files will be purged from this public area when space is needed.

Note too that FITTP will write only one disk file per execution; the DOALL option is disabled when writing to disk.

In the 31DEC02 release of *AIPS*, there is a package of procedures to assist in writing and reading more than one FITS-disk file at a time. Enter RUN WRTPROCS to define the procedures. The procedure FITDISK will write a single disk catalog file to a disk file using a name based on the *AIPS* file name parameters. You may then construct loops invoking FITDISK to write multiple files. For example:

> FOR I=1:10; GETN(I); FITDISK; END C_R

Such file names are useful for their mnemonic content, but must be read back one at a time. The procedure WRTDISK will dump a range of catalog numbers to disk under names that allow the procedure READISK to read them back as a group. These two procedures are particularly useful when moving your data between computer architectures (*e.g.*, from a Solaris to a Linux computer). Note that 31DEC07 contains a stand-alone program REBYTE which can do the conversion directly including files of all types.

Beginning with the 31DEC03 release, FITLD can read multiple disk files in either the normal FITS format (as written by FITTP) or the special FITS format written by the VLBA correlator. The only requirement for this operation is that file names end in sequential numbers beginning with 1. FITAB has the ability to write special FITS files with visibility data in tables. These files may be broken up into multiple files, called "pieces," for size and reliability considerations. These pieces, when written to disk, have names ending in sequential numbers. Special code in FITLD and UVLOD recognize these pieces and read the requested number of them as if they were in one file.

Remote FITS-disk files may be read in much the same manner as remote magnetic tapes. Type HELP DATAIN C_R or HELP DATAOUT C_R for details.

FITS-disk files are written as Fortran files and hence are available also to user-coded programs. The Fortran specifications for the file are ACCESS='DIRECT', RECL=2880, FORM='UNFORMATTED' in the OPEN statement for Unix systems. Most Fortrans cannot read or write files larger than 2 Gigabytes, so *AIPS* now reads and writes these files with C subroutines. Users may also, of course, code programs to create such files to be read by FITLD, IMLOD or UVLOD. Consult *GOING AIPS*, Volume 2, Chapter 13 for details on how to do this.

One of the main uses for FITS-disk files is to transfer data over the Internet between computers. For example, to transfer a file from rhesus (in Charlottesville) to kiowa (at the AOC), log in to rhesus, change to the directory in which you wish to store the file (for example, cd $FITS C_R), and enter:

| | |
|---|---|
| % ftp kiowa C_R | to start ftp to the remote system. |
| Name (kiowa:...): *loginame* C_R | to log in to account *loginame*. |
| Password: *password* C_R | to give the account's password. |
| ftp> cd *directory* C_R | to change to the *directory* name containing the file. |
| ftp> binary C_R | to allow reading of a binary file. |
| ftp> hash C_R | to get progress symbols as the copy proceeds. |
| ftp> put *filename* C_R | to send the file |
| ftp> quit C_R | to exit from ftp. |

The file should then be in the desired directory. You may have to rename it, however, to a name in all upper-case letters since that may be required by *AIPS*. (See § 3.10.1 for a trick that allows you to use lower-case letters in file names.) The file format will be correct. In general it is better to use the ftp program to "get" files instead of "put"ting them; things tend to go faster that way.

An alternative to using ftp is to use the rcp (remote copy) Unix utility or to write the output file directory in the appropriate area on the other computer. In order to do this, you have to have accounts on both machines, and you should have set up a .rhosts file (see the Unix manual page on rhosts for instructions). Once you know this works (test it via, *e.g.*, rsh rhesus whoami), the syntax for the remote copy is:

% rcp $FITS/MYFILE.FITS kiowa:/AIPS/FITS/MYFILE C_R (this shows how you would copy it from `rhesus` to `kiowa`). A secure copy (`scp`) would be better if you have set up the secure connection capability.

If you wish to copy a FITS-disk file from one machine to another within a site, check if you can just use the Unix `cp` command; this is often possible if the remote disk is mounted (or can be auto-mounted) via NFS (the Network File System).

FITS files may be compressed with standard utility programs such as `gzip`. This does not produce much compression for files written with full dynamic range and floating-point format. However, `FITAB` offers the option of writing images (not *uv* data) which are quantized at some suitable level. These are capable of significant compression even if they are in floating-point format.

### 3.10.4 Other binary data disk files

Data written by the on-line system of the VLA are now often found in disk files rather than on tape. These data are available from an archive of all VLA data. See

`http://archive.cv.nrao.edu/`

for information on how to access your current data and all data for which the proprietary period has expired. `FILLM` and `PRTTP` can read the disk files produced from the archive, including reading more than one such file in a single execution. In this case, the file names must end in consecutive numbers beginning with `NFILES`+1.

## 3.11 The array processor

In running numerous important tasks in *AIPS* you will notice references to an "array processor." This used to be an expensive device attached to computers which allowed them to run some *AIPS* tasks 100 times faster than they would run without the device. To support our less fortunate colleagues, we wrote a software emulation of the array processor which we call the pseudo array processor. This uses highly optimized routines running on data stored in the "AP memory." By now, the hardware devices are all gone and only the software emulation remains. We have found that this is still a good model to obtain highly optimized software performance.

In the `31DEC07` release, the pseudo-AP changed to use dynamic memory allocated by the calling task as needed rather than a fixed amount of memory that would be much too large for some problems and too small for others. In `31DEC08`, the largest *AIPS* tasks, including `IMAGR` and `CALIB` in self-cal mode, changed to use rather large amounts of memory if needed to reduce the number of times the visibility data need to be read. Two new verbs appeared at this time: `SIZEFILE` returns the size of a disk file and `SETMAXAP` sets the maximum computer memory that may be used for the pseudo-AP. The latter allows the user to limit the AP on smaller or busier machines or to permit really large memory usage when large amounts of memory are available. See HELP SETMAXAP for a discussion of the essential considerations.

## 3.12 Additional recipes

### 3.12.1 Cream of banana soup

1. Cook 1 quart green **banana** pulp, 1 1/2 quarts **chicken stock**, 1 small **celery stalk**, 1/2 **onion**, 1 **carrot**, 1 small **bay leaf**, 5 **peppercorns**, and **salt** to taste together for about 30 minutes until the mixture thickens.
2. Strain over 1/4 cup **flour** and 1/4 cup **butter** which have been combined as for a white sauce. Cook until thickened.
3. Just before serving, add 2 cups **cream** or **milk** and heat.
4. Serve with a slice of lemon on each plate as a garnish.

### 3.12.2 Banana curried chicken

1. Fry 2 chopped **onions** in 50 ml **cooking oil** until light brown.
2. Add 1/4 cup **cake flour** and mix well. Add 1 (cup?) **chicken stock** gradually while stirring.
3. Add 1 cup **raisins**, 1 teaspoon **salt**, 2 pounds cooked, boned **chicken**, 5 sliced **bananas**, 2 grated **apples**, 2 tablespoons grated **lemon rind**, 1 tablespoon **sugar**, 1 1/2 tablespoons **curry powder**, 1 **bay leaf**, 4 **peppercorns**.
4. Cover saucepan and simmer for 20 minutes.
5. Remove bay leaf. Add 1 cup **cream** and heat just before serving.
6. Serve on a bed of rice. Decorate with pineapples if preferred.

Thanks to Turbana Corporation (`www.turbana.com`).

### 3.12.3 Banana storage

Bananas ripen after harvesting. They do it best at room temperature. Because of this there are three stages to banana storage.

1. **On the counter:** When you buy a bunch of bananas that are not exactly at the ripeness you want, you can keep them at room temperature until they are just right for you. Be sure to keep them out of any plastic bags or containers.
2. **In the refrigerator:** If there are any bananas left, and they are at the ripeness you like, you can put them in the refrigerator. The peel will get dusty brown and speckled, but the fruit inside will stay clear and fresh and at that stage of ripeness for 3 to 6 days.
3. **In the freezer:** If you want to keep your bananas even longer, you can freeze them. Mash the bananas with a little lemon juice, put them in an air tight freezer container and freeze. Once they're defrosted, you'll go bananas baking bread, muffins and a world of other banana yummies. Or, you can freeze a whole banana on a Popsicle stick. When it is frozen, dip it in chocolate sauce, maybe even roll it in nuts, then wrap it in aluminum foil and put it back in the freezer. Talk about a scrumptious snack.

# 4 CALIBRATING INTERFEROMETER DATA

This chapter focuses on ways to do the initial calibration of interferometric fringe-visibility data in $\mathcal{AIPS}$. The sections which follow concentrate primarily on continuum calibration for connected-element interferometers, especially the VLA. However, the information in these sections is useful to spectral-line, solar, and VLBI observers as well. For specific advice on the new EVLA, consult Appendix E. For additional advice on spectral-line calibration, see § 4.7; for advice on calibrating observations of the Sun, see § 4.8; and for the gory details of VLBI, read Chapter 9. After the initial calibration has been completed, data for sources with good signal-to-noise are often taken through a number of cycles of imaging with self-calibration. See § 5.4 for information on these later stages of the reduction process. For accurate calibration, you must have accurate *a priori* positions and structural information for all your calibration sources and accurate flux densities for at least one of them. It is best if the calibration sources are unresolved "point" sources, but it is not required.

For the basic calibrations, visibility ("*uv*") data are kept in "multi-source data sets," each of which contains, in time order, visibility data for one or more "unknown" sources and one or more calibration sources. Associated with these data are "extension" files containing tables describing these data. When VLA archive data are first read into $\mathcal{AIPS}$ a number of basic tables are created and filled with information describing the data set. These are

1. `AN` (antennas) for sub-array geometric data, date, frequency, polarization information, *etc.*,
2. `FQ` (frequency) for frequency offsets of the different IFs (IF pairs in VLA nomenclature),
3. `NX` (index) to assist rapid access to the data,
4. `SU` (source) for source specific information such as name, position, velocity, and
5. `TY` (temperature) for measured system temperatures and nominal sensitivities
6. `CL` (calibration) for calibration and model information,

An initial `CL` table contains gains due to known antenna functions of elevation and measured atmospheric opacities. VLBI, and especially VLBA, data sets will end up with even more table files. Calibration and editing tasks then create, as needed, other tables including

7. `BP` (bandpass) for bandpass calibration,
8. `FG` (flag) for flagging (editing) information, and
9. `SN` (solution) for gain solutions from the calibration routines.
10. `BL` (baseline) for baseline-, or correlator-, dependent corrections,

All of these tables can be written to, and read back from, FITS files along with the visibility data. These, and any other, $\mathcal{AIPS}$ tables can be manipulated and examined using the general tasks `PRTAB`, `TACOP`, `TABED`, `TAMRG`, `TASRT`, `TAFLG` and `TAPPE`.

The visibility data within the multi-source data set are not normally altered by the calibration tasks. Instead, these tasks manipulate the tabular information to describe the calibration corrections to be applied to the data and any flagging (deletion) of the data.

The AIPS programs discussed in this chapter are part of a package that has been developed to calibrate interferometer data from a wide range of connected-element and VLB arrays, especially the VLA and VLBA. These programs therefore support many functions (and inputs) that are not required when calibrating normal VLA data. The examples given below show only the essential parameters for the operation being described, but, to get the results described, it is essential that you check *all* the input parameters before running any task. Remember that AIPS adverbs are global and will be "remembered" as you proceed. A list of calibration-related symbols is given in § 13.6, but a possibly more up-to-date list can be obtained by typing ABOUT CALIBRAT in your AIPS session. More general information on calibration can be routed to your printer by typing DOCRT FALSE ; EXPLAIN CALIBRAT C_R, while deeper information on a specific task is obtained with EXPLAIN *taskname* C_R.

When you are satisfied with the calibration and editing (or are simply exhausted), the task SPLIT is used to apply the calibration and editing tables and to write *uv* files, each containing the data for only one source. These "single-source" *uv* files are used by imaging and deconvolution tasks that work with only one source at a time. Many of the tasks described in this chapter will also work on single-source files. For VLA calibration, there are several useful procedures described in this chapter and contained in the RUN file called VLAPROCS. Each of these procedures has an associated HELP file and inputs. Before any of these procedures can be used, this RUN file must be invoked with:

> RUN VLAPROCS C_R — to compile the procedures.

There is a "pipeline" procedure designed to do a preliminary calibration and imaging of ordinary VLA data sets. This provides a good first look at the data and was much improved in 31DEC06. Nonetheless, the results are still not likely to be of publishable quality. To run the pipeline, enter

> RUN VLARUN C_R — to compile the procedures.
> INP VLARUN C_R — to review the input adverbs and, when ready,
> VLARUN C_R — to execute the pipeline.

## 4.1 Copying data into AIPS multi-source disk files

There are several ways to write VLA data to AIPS multi-source *uv* data sets on disk. They include:

1. For VLA data from the archive, use FILLM to read one or more disk files; see § 3.10.4. The VLA format was changed on January 1, 1988, but all older data were translated and archived in the modern format. On July 1, 2007, the ModComps were replaced with modern computers and the format had an essential change made to it. Use 31DEC06 or later FILLM to read data from the post-ModComp era. Archive data are obtained from `https://archive.nrao.edu/archive/e2earchive.jsp`

2. For an AIPS multi-source data set written to a FITS tape or FITS disk during an earlier AIPS session, use UVLOD or FITLD to read the tape.

3. For single-source data sets that are already on disk and are very similar in structure, use UV2MS on one of them to create a multi-source data set, and then on each of the others to append them to that multi-source data set. Each of the input data sets should have the same number of polarizations, IFs, spectral channels, and "random parameters." UV2MS also makes no corrections for differences in observed source positions or frequencies. After all are appended, use UVSRT to put the data in time-baseline order and INDXR to make an index and initial (null) calibration file.

4. For single-source data sets that are already on disk and are not sufficiently similar in structure for the method above, use MULTI on each single-source file to convert to multi-source format. Then use DBCON to concatenate the individual multi-source files into one big multi-source file. Finally use UVSRT, if needed, to put the data in time-baseline order and INDXR to make an index and initial (null) calibration file.

5. Data from the Australia Telescope may be loaded from disk files into AIPS using the task ATLOD which is now included with AIPS.

Data from other telescopes can be read into AIPS only if they are written in AIPS-like FITS files already or if you have a special format-translation program for that telescope. The VLBA correlator produces a format which is translated by the standard AIPS task FITLD; see § 4.1.2. A translation task for the Westerbork Synthesis Telescope (WSLOD) is available from the Dutch, but is not distributed by the NRAO with the normal AIPS system.

### 4.1.1 Reading from a VLA archive tape or file using FILLM

To load a *uv* data file to disk from a VLA archive tape, you must (hardware) mount the tape on a tape drive and then (software) mount the tape inside the AIPS program. See § 3.9 for a discussion of this process. Note that data taken with the (E)VLA starting in 2007 must be loaded with a FILLM from AIPS version 31DEC06 or later. It is strongly recommended that you begin by obtaining an index of the contents of your data tape. Reference dates, time ranges, file numbers, frequencies observed, and the like are reported in the index and are needed to guide the actual loading of the data. To print an index of the archive tape, use task PRTTP:

| | |
|---|---|
| > TASK 'PRTTP' ; INP C_R | to review the inputs needed. |
| > NFILES 0 C_R | to start at the beginning of tape. |
| > PRTLEV 0 C_R | to give complete summaries; only PRTLEV = -3 actually affects the output (adversely). |
| > DOCRT FALSE C_R | to send output to the line printer. |
| > DATAIN ' ' C_R | to read from tape not disk. Multiple VLA archive files may be read from disk beginning with 31DEC02. |
| > GO C_R | to index the tape. |

Typical inputs to FILLM might be:

| | |
|---|---|
| > TASK 'FILLM' ; INP C_R | to review the inputs needed. |
| > DATAIN ' ' C_R | to read from tape not disk. Multiple VLA archive files may be read from disk beginning with 31DEC02. |
| > OUTNA ' ' C_R | to take the default output file name. |
| > OUTDI 3 C_R | to write the data to disk 3 (one with enough space). |
| > DOUVCOMP TRUE C_R | to write visibilities in compressed format to save disk space. |
| > DOCONCAT TRUE C_R | to concatenate files if this is second tape. |
| > VLAOBS 'AC238' C_R | to select only data from observing program AC238. The default is to load data from *all* programs. |
| > NFILES 4 C_R | to skip the first 4 files on the archive tape. |
| > DOWEIGHT 1 C_R | Data weights will depend on the "nominal sensitivity" and should be calibrated along with the visibility amplitudes (DOCALIB = 1). |
| > CPARM 30, 0 C_R | to average the data for 30 seconds; default is no averaging. |
| > CPARM(6) 1 C_R | to select VLA sub-array 1. |
| > CPARM(7) 2000 C_R | to have observations within 2 MHz be regarded as being at the same frequency. |
| > CPARM(8) 2 C_R | to use a 2-minute interval for the CL table; default is 5 min. |
| > CPARM(9) 0.25 C_R | to use a 15-second interval for the TY table; default is the input data interval. |

| | |
|---|---|
| > DPARM 0 C_R | to have no selection by specific frequency. |
| > REFDATE '*yyyymmdd*' C_R | to specify the year, month, and day of the reference date. This should be the first date in the data set (or earlier). All times in *AIPS* will be measured with respect to that date and must be positive. The default is the first date included by the data selection adverbs, which may not be the desired one. Note that REFDATE is only a reference point; it does not affect which data are loaded from the tape. |
| > TIMERANG *db* , *hb* , *mb* , *sb* , *de*, *he* , *me* , *se* C_R | to specify the beginning day, hour, minute, and second and ending day, hour, minute, and second (wrt REFDATE) of the data to be included. The default is to include all times. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when you're satisfied with inputs. |

Be careful when choosing the averaging time with CPARM(1). If you have a large data set, setting this time too *low* will make an unnecessarily large output file; this may waste disk space and slow the execution of subsequent programs. Setting it too *high* can, however, (1) smear bad data into good, limiting the ability to recognize and precisely remove bad data, (2) smear features of the image that are far from the phase center, and (3) limit the dynamic range that can be obtained using self-calibration. If you need a different (usually shorter) averaging time for the calibrator sources than for your program sources, use CPARM(10) to specify the averaging time for calibrators. See Lectures 12 and 13 in *Synthesis Imaging in Radio Astronomy*[1] for general guidance about the choice of averaging time given the size of the required field of view and the observing bandwidth.

CPARM(2) controls a number of mostly esoteric options. If your data include the Sun or planets, you must set CPARM(2) = 16 to avoid having each scan on the moving source assigned a different name. The adverb DOWEIGHT = 1 has the same affect as CPARM(2) = 8 and both select the use of the nominal sensitivity to scale the data weights. When this is done, the weights will be $1/\sigma^2$ as they should for imaging, with $\sigma$ in "Jy" in the same uncalibrated scale as the fringe visibilities. Having selected this option, you should apply any amplitude calibration to the weights as well as the visibilities. If you store the data in compressed form, only one weight may be retained with each sample. Any differences between polarizations and/or IFs in that sample will be lost. Uncompressed data require less cpu, but more real, to read but 2 to 3 times as much disk space to store.

CPARM(2)=2048 allows you to load data as correlation coefficients, which can be scaled to visibilities later with TYAPL (§ 4.1.1.1). CPARM(3) controls which on-line flags are applied by FILLM, which now always writes an OF table containing information about these flags. That information can be viewed with PRTOF and applied selectively to the data at a later time with OFLAG.

FILLM was changed September 21, 2001 in the 31DEC01 release to write a weather (WX) table to the output file. At the same time, it was changed to use "canned" VLA antenna gain curves and a balance of the current with a seasonal model weather data to estimate opacity and gain corrections to be written into the first calibration (CL) table. These functions are controlled by adverbs CALIN and BPARM and may be turned off, although the default is to make the corrections. In subsequent tasks, set DOCALIB = 1 to use these initial calibration data. If, for some reason, the data weights do not depend on the nominal sensitivity, use DOCALIB=100 to apply calibration.

Some words of warning about the use of NFILES are appropriate here. VLA archive tapes used to contain 3 tapes files for every actual data file. Most archive tapes today do not have these ANSI standard-label files,

[1] *Synthesis Imaging in Radio Astronomy*, Astronomical Society of the Pacific Conference Series, Volume 6 "A Collection of Lectures from the Third NRAO Synthesis Imaging Summer School" eds. R. A. Perley, F. R. Schwab and A. H. Bridle (1989)

but still tend to begin with a header (non-data) tape file. If you set the NFILES adverb carefully based on the index printed by PRTTP, you should have no problem with these "excess" tape files.

FILLM is designed to read all your data from tape in one pass. All data meeting the selection criteria will be read from the input tape and filled into a *uv* multi-source file. Three selection criteria are always active: (a) TIMERANG, if non-zero, will restrict processing of data to the specified range of times (with respect to REFDATE); (b) VLAOBS, will restrict processing to the specified VLA observing code (which will be set to the code in the first valid data record if you do not specify it); and (c) CPARM(6) will restrict processing to the specified VLA sub-array (which, if you do not specify it, will be set to 1 if VLAOBS is not specified or to the first sub-array belonging to VLAOBS). All other selection criteria may be overridden by setting DOALL to TRUE.

Where possible, FILLM will try to place all data in one file. However, in many cases this is not possible. For instance so-called "channel 0" data from a spectral-line observation will be placed in a separate file from its associated line data. Similarly, scans which have differing numbers of frequency channels will also be placed into separate files. Another case is observations made in mode LP, *i.e.*, one IF-pair is set to L band, the other to P band. In this case the two bands will be split into separate files. Yet another case arises when there are observations of different bandwidths. All of this should be relatively transparent to the user.

If your data are on multiple tapes, you can write them all into the same data file by specifying DOCONCAT on the second (and subsequent) runs of FILLM.

A significant reduction in the disk space used may be achieved using the compressed format invoked by adverb DOUVCOMP; this factor is 1.89 for 2-IF continuum data and approaches 3.0 for line data. Almost all tasks can process compressed *uv* data. The task UVCMP allows you to change the formats of *uv* data sets between *compressed* and *uncompressed*, if required to use one of the few aberrant tasks.

FILLM and many *AIPS* tasks are able to handle multiple, logically different, frequencies within a multi-source data set. FILLM does this by assigning an FQ number to each observation and associating a line of information about that frequency in the FQ file associated with the data set. Users should note that this concept can become quite complicated and that not all tasks can handle it in full generality. In fact, most tasks can only process one FQ number at a time. Polarization calibration works only on one FQ at a time since the antenna file format allows for only one set of instrumental polarization parameters. Therefore, it is *strongly* advised that you fill continuum experiments which involve multiple frequencies into separate data sets. FILLM will separate bands automatically, but you will have to force any remaining separation. To do this, (a) use the QUAL adverb in FILLM, assuming that you have used separate qualifiers in OBSERVE for each frequency pair; (b) use the DPARM adverb array in FILLM to specify the desired frequencies precisely; or (c) use the UVCOP task to separate a multiple FQ data set into its constituent parts. Note that the first two options require multiple executions of FILLM, while the third option requires more disk space.

Spectral-line users and continuum observers using different frequencies in the same band should be aware of the FQ entry tolerance. Each frequency in a *uv* file will be assigned an FQ number as it is read from tape by FILLM. For spectral-line users, the observing frequency will normally change as a function of time due to Doppler tracking of the Earth's rotation, or switching between sources or between spectral lines; in general, this will cause different scans to have different FQ numbers. FILLM assigns an FQ number to a scan based on the FQ tolerance adverb CPARM(7) which defines the maximum change of frequency allowed before a new FQ number is allocated. If CPARM(7) < 0, the the same FQ number is assigned to all data in spectral-line data sets. If CPARM(7) is positive, a scan will be assigned to an existing FQ number if

$$\|\nu_{current} - \nu_{firstFQ}\| < \texttt{CPARM}(7)$$

where $\nu_{firstFQ}$ is the frequency of the first sample to which the particular FQ number was assigned. If no match is found, then a new FQ number is created and assigned and another line added to the FQ table file. Alternatively, if CPARM(7) is zero, then the FQ tolerance is assumed to be half of the maximum frequency difference caused by observing in directions 180 degrees apart (*i.e.*, $\Delta\nu = 10^{-4} \times \nu$).

An example: if an observer observes the 1612, 1665 and 1667 MHz OH masers in VY CMa and NML Cygnus, then presumably he would like his data to have 3 FQ numbers, one associated with each OH transition. However, running FILLM with CPARM(7) set to 0 would produce 6 FQ numbers because the frequency difference between the masers in VY CMa and NML Cygnus is greater than the calculated tolerance of 160 kHz. Therefore, in order to ensure that only 3 FQ numbers are assigned, he should set CPARM(7) to 1000 kHz. Setting CPARM(7) < 0 would result in all data having the same FQ number, which is clearly undesirable.

For most continuum experiments the FQ number will be constant throughout the database. Normally any change in frequency should be given a new FQ number. To achieve this, FILLM treats CPARM(7) differently for continuum. If CPARM(7) $\leq 0.0$, then FILLM assumes a value of 100 kHz. A positive value of CPARM(7) is treated as a tolerance in kHz as in the spectral line case.

**Note:** *If your uv database contains several frequency identifiers, you should go through the calibration steps for each* FQ *code separately.*

FILLM is prepared to try to read past up to 50 parity or other tape errors. Do not be alarmed by a few warning messages, especially at the end of tape on old 9-track, half-inch tapes. These are relatively normal and will cause no harm. If FILLM is executing correctly, your message terminal will report the number of your observing program, the VLA archive tape format revision number, and then the names of the sources as they are found on the tape. Once FILLM has completed, you can find the database on disk using:

> INDI 0 ; UCAT C_R

This should produce a listing such as:

```
Catalog on disk  3
Cat Usid Mapname      Class  Seq  Pt     Last access      Stat
  1  103 25/11/88    .X BAND.   1 UV 05-FEB-1994 12:34:16
```

You might then examine the header information for the disk data set by:

> INDI 3 ; GETN 1 ; IMH C_R

This should produce a listing like:

```
 Image=MULTI     (UV)         Filename=25/11/88    .X BAND.   1
 Telescope=VLA                Receiver=VLA
 Observer=AC238               User #=  103
 Observ. date=25-NOV-1988     Map date=05-FEB-1994
 # visibilities    191317     Sort order  TB
 Rand axes: UU-L-SIN  VV-L-SIN  WW-L-SIN  BASELINE  TIME1
            SOURCE  FREQSEL WEIGHT  SCALE
 --------------------------------------------------------------
 Type    Pixels   Coord value  at Pixel    Coord incr   Rotat
 COMPLEX      1   1.0000000E+00    1.00 1.0000000E+00    0.00
 STOKES       4  -1.0000000E+00    1.00-1.0000000E+00    0.00
 IF           2   1.0000000E+00    1.00 1.0000000E+00    0.00
 FREQ         1   8.4110000E+09    1.00 1.2500000E+07    0.00
 RA           1    00 00 00.000    1.00      3600.000    0.00
 DEC          1    00 00 00.000    1.00      3600.000    0.00
 --------------------------------------------------------------
 Maximum version number of extension files of type HI is   1
 Maximum version number of extension files of type AN is   1
 Maximum version number of extension files of type NX is   1
 Maximum version number of extension files of type SU is   1
 Maximum version number of extension files of type FQ is   1
 Maximum version number of extension files of type WX is   1
 Maximum version number of extension files of type CL is   1
```

```
 Keyword = 'CORRMODE'  value = '        '
 Keyword = 'VLAIFS  '  value = 'ABCD    '
```

This header identifies the file as a multi-source file (Image=MULTI) with 191317 floating-point visibilities in time-baseline (TB) order. There are two entries on the IF axis. These correspond to the VLA's "AC" and "BD" IF-pairs respectively. The description of the frequency (FREQ) axis shows that the first IF ("AC") is at 8411 MHz and has 12.5 MHz bandwidth. The parameters of the second IF-pair ("BD") are determined from the data in the FQ table file and cannot be read directly from this header; these values are shown in the 'SCAN' listing from LISTR. The header shown above indicates that the data are in compressed format since the number of pixels on the COMPLEX axis is 1 and the WEIGHT and SCALE random parameters are present. Uncompressed data does not use these random parameters and has 3 pixels on the COMPLEX axis.

The term "IF" can be confusing. At the VLA, IFs "A" and "C" correspond to right-hand and left-hand circularly polarized (RHC and LHC) signals, respectively, and are normally for the same frequency in an observing band. Such pairs, if at the same frequency, are considered to be one "IF" in AIPS. An observation which was made in spectral line mode "2AC" is considered at the VLA to have two "IFs" whereas within AIPS this would be filled as one "IF" with two polarizations if they were both observed with the same frequency, the same number of channels, and the same channel separation. If these conditions do not hold, then they are filled into separate *uv* files, each with a single IF and a single polarization. The term "sub-array" is also confusing. At the VLA — and in task FILLM — sub-array means the subset of the 27 antennas actually used to observe your sources. (The VLA allows up to 5 simultaneous sub-arrays in this sense.) In the rest of AIPS, sub-array refers to sets of antennas used together at the same time. If observations from separate times (*e.g.*, separate array configurations) are concatenated into the same file, then AIPS will regard the separate sets of antennas as different "sub-arrays" whether or not the same physical antennas occur within more than one of these sub-arrays.

If your experiment contains data from several bands FILLM will place the data from each band in separate data sets. Also, if you observed with several sets of frequencies or bandwidths in a given observing run these will be assigned different FQ numbers by FILLM. You can determine which frequencies correspond to which FQ numbers from the 'SCAN' listing provided by LISTR. Line data are divided into the "channel 0" (central 3/4 of the of the observing band averaged) and the spectra. Data observed in the "LP" mode (or any other two-band mode) will be broken into separate data sets, one for each band.

As a practical note, setting the start and stop times of the data for your experiment with TIMERANG will cause FILLM to read all valid data up to the stop time you have specified and then exit normally. This way, it will not read to the end of the VLA archive file. The default action of FILLM (to read to the end of the tape if TIMERANG = 0) can be particularly annoying if your data are at the very start of a large archive data file. When the data are successfully loaded to disk, type DISMOUNT C_R to dismount your input tape.

#### 4.1.1.1 Editing and applying nominal sensitivities to VLA data

FILLM scales the correlation coefficients by the instantaneous measured "nominal sensitivities," producing data approximately in deci-Jy. The VLA nominal sensitivities are stored in the TY table as "system temperatures" ($T_{sys}$). For calibration purposes, it is best to have the nominal sensitivities applied, but it may be better to use a clipped and/or time-smoothed version of those sensitivities. If you want to do this, load the $T_{sys}$ data into the TY table with the highest time resolution possible by setting CPARM(9)=0 in FILLM. FILLM can also be told not to apply the nominal sensitivities and therefor produce correlation coefficients by setting CPARM(2)=2048, but this is not strictly necessary. In order to smooth and clip the TY table use the task TYSMO. If you have done editing such as QUACK, it may help to copy the data with UVCOP, applying your flag table not only to the visibilities but also to the TY table (UVCOPPRM(6)=3) before running TYSMO to remove questionable values at the start of scans. Alternatively, in 31DEC10, SNEDT will apply the data flags to the table allowing you to write a new, cleaned-up version of the table. Then a TY table may be applied (and/or removed) from a data set with TYAPL:

| | |
|---|---|
| > TASK 'TYAPL' ; INP C_R | to review the inputs needed. |
| > INDI *n* ; GETN *m* C_R | to select the correct data set. |
| > FREQID 1 C_R | to select FQ number 1. |
| > INVERS 1 C_R | TY table to remove from data, will only work if data are not already correlation coefficients. |
| > IN2VERS 2 C_R | smoothed TY table to apply to data, will only work if data is in correlation coefficient form — either initially or after removal of INVERS. |
| > INP C_R | to re-check *all* the inputs parameters. |
| > GO C_R | to start the task. |

EVLA users (see Appendix E) should have an SY table which contains system gain and temperature data. These data *should* be applied to the visibility data in order to correct for measured gain changes and to convert the data weights from a simple count of the integration time into more meaningful values. Tasks TYSMO and SNEDT may be used to clean up the SY data and then TYAPL may be used to apply the gain and system temperature data.

### 4.1.2 Reading data from FITS files with FITLD

FITLD is used to read FITS-format tapes and FITS files on disk into AIPS. It recognizes images, single- and multi-source *uv* data sets, and the special FITS *uv*-data tables produced by the VLBA correlator. In particular, VLA data sets that have been read into AIPS previously with FILLM and then saved to tape (or pseudo-tape disk) files with FITTP can be recovered for further processing with task FITLD. (The older task UVLOD will also work with *uv* data sets in FITS format, but it cannot handle image or VLBA-format files.)

A multi-source data file with all of its tables can be read from a FITS tape by:

| | |
|---|---|
| > TASK 'FITLD' ; INP C_R | to review the inputs needed. |
| > INTAPE *n* C_R | to specify the tape drive for input from tape. |
| > DATAIN '*filename*' C_R | if the input is from a FITS disk file (see § 3.10.3). |
| > DOUVCOMP TRUE C_R | to write visibilities in compressed format. |
| > OUTNA ' ' C_R | take default (previous AIPS) name. |
| > OUTCL ' ' C_R | take default (previous AIPS) class. |
| > OUTSEQ 0 C_R | take default (previous AIPS) sequence #. |
| > OUTDI 3 C_R | to write the data to disk 3 (one with enough space). |
| > INP C_R | to review the inputs (several apply only to VLBA format files). |
| > GO C_R | to run the program when you're satisfied with inputs. |

FITLD is the equivalent of FILLM, but for output from the VLBA, rather than the VLA, correlator. The data-selection adverbs SOURCES, QUAL, CALCODE, and TIMERANG and the table-control adverbs CLINT and FQTOL are used, for VLBA-format data only, in FITLD in ways similar to the data-selection and control adverbs of FILLM. See Chapter 9 for more specific information.

## 4.2 Record keeping and data management

### 4.2.1 Calibrating data with multiple FQ entries

In general an observing run with the VLA, especially a spectral-line run, will result in a *uv* data file containing multiple FQ entries. In early versions of the AIPS software, the different FQ entries would automatically have been placed in different physical files. Now, FILLM allows you to place all of them in the same file. This may be convenient, but it has a number of costs. If a file contains multiple, independent frequencies, then it occupies more disk space and costs time in every program to skip the currently unwanted data (either a small cost when the index file is used or a rather larger cost when the file must be read sequentially). Since multiple frequencies are still not handled correctly in all programs (*i.e.*, polarization calibration) and since it is not possible to calibrate all of the different FQ data in one pass, you might consider separating the multiple frequencies into separate files (as described in § 4.1.1). In either case, you must calibrate each frequency with a separate pass of the scheme outlined below. There are three adverbs to enable you to differentiate between the different FQ entries: FREQID enables the user to specify the FQ number directly (with -1 or 0 meaning to take the first found); SELFREQ and SELBAND enable the user to specify the observing frequency and bandwidth to be calibrated (the tasks then determine to which FQ number these adverbs correspond). If SELFREQ and SELBAND are specified they override the value of FREQID.

There are certain bookkeeping tasks that must be performed between calibrating each FQ set. First, you must ensure that you have reset the fluxes of your secondary calibrators by running SETJY with OPTYPE = 'REJY' — if not, this will cause the amplitudes of your data to be incorrect. Second, it is wise to remove the SN tables associated with any previous calibration using the verb EXTDEST. Although this is not strictly necessary, it will simplify your bookkeeping.

A practical note: it is often useful to have used different qualifiers for different frequencies. This gives you another "handle" on the data. Unfortunately, not all programs use the QUAL, or even the CALCODE, adverb.

### 4.2.2 Recommended record keeping

It is useful to print a summary of the time stamps and source names of the scans in your data set. This reminds you of the structure of your observing program when you decide on interpolation and editing strategies, and may help to clarify relationships between later, more detailed listings of parts of the data set. It is also useful to have a printed scan summary and a map of the antenna layout if you need to return to processing the data months or years later. Finally, it is also making sure that all AIPS input parameters have their null (default) values before invoking the parts of the calibration package, such as CALIB, that have many inputs. The null settings of most parameters are arranged to be sensible ones so that basic VLA calibration can be done with a minimum of specific inputs; but some inputs may lose their default values if you interleave other AIPS tasks with the calibration pattern recommended below. Therefore, you should *always* review the input parameters with INP *taskname* C_R before running task *taskname*.

We suggest that you begin a calibration session with the following inputs:

| | |
|---|---|
| > DEFAULT LISTR C_R | to set all LISTR's inputs to null (default) values. |
| > TASK 'LISTR' ; INP C_R | to review the inputs needed. |
| > INDI $n$; GETN $m$ C_R | to select the data set, $n = 3$ and $m = 1$ in FILLM example above. |
| > TPUT CALIB C_R | to store null values for later use with CALIB. |
| > OPTYP 'SCAN' C_R | to select scan summary listing. |
| > DOCRT -1 C_R | to send the output to the printer. |

| | |
|---|---|
| > INP C_R | to review the inputs for LISTR. |
| > GO C_R | to run the program when the inputs are set correctly. |

Note that the DEFAULT LISTR sets the adverbs to select all sources and all times and to send printed output to the terminal rather than the printer. It is also very useful to have a printed summary of your antenna locations, especially a list of which ones you actually ended up using. To do this, enter

| | |
|---|---|
| > NPRINT 0 C_R | to do all antennas |
| > INVERS n C_R | to do sub-array *n* |
| > GO PRTAN C_R | to print the list and a map of antenna locations. |

In looking over the output from LISTR, you may notice that some of the sources you wish to use as calibrators have a blank "Calcode". To mark them as calibrators, use:

| | |
|---|---|
| > TASK 'SETJY' ; INP C_R | to select the task and review its inputs. |
| > SOURCES '*sor1*' , '*sor2*' , '*sor3*' , . . . C_R | to select the unmarked calibrator sources. |
| > OPTYPE 'RESE' C_R | to reset fluxes and velocities. |
| > CALCODE 'C' C_R | to mark the sources as "C" calibrators. |
| > GO C_R | to run the task. |

This operation will let you select the calibrators by their Calcodes rather than having to spell out their names over and over again. You may wish to consider separate calibrator codes for primary and secondary gain calibrators to make them easier to separate. You may reset a calibrator code to blank by specifying CALCODE = '----'.

## 4.3 Beginning the calibration

After loading the data to disk, it has been traditional to begin with a substantial session of data checking and editing. With data from the VLA, this is always time consuming and often not necessary. Nonetheless, it is probably a good idea to check for two specific kinds of problems before beginning the actual calibration. These are corrupted data in the first record of most scans and totally dead antennas. Many other problems in the data are quickly and easily diagnosed by carefully inspecting the solution tables produced from the calibrators on un-edited data. Missing antennas and erratic amplitudes due to sampling problems and RF interference can be spotted from the SN tables and the closure-error messages produced by CALIB. If you *can't* spot errors from these, you may not need to edit the calibrator data. If the SN tables have well-behaved phases for most antennas and rapidly rotating phases for one or two, then you may need to apply baseline corrections rather than editing. See § 4.4.4 for details of how to make antenna-position corrections.

The next section tells how to detect simple problems in the data and eliminate them to reduce the warnings from the calibration tasks. The following sections tell you how to enter fluxes for the primary calibrator sources and do a preliminary calibration for all calibrators. In so doing, you should generate one or more solution (SN) tables containing the complex gains at the times of the calibration observations. These tables may be examined for problems with the observations. If you find problems, then you need to edit the data or apply baseline corrections and should consult § 4.4. If you do not find problems, you may proceed directly to § 4.5. (Of course, you may decide to edit the data from your program sources at a later stage of the data reduction and have to return to § 4.4 then.)

### 4.3.1 Initial editing

The warning messages from the calibrations described in the next sections may be reduced by flagging those antennas which were not actually working, but which were not flagged by the on-line system. Another problem that has plagued the VLA (and other interferometers) persistently is that the first record in scans can be corrupted; usually its amplitudes are lower than they should be. These data can be flagged using TVFLG or UVFLG, but this can be time consuming. The task EDITA described in § 4.4.2 is now likely to be the best initial (and perhaps only) editing tool which you need. For a more traditional approach, we recommend that you do the following before beginning your regular data editing. Use the task LISTR on your terminal (to save time and paper) to see if you have the problem:

| | |
|---|---|
| > TASK 'LISTR' C<sub>R</sub> | to set the data listing task |
| > INDI *n* ; GETN *m* C<sub>R</sub> | to select the data set, $n = 3$ and $m = 1$ above. |
| > OPTYPE 'LIST' C<sub>R</sub> | to select column listing format |
| > ANTEN *a1* , 0 C<sub>R</sub> | to select one reliable antenna to display. |
| > BASEL 0 C<sub>R</sub> | to select all baselines to this antenna. |
| > SOURCES ' ' ; CALCODE '*' C<sub>R</sub> | to select all calibrator sources only. |
| > TIMER 0 C<sub>R</sub> | to select all times. |
| > STOKES 'RR' C<sub>R</sub> | to examine only one Stokes at a time. |
| > BIF 1 ; EIF BIF C<sub>R</sub> | to specify the "AC" IFs only; it is quicker to look at only 1 IF at a time although more than one can be listed in sequence. |
| > FREQID 1 C<sub>R</sub> | to select FQ number (each FQ number must be done separately). |
| > DOCRT 132 C<sub>R</sub> | to see full width display on the terminal. Use your window manager to stretch the window to ≥ 132 characters width. |
| > DOCALIB -1 C<sub>R</sub> | to turn off calibration. |
| > DPARM 0 C<sub>R</sub> | to select amplitudes with no averaging. |
| > INP C<sub>R</sub> | to re-check *all* the inputs parameters. |
| > GO C<sub>R</sub> | to start the task. |

The task will prompt you for a C<sub>R</sub> after each "page full" of output. When you have seen enough, enter Q. This display will let you determine whether the start-of-scan problem infects your data and, if so, how badly. If it is rare, forget it for now and use manual flagging methods later if needed. If it is widespread, use the *AIPS* task QUACK:

| | |
|---|---|
| > TASK 'QUACK' C<sub>R</sub> | |
| > SOURCES ' ' C<sub>R</sub> | to select all sources. |
| > TIMER 0 C<sub>R</sub> | to select all times. |
| > ANTENNAS 0 C<sub>R</sub> | to select all antennas. |
| > FLAGVER 1 C<sub>R</sub> | to insert flagging information in FG table 1. |
| > OPCODE 'BEG' C<sub>R</sub> | flag first APARM(2) min of each scan. |
| > REASON 'BAD START OF SCAN' C<sub>R</sub> | reason for the flagging. |
| > APARM 0 , 1/6 , 0 C<sub>R</sub> | flag first 10 seconds of each scan. |
| > GO C<sub>R</sub> | |

The display generated above will also allow you to determine quickly which antennas are absent, which antennas are present but dead, and, with more careful examination, which antennas are flaky and may need special consideration. "Dead" antennas are visible in this display as columns with small numbers — columns that differ by factors of two or so from the others are generally fine. To be thorough, it is probably best to check the other IF:

| | |
|---|---|
| > BIF 2 ; EIF 2 C<sub>R</sub> | to specify the "BD" IFs. |
| > GO C<sub>R</sub> | to run the program again. |

as well as STOKES = 'LL'.

To remove the dead antennas, run UVFLG. For example, if antennas 6, 9, and 22 were bad for the full run in both IFs and Stokes, they could be deleted with

| | |
|---|---|
| > TASK 'UVFLG' ; INP C<sub>R</sub> | to select the editor and check its inputs. |
| > TIMER 0 C<sub>R</sub> | to select all times. |

| | |
|---|---|
| > BIF 1 ; EIF 2 C_R | to specify the "AC" and "BD" IFs. |
| > BCHAN 0 ; ECHAN 0 C_R | to flag all channels. |
| > FREQID 1 C_R | to flag only the present FQ number. |
| > ANTEN 6 , 9, 22 C_R | to select the antennas. |
| > BASEL 0 C_R | to select all baselines to these antennas. |
| > STOKES ' ' C_R | to select all Stokes. |
| > REASON = 'ZOMBIE ANTENNA' C_R | to set a reason. |
| > OUTFGVER 1 C_R | to select the first (only) flag table. |
| > INP C_R | be careful with the inputs here! |
| > GO C_R | to run the task when ready. |

### 4.3.2 Primary flux density calibrators

The flux densities of 3C286 (1328+307) and 3C48 (0134+329) on the scale of Baars *et al.* (Astr. & Ap., **61**, 99 (1977)) are given in the 1990 VLA Calibrator Manual as:

3C286:

$$\log S = 1.480 + 0.292 \log \nu - 0.124 (\log \nu)^2$$

3C48:

$$\log S = 2.345 + 0.071 \log \nu - 0.138 (\log \nu)^2$$

where $S$ = flux density in Jy and $\nu$ is Frequency in MHz. These values are, at a few selected frequencies:

| Frequency (MHz) | S 3C286 (Jy) | S 3C48 (Jy) |
|---|---|---|
| 1465 | 14.51 | 15.37 |
| 1680 | 13.55 | 13.76 |
| 4885 | 7.41 | 5.36 |
| 8415 | 5.20 | 3.15 |
| 14765 | 3.48 | 1.75 |
| 15035 | 3.44 | 1.71 |
| 22485 | 2.53 | 1.09 |

Careful measurements made with the D array of the VLA have shown that the Baars *et al.* (1977) coefficients are in error slightly, based on the assumption that the Baars' expression for 3C295 is correct; see the VLA Calibrator Manual. Revised values of the coefficients have been derived by Rick Perley. Task SETJY has these formulae built into it, giving you the option (OPTYPE 'CALC') of letting it calculate the fluxes for primary calibrator sources 3C295, 3C48, 3C286, 3C147, 3C138, and 1934-638. The default setting of APARM(2) = 0) will calculate the flux densities of 3C48, 3C147, and 3C286 according to the 2010 Perley coefficients, while APARM(2) = 1 will calculate the flux densities using the 1999.2 Perley values , and APARM(2) = 2 will compute the flux densities using the original Baars *et al.* coefficients. Earlier (1990, 1995) Perley coefficients may also be selected with still higher values of APARM(2). SETJY will recognize both the 3C and IAU designations (B1950 and J2000) for these sources. You may insert your own favorite values for these sources instead (OPTYPE = ' ') and you will have to insert values for any other gain calibrators you intend to use. In 31DEC10 adverbs SPECINDX and SPECURVE allow you to enter spectral index information to help set the calibrator fluxes.

Unfortunately, since all the primary flux calibrators are resolved by the VLA in most configurations and at most frequencies, they cannot be used directly to determine the amplitude calibration of the antennas without a detailed model of the source structure, see Figure 4.1 as an example. Beginning in April 2004, model images for the calibrators at some frequencies are included with AIPS. Models of 3C286, 3C48, 3C138, and 3C147 are available for all 6 traditional bands of the VLA *except* 90 cm. Type CALDIR C_R to see a list of the currently available calibrator models. Sources which are small enough to be substantially unresolved by the VLA have variable flux densities which must be determined in each observing session. A common method used to determine the flux densities of the secondary calibrators from the primary calibrator(s) is to compare the amplitudes of the gain solutions from the procedure described below.

Use SETJY to enter/calculate the flux density of each primary flux density calibrator. The ultimate reference for the VLA is 3C295, but 3C286 (1328+307), which is slightly resolved in most configurations at most frequencies, is the most useful primary calibrator. CALIB has an option that will allow you to make use of Clean component models for calibrator sources. You are strongly encouraged to use the existing models. If you follow past practice at the VLA, you may have to restrict the *uv* range over which you compute antenna gain solutions for 3C286, and may therefore insert a "phony" flux density appropriate only for that *uv* range at this point. In both cases, the following step should be done. CALIB will scale the total flux of the model to match the total flux of the source recorded by SETJY in the source table. This corrects for the model being taken at a somewhat different frequency than your observations and for the model containing most, but not all, of the total flux. An example of the inputs for SETJY, where you let it calculate the flux, would be:

| | |
|---|---|
| > TASK 'SETJY' ; INP C_R | |
| > SOURCES '3C286' , ' ' C_R | if you used 3C286 as the source name. |
| > BIF 1 ; EIF 2 C_R | will calculate for both "AC" and "BD" IFs. |
| > OPTYPE 'CALC' C_R | perform the calculation. |
| > APARM(2) = 0 C_R | to use the VLA "1990" coefficients. |
| > INP C_R | to review inputs. |
| > GO C_R | when inputs okay. |

Or you can set the flux manually as shown below:

| | |
|---|---|
| > TASK 'SETJY' ; INP C_R | |
| > SOURCES '3C286' , ' ' C_R | if you used 3C286 as the source name. |
| > ZEROSP 7.41 , 0 C_R | I flux 7.41 Jy, Q, U, V fluxes 0. |
| > BIF 1 ; EIF 1 C_R | selects "AC" IF. |
| > INP C_R | to review inputs. |
| > OPTYPE ' ' | use values given in ZEROSP. |
| > GO C_R | when inputs okay. |
| > BIF 2 ; EIF 2 C_R | selects "BD" IF. |
| > ZEROSP 7.46, 0 C_R | I flux 7.46 Jy at the 2$^{nd}$ IF, Q, U, V fluxes 0. |
| > GO C_R | |

Note that, although SOURCES can accept a source list, ZEROSP has room for only one set of I, Q, U, V flux densities. To set the flux densities for several different sources or IFs, you must therefore rerun SETJY for each source and each IF, changing the SOURCES, BIF, EIF, and ZEROSP inputs each time. Alternatively, set ZEROSP to the flux at 1 GHz and enter SPECINDX and SPECURVE adverbs to describe the dependence with frequency.

CALIB will use the V polarization flux in the source table if one has been entered. The RR polarization will be calibrated to I+V and the LL to I-V. While this has little practical use with circular polarizations because V is almost always negligible, it can be used for linearly polarized data from the WSRT. That telescope has equatorially mounted dishes, so the XX polarization is I-Q and the YY is I+Q independent of parallactic angle. For WSRT data, you should relabel the polarizations to RR/LL and enter `I, 0, 0, -Q` for ZEROSP, since Q is not negligible in standard calibrators.

### 4.3.3 First pass of the gain calibration

#### 4.3.3.1 Using calibrator models

It is now considered standard practice to use flux calibrator models and you are strongly encouraged to do so. As mentioned above, all the primary flux calibrators are resolved at *most* frequencies and configurations. Figure 4.1 shows the visibilities and image of the commonly used calibrator 3C48 at X-band, it is obvious this source is far from being point like. Since April 2004, source models have been shipped with *AIPS* as FITS files. Currently, models for 3C48, 3C286 and 3C137 are available for all bands except 90 cm and 3C147 at all bands except, X, C and 90 cm. Additional models are in the works, so you should always check to see what is available:

> CALDIR C<sub>R</sub> — to list the available models by source name and band code.

The primary calibration task in *AIPS* is CALIB. Most of the complexity of CALIB can be hidden using the procedure VLACALIB. Before attempting to use this procedure, you must first load it by typing:

> RUN VLAPROCS C_R — to compile the procedures.

Type HELP VLAPROCS for a full list of the procedures available in VLAPROCS.

The procedure VLACALIB *automatically* downloads and uses calibrator models, if one is available and the inputs are set correctly. After you have loaded VLACALIB you may invoke the calibrator model usage by setting:

| | |
|---|---|
| > INDI *n* ; GETN *m* C_R | to select the data set, $n = 3$ and $m = 1$ above. |
| > CALSOUR = '*Cala*' C_R | to name *one* primary flux calibrator to invoke automatic calibrator model usage. |
| > UVRANGE 0 C_R | set to zero to invoke automatic calibrator model usage. |
| > ANTENNAS 0 C_R | set to zero to invoke automatic calibrator model usage. |
| > REFANT *n* C_R | reference antenna number — use a reliable antenna located near the center of the array. |
| > MINAMPER 10 C_R | display warning if baseline disagrees in amplitude by more than *10%* from the model. |
| > MINPHSER 10 C_R | display warning if baseline disagrees by more than 10° of phase from the model. |
| > DOPRINT 1 ; OUTPRINT ' ' C_R | to generate significant printed output on the line printer. |
| > FREQID 1 C_R | use FQ number 1. |
| > INP VLACALIB C_R | to review inputs. |
| > VLACALIB C_R | to make the solution and print results. |

This procedure load the will load the calibrator model (using CALRD) and use it when it runs CALIB, then print any messages from CALIB about closure errors on the line printer, and finally run LISTR to print the amplitudes and phases of the derived solutions. Plots of these values may be obtained using task SNPLT.

Alternatively, you can load the model in manually using CALRD :

| | |
|---|---|
| > TASK 'CALRD' C_R | to select the calibrator source reading task. |
| > OBJECT '3C286' C_R | to load a model of 3C286. |
| > BAND 'K' C_R | to select the available model at K band. |
| > OUTDISK *n* C_R | to write the model image and Clean components to disk *n*. |
| > GO C_R | to run the task and load the model. |

Then you may select the model image with GET2N for use in CALIB. Example inputs for CALIB are:

> TASK 'CALIB'; INP C_R — to select task and review inputs.

| | |
|---|---|
| > INDI $n$ ; GETN $m$ CR | to select the data set, $n = 3$ and $m = 1$ above. |
| > CALSOUR = '*Cala*' , ' ' CR | flux calibrator for which you have a model. |
| > UVRANGE 0 CR | no *uv* limits needed. |
| > ANTENNAS 0 CR | antenna selection not needed. |
| > REFANT $n$ CR | reference antenna number — use a reliable antenna located near the center of the array. |
| > WEIGHTIT 1 CR | to select $1/\sigma$ weights which may be more stable. |
| > IN2DI $o$ ; GET2N $p$ CR | to select the model. |
| > NCOMP 0 CR | to use all components. |
| > SOLMODE 'A&P' CR | to do amplitude and phase solutions. |
| > APARM(6) 2 CR | to print closure failures. |
| > MINAMPER 10 CR | to display warning if baseline disagrees in amplitude by more than *10%* from the model. |
| > MINPHSER 10 CR | to display warning if baseline disagrees by more than 10° of phase from the model. |
| > CPARM(5) 1 CR | to vector average amplitudes over spetral channels and then scalar average them over time before determining solution. |
| > FREQID 1 CR | to use FQ number 1. |
| > INP CALIB CR | to review inputs. |
| > GO CR | to make the solution. |

CALIB will use the clean components table attached to the model to find antenna gain solutions. It will sum the clean components within a certain radius of the center of the map (so that confusing sources that are part of the model do not influence the gain) and scale them to the flux in the SU table. Therefore, you must still run SETJY before running CALIB.

After running CALIB check the solutions for all antennas with SNPLT or LISTR (OPTYPE='GAIN'). If you have multiple primary or secondary calibrators you will have to run CALIB separately for each, using models where they are available and restricting the UVRANGE and ANTENNAS where they are not. You can either write into the same SN table by setting SNVER to a table number or to different SN tables by setting SNVER = 0. Then you you can proceed as normal flagging and editing your data and proceed to final calibration as described in § 4.5.

#### 4.3.3.2 Flux calibration without calibrator models

We strongly encourage you to use the available models. If words alone do not convince you, we encourage you to look at Figure 4.1 which shows you the visibilities and image of 3C48 at X-band. It is rather far from a point source. At lower frequencies there are other sources in the field which have an effect on phases as well. If you must do it the old-fashioned way, then you have to limit the *uv* ranges and antennas to where the calibrator is a point source. The range of baseline length used can be controlled by the adverb UVRANGE. If there are too few baselines to a given antenna, accurate solutions may not be possible; therefore, it is frequently necessary to limit the antennas used to the inner antennas on each arm. (The antenna pad numbers which include the order number from the array center on each arm can be determined by running PRTAN; see § 4.2.2.) CALIB may fail to produce any valid solutions if antennas with no data are included in the solution. The VLA Calibrator Manual suggests the following sets of UVRANGE (in kilo$\lambda$) and inner number of antennas.

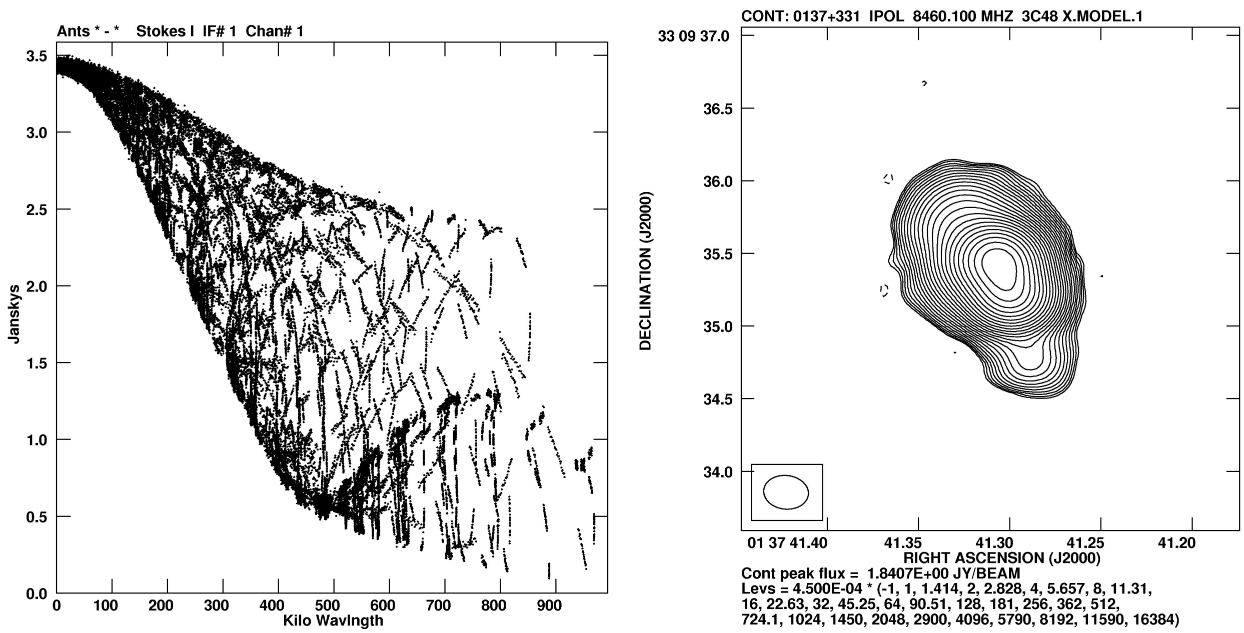



Figure 4.1: Displays of the visibilities (left) and image (right) for the fundamental calibration source 3C48. The plots were made using UVPLT, KNTR, and LWPLA; see § 6.3.1 and § 6.3.2.1. Data from all VLA configurations including the VLBA antenna in Pie Town were used. A point source would have visibilities that have a constant amplitude at all baselines and an image matching the beam plotted in the lower-left corner.

3C48, 3C147, 3C138:

| Band | UVRANGE | Array | No. ant. per arm | Notes |
|---|---|---|---|---|
| 90cm | 0- 40 | All | All | |
| 20cm | 0- 40 | A | 7 | |
| | " | B,C,D | All | |
| 6cm | 0- 40 | A | 3 | |
| | " | B,C,D | All | |
| 3.6cm | 0- 40 | A | 2 | |
| | " | B | 6 | |
| | " | C,D | All | |
| 2cm | 0- 40 | A | 1 | Not recommended |
| | " | B | 4 | |
| | " | C,D | All | |
| 1.3cm | 0- 40 | A | 1 | Not recommended |
| | " | B | 3 | |
| | " | C,D | All | |

```
3C286:
Band     UVRANGE    Array   No. ant. per arm   Notes
----   -----------  -----   ----------------  -----------------
90cm       0- 18      A            7
             "      B,C,D         All

20cm       0- 18      A            4
             "      B,C,D         All
          90-180      A           All          Reduce flux 6%

6cm        0- 25      A            1           Not recommended
             "        B            4
             "       C,D          All
         150-300      A           All          Reduce flux 2%

3.6cm     50-300      A            3           Reduce flux 1%
             "        B            7           Reduce flux 1%
             "        C           All          Reduce flux 1%
           0- 15      D           All

2cm        0-150      A            3
             "      B,C,D         All

1.3cm      0-185      A            2
             "        B            7
             "       C,D          All
```

The values of UVRANGE for each secondary calibrator may be determined from the VLA Calibrator manual or by using UVPLT to plot the amplitudes as a function of baseline length. Since the latter works correctly only after a complete calibration has been done, it is often reasonable to use the 3C286/3C48 restrictions for all calibrator sources (at this stage). If your secondary calibrators are point sources over most baselines, then it may save you time to do the full calibration now. Not only will it save you, possibly, from re-running CALIB at a later time with a wider UVRANGE, but it will provide information on the data quality from the longer baselines.

Once you have read in procedure VLACALIB (see § 4.3.3.1), you may use it to invoke CALIB. You will have to do this once for each calibrator, unless you can use the same UVRANGE for more than one of them. Thus,

| | |
|---|---|
| > INDI *n* ; GETN *m* C<sub>R</sub> | to select the data set, $n = 3$ and $m = 1$ above. |
| > CALSOUR = '*Cala*' , '*Calx*' C<sub>R</sub> | to name two calibrators using the same UVRANGE and other adverb values. |
| > UVRANGE *uvmin uvmax* C<sub>R</sub> | *uv* limits, if any, in kilo$\lambda$. |
| > ANTENNAS *list of antennas* C<sub>R</sub> | antennas to use for the solutions, see discussion above. |
| > REFANT *n* C<sub>R</sub> | reference antenna number — use a reliable antenna located near the center of the array. |
| > MINAMPER 10 C<sub>R</sub> | display warning if baseline disagrees in amplitude by more than *10%* from the model. |
| > MINPHSER 10 C<sub>R</sub> | display warning if baseline disagrees by more than 10° of phase from the model. |
| > DOPRINT 1 ; OUTPRINT ' ' C<sub>R</sub> | to generate significant printed output on the line printer. |
| > FREQID 1 C<sub>R</sub> | use FQ number 1. |
| > INP VLACALIB C<sub>R</sub> | to review inputs. |
| > VLACALIB C<sub>R</sub> | to make the solution and print results. |

This procedure will first run CALIB, then print any messages from CALIB about closure errors on the line printer, and finally run LISTR to print the amplitudes and phases of the derived solutions. Plots of these values may be obtained using task SNPLT.

If the secondary calibrators require different values of UVRANGE, then CALIB must be run until it has run for all calibration sources. Attached to your input data set is a solution SN table. Each run of CALIB writes in this table (if SNVER = 1), for the times of the included calibration scans, the solutions for both the "AC" and "BD" IFs using the flux densities you set for your calibrators with SETJY or GETJY. (CALIB assumes a flux density of 1 Jy if no flux density is given in the SU table.) If a solution fails, however, the whole SN table can be compromised, forcing you to start over. It is possible to write multiple SN tables with SNVER = 0. Later programs such as GETJY and CLCAL will merge all SN tables which they find (if told to do so). Tables with failed solutions must be deleted.

The LISTR outputs provided by VLACALIB should be examined carefully to check on the calibration; amplitudes should be consistent (both among antennas and among time stamps) and phases should vary smoothly. If you decide that the solutions are not acceptable (*e.g.*, there are no valid solutions) *and* you are creating a new SN table on each run of CALIB, then delete that SN table using EXTDEST before proceeding. The later stages of processing assume that all extant SN tables are valid. Note that re-running CALIB on the same SN table simply over-writes the old solutions with new ones. CALIB gives messages which indicate the number of valid and invalid solutions which should help you evaluate the results. If VLACALIB is run using the values of MINAMPER and MINPHSER shown above, it will print a list of baselines and times which show substantial "closure" errors. (If you use CALIB directly rather than VLACALIB, you may use these adverbs plus CPARM(2-4) to get additional reports and statistics on closure errors and CPARM(7) to limit reporting of individual closure errors.) It is important to remember that normal thermal noise and, at longer wavelengths, background confusion cause closure errors too. Thus, some closure error on weaker calibrators is to be expected and may be ignored. CALIB will ignore errors larger than MINAMPER and MINPHSER if the data weights (after application of the source model) indicate that they have significance less than CPARM(7) times the expected error. Interpreting closure errors is a real art, but a couple of generalizations are possible. If the same closure error shows up in both polarizations and both IFs, then you have probably got a resolved object. If one antenna dominates the closure list, especially if it is at only one IF and/or one polarization, then you have got a bad antenna. If the errors are uniformly small, distributed amongst all antennas, and not correlated between IFs or polarizations, then you have simply noise and/or background confusion. In this case, do *not* edit the data — the randomness of the "errors" nearly always averages out nicely and the solution is just fine. Large or systematic errors indicate either that the calibrator source is resolved or that there are problems with the data requiring editing. If a calibrator is being resolved, delete the bad SN table and re-run VLACALIB with an appropriate UVRANGE. One can now actually flag data based on closure errors using the DOFLAG option. This should be used carefully, if at all and then only if the model of the calibration source contains all of its flux. Modern versions of CALIB display some statistics of closure problems automatically and allow the use of "robust" solution methods.

## 4.4 Assessing the data quality and initial editing

At each stage in the data calibration process, it is a good idea to take a look at the data to determine their quality and then to "flag" (edit, delete) those that are suspect or clearly bad. Having begun the actual calibration, it is important to get an impression of the overall quality of the data and to edit out any obviously corrupted data, (*e.g.*, bad integrations that were not detected and expunged by the on-line monitoring system, high amplitudes due to interference, unstable amplitudes due to undetected equipment problems, *etc*). During the initial calibration, you need to do this only on the observations of calibration sources. However, at a later stage, you may also need to apply techniques similar to those described below to your program sources. If you do edit any calibration data at this point, you must re-run CALIB following the instructions given above for the affected sources.

The philosophy of editing and the choice of methods are matters of personal taste and the advice given below should, therefore, be taken with a few grains of salt. When interferometers consisted of only a couple of movable antennas, there was very little data and it was sparsely sampled. At that time, careful editing to delete all suspect samples, but to preserve all samples which can be calibrated, was probably justified. But modern instruments produce a flood of data, with the substantial redundancy that allows for self-calibration on strong sources. Devoting the same care today to editing is therefore very expensive in your time, while the loss of data needlessly flagged is rarely significant. A couple of guidelines you might consider are:

- Don't flag on the basis of phase. At least with the VLA, most phase fluctuations are due to the atmosphere rather than the instrument. Calibration can deal with these up to a point, and self-calibration (if you have enough signal) can refine the phases to levels that you would never reach by flagging. The exceptions are (1) IF phase jumps which still happen on rare occasions, and (2) RF interference which sometimes is seen as an excursion in phase rather than amplitude.
- Don't flag on minor amplitude errors, especially if they are not common. Except for very high dynamic range imaging, these will not be a problem, and in those cases, self-calibration always repairs or sufficiently represses the problem.
- Don't flag if `CALIB` reports few closure errors and the `SN` tables viewed with `EDITA`, `SNPLT`, and `LISTR` and the calibrator data viewed with the matrix format of `LISTR` show only a few problems.

There are three general methods of editing in *AIPS*. The "old-fashioned" route uses `LISTR` to print listings of the data on the printer or the user's terminal. The user scans these listings with his eyes and, upon finding a bad point, enters a specific flag command for the data set using `UVFLG`. While this may sound clumsy, it is in fact quite simple and by far the faster method when there are only a few problems. In a highly corrupted data set, it can use a lot of paper and may force you to run `LISTR` multiple times to pin down the exact problems. The "hands-off" route uses tasks which attempt to determine which data are bad using only modest guidance from the user. The most general of these is `FLAGR` mentioned below. The third and "modern" route uses interactive ("TV"-based) tasks to display the data in a variety of ways and to allow you to delete sections of bad data simply by pointing at them with the TV cursor. These tasks are `TVFLG` (§ 4.4.3) for all baselines and times (but only shows one IF, one Stokes, and one spectral channel at a time), `SPFLG` (§ 10.2.2) for all spectral channels, IFs, and times (but only shows one baseline and one Stokes at a time), `EDITA` (§ 4.4.2) for editing based on `TY` ($T_{ant}$), `SN` or `CL` table values, `EDITR` (§ 5.5.2) for all times (but only shows a single antenna (1–11 baselines) and one channel average at a time) and `WIPER` for all types of data (but with the time, polarization, and sometimes antenna of the points not available while editing). `TVFLG` is the one used for continuum and channel-0 data from the VLA, while `SPFLG` is only used to check for channel-dependent interference. `SPFLG` is useful for spectral-line editing in smaller arrays, such as the Australia Telescope and the VLBA. (The redundancy in the spectral domain on calibrator sources helps the eyes to locate bad data.) `EDITR` is more useful for small arrays such as those common in VLBI experiments. `EDITA` has been found to be remarkably effective using VLA system temperature tables. All four tasks have the advantage of being very specific in displaying the bad data. Multiple executions should not be required. However, they may require you to look at each IF, Stokes, channel (or baseline) separately (unless you make certain broad assumptions); `EDITA` and `EDITR` do allow you to look at all polarizations and/or IFs at once if you want. They all require you to develop special skills since they offer so many options and operations with the TV cursor (mouse these days). A couple of general statements can be made

- For highly corrupted data (say with considerable RF interference, significant cross-talk between antennas, or erratic antennas) `TVFLG` is definitely preferred. It gives an overall view of the data which is far superior to that given by `LISTR`. RFI and similar problems are more troublesome at lower frequencies, so `TVFLG` is probably preferred for L, P, and "4" bands.
- Most VLA data at higher frequencies are of good quality and the flexibility of `TVFLG` is not needed. In such cases, `LISTR` with `OPCODE = 'MATX'` can find scans with erroneous points efficiently.

- The displays given by TVFLG and, to a lesser extent, LISTR in its MATX mode are less useful when there are only a few baselines. Thus, for arrays smaller than the VLA, users may wish to use SPFLG on spectral-line data sets and EDITR on continuum data sets.
- A reasonable strategy to use is to run LISTR first. If there are only a few questionable points, use LISTR and UVFLG, otherwise switch to an interactive task, such as EDITA followed by TVFLG.
- Task FLAGR is a new, somewhat experimental task to measure the rms in the data on either a baseline or an antenna basis and then delete seriously discrepant points and times when many antennas/correlators are questionable. It also clips amplitudes and weights which are outside specified normal ranges. Task FINDR reports the rmses and excessive values to assist in running FLAGR.
- Task CLIP makes entries in a flag table, applying calibration and then testing amplitudes for reasonableness on a source-by-source basis. It can be very useful for large data sets, but does not show you the bad data to evaluate yourself.
- Task DEFLG makes entries in a flag table whenever the phases are too variable as measured by too low a ratio of vector-averaged to scalar-averaged amplitudes. This may be useful when applied to the calibrator source in phase-referencing observations and for other data at the highest and lowest frequencies which are affected by atmospheric and ionospheric phase variability.
- Task SNFLG makes entries in a flag table whenever the phase solutions in an SN or CL table change excessively between samples on a baseline basis. In 31DEC09 it can also flag data if the amplitude solutions differ from their mean excessively.
- Task WIPER makes entries in a flag table for all data samples wiped from a UVPLT-like display of any *uv* data set parameter versus any other parameter. The source, Stokes, IF, time, etc. of the points are not known during the interactive editing phase, but some baseline information is displayed. It can plot and edit any choice of STOKES in one execution and can flag/unflag by baseline.
- Task WETHR makes entries in a flag table whenever various weather parameters exceed specified limits. WETHR also plots the weather (WX) table contents.
- Task VPFLG flags all correlators in a sample whenever one is flagged. Observations of sources with circular polarization (Stokes V) require this operation to correct the flagging done on-line (which flags only known bad correlators).
- Task FGPLT plots the times of selected flag-table entries to provide you information on what these powerful tasks have done.

### 4.4.1 Editing with LISTR and UVFLG

Data may be flagged using task UVFLG based on listings from LISTR. To print out the scalar-averaged raw amplitude data for the calibrators, and their *rms* values, once per scan in a matrix format, the following inputs are suggested:

| | |
|---|---|
| > TASK 'LISTR' ; INP C_R | to review the inputs needed. |
| > INDI *n*; GETN *m* C_R | to select the data set, $n = 3$ and $m = 1$ above. |
| > SOURCES ' ' ; CALCODE '*' C_R | to select calibrators. |
| > TIMER 0 C_R | to select all times. |
| > ANTENNAS 0 C_R | to list data for all antennas. |
| > OPTYPE 'MATX' C_R | to select matrix listing format. |
| > DOCRT FALSE C_R | to route the output to printer, not terminal. |
| > DPARM 3 , 1 , 0 C_R | amplitude and *rms*, scalar scan averaging. |

| | |
|---|---|
| > BIF 1; EIF 0 C_R | to select all IFs, LISTR will list IFs separately. |
| > FREQID 1 C_R | to select FQ number 1 (note that FQ numbers must also be done separately). |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when inputs set correctly. |

For unresolved calibrators, the VLA on-line gain settings normally produce roughly the same values in all rows and columns within each matrix. At L, C, X, and U bands, these values should be approximately 0.1 of the expected source flux densities. At P band, the factor is about 0.01. The factors for other bands are unspecified. Any rows or columns with consistently high or low values in either the amplitude or the *rms* matrices should be noted, as they probably indicate flaky antennas. In particular, you should look for

- In the amp-scalar averages, look for *dead* antennas, which are easily visible as rows or columns with small numbers. Rows or columns that differ by factors of two or so from the others are generally fine. Such deviations mean only that the on-line gains were not set entirely correctly.
- In the *rms* listings, look for discrepant high values. Almost all problems are antenna based and will be seen as a row or column. Factors of 2 too high are normally okay, while factors of 5 high are almost certainly indicative of serious trouble.

The next step is to locate the bad data more precisely. Suppose that you have found a bad row for antenna 3 in right circular polarization in IF 2 between times (*d1*, *h1*, *m1*, *s1*) and (*d2*, *h2*, *m2*, *s2*). You might then rerun LISTR with the following new inputs:

| | |
|---|---|
| > SOURCES ' ' C_R | to select all sources. |
| > TIMER *d1 h1 m1 s1 d2 h2 m2 s2* C_R | to select by time range. |
| > ANTENNAS 1 , 2 , 3 C_R | to list data for antenna 3 with two "control" antennas. |
| > BASEL 1 , 2 , 3 C_R | to list all baselines with these three antennas. |
| > OPTYPE 'LIST' C_R | to select column listing format. |
| > DOCRT 1 C_R | to route the output to terminal at its width. |
| > DPARM = 0 C_R | amplitude only, no averaging. |
| > STOKES 'RR' C_R | to select right circular. |
| > BIF 2 C_R | to specify the "BD" IFs. |
| > FLAGVER 1 C_R | to choose flag table 1. |
| > GO C_R | to run the program. |

This produces a column listing on your terminal of the amplitude for baselines 1–2, 1–3 and 2–3 at every time stamp between the specified start and stop times. The '1–2" column provides a control for comparison with the two columns containing the suspicious antenna.

Note that "amp-scalar" averaging ignores phase entirely and is therefore not useful on weak sources, nor can it find jumps or other problems with the phases. To examine the data in a phase-sensitive way, repeat the above process, but set DPARM(2) = 0 rather than 1. Bad phases will show up as reduced amplitudes and increased *rms*'s.

Once bad data have been identified, they can be expunged using UVFLG. For example, if antenna 3 RR was bad for the full interval shown above, it could be deleted with

| | |
|---|---|
| > TASK 'UVFLG' ; INP C_R | to select the editor and check its inputs. |
| > TIMER *d1 h1 m1 s1 d2 h2 m2 s2* C_R | to select by time range. |
| > BIF 2 ; EIF = BIF C_R | to specify the "BD" IFs. |
| > BCHAN 0 ; ECHAN 0 C_R | to flag all channels. |
| > FREQID 1 C_R | to flag only the present FQ number. |

| | |
|---|---|
| > ANTEN 3 , 0 C_R | to select antenna 3. |
| > BASEL 0 C_R | to select all baselines to antenna 3. |
| > STOKES 'RR' C_R | to select only the RR Stokes (LL was found to be okay in this example). |
| > REASON = 'BAD RMS WHOLE SCAN' C_R | to set a reason. |
| > OUTFGVER 1 C_R | to select the first (only) flag table. |
| > INP C_R | be careful with the inputs here! |
| > GO C_R | to run the task when ready. |

Continue the process until you have looked at all parts of the data set that seemed anomalous in the first matrix listing, then rerun that listing to be sure that the flagging has cleaned up the data set sufficiently. If there are lots of bad data, you may find that you have missed a few on the first pass. If you change your mind about a flagging entry, you can use UVFLG with OPCODE = 'UFLG' to remove entries from the flag table. All adverbs of UVFLG are used when removing entries, so you may use REASON along with the channel, IF, source, et al. adverbs to select the entries to be removed. OPCODEs 'REAS' and 'WILD' may be used to undo an entry solely based on the REASON. If the table becomes hopelessly messed up, use EXTDEST to delete the flag table and start over or use a higher numbered flag table. The contents of the flag table may be examined at any time with the general task PRTAB and entries in it may also be removed with TABED and/or TAFLG. Two flag tables can be merged using TAPPE.

### 4.4.2 Editing with EDITA

The task EDITA uses the graphics planes on the *AIPS* TV display to plot data from tables and to offer options for editing (deleting, flagging) the associated *uv* data. Only the TY (system temperature), SN (solution), and CL (calibration) tables may be used. EVLA users will not have a TY table, but they may have an SY (SysPower) table which may be used instead. We recommend using EDITA with the TY or SY tables to do the initial editing of VLA and EVLA data sets, probably before running the programs described in § 4.3. For accuracy in evaluating and flagging your data, it is a good idea to have the TY table filled with the same interval as the data themselves; see § 4.1.1. Try:

| | |
|---|---|
| > TASK 'EDITA ; INP C_R | to review the inputs needed. |
| > INDI $n$ ; GETN $m$ C_R | to select the data set, $n = 3$ and $m = 1$ above. |
| > INEXT 'TY' C_R | to use the system temperature table. |
| > INVERS 0 C_R | to use the highest numbered table, usually 1. |
| > TIMER 0 C_R | to select all times. |
| > FREQID 3 C_R | Select FQ entry 3. |
| > BIF 1 ; EIF 0 C_R | to specify all IFs; you can then toggle between them interactively and even display all at once. |
| > ANTENNAS 0 C_R | to display data for all antennas. |
| > ANTUSE 1 , 2 , 3 , 4 , 5 , 6 , 7 C_R | to display initially the first 7 antennæ, editing antenna 1. Others may be selected interactively. |
| > FLAGVER 1 C_R | to use flag (FG) table 1. |
| > OUTFGVER 0 C_R | to create a new flag table with the flags from FG table 1 plus the new flags. |
| > SOLINT 0 C_R | to avoid averaging any samples. |
| > DOHIST FALSE C_R | to omit recording the flagging in the history file. |
| > DOTWO TRUE C_R | to view a $2^{\text{nd}}$ observable for comparison |
| > CROWDED TRUE C_R | to allow plots with all polarizations and/or IFs simultaneously. |
| > INP C_R | to review the inputs. |

> GO C_R to run the program when inputs set correctly.

If you make multiple runs of EDITA, it is important to make sure that the flagging table entries are all in one version of the FG table. The easiest way to ensure this is to should set FLAGVER and OUTFGVER to 0 and keep it that way for all runs of EDITA. This may create an excessive number of flag tables, but unwanted ones may be deleted with EXTDEST. If you make a mistake two flag tables may be merged with the task TAPPE. A sample display from EDITA is shown on the next page.

The following discussion assumes that you have read § 2.3.2 and are familiar with using the AIPS TV display. An item in a menu such as that shown in the figure is selected by moving the TV cursor to the item (holding down or pressing the left mouse button). At this point, the menu item will change color. To obtain information about the item, press AIPS TV "button D" (usually the D key and also the F6 key on your keyboard). To tell the program to execute the menu item, press any of AIPS TV buttons A, B, or C. Status lines around the display indicate what is plotted and which data will be flagged by the next flagging command. In the figure below, only the displayed antenna (2), and time range will be flagged. You must display at least a few lines of the message window and your main AIPS window since the former will be used for instructions and reports and the latter will be needed for data entry (*e.g.*, antenna selection).

The first thing to do with EDITA is to look at all of the polarizations, IFs, and antennæ, in order to flag the obviously bad samples (if any). Use SWITCH POLARIZATION to switch between polarizations and ENTER IF to select the IF to edit. Alternatively, NEXT CORRELATOR will cycle through all polarizations and IFs. If CROWDED was set to true, SWITCH POLARIZATION will cycle through displaying both polarizations as well as each separately, and ENTER IF will accept 0 as indicating all. NEXT CORRELATOR shows only one correlator at a time, but can switch away from a multi-correlator display. These options appear only if there is more than one polarization and/or more than one IF in the loaded data. Use ENTER ANTENNA to select the antenna to be flagged and ENTER OTHER ANT to select secondary antennæ to be displayed around the editing area. If the secondary antennæ have no obvious problems, then they do not have to be selected for editing. EDITA will plot all of the times in the available area, potentially making a very crowded display. You may select interactively a smaller time range or "frame" in order to see the samples more clearly. It is necessary to select each frame in order to edit the data in that frame so it helps to make the TV screen as big as possible with the F2 button or your window manager. Note that the vertical scales used by EDITA are linear, but that the horizontal scale is irregular and potentially discontinuous. Integer hours are indicated by tick marks and the time range of the frame is indicated. Use FLAG TIME or FLAG TIME RANGE to delete data following instructions which will appear on the message window. While you are editing, the source name, sample time and sample value currently selected will be displayed in the upper left corner of the TV screen. This information can also be used to determine if QUACK is needed.

Having flagged all obviously bad points, select SWITCH ALL IF, SWITCH ALL TIME, SWITCH ALL ANT, and SWITCH ALL POL so that the next flag command(s) apply to all of the data. (Decide whether the flags should apply only to the source(s) displayed or to all sources and set SWITCH ALL SOURC appropriately.) Set the SCAN LENGTH long enough to include the shorter of the full scan and about 12 samples. Then display the difference between the current sample and the running mean by selecting SHOW TSYS - <T>. Use FLAG ABOVE and FLAG BELOW to flag all samples more than a few sigma away from the local mean. Finally, apply your flagging to your *uv* data set by selecting EXIT.

At this point, return to § 4.3.1 to run QUACK followed by the first pass of the gain calibration. Then run TVFLG below with DOCAL TRUE so that the data will be displayed on the same flux scale for all baselines.

### 4.4.3 Editing with TVFLG

If your data are seriously corrupted, contain numerous baselines, and you like video games, TVFLG is the visibility editor of choice. The following discussion assumes that you have read § 2.3.2 and are familiar with using the AIPS TV display. The following inputs are suggested:

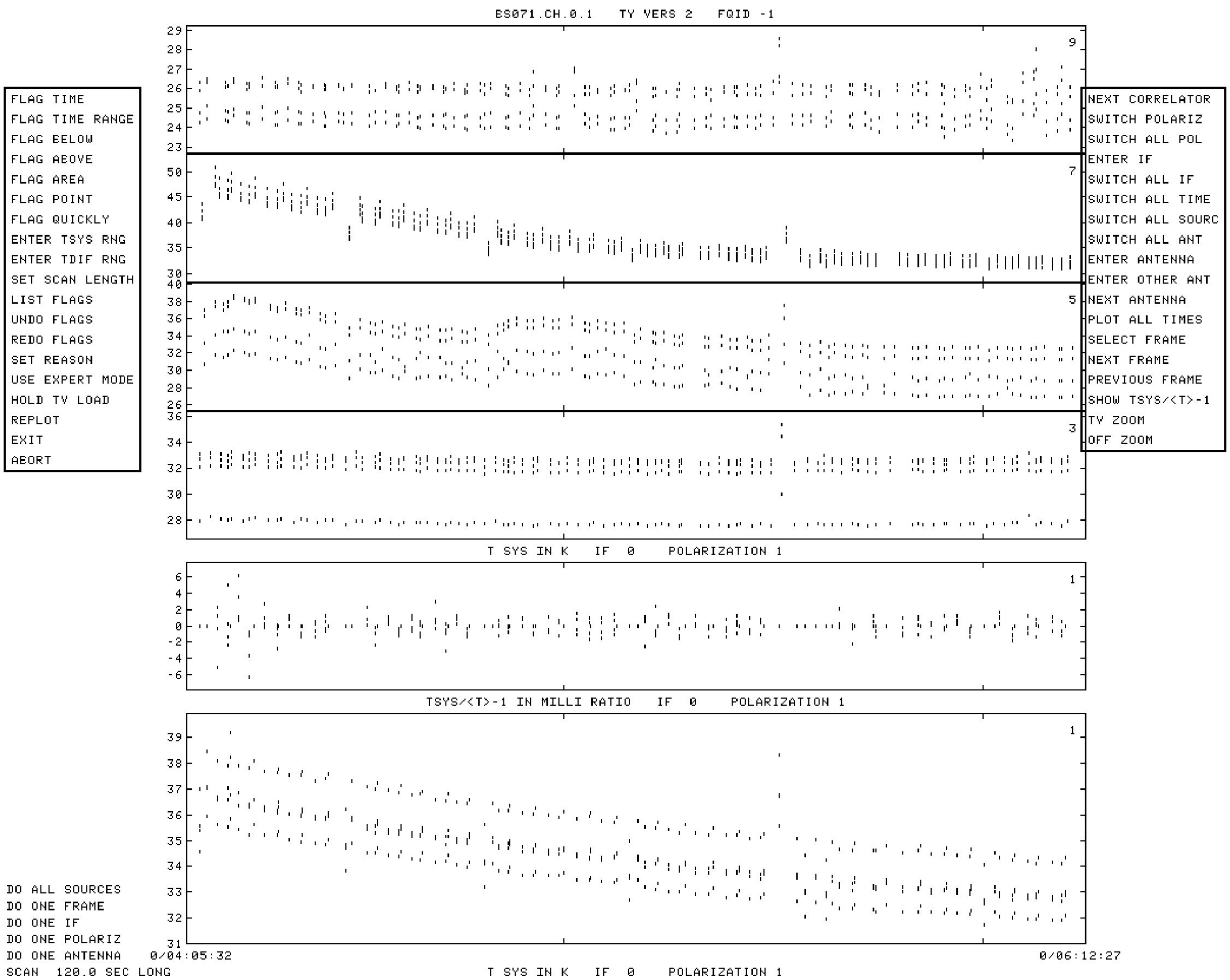



Figure 4.2: A display of a sample TV screen from EDITA, made using the AIPS task TVCPS to produce a negative black-and-white display. System temperatures are being used to edit VLBA data. The EDITA menu (in the boxes), the status lines (at the bottom), the editing area (bottom) of a portion of the data from the selected antenna (1), the subsidiary plots of data from selected secondary antennæ (3, 5, 7, 9), the edit tool (bar or box), and the edit location values are displayed in different graphics planes which normally appear in different colors. In this example, with CROWDED=TRUE, four IFs but only one polarization are displayed and may be edited simultaneously. Both polarizations can be displayed together along with either one or all four IFs.

| | |
|---|---|
| > TASK 'TVFLG' ; INP C_R | to review the inputs needed. |
| > INDI $n$ ; GETN $m$ C_R | to select the data set, $n = 3$ and $m = 1$ above. |
| > SOURCES ' ' C_R | to select all sources. |
| > TIMER 0 C_R | to select all times. |
| > STOKES 'RRLL' C_R | to select both right and left circular polarizations; you can then toggle between RR and LL interactively. |
| > FREQID 3 C_R | Select FQ entry 3. |
| > BIF 1 ; EIF 2 C_R | to specify both VLA IFs; you can then toggle between the two interactively. |
| > ANTENNAS 0 C_R | to display data for all antennas. |
| > BASELINE 0 C_R | to display data for all baselines. |
| > DOCALIB 1 C_R | to apply initial calibration to the data. |
| > FLAGVER 1 C_R | to use flag (FG) table 1. |
| > OUTFGVER 0 C_R | to create a new flag table with the flags from FG table 1 plus the new flags. |
| > DPARM = 0 C_R | to use default initial displays and normal baseline ordering. |
| > DPARM(6) = 30 C_R | to declare that the input data are 30-second averages, or to have the data averaged to 30 seconds. |
| > DPARM(5) = 10 C_R | to expand the flagging time ranges by 10 seconds in each direction. The times in the master grid are average times and may not encompass the times of the samples entering the average without this expansion. |
| > DOCAT 1 C_R | to save the master grid file. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when inputs set correctly. |

If you make multiple runs of TVFLG, it is important to make sure that the flagging table entries are all in one version of the FG table. The easiest way to ensure this is to set FLAGVER and OUTFGVER to 0 and keep it that way for all runs of TVFLG. If you make a mistake, two flag tables may be merged with the task TAPPE.

TVFLG begins by constructing a "master grid" file of all included data. This can be a long process if you include lots of data at once. It is probably better to use the channel selection (including averaging channels with NCHAV), IF selection, source selection, and time range selection adverbs to build rather smaller master grid files and then to run TVFLG multiple times. It will work with all data included, allowing you to select interactively which data to edit at any one moment and allowing you to resume the editing as often as you like. But certain operations (such as undoing flags) have to read and process the entire grid, and will be slow if that grid is large. The master grid file is always cataloged (on IN2DISK with class TVFLGR), but is saved at the end of your session only if you set DOCAT = 1 (actually > 0) before starting the task. To resume TVFLG with a pre-existing master grid file, set the adverb IN2SEQ (and IN2DISK) to point at it. When resuming in this way, TVFLG ignores all of its data selection adverbs since they might result in a different master grid than the one it is going to use. If you wish to change any of the data selection parameters, *e.g.*, channels, IFs, sources, times, or time averaging, then you must use a new master grid.

Kept with the master grid file is a special file of TVFLG flagging commands. This file is updated as soon as you enter a new flagging command, making the master grid and your long editing time virtually proof from power failures and other abrupt program terminations. These flagging commands are not entered into your actual *uv* data set's flagging (FG) table until you exit from TVFLG and tell it to do so. During editing, TVFLG does not delete data from its master grid; it just marks the flagged data so that they will not be displayed. This allows you to undo editing as needed during your TVFLG session(s). When the flags are transferred to the main *uv* data set, however, the flagged data in the master grid are fully deleted since undoing the flags at that point has no further meaning. When you are done with a master grid file, be sure to delete it (with

ZAP) since it is likely to occupy a significant amount of disk.

TVFLG keeps track of the source name associated with each row of data. When averaging to build the master grid and to build the displayed grids, TVFLG will not average data from different sources and will inform you that it has omitted data if it has had to do so for this reason. For multi-source files, the source name is displayed during the CURVALUE-like sections. However, the flagging table is prepared to flag *all* sources for the specified antennas, times, *etc.* or just the displayed source. If you are flagging two calibrator scans, you may wish to do all source in between as well. Use the SWITCH SOURCE FLAG interactive option to make your selection before you create flagging commands. Similarly, you will need to decide whether flagging commands that you are about to prepare apply only to the displayed channel and/or IF, or to all possible channels and/or IFs. In particular, spectral-line observers often use TVFLG on the pseudo-continuum "channel-0" data set, but want the resulting flags to apply to all spectral channels when copied to the spectral-line data set. They should be careful to select all channels before generating any flagging commands. Each flagging command generated is applied to a list of Stokes parameters, which *does not have to include* the Stokes currently being displayed. When you begin TVFLG and whenever you switch displayed Stokes, you should use the ENTER STOKES FLAG option to select which Stokes are to be flagged by subsequent flagging commands.

If you get some of this wrong, you can use the UNDO FLAGS option in TVFLG if the flags have not yet been applied to the *uv* data set. Or you can use tasks UVFLG, TABED or TAFLG to correct errors written into the FG table of your multi-source *uv* data set. Flag tables are now used with both single- and multi-source data sets.

TVFLG displays the data, for a single IF, channel (average), and Stokes, as a grey-scale display with time increasing up the screen and baseline number increasing to the right. Thus baselines for the VLA run from left to right as 1–1, 1–2, 1–3, . . ., 2–2, 2–3, . . ., 27–27, 27–28, and 28–28. An input parameter (DPARM(3) = 1 allows you to create a master grid and display baselines both as, say 1–2 and 2–1. An interactive (switchable) option allows you to order the baselines from shortest to longest (ignoring projection effects) along the horizontal axis.

The interactive session is driven by a menu which is displayed on a graphics overlay of the TV display. An example of this full display is shown on the next page. Move the cursor to the desired operation (noting that the currently selected one is highlighted in a different color on many TVs) and press button A, B, or C to select the desired operation; pressing button D produces on-line help for the selected operation. The first (left-most column) of choices is:

| | |
|---|---|
| OFFZOOM | turn off any zoom magnification |
| OFFTRANS | turn off any black & white enhancement |
| OFFCOLOR | turn off any pseudo-coloring |
| TVFIDDLE | interactive zoom, black & and white enhancement, and pseudo-color contours as in AIPS |
| TVTRANSF | black & white enhancement as in AIPS |
| TVPSEUDO | many pseudo-colorings as in AIPS |
| DO WEDGE ? | switches choice of displaying a step wedge |
| LIST FLAGS | list selected range of flag commands |
| UNDO FLAGS | remove flags by number from the FC table master grid |
| REDO FLAGS | re-apply all remaining flags to master grid |
| SET REASON | set reason to be attached to flagging commands |
| DO LABEL ? | turn axis labeling on and off |

Note: when a flag is undone, all cells in the master grid which were first flagged by that command are restored to use. Flag commands done after the one that was undone may also, however, have applied to some of those cells. To check this and correct any improperly un-flagged pixels, use the REDO FLAGS option. This option even re-does CLIP operations! After an UNDO or REDO FLAGS operation, the TV is automatically re-loaded if needed. Note that the UNDO operation is one that reads and writes the full master grid.

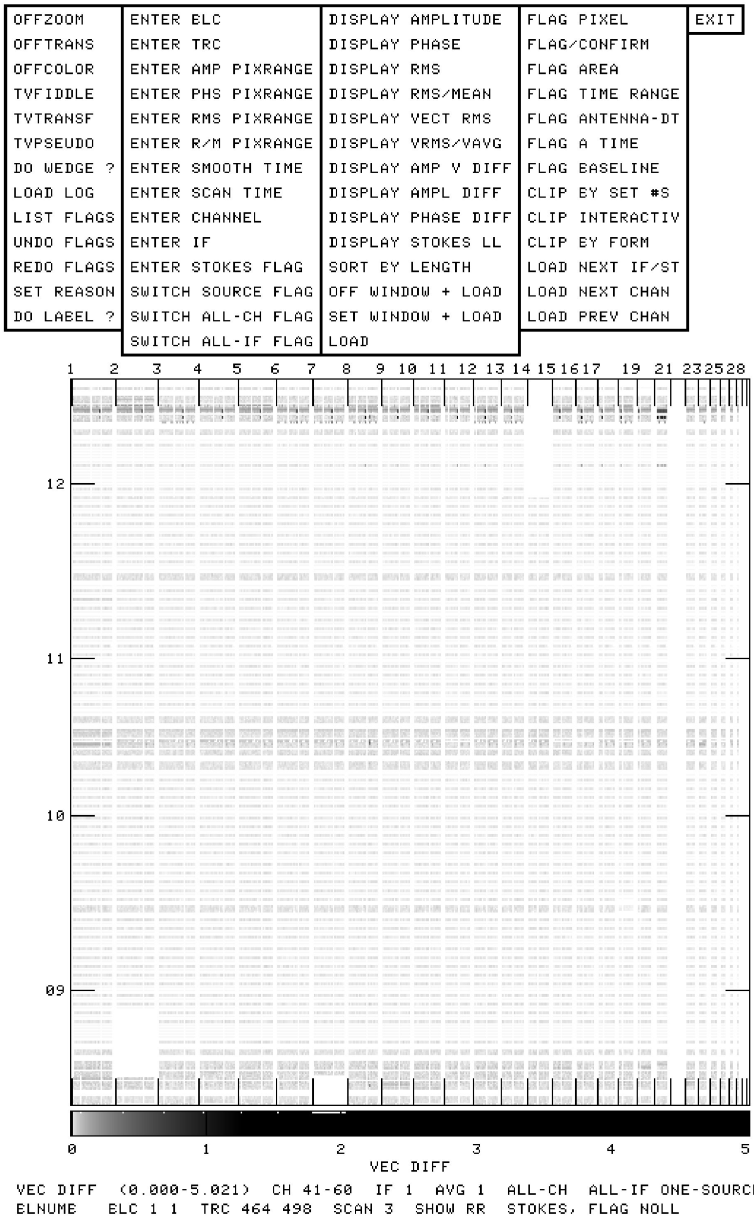



Figure 4.3: A display of a sample TV screen from TVFLG, made using the *AIPS* task TVCPS to produce a negative black-and-white display. The TVFLG menu (in the boxes) and status lines (at the bottom) are displayed in a graphics plane which is normally colored light green. The data are grey scales in a TV memory and may be enhanced in black-and-white or pseudo-colored. The particular display chosen is the amplitude of the vector difference between the sample and a running vector average of samples surrounding it. This particular parameter is sensitive to both phase and amplitude problems and may save you the extra time of looking at phase and amplitude separately. It requires that there be data to average, but does not blur the flagging by the averaging interval (as the RMS method does). The visibility data are from the VLA. All baselines are shown once only in baseline number order. Antenna 21 is missing for all times, while antenna 14 is missing toward the end of the run and and antennas 2 and 7 are missing for some times near the start of the observation. The displayed data are the RR Stokes samples and have been windowed to exclude some times. Flag commands generated at the moment illustrated will flag one source name, all spectral channels, all IFs, and all Stokes except LL. The step wedge and labeling options have been selected. Antenna 21 appears to have problems especially at times after 12 hours.

Column 2 offers type-in controls of the TV display and controls of which data are to be flagged. In general, the master grid will be too large to display on the TV screen in its entirety. The program begins by loading every $n^{\text{th}}$ baseline and time smoothing by $m$ time intervals in order to fit the full image on the screen. However, you may select a sub-window in order to see the data in more detail. You may also control the range of intensities displayed (like the adverb PIXRANGE in TVLOD inside AIPS). The averaging time to smooth the data for the TV display may be chosen, as may the averaging time for the "scan average" used in some of the displays. Which correlators are to be flagged by the next flagging command may be typed in. All of the standard Stokes values, plus any 4-bit mask may be entered. The spectral channel and IF may be typed in. Flagging may be done only for the current channel and IF and source, or it may be done for all channels and/or IFs and/or sources. Note that these controls affect the next LOADs to the TV or the flagging commands prepared after the parameter is changed. When the menu of options is displayed at the top of the TV, the current selections are shown along the bottom. If some will change on the next load, they are shown with an asterisk following. Column 2 contains

| | |
|---|---|
| ENTER BLC | Type in a bottom left corner pixel number on the terminal |
| ENTER TRC | Type in a top right corner pixel number on the terminal |
| ENTER AMP PIXRANGE | Type in the intensity range to be used for loading amplitude images to the TV |
| ENTER PHS PIXRANGE | Type in the phase range to be used for loading phase images to the TV |
| ENTER RMS PIXRANGE | Type in the intensity range to be used for loading images of the rms to the TV |
| ENTER R/M PIXRANGE | Type in the value range to be used for loading rms/mean images to the TV |
| ENTER SMOOTH TIME | Type in the time smoothing length in units of the master grid cell size |
| ENTER SCAN TIME | Type in the time averaging length for the "scan average" in units of the master grid cell size |
| ENTER CHANNEL | Type in the desired spectral channel number using the terminal |
| ENTER IF | Type in, on the terminal, the desired IF number |
| ENTER STOKES FLAG | To type in the 4-character string which will control which correlators (polarizations) are flagged. Note: this will apply only to subsequent flagging commands. It should be changed whenever a different Stokes is displayed. |
| SWITCH SOURCE FLAG | To switch between having all sources flagged by the current flag commands and having only those sources included in this execution of TVFLG flagged. The former is desirable when a time range encompasses all of 2 calibrator scans. |
| SWITCH ALL-CH FLAG | To reverse the flag all channel status; applies to subsequent flag commands |
| SWITCH ALL-IF FLAG | To reverse the flag all IFs status; applies to subsequent flag commands |

The all-channel flag remains true if the input data set has only one channel and the all-IF flag remains true if the input data set has no more than one IF.

An extra word should be said about the "scan average" to which reference was made above. This is used solely for displaying the difference of the data at time $T$ and the average of the data at times near $T$. This average is computed with a "rolling buffer." Thus, for a scan average time of 30 seconds and data at 10-second intervals, the average for a set of 7 points is as follows:

```
time        average of times
 00           00   10   20
 10           00   10   20
 20           10   20   30
 30           20   30   40
 40           30   40   50
 50           40   50   60
 60           40   50   60
```

The third column of options is used to control which data are displayed and to cause the TV display to be updated. The master grid must be converted from complex to amplitude, phase, the rms of the amplitude, or the rms divided by the mean of the amplitude for display. It may also be converted to the amplitude of the vector difference between the current observation and the "scan average" as defined above or the absolute value of the difference in amplitude with the scalar-average amplitude or the absolute value of the difference in phase with the vector scan average. Furthermore, the baselines may be reordered in the TV display by their length rather than their numerical position. This column has the options:

| | |
|---|---|
| DISPLAY AMPLITUDE | To display amplitudes on the TV |
| DISPLAY PHASE | To display phases on the TV |
| DISPLAY RMS | To display amplitude rms on the TV |
| DISPLAY RMS/MEAN | To display amplitude rms/mean on the TV |
| DISPLAY VECT RMS | To display vector amplitude rms on the TV |
| DISPLAY VRMS/VAVG | To display vector amplitude rms/mean on the TV |
| DISPLAY AMP V DIFF | To display the amplitude of the difference between the data and a running (vector) "scan average" |
| DISPLAY AMPL DIFF | To display the abs(difference) of the amplitude of the data and a running scalar average of the amplitudes in the "scan" |
| DISPLAY PHASE DIFF | To display the abs(difference) of the phase of the data and the phase of a running (vector) "scan average" |
| DISPLAY STOKES *xx* | To switch to Stokes type *xx* (where *xx* can be RR, LL, RL, LR, etc as chosen by the `STOKES` adverb). |
| SORT BY *xxxxxxxx* | To switch to a display with the *x* axis (baseline) sorted by ordered by `LENGTH` or by `BASELINE` number |
| OFF WINDOW + LOAD | Reset the window to the full image and reload the TV |
| SET WINDOW + LOAD | Interactive window setting (like `TVWINDOW`) followed by reloading the TV |
| LOAD NEXT CH/IF/ST | Load TV with the next spectral channel, IF, or polarization. |
| LOAD | Reload TV with the current parameters |

`SET WINDOW + LOAD` is "smarter" than `TVWINDOW` and will not let you set a window larger than the basic image. Therefore, if you wish to include all pixels on some axis, move the TV cursor outside the image in that direction. The selected window will be shown.

The fourth column is used to select the type of flagging to be done. During flagging, a TV graphics plane is used to display the current pixel much like `CURVALUE` in `AIPS`. Buttons A and B do the flagging (except A switches corners for the area and time-range modes). Button C also does the flagging, but the program then returns to the main menu rather than prompting for more flagging selections. Button D exits back to the menu without doing any additional flagging. Another graphics plane is used to show the current area/time/baseline being flagged. All flagging commands can create zero, one, two, or more entries in the flagging list; hit button D at any time. There are also two clipping modes, an interactive one and one in which the user enters the clip limits from the terminal. In both, the current image computed for the TV (with user-set windows and data type, but not any other windows or alternate pixels etc. required to fit the image on the TV) is examined for pixels which fall outside the allowed intensity range. Flagging commands are prepared and the master file blanked for all such pixels. In the interactive mode, buttons A and B switch between setting the lower and upper clip limits, button C causes the clipping to occur followed by a return to the main menu, and button D exits to the menu with no flagging. The options are

| | |
|---|---|
| FLAG PIXEL | To flag single pixels |
| FLAG/CONFIRM | To flag single pixels, but request a yes or no on the terminal before proceeding |
| FLAG AREA | To flag a rectangular area in baseline-time |
| FLAG TIME RANGE | To flag all baselines for a range of times |
| FLAG ANTENNA-DT | To flag all baselines to a specific antenna for a range of times |
| FLAG A TIME | To flag all baselines for a specific time |
| FLAG BASELINE | To flag all times for a specific baseline |
| CLIP BY SET #S | To enter from the terminal a clipping range for the current mode and then clip high and low samples |
| CLIP INTERACTIV | To enter with the cursor and LUTs a clipping range for the current mode and then clip data outside the range. |
| CLIP BY FORM | To clip selected channels/IFs using the "method" and clipping range of some previous clip operation |
| LOAD NEXT CHAN | To load the next spectral channel to the TV with current parameters |
| LOAD PREV CHAN | To load the previous spectral channel to the TV with current parameters |

The CLIP BY FORM operation allows you to apply a clipping method already used on one channel/IF to other channels and/or IFs. It asks for a command number (use LIST FLAGS to find it) and applies its display type (amp, phase, rms, rms/mean, differences), averaging and scan intervals and clip levels to a range of channels, IFs and Stokes (as entered from the terminal). To terminate the operation, doing nothing, enter a letter instead of one of the requested channel or IF numbers. To omit a Stokes, reply, if requested for a flag pattern, with a blank line. You may watch the operation being carried out on the TV as it proceeds.

The right-most column has only the option:

| | |
|---|---|
| EXIT | Go resume AIPS and, optionally, enter the flags in the data |

Before the flags are entered in the data, TVFLG asks you whether or not you actually wish to do this. You must respond yes or no. Note that, if the master grid is to remain cataloged, there is no need to enter the flagging commands every time you decide to exit the program for a while. In fact, if you do not enter the commands, you can still undo them later, giving you a reason not to enter them in the main *uv* data set too hastily.

The two most useful data modes for editing are probably amplitude and amplitude of the vector difference. The former is useful for spotting bad data over longer time intervals, such as whole scans. The latter is excellent for detecting short excursions from the norm. For editing uncalibrated data, rms of two time intervals is useful, but the rms modes require data to be averaged (inside TVFLG) and therefore reduce the time resolution accuracy of the flagging. If you edit by phase, consider using the pseudo-coloration scheme that is circular in color (option TVPSEUDO followed by button B) since your phases are also circular.

Using TVFLG on a workstation requires you to plan the real estate of your screen. We suggest that you place your message server window and your input window side-by-side at the bottom of the screen. Then put the TV window above them, occupying the upper 70–90% of the screen area. (Use your window manager's tools to move and stretch the TV window to fill this area.) Instructions and informative, warning and error messages will appear in the message server window. Prompts for data entry (and your data entry) appear in the input window. Remember to move the workstation cursor into the input window to enter data (such as IF, channel, antenna numbers, and the like) and then to move the cursor back into the TV area to select options, mark regions to be flagged, adjust enhancements, and so on.

### 4.4.4 Baseline corrections

Sometimes, *e.g.*, during a VLA array re-configuration, your observations may have been made when one or more of the antennas had their positions poorly determined. The positional error is usually less than a centimeter at the VLA, but even this may affect your data significantly. The most important effect is a slow and erroneous phase wind which is a function of source position and time. Since this error is a function of source position, it cannot be removed exactly using observations of a nearby calibrator, although the error will be small if the target source is close to the calibrator. In many observations, the target sources and calibrators are sufficiently close to allow this phase error to be ignored. Self-calibration will remove this error completely *if* you have enough signal-to-noise to determine the correction during each integration.

The maximum phase error introduced into the calibrated visibility data by incorrect antenna coordinates $\Delta\phi_B$, in radians, by a baseline error of $\Delta B$ meters is given by

$$\Delta\phi_B \approx 2\pi\Delta\theta\Delta B/\lambda$$

where $\Delta\theta$ is the angular separation between the calibrator and the target source in radians and $\lambda$ is the wavelength in meters.

Note, however, that the error due to the phase-wind is not the only error introduced by incorrect antenna positions. A further, but much smaller effect, will be incorrect gridding of the data due to the erroneous calculation of the baseline spatial frequency components $u$, $v$ and $w$. This effect is important only for full primary beam observations in which the antenna position error is of the order of a meter. It is highly unlikely that such a condition will occur. Note too, that this error *cannot* be corrected by the use of self-calibration. However, after correcting the antenna position with `CLCOR`, you may run `UVFIX` to compute corrected values of $u, v$, and $w$. The maximum phase error in degrees, $\Delta\phi_G$, caused by incorrect gridding of the $u$,$v$,$w$ data is

$$\Delta\phi_G \approx 360\Delta\epsilon\Delta\Theta$$

where $\Delta\epsilon$ is the antenna position error in antenna diameters and $\Delta\Theta$ is the angular offset in primary beams.

If baseline errors are significant they need to be removed from your data before calibration. It is important to do this to `CL` table 1, right after running `FILLM`. For the VLA, use the task `VLANT`. This task determines and applies the antenna position corrections found by the VLA operations staff after your observation was complete. To run `VLANT`:

| | |
|---|---|
| > TASK 'VLANT' C_R | |
| > INDISK *m* ; GETN *n* C_R | to get the correct data set. Note that you don't have to keep doing this unless you switch between different input data files. |
| > FREQID *1* C_R | to choose `FQ` 1. |
| > SUBARRAY *x* C_R | to choose the antenna table to correct. |
| > GAINVER 1 C_R | to choose the correct version of the `CL` table to read. A new one will produced. |
| > GO C_R | to run `VLANT`. |

For arrays other than the VLA, use `CLCOR` to enter the antenna position corrections (in meters) in a new `CL` table and the old `AN` table. This must be done for each affected antenna in turn. `CLCOR` puts the corrections into the `AN` table as well as the `CL` table, so it is wise to save the `AN` table before running `CLCOR` by running `TASAV`.

| | |
|---|---|
| > TASK 'CLCOR' C_R | |
| > INDISK *m* ; GETN *n* C_R | to get the correct data set. Note that you don't have to keep doing this unless you switch between different input data files. |
| > SOURCES ' ' ;STOKES ' ' C_R | to do all sources, all Stokes, |
| > BIF 0 ; EIF 0 C_R | and all IFs. |

> SUBARRAY $x$ C_R   to choose the correct sub-array.
> OPCODE 'ANTP' C_R   to select the antenna position correction mode.
> GAINVER 1 C_R   to choose the correct version of the CL table to read.
> GAINUSE 0 C_R   to have CLCOR create a new table.
> ANTENNA $k$ C_R   to select antenna.
> CLCORPRM $\Delta b_x, \Delta b_y, \Delta b_z, 0, 0, 0, 1$ C_R   to add the appropriate antenna corrections in meters; the 1 in CLCORPRM(7) indicates VLA phase conventions rather than VLB conventions.
> GO C_R   to run CLCOR.

The program will need to be run as many times as there are antennas for which positional corrections must be made. Set GAINUSE and GAINVER both to 2 after the first correction. Otherwise, with the above adverbs, CLCOR will make multiple CL table versions each with only one correction in them. Note that subsequent calibration must be applied to CL table 2 to create higher versions of the calibration table. This new CL table (version 2) will replace version 1 in all of the subsequent sections on calibration. Thus, in subsequent executions of CALIB, you must apply these corrections by specifying DOCALIB TRUE ; GAINUSE 2 (or higher). Note too that CLCOR and VLANT change the antenna file for the changed antenna location(s). Therefore, it is wise to save the AN table before running CLCOR or VLANT by running TASAV.

Note that NRAO's data analysts use the AIPS task LOCIT and procedure BASFIT to determine the antenna position corrections. These are available to the general user, but a data set designed to determine antenna corrections is normally required. Such data sets consist of about 100 observations of a wide range of phase calibrators taken as rapidly as possible.

## 4.5 Antenna-based complex gain solutions

At this point, we assume that you have removed the worst of the bad calibrator data (if any) and have run CALIB over as large a UVRANGE as possible for each calibrator. The resulting gain tables can be brought to a consistent amplitude scale, bootstrapping the unknown fluxes of the secondary calibrators. Final pass(es) of CALIB are done if needed and then the solution tables are merged into a full calibration (CL) table.

### 4.5.1 Bootstrapping secondary flux-density calibrators

Task GETJY can be used to determine the flux density of the secondary flux calibrators from the primary flux calibrator based on the flux densities set in the SU table and the antenna gain solutions in the SN tables. The SU and SN tables will be updated by GETJY to reflect the calculated values of the secondary calibrators' flux densities. This procedure should also work if (incorrect) values of the secondary calibrators' flux densities were present in the SU table when CALIB was run. Bad or redundant SN tables should be deleted using EXTDEST before running GETJY, or avoided by selecting tables one at a time with adverb SNVER.

To use GETJY:

> TASK 'GETJY' ; INP C_R
> SOURCES '*cal1*' , '*cal2*' , '*cal3*' ... C_R   to select secondary flux calibrators.
> CALSOU '3C286' , ' ' C_R   to specify primary flux calibrator(s).
> CALCODE ' ' C_R   to use all calibrator codes.
> BIF 1 ; EIF 2 C_R   to do both IFs.
> FREQID 1 C_R   to use FQ number 1.
> ANTENNAS 0 C_R   to include solutions for all antennas.

| | |
|---|---|
| > TIMERANG 0 CR | to include all times. |
| > SNVER 0 CR | to use all SN tables. |
| > INP CR | to review inputs. |
| > GO CR | to run the task when the inputs are okay. |

GETJY will give a list of the derived flux densities and estimates of their uncertainties. These are now found by "robust" methods and additional information about numbers of aberrant solutions are given. If any of the uncertainties are large, then reexamine the SN tables as described above and re-run CALIB and/or GETJY as necessary. Multiple executions of GETJY will not cause problems as previous solutions for the unknown flux densities are simply overwritten. In 31DEC10, you may wish to run the new task SOUSP to determine the spectral indices of your calibrators from their fluxes in the SU table. These spectral index parameters will be useful in running BPASS and PCAL.

### 4.5.2 Full calibration

Once you have determined the flux densities of all your gain calibrators, you are ready to complete the first pass of the calibration. At this point, many observers take a conservative viewpoint and delete their existing SN table(s) with

| | |
|---|---|
| > INEXT 'SN' CR | to specify the SN table. |
| > INVERS -1 CR | to delete all versions. |
| > EXTDEST CR | to do the deletion. |

This step forces you to re-run CALIB for all your gain calibration sources and is not required if the previous bootstrapping calibrations included all antennas and most correlators, for these calibrators.

Procedure VLACALIB may be used for your gain calibration sources as you did previously.

| | |
|---|---|
| > INDI *n* ; GETN *m* CR | to select the data set, $n = 3$ and $m = 1$ above. |
| > CALSOUR = '*aaaa*' , '*xxxx*' CR | to name two calibration sources using the same UVRANGE. |
| > UVRANGE *uvmin uvmax* CR | *uv* limits, if any, in kilo$\lambda$. |
| > ANTENNAS *list of antennas* CR | antennas to use for the solutions, see discussion above. |
| > REFANT *n* CR | reference antenna number. |
| > MINAMPER 10 CR | display warning if baseline disagrees in amplitude by more than *10%* from the model. |
| > MINPHSER 10 CR | display warning if baseline disagrees by more than 10° of phase from the model. |
| > DOPRINT -1 CR | to dispense with all the print out this time. |
| > FREQID 1 CR | use FQ number 1. |
| > INP VLACALIB CR | to review inputs. |
| > VLACALIB CR | to make the solution and print results. |

If there are different *uv* ranges for different sources, then re-run the procedure with changed parameters, such as:

| | |
|---|---|
| > CALSOUR = '*cal1*' , '*cal2*' , '*cal3*' CR | to name secondary flux calibrator(s). |
| > ANTENNAS 0 CR | solutions for all antennas. |
| > UVRANGE 0 CR | no *uv* limits, or range if any, in kilo$\lambda$. |
| > INP VLACALIB CR | to review inputs. |
| > VLACALIB CR | to process the secondary calibrators. |

At this time, you should use as many antennas and as large a UVRANGE as you can for each calibrator, consistent with its spatial structure.

### 4.5.3 Final (?) initial global calibration

At this point you should have gain and phase solutions for the times of all calibration scans, including the correct flux densities for the secondary calibrators. The next step is to interpolate the solutions derived from the calibrators into the CL table for all the sources. CLCAL may be run multiple times if subsets of the sources are to be calibrated by corresponding subsets of the calibrators, unless you limit it to one or more tables with SNVER and INVERS, CLCAL assumes that all SN tables contain only valid solutions and concatenates all of the SN tables with the highest numbered one. Therefore, any bad SN tables should be removed before using CLCAL. For polarization calibration, it is essential that you calibrate the primary flux calibrator (3C48 or 3C286) also so that you can solve for the left minus right phase offsets and apply PCAL.

To use CLCAL:

| | |
|---|---|
| > TASK CLCAL ; INP CR | to review the inputs. |
| > SOURCES '*sou1*' , '*sou2*' , '*sou3*' , . . . CR | sources to calibrate, ' ' means all. |
| > CALSOUR '*cal1*' , '*cal2*' , '*cal3*' , . . . CR | calibrators to use for SOURCES. |
| > FREQID *n* CR | use FQ number *n*. |
| > OPCODE 'CALI' CR | to combine SN tables into a CL table. |
| > GAINVER 1 CR | to select the input CL table; 1 for first calibration, 2 if there are baseline corrections. |
| > GAINUSE 2 CR | to select the output CL table; 2 is normal, 3 if there are baseline corrections. |
| > REFANT *m* CR | to select the reference antenna; needed only if REFANT reset since CALIB was run. |
| > INTERP '2PT' CR | to use linear interpolation of the possibly smoothed calibrations.. |
| > SAMPTYPE ' ' CR | to do no time-smoothing before the interpolation. |
| > SAMPTYPE 'BOX' CR | to use boxcar smoothing, followed by interpolation. |
| > BPARM *n* , *n* CR | to smooth, if BOX selected, with an *n*-hr long boxcar in amplitude and phase. |
| > DOBLANK 1 CR | to replace failed solutions with smoothed ones but to use all previously good solutions without smoothing. |
| > INP CR | to check inputs. |
| > GO CR | to run CLCAL. |

Calibrator sources may also be selected with the QUAL and CALCODE adverbs; QUAL also applies to the sources to be calibrated. Note that REFANT appears in the inputs because *AIPS* references all phases to those of the reference antenna. If none is given, it defaults to the one used in the most solutions.

Users should note that the inputs to CLCAL have changed for the 31DEC03 release. The smoothing and interpolation functions have been separated into two adverbs and the smoothing parameters are now conveyed with BPARM and ICUT. In smoothing, the DOBLANK adverb is particularly important; it controls whether good solutions are replaced with smoothed ones and whether previously failed solutions are replaced with smoothed ones. One can select either or both.

Note that CLCAL uses both the GAINUSE and GAINVER adverbs. This is to specify the input and output CL table versions, which should be different. CL table version 1 is intended to be a "virgin" table, free of all injury from any calibration you do using the *AIPS* package. It may not always be devoid of information, as "on-line" corrections may be made and recorded here by some telescope systems, *e.g.*, the VLBA. The VLA, through tasks FILLM or INDXR, can now put opacity and antenna gain information in this file. CLCAL and most other *AIPS* tasks are forbidden to over-write version 1 of the CL table. This protects it from modification, and keeps it around so that you may *reset* your calibration to the raw state by using EXTDEST to destroy all CL table extensions with versions higher than 1. Be careful doing this, since you rarely want to delete CL version 1. (All past versions of AIPS have allowed you to do this, but, beginning with the 15JUL94 release, AIPS will ask for special confirmation before allowing you to delete CL version 1.) Should you destroy CL table version 1 accidentally, you may generate a *new* CL table version 1 with the task INDXR. This new CL table may contain the calibration generated from the weather and antenna gain files. If you have made baseline corrections — or any of the many other sorts of corrections allowed by CLCOR — then you will probably want to protect (and use for input) CL table version 2 as well. In that case, GAINVER = 3 is recommended.

If you have any reason to suspect that the calibration has gone wrong — or if you are calibrating data for the first time — you should examine the contents of the output CL table. LISTR with OPTYPE = 'GAIN' will print out the amplitudes and phases in the specified CL or SN table. Note that these tables can be vary large. Use the SOURCES and TIMERANG adverbs to limit the output, or look at it on your terminal (DOCRT = 1) so that you can stop the display whenever you have had enough. Task SNPLT will provide you with a graphical display which may be easier on the eye.

In 31DEC10, the new task EVASN may help you determine the degree of phase and amplitude coherence in your calibration table. A lack of coherence suggests that the calibration is rather uncertain.

The most important step in the calibration is your verification that everything has gone according to plan. To check this, you should produce matrix listings for all your calibrator sources. For simplicity in interpretation, limit each listing to the UVRANGE to which you limited the calibrator during calibration. Thus:

| | |
|---|---|
| > TASK 'LISTR' C_R | |
| > DOCRT -1 C_R | to direct output to the printer. |
| > SOURCES '*cal1*' , '*cal2*' , '*cal3*' , . . . C_R | to list all selected calibrators by name. |
| > UVRANGE *uvmin uvmax* C_R | *uv* limits, if any, in kilo$\lambda$. |
| > OPTYP 'MATX' C_R | to get the matrix form of listing. |
| > DOCALIB TRUE C_R | to list with calibration applied. |
| > GAINUSE 2 C_R | or 3, to point to the *new* gain table. |
| > FREQID *n* C_R | list data for FQ *n*. |
| > DPARM = 5 , 1 , 0 C_R | to have amplitude and phase using scalar scan averaging. |
| > BIF 1; EIF 0 C_R | to select all IFs, LISTR will loop over IFs. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when inputs set correctly. |

The matrix average amplitudes for the calibrators in this listing should be very close to the values that you entered with SETJY (or which were derived by GETJY) and the phases in all rows and columns for these sources should be very close to zero.

If some rows and columns of the amplitude matrices are systematically different from the mean, the amplitude calibration for the associated antennas is imperfect. The reasons for this should be investigated. More flagging of visibilities, scans, or antennas, may be indicated. If the phase matrices have all elements near zero, then the phase calibration is in good shape. If some calibrators have discrepant phases and others do not, the discrepant calibrators are probably resolved. Note that you will not be able to detect errors in the assumed positions of your calibrators at this stage if you have used the usual 2-point interpolation of the calibration. Position errors in the calibrators have now become phase and position errors in the target sources.

In 31DEC06, a new method for examining the effects of amplitude calibration became available. ANBPL converts baseline-based data before or after calibration into antenna-based quantities. In particular, the calibrated weights are very sensitive to problems with amplitude calibration.

| | |
|---|---|
| > DEFAULT ANBPL C_R | to select task and initialize all its parameters. |
| > IND *m* ; GETN *n* C_R | to specify the multi-source data set. |

| | |
|---|---|
| > STOKES 'HALF' ; TIMERANG 0 $C_R$ | to DISPLAY both parallel-hand polarizations. |
| > FREQID 1 $C_R$ | to select FQ value to image. |
| > BIF 1 ; EIF 0 $C_R$ | to select all IFs. |
| > BCHAN *n* ; ECHAN *m* $C_R$ | to combine a range of channels. |
| > DOCALIB 1 $C_R$ | to apply calibration. |
| > GAINUSE 0 $C_R$ | to use highest numbered CL table. |
| > FLAGVER 1 $C_R$ | to edit data. |
| > DOBAND 3 ; BPVER 1 $C_R$ | to correct bandpass with time smoothing using table 1. |
| > BPARM 2, 17 $C_R$ | to plot weight versus time. |
| > NPLOTS 3 ; DOTV 1 $C_R$ | To plot 4 antennas per page on the TV. |
| > DOCRT 0 $C_R$ | to suppress printed versions of the antenna-based values. |
| > INP $C_R$ | to review the inputs. |
| > GO $C_R$ | to run ANBPL. |

If the previous steps indicate serious problems and/or you are seriously confused about what you have done and you want to start the calibration again, you can use the procedure VLARESET from the RUN file VLAPROCS to reset the SN and CL tables.

| | |
|---|---|
| > INP VLARESET $C_R$ | to verify the data set to be reset. |
| > VLARESET $C_R$ | to reset SN and CL tables. |

## 4.6 Polarization calibration

The calibration of visibility data sensitive to linear polarization involves two distinct operations: (1) determining and correcting the data for the effects of imperfect telescope feeds and (2) removing any systematic phase offsets between the two systems of orthogonal polarization. These two components of polarization calibration will be considered separately.

The effective feed response is parametrized most generally by its polarization ellipticity and the orientation of the major axis of that ellipse. For the VLA, it appears to be adequate to make the simpler assumption that each polarization is corrupted by a small complex gain times the orthogonal polarization.

In general, the polarization of the calibrator(s) to be used to determine the feed parameters will not be known *a priori* and must be determined along with the feed parameters. Observations of a given source (or sources) over a wide range ($\geq 90°$) of parallactic angles is necessary to separate calibrator polarization from the feed parameters. Task LISTR may be used to determine the parallactic angles at which data have been taken:

| | |
|---|---|
| > TASK 'LISTR' $C_R$ | |
| > SOURCES '*cal1*' , '*cal2*' , '*cal3*' , . . . $C_R$ | list all calibrators to be used. |
| > INEXT 'CL' $C_R$ | to determine parallactic angle at times in CL table. |
| > INVER 1 $C_R$ | CL version 1. |
| > FREQID *n* $C_R$ | to use FQ number *n*. |
| > OPTYPE 'GAIN' $C_R$ | to use gain table rather than visibility data. |
| > DPARM = 9 , 0 $C_R$ | to display parallactic angle. |
| > INP $C_R$ | to review the inputs. |
| > GO $C_R$ | to run the program when inputs set correctly. |

Multiple calibrators may be used in determining the feed polarization, but the data from them must be accurately calibrated. In particular, the phase calibration of any calibrator used to determine antenna polarizations should be determined from that calibrator itself (*i.e.*, the source should be self-calibrated). Note that this will normally have occurred for all gain calibrators if the procedure described in the previous sections was followed.

The normal phase calibration technique treats parallel-hand visibilities in the two orthogonal polarizations independently. Thus, there will be a systematic phase difference between the two polarizations systems. This difference may be due to differences in instrumental phase offset for the two systems or due to the propagation medium (*i.e.*, Faraday rotation) or both. Faraday rotation effects are particularly bothersome as they may be time variable and increase rapidly with wavelength. For data at L band or longer wavelengths, *AIPS* should be given an estimate of the ionospheric Faraday rotation measure using task FARAD. This task computes the ionospheric rotation measure using either total electron content from a nearby ionospheric monitoring station (Boulder Colorado for the VLA) or an empirical model that uses the monthly mean Zurich sunspot number (R1) as a measure of solar activity. If monitoring data are available, they should be used in preference to the model. FARAD enters the ionospheric Faraday rotation measure into the CL table. This is used by PCAL when determining antenna polarization parameters and is used by other calibration tasks to de-rotate the data when polarization corrections are applied. FARAD may be run any number of times with different parameters before PCAL is run; each run of FARAD over-writes the values written previously.

Data from Boulder for the total electron content for year *mm* is contained in the file TECB.*mm* in the directory with logical name AIPSIONS. Currently, data are available for 1980 onwards through part of 1992. Some gaps in the TEC data occur, particularly for years 1980 and 1988 and for times when solar activity has been high and no reliable estimate of the total electron content could be made. Unfortunately, we are no longer able to get the TEC data from Boulder. If your VLA data are more recent than early 1992, you can consider using the ionospheric model in FARAD, but you should be aware that the model is crude and should check that it improves matters before using it in your final calibration.

The phase offsets between the right-hand and left-hand polarizations at a given time may be determined using, from a source with a known angle of linear polarization, data which have had the effects of imperfect feeds removed. The phase of the right-left correlations or the conjugate of the left-right correlations indicates the phase difference between the two polarizations.

The (initial) need for ionospheric corrections can be bypassed if either (1) you use unpolarized sources in PCAL, and/or (2) the ionosphere was well behaved during your observations. Typical rotation measures are only a few and therefore affect only L and longer-wavelength bands. The ionosphere is almost always well enough behaved to be ignored at shorter wavelengths and is usually able to be ignored even at L band. Changes of around 10° in the relative phases of R and L polarizations are not enough to disrupt a PCAL solution seriously. And, fortunately, calibrators at long wavelengths, such as P band, tend to be unpolarized. In general, if the ionosphere is well behaved, it can be ignored. If it is bad, no simple model is able to correct it and you may simply have to forget about polarization for that observing run. Note that an apparent position angle variation of 3C286 with time probably indicates that ionospheric rotation is significant. But, if 3C286 shows large rotations, it does not follow that *its* rotation can be applied to other directions in the sky. All it implies reliably is that a *model* is needed.

Polarization calibration of EVLA data is discussed extensively in Appendix E. These data are fundamentally multi-channel and a spectral-dependent polarization solution is required. In 31DEC10, PCAL and RLDIF were modified to determine and apply the calibration in a channel-dependent fashion. For data not requiring the spectral options, polarization calibration may be performed on amplitude- and phase-calibrated VLA data using the following five-step procedure:

**Step 1:** Run PCAL on one or more phase calibrator sources observed with a wide range of parallactic angles:

| | |
|---|---|
| > TASK 'PCAL' C_R | |
| > CALSOUR '*cal1*' , '*cal2*' , '*cal3*' , . . . C_R | list all calibrators to be used. |
| > TIMERANG 0 C_R | to use all times. |
| > ANTENNAS 0 C_R | to solve for all antennas. |

| | |
|---|---|
| > UVRANGE *uvmin uvmax* C_R | to set *uv* limits, if any, in kilo$\lambda$. |
| > BIF 1 ; EIF 2 C_R | to do both IFs. |
| > DOCALIB 1 C_R | to apply the calibration to the sources (very important!). |
| > GAINUSE 2 C_R | or 3 or whatever, to use the latest CL table. |
| > CLR2N C_R | to clear IN2NAME *etc.* since there is no Clean-image model. |
| > FREQID *n* C_R | to use FQ value *n*; only one polarization solution can be stored. |
| > PMODEL 0 C_R | to use polarization parameters in the source table. |
| > SOLINT 2 C_R | to use a 2-minute solution interval; scan averages are usually sufficient. |
| > SOLTYPE 'APPR' C_R | to use linear approximation model. |
| > PRTLEV 1 C_R | to display the results and some diagnostic information. |
| > REFANT n C_R | only if REFANT reset since CALIB run. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when inputs set correctly. |

PCAL will list the fitted values of the antenna polarization parameters and the source polarizations with estimates of the uncertainties. If these results do not appear reasonable (*e.g.*, large errors or large corrections or inconsistent solutions for the calibrator polarizations at neighboring frequencies), more editing and a rerun of PCAL may be necessary. PCAL puts the derived source polarizations in the SU table and the antenna feed values in the AN table. These values may be examined later with PRTAN and PRTAB.

**Step 2:**. Use RLDIF to determine the apparent right minus left phase angle of the polarization calibrator source, *e.g.*, 3C286 or 3C138:

| | |
|---|---|
| > TASK 'RLDIF' C_R | |
| > SOURCE '3C286' , ' ' C_R | to view only the polarization angle calibrator. |
| > TIMERANG 0 C_R | to check all times. |
| > ANTENNAS *list of antennas* C_R | antennas to use; the list used for CALIB. |
| > UVRANGE *uvmin uvmax* C_R | to limit *uv*, if appropriate. |
| > BIF 1 ; EIF 0 C_R | to view all IFs. |
| > FREQID *n* C_R | to view the current FQ value (*n*). |
| > DOCALIB TRUE C_R | to list with calibration applied. |
| > DOPOL TRUE C_R | to correct for feed polarization and Faraday rotation. |
| > GAINUSE 2 C_R | to use the latest CL table. |
| > DOCRT -1 C_R | to print the results on the line printer; DOCRT > 0 prints on your terminal screen and DOCRT = 0 does no printing. Answers are rerun in all cases. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when inputs set correctly. |

The matrix of scan-averaged right minus left phase angles (actually RL and conjugate of LR polarizations) will be printed. Check that none of the phases differ from the mean by more than a few degrees. If any do, then use UVFLG to edit these data and go back to step 1. After the matrix of phases, the average over the matrix of the right minus left phases is displayed. This is the number to be used in step 4. RLDIF returns these, one for each IF, in the CLCORPRM adverb array. It even averages over multiple calibrator scans, getting a reliable estimate of the average by iteratively discarding outliers. To see the results, type

| | |
|---|---|
| > OUTPUTS C_R | to examine the output adverb values. |

LISTR may also be used with OPTYPE 'MATX' ; STOKES 'POLC' to make the printer display, one IF at a time. But you will have to do any averaging and placing of the results in CLCORPRM yourself.

This method will fail if the calibrator source (3C286 or 3C138, usually) is heavily resolved and the atmospheric phase stability is poor. (These two are frequently coupled!) Under these conditions, the self-calibration of the calibrator will have failed and will have to be done especially for the polarization calibration. In the steps below, you may safely relax the *uv* limits by about 20%, but should solve only for phases using SOLMODE = 'P'. The process consists of:

2.1 Apply CALIB to the inner (short-baseline) antennas on the calibrator source using the rules in the table found in § 4.3.3 but relaxed a bit. Set DOCALIB = 1 ; GAINUSE = 2 ; SOLMODE = 'P'.

2.2 Use CLCAL to apply these solutions to the calibrator source using GAINVER = 2 ; GAINUSE = 3.

2.3 Run LISTR for cross-hand phases using *only* the antennas used with CALIB.

2.4 Use EXTDEST to delete CL table 3, a most important step.

After correcting the calibration, repeat steps 2.1 and 2.2 and the special calibration until satisfactory results are obtained.

**Step 3:** Use TASAV to copy all your table files to a dummy *uv* data set, saving in particular the CL table with the results of the amplitude and phase calibration. This step is not essential, but it reduces the magnitude of the disaster if the the next step is done incorrectly. (Note - this may be a good idea at several stages of the calibration process!)

| | |
|---|---|
| > TASK 'TASAV' C_R | |
| > CLRO C_R | Use default output file file name. |
| > INP C_R | to review the (few) inputs. |
| > GO C_R | to run the program. |

The task TACOP may be used to recover any tables that get trashed during later steps. CLCOR will make a new CL table now, so a TACOP step is not needed.

**Step 4:** The right minus left phase offset corrections are made using task CLCOR. In 31DEC10, they may also be made by RLDIF. The phase offset correction is the expected value (*twice* the source polarization angle) minus the observed phases from step 2. The expected value is 66 degrees for 3C286, -18 for 3C138 (at L band, perhaps -24 at higher frequencies), and -140 for 3C48 (at 6-cm or shorter wavelengths). Thus, having used RLDIF and 3C286 in step 2 above

| | |
|---|---|
| > FOR I = 1 : $n$ ; CLCORP(I) = 66 - CLCORP(I) ; END C_R | to convert the returned phases into corrections for CLCOR, where $n$ is the number of IFs. |

Then

| | |
|---|---|
| > TASK 'CLCOR' C_R | |
| > SOURCE ' ' ; ANTENNAS 0 C_R | to correct all sources and all antennas. |
| > TIMERANG 0 C_R | to correct all times. |
| > BIF 1 ; EIF 2 C_R | to correct both IFs. |
| > FREQID $n$ C_R | to correct only the current FQ value. |
| > GAINVER 2 C_R | to modify the CL table produced by CLCAL; value is 3 is baseline corrections were done. |
| > GAINUSE 0 C_R | to make a new CL table containing the phase corrections as well as all previous calibrations. |
| > OPCODE 'POLR' C_R | to do right minus left phase offset correction. |
| > STOKES 'L' C_R | correction applied to left circular polarization. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when inputs set correctly. |

In 31DEC09, task RLCOR may be used to apply this correction directly to a *uv* data set which is especially useful for single-source files to which CLCOR does not apply.

This will cause CLCOR to apply appropriate corrections to the CL and AN tables. If the CL table becomes hopelessly corrupted, delete it and return to Step 3. If the AN table is corrupted, then PCAL must be re-run. If more than one CL table needs to be corrected, use the OPCODE='POLR' option only once; other CL tables must be corrected using OPCODE='PHAS' and correcting 1 IF at a time. CLCOR (with OPCODE = 'POLR') may be applied multiple times to the *same* CL table, in order to get the R-L phases "right." But you must *not* apply CLCOR in succession to different CL tables of the same database. If there is any doubt, rerun PCAL. The best way to judge if all is well in the final polarization solution is to look at the spread in the cross-hand phases for 3C286 or 3C138 (step 5 below). If the spread ("eyeball rms") is less than 3 degrees, then all is well. If more than ten, then there is definitely something wrong.

**Step 5:** Use RLDIF to verify the polarization corrections:

| | |
|---|---|
| > TASK 'RLDIF' C_R | |
| > SOURCE '*cal1*' , '*cal2*' , . . . C_R | to list the calibrators to be checked. |
| > TIMERANG 0 C_R | to display all times. |
| > ANTENNAS *list of antennas* C_R | to list the antennas to use. |
| > UVRANGE *uvmin uvmax* C_R | to set *uv* limits, if appropriate. |
| > BIF 1 ; EIF 0 C_R | to list all IFs. |
| > FREQID *n* C_R | to use the current FQ value (*n*). |
| > DOCALIB 1 C_R | to list with calibration applied. |
| > DOPOL TRUE C_R | to correct for feed polarization and Faraday rotation. |
| > GAINUSE 0 C_R | to use CL table written by CLCOR. |
| > DOCRT 1 | to display on your terminal. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when inputs set correctly. |

Note well: all of this calibration process must be done with only one FQ at a time. PCAL with FQID = 2 will over-write solutions done for any other FQID.

The phases produced should be consistent. Significant deviations of the phase may indicate that further editing is needed or that residual atmospheric phase errors are still present. If this display appears okay, then the polarization corrections may be applied in SPLIT (see below) by specifying DOPOL = 1 when applying the calibration to produce single-source files.

## 4.7 Spectral-line calibration

The calibration of spectral-line data is very similar to that of continuum data with the exception that the antenna gains have to be determined and corrected as a function of frequency as well as time. The model used by *AIPS* is to determine the antenna gains as a function of time using a pseudo-continuum ("channel-0") form of the data. Then the complex spectral response function ("bandpass") is determined from observations of one or more strong continuum sources at or near the same frequency as the line observation. In general, the channel-0 data are calibrated using the recipes in the previous sections of this chapter. The sub-sections below are designed to bring out the few areas in which spectral-line calibration differs from continuum.

### 4.7.1 Reading the data

If your data are on a VLA archive tape then they should be read into *AIPS* using FILLM, as described in § 4.1.1. FILLM will fill a typical line observation into two files, a large one containing the line data only, and a smaller file containing the "channel-0" data. (Note that, beginning with 31DEC01, FILLM computes channel-0 from the line data rather than using the channel-0 provided by the on-line system.) The standard calibration and editing steps are performed on channel 0 and the results copied over to the line data set. *You must be careful with the tolerance you allow* FILLM *to use in determining the* FQ *numbers. If you desire all of your data to have the same* FQ *number, so that you can calibrate it all in one pass, then set* CPARM(7) *in* FILLM *to an appropriately large value.* If you wish to retain spectral-line autocorrelation data, you must set DOACOR to true.

By default for the VLA, the channel-0 data are generated by the vector average of the central *3/4* of the observing band. If this algorithm is not appropriate for your data, you may generate your own channel-0 data set by averaging only selected channels. You may now select different spectral channels in different IFs. To do this, use the task AVSPC:

| | |
|---|---|
| > TASK 'AVSPC' C_R | |
| > INDI *n* ; GETN *m* C_R | to specify line data set. |
| > OUTDI *i* ; OUTCL 'CH 0' C_R | to specify output "channel-0" data set disk and class. |
| > ICHANSEL 10, 30, 1, 0, 31, 55, 2, 1 C_R | for example, to average every channel between 10 and 30 in all IFs and also every other channel between 31 and 55, but only in IF 1. |
| > GO C_R | to create a new channel-0 data set. |

You might find this necessary when observing neutral hydrogen at galactic velocities. Most calibrator sources have some absorption features at these frequencies.

### 4.7.2 Editing the data

You should follow the steps outlined in § 4.4 to edit the calibrator data using the channel-0 data set. Even though channel-0 data is continuum, be careful to have TVFLG and UVFLG generate the flagging commands for all channels, not just channel 1. Then, copy the resulting FG table to the line file. Use TACOP:

| | |
|---|---|
| > TASK 'TACOP' C_R | |
| > INDI *n* ; GETN *m* C_R | to specify channel-0 data set. |
| > OUTDI *i* ; GETO *j* C_R | to specify the line data set. |
| > INEXT 'FG' C_R | to copy the FG table. |
| > INVER 1 C_R | to copy table 1. |
| > NCOUNT 1 C_R | to copy only one table. |
| > OUTVER 1 C_R | to copy it to output table 1 |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when inputs set correctly. |

Specifying the "ALL-CH" setting in TVFLG and specifying BCHAN 1 ; ECHAN 0 C_R in UVFLG cause all channels to be flagged when the FG table is copied to the line data set.

Spectral-line observers should also use SPFLG (§ 10.2.2) to examine and, perhaps, to edit their data. This task is very similar to TVFLG described in § 4.4.3, but SPFLG displays spectral channels for all IFs on the horizontal axis, one baseline at a time. If you have a large number of baselines, as with the VLA, then you should examine a few of the baselines to check for interference, absorption (or emission) in your calibrator sources, and other frequency-dependent effects. Use the ANTENNAS and BASELINE adverbs to limit the displays to a few short spacings and one or two longer ones as well. If there are serious frequency-dependent effects in your calibrators, use SPFLG and UVFLG to delete them. (You might wish to delete the FG table with EXTDEST to begin all over again.) Then use AVSPC to build a new channel-0 data set and repeat the continuum editing. Note that you should not copy the FG table from the spectral-line data set to the new continuum one. The reason for this is the confusion over the term "channel." If you have flagged channel 1, but not all channels, in the spectral-line data set — a very common occurrence — then a copied FG table would flag all of the continuum data since it has only one "channel." When you have flagged the channel-0 data set, you can merge the new flags back into the spectral-line FG table with task TABED.

| | |
|---|---|
| > TASK 'TABED' C_R | |
| > INDI *n* ; GETN *m* C_R | to specify channel-0 data set. |
| > OUTDI *i* ; GETO *j* C_R | to specify the line data set. |
| > INEXT 'FG' C_R | to copy the FG table. |
| > INVER 1 C_R | to copy table 1. |
| > OUTVER 1 C_R | to copy it to output table 1. |
| > BCOUNT 1 ; ECOUNT 0 C_R | to copy from the beginning to the end. |
| > OPTYPE 'COPY' C_R | to do a simple copy appending the input table to the output table. |
| > TIMER 0 C_R | to copy all times. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when inputs set correctly. |

If the channel-0 data set is meaningful for your program sources, you might consider doing a first-pass editing of them along with your calibrators before copying the FG table back to the line data set. If your program sources contain significant continuum emission, then this is a reasonable operation to perform. If they do not, then the standard channel-0 data set is not useful for editing program sources. You can use SPFLG to edit all channels, or if the signal is strong in a few channels, you could run TVFLG on those channels from the spectral-line data set or average those with the BCHAN, ECHAN, and NCHAV adverbs.

### 4.7.3 Bandpass calibration

The task BPASS is designed to take visibility data from specified calibrator(s) to determine the antenna-based complex bandpass functions. It does this in a manner analogous to self-calibration in that the data are divided by a source model or the so-called "channel 0" before the antenna gains are determined as a function of frequency. These are written to a BandPass (BP) table. The bandpass calibration is the first operation that should be performed on the line data. So long as one uses the mode in which the data are divided by the so-called "channel 0," it is not necessary to calibrate the data before estimating the bandpasses.

| | |
|---|---|
| > TASK 'BPASS' C_R | |
| > INDI *i* ; GETN *j* C_R | to specify the line data set. |
| > CALSOUR '*cal1*' , '*cal2*' , . . . C_R | to specify bandpass calibrators. |
| > FREQID 1 C_R | to select which FQ value to use. |
| > ANTENNAS 0 C_R | to solve for all antennas. |
| > REFANT *n* C_R | to set the reference antenna number. |
| > DOCALIB FALSE C_R | to avoid applying calibration. |
| > BPASSPRM 0 C_R | to turn off all "parameters." |
| > BPASSPRM(5) 0 C_R | to divide by channel 0 on a record-by-record basis before determining antenna-based bandpasses. Other normalization options are available and may be preferred. |
| > IN3DI *a* ; GET3N *b* C_R | to specify the channel 0 data file, or |
| > CLR3NAME C_R | to have channel 0 found from the input data themselves. |
| > ICHANSEL 20 50 1 | to use the average, in each IF, of all channels from 20 through 50, for example, to determine channel 0, when the third input file name is empty. |
| > FLAGVER 1 C_R | to apply flag table 1. |

| | |
|---|---|
| > SOLINT 0 C_R | to use scan averages. |
| > BPVER 1 C_R | to select the output BP table number. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when inputs set correctly. |

Be careful with the adverb SMOOTH. If you smooth, or do not smooth, the data while finding a bandpass solution, then you must apply the same SMOOTH adverb values whenever you apply that bandpass solution to the data. The only exception is that you may smooth the data after applying the bandpass solution with SMOOTH(1) values 5 through 8 when you did no smoothing in BPASS.

The stored bandpass correction table should be corrected for the spectral index of the calibration source. Use adverbs SPECINDX and SPECURVE to describe the spectral index to BPASS and new task SOUSP to find the spectral index values from the fluxes in the source table.

The divide by channel 0 option is very convenient in that it allows one to ignore both source structure (when the bandwidth is narrow enough) and continuum calibration. However, the average of some channels on a record-by-record basis can be rather noisy and the "division" operation is actually a subtraction of the average phase and a division by the average amplitude. The latter suffers from a "Ricean" bias — the average amplitude will always be larger than the correct amplitude, averaging one rms larger. Therefore, if the continuum calibration is stable (or already known and able to be applied) and the source structure is negligible, then it would be better to defer the normalization (on a baseline by baseline basis) until the data are averaged over SOLINT or, better still, to defer the normalization (on an antenna basis) until the unnormalized solutions are determined. BPASSPRM(5) and BPASSPRM(10) control the normalization options. Do note also that, with no normalization, BPASS is capable of replacing any use of CALIB including calibration of the data weights.

The spectral quality of the final images has been found to be determined in part by the quality of the bandpass solutions. In particular, for reasons which are not yet known, the bandpasses are not exactly antenna dependent especially in the edge channels. This "closure error" may be measured in individual and statistical ways by BPASS and reported to you. To check on this problem for your data set, set

| | |
|---|---|
| > MINAMPER *a* C_R | to count and, if BPASSPRM(2)$>1$, to report amplitude closure failures $> a$ per cent. Note that closure errors are accumulated as logarithms so that 0.5 and 2.0 are both errors of 100%. |
| > MINPHSER *p* C_R | to count and, if BPASSPRM(2)$>$ 1, to report phase closure failures $> p$ degrees. |
| > BPASSPRM(2) 1 C_R | to report statistics of amplitude and phase closure failures without reporting individual failures. |
| > BPASSPRM(6) *a* C_R | to report all channels in which the average amplitude closure error $> a$ per cent. |
| > BPASSPRM(7) *p* C_R | to report all channels in which the average phase closure error $> p$ degrees. |
| > SOLTYPE 'R' C_R | to select robust solutions which discard data with serious closure problems. Try other types if there are solution failures. |

It is probably a good idea to set MINAMPER and MINPHSER fairly high (*i.e.*, 20 and 12) to make a big deal only about major excursions, but to set BPASSPRM(6) and (7) fairly low (*i.e.*, 0.5 and 0.5) to view the spectrum of closure errors (which will look a lot like the spectrum of noise on your final Clean images). There is even a task called BPERR which will summarize and plot the error reports generated by PBASS and written to text files by PRTMSG.

The bandpass solutions are calculated at each bandpass calibrator scan. As a consequence, they are likely to be unevenly spaced in time and may even have times (due to on-line or later editing) at which there are solutions for some IFs and polarizations but not all. When the latter happens, program source data will be lost unless the missing solutions are filled in. The task BPSMO may be used for this purpose or to create a new BP table at regular time intervals using one of a number of time-smoothing functions. Set APARM(4) = -1 for the "repair" mode or set APARM(4) to the desired BP interval.

After the bandpasses have been generated, you can examine them using tasks BPLOT and POSSM. You can obtain an average from all antennas with

| | |
|---|---|
| > TASK 'POSSM' C_R | |
| > INDI *i* ; GETN *j* C_R | to specify the line data set. |
| > SOURCES '*cal1*' , '*cal2*' , . . . C_R | to specify the bandpass calibrators. |
| > ANTENNAS 0 C_R | to include all antennas. |
| > TIMER 0 C_R | to average over all times. |
| > BCHAN 1 ; ECHAN 0 C_R | to display all channels. |
| > BPVER 1 C_R | to select the BP table. |
| > FREQID 1 C_R | to set the FQ value to use. |
| > APARM = -1, 0 C_R | to do a scalar average and have the plot self-scaled and labeled in channels. |
| > APARM(8) 2 C_R | to plot BP table data. |
| > NPLOTS 0 C_R | to make one plot only, averaging all included data. |
| > INP C_R | to review the inputs — check closely. |
| > GO C_R | to run the program when inputs set correctly. |
| > GO LWPLA C_R | to send the plot to the (PostScript) printer/plotter. |

To view each antenna individually, using the TV to save paper

| | |
|---|---|
| > DOTV TRUE C_R | to use the TV. |
| > NPLOTS 1 C_R | to plot one antenna per page/screen. |
| > GO C_R | to display the bandpasses, averaged over time, on the TV with one antenna per screen. |

POSSM shows each screen for 30 seconds before going ahead. You can cause it wait indefinitely by hitting button A, speed it up by hitting TV buttons B or C, or tell it to quit by hitting button D. If DOTV = -1, then POSSM makes multiple plot extension files, which can be sent to the printer (individually or collectively) by LWPLA. You might want to use a larger value of NPLOTS to reduce the number of pieces of paper.

BPLOT is used to create one or more plots (on the TV or in plot files) of the selected bandpass table. The plots will be a set of profiles separated on the vertical axis by an increment in time or antenna number (depending on the sort selected). More than one plot for more than one antenna or more than one time may be generated. Multiple IFs and polarizations will be plotted along the horizontal axis if they are present in the BP table and selected by the adverbs. Thus, BPLOT is useful for plotting the change in bandpass shape as a function either of time or of antenna.

The BP tables are applied to the data by setting the adverb DOBAND > 0 and selecting the relevant BP table with the adverb BPVER. There are three modes of bandpass application. The first (DOBAND 1) will average all bandpasses for each antenna within the time range requested, generating a global solution for each antenna. The second mode (DOBAND 2) will use the antenna bandpasses nearest in time to the data point being calibrated. The third mode (DOBAND 3) interpolates in time between the antenna bandpasses and generates the correction from the interpolated data. This mode has been found to be required for VLA data. If BPSMO was used to make a fairly finely sampled BP table, then DOBAND 2 may be used. Modes DOBAND 4 and DOBAND 5 are the same as modes 2 and 3, respectively, except that data weights are ignored.

It is often not possible to observe a strong bandpass calibrator many times during a run. In this case, one can run BPASS on the single scan on the strong calibrator and then remove the main bandpass shape with DOBAND 1 in task SPLAT. Corrections to this basic bandpass shape as a function of time may then be determined with adequate signal-to-noise using task CPASS. This task can be used to fit the residual bandpass with a small number of parameters (<< the number of spectral channels) at each calibrator scan. The results may then be applied with DOBAND 2. Check the output of CPASS carefully — it is capable of making bandpass shapes with large ripples that are not present in the data.

### 4.7.4 Amplitude and phase calibration

The channel-0 data set should be calibrated as described above for continuum data (§ 4.4 and § 4.5). When you are satisfied with your results, you should copy the relevant CL table over to the line data set with TACOP:

| | |
|---|---|
| > TASK 'TACOP' C_R | |
| > INDI *n* ; GETN *m* C_R | to specify the channel-0 data set. |
| > OUTDI *i* ; GETO *j* C_R | to specify the line data set. |
| > INEXT 'CL' C_R | to copy a CL table. |
| > INVER 2 C_R | to copy table 2 from CLCAL step. |
| > NCOUNT 1 C_R | to copy only one table. |
| > OUTVER 0 C_R | to create new output table. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when inputs set correctly. |

At this point it is often useful to examine your fully calibrated data using POSSM:

| | |
|---|---|
| > TASK 'POSSM' C_R | |
| > INDI *i* ; GETN *j* C_R | specify line data. |
| > SOURCES '*source1*' , ' ' C_R | to specify the source of interest. |
| > ANTENNAS 0 C_R | to plot all antennas. |
| > BCHAN 10 ; ECHAN 55 C_R | to plot spectrum for this channel range only. |
| > DOCALIB 1 C_R | to apply the antenna gain to both visibilities and weights (if appropriate). calibration. |
| > GAINUSE 0 C_R | to use most recent CL table. |
| > DOBAND 3 C_R | to apply the bandpass calibration time smoothed. |
| > BPVER 1 C_R | to use BP table 1. |
| > FREQID 1 C_R | to use only one FQ value. |
| > APARM 0 C_R | to do vector averaging of amplitudes and self-scale the plots. |
| > SMOOTH 5 , 0 C_R | to apply Hanning smoothing in the spectral domain after bandpass calibration is applied. Use 1,0 only if the data were Hanning smoothed when BPASS was run. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when inputs set correctly. |
| > GO LWPLA C_R | to send the plot to the (PostScript) printer/plotter. |

If you have multiple FQ entries in your data set, you should repeat the calibration for each additional FQ entry. Bookkeeping is simplified if you eliminate all extant SN tables before calibrating the data associated with each frequency identifier. However, it is not essential to do this.

## 4.8 Solar data calibration

The calibration of solar *uv* data differs from normal continuum and spectral-line calibration in one critical respect: the system temperature correction to the visibility data is applied by the observer in AIPS. See Lecture 21 in *Synthesis Imaging in Radio Astronomy* for a discussion of the system temperature correction as it applies to VLA solar visibility data. The system temperature correction is embodied in a quantity referred to as the "nominal sensitivity," an antenna-based numerical factor normally applied in real time to the scaled correlation coefficients before they are written on the VLA archive tape. With the exception of X and L band, only a handful of VLA antennas are equipped with so-called "solar CALs." The nominal sensitivity is only computed for those antennas so-equipped, namely antennas 5, 11, 12, and 18 (at K, U,and C bands) and antennas 7, 12, 21, and 27 (at P band). The system-temperature correction for those antennas without solar CALs must, therefore, be bootstrapped from those antennas which do. This is accomplished through two tasks. `FILLM` fills the uncalibrated visibility data to disk and places the nominal sensitivities in a `TY` extension table. Then, `SOLCL` applies the nominal sensitivities to calibration parameters in the `CL` table.

### 4.8.1 Reading solar data from a VLA archive tape

To load a solar *uv*-data file to disk from a VLA archive tape follow the general instructions given above (§ 4.1.1 and § 4.7.1) with the following additions:

> VLAMODE 'S ' C_R        to indicate solar mode observing.
> CPARM(2) 16 C_R        to indicate that moving sources are allowed without renaming.

If your experiment involved observing active solar phenomena, (*e.g.*, flares), you may wish to update the system-temperature correction every integration time. For example, if you observed a flare with an integration time $\tau = 1.67$ seconds, choose

> CPARM(8) 1.67 / 60 C_R        for 1.67 sec `CL` and `TY` table intervals.

Loading an entire solar *uv*-data set to disk with the minimum integration time results in very large disk files which make all subsequent programs take a long time to run. A useful strategy is to load the data with relatively low time resolution (20–30 seconds for observations of active solar phenomena) and to proceed with the usual continuum data calibration, deferring the system temperature correction. When a satisfactory calibration is obtained, the relevant `SN` table may be saved using `TASAV`. (Note that you must save the `SN` table, before running `CLCAL` rather than the final `CL` table.) Then run `CLCAL` and inspect the data for interesting periods of activity — try `UVPLT` with BPARM = 11, 1 for plots of amplitude versus time or `TVFLG`, displaying amplitudes as a function of baseline length and time. Use `FILLM` to load the relevant time ranges of solar *uv* data to disk with no averaging. The saved `SN` table is then copied to each high-time resolution data set. Assess, and possibly edit, the nominal sensitivities (§ 4.8.2) and then apply the system-temperature corrections (§ 4.8.3). Finally, apply the saved/copied `SN` table to the `CL` table 2 of each using `CLCAL`.

### 4.8.2 Using SNPLT and LISTR to assess the nominal sensitivities

When solar *uv* data are written to disk, `FILLM` writes the nominal sensitivities of those antennas equipped with solar CALs into the `TY` table. Before bootstrapping the system temperature correction for antennas without solar CALs from those which do, it is always wise to examine the nominal sensitivity for each of the solar CAL antennas for each of the IFs. The tools available for this purpose include: `SNPLT`, which plots the nominal sensitivities in graphical form, `LISTR` or `PRTAB`, which allow one to inspect the values directly, and `EDITA`, which provides an interactive display of the `TY` data and allows you to edit the data. To make plots:

> TASK 'SNPLT' ; INP C_R        to review the inputs needed.

| | |
|---|---|
| > IND *m* ; GETN *n* C_R | to specify the input *uv* file. |
| > INEXT 'TY' C_R | to plot data from TY extension table. |
| > INVERS 0 C_R | to use the highest version number. |
| > SOURCES 'SUN' , ' ' C_R | to plot solar source only. |
| > TIMERANG 0 C_R | to select all times. |
| > ANTENNAS 5 11 12 18 C_R | to select only CAL-equipped antennas; this sample list for K, U, or C band. |
| > PIXRANGE 0 C_R | to self-scale each plot. |
| > NPLOTS 4 C_R | to do 4 plots on a page. |
| > FACTOR 2 ; SYMBOL 5 C_R | to use triangles to mark the data and enlarge them by a factor of 2. The symbols may even be connected by lines. |
| > XINC 1 C_R | to plot every XINC$^{th}$ point. |
| > OPTYPE 'TSYS' C_R | to plot nominal sensitivities. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when you're satisfied with inputs. |

SNPLT produces a PL extension file which may be plotted using LWPLA, TKPL, or TVPL — or you could set DOTV TRUE in SNPLT and get the display directly (and temporarily) on the TV. Then to inspect the values over some limited time range in detail, run LISTR (assuming the adverbs set above and):

| | |
|---|---|
| > TASK 'LISTR' ; INP C_R | to review the inputs needed. |
| > OPTYPE 'GAIN' C_R | to list quantities in a calibration file. |
| > INEXT 'TY' C_R | to select the sensitivities. |
| > TIMER *d1 h1 m1 s1 d2 h2 m2 s2* C_R | to select by suspect time range. |
| > DOCRT -1 C_R | to route output to the printer. |
| > DPARM 10 0 C_R | to list nominal sensitivities. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when you're satisfied with inputs. |

The use of EDITA with TY tables is described extensively in § 4.4.2 and need not be described further here.

### 4.8.3 Using SOLCL to apply the system-temperature correction

Once you have identified the appropriate subset of reference solar CAL antennas for each source and IF, you are ready to bootstrap the system-temperature correction of the remaining antennas. It is recommended that you run SOLCL before applying any other calibration to the CL table. In this way, you can easily verify that the appropriate corrections have been made to each antenna. If you are using a version of AIPS older than 15JUL94, you must copy CL table version 1 into CL table version 2 before running SOLCL (which does the copy for you in later releases). Then you apply the system-temperature correction to version 2 and correct mistakes by deleting and recreating version 2. To run SOLCL:

| | |
|---|---|
| > TASK 'SOLCL' ; INP C_R | to review the inputs needed. |
| > SOURCES '*' C_R | to correct all sources. |
| > STOKES ' ' C_R | to correct both polarizations. |
| > TIMERANG 0 C_R | to correct all times. |
| > ANTENNAS 5 11 12 18 C_R | to use the listed antennas as references. |
| > SUBARRAY 1 C_R | to modify sub-array 1. |
| > GAINVER 2 C_R | to write corrected entries to CL table version 2. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when you're satisfied with inputs. |

After applying the system temperature correction, you may proceed with the usual *AIPS* data calibration procedures outlined in previous sections, including the special solar tactics described in § 4.8.1.

## 4.9 Completing the initial calibration

When you are satisfied with the initial calibration (pre self-calibration) of your data set, you should back up your full multi-source data set on magnetic tape. Then you can apply the calibration to the data for each program source, creating a separate single-source *uv* data set for each. These data sets are used with the imaging and self-calibration tasks to be described in the following chapters. For the impatient, the recommended imaging task reads the multi-source data set directly, applying any calibration,

### 4.9.1 Using FITTP and FITAB to write multi-source data to tape

The recommended way out of *AIPS* for multi-source *uv* data is to use FITTP to write a FITS-format tape. This will preserve the data and all associated calibration and editing tables in a machine-independent form. FITAB also writes a FITS-format tape or disk file using tables rather than random groups. This has the advantages of allowing a compressed format and of allowing *uv* files to be broken into "pieces" for increased reliability and control of space. FITAB output from earlier than 15-Oct-2007 can be read by versions of *AIPS* between 15APR99 and 15-Oct-2007, after 15-Oct-2007 it can only be read by versions of UVLOD or FITLD later than 15-Oct-2007. Also note that FITAB output cannot be read by other *uv*-data software packages, except *obit*. FITTP output can be read by some other packages. Consult § 3.9 about magnetic tapes in *AIPS*. That section tells you to mount your tape on the hardware device and then to do a software mount in AIPS. For example,

| | |
|---|---|
| > INTAP *n* C_R | to specify which tape drive to use. |
| > DENSITY 6250 C_R | to set the density to 6250-bpi, if needed. |
| > MOUNT C_R | to mount the tape in software. |

This step used to be optional for some operating systems. However, in recent versions of *AIPS*, it is required on all operating systems.

To write the data to tape:

| | |
|---|---|
| > TASK 'FITTP' C_R | |
| > IND *m* ; GETN *n* C_R | to specify the multi-source data set. |
| > DOEOT TRUE C_R | to write at the end of tape — if there are other data files on the tape you wish to preserve. |
| > OUTTA INTAP C_R | to write to tape just mounted. |
| > DOTABLE TRUE C_R | to write associated tables. |
| > FORMAT 3 C_R | to use IEEE floating format for data. |
| > BLOCKING 10 C_R | to use blocked FITS for tape efficiency. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when inputs set correctly. |

Most people use 8mm Exabyte or 4mm DAT tapes today. These have very large capacities. However, if you must still use half-inch reel tapes, you will find that many data sets (particularly spectral line) may be too large to fit on one 6250 bpi tape even with BLOCKING = 10. Since it is not possible to write multi-volume FITS tapes, it is recommended that you back up the single-source data sets formed after applying the calibration tables in SPLIT (see § 4.9.2). FITAB allows you to break up the data set into pieces which can fit on your tape. Multiple executions will be needed for multiple tapes. Alternatively, since all of the calibration information is contained in the extension tables, you may copy these to a dummy *uv* file with task TASAV and write this new file to tape with FITTP.

Be sure to run task PRTTP to make sure that the data were written successfully on your tape *before* you delete your multi-source *uv* data set!

### 4.9.2 Creating single-source data files with SPLIT

When you are happy with the calibration and editing represented by the current set of calibration and flag tables, you can convert the multi-source file into single-source files, applying your calibration and editing tables. Remember that only one FREQID can be SPLIT at a time.

| | |
|---|---|
| > TASK 'SPLIT' C_R | |
| > SOURCE '*sou1*' , '*sou2*' , . . . C_R | to select sources, ' ' means all. |
| > TIMERANG 0 C_R | to keep all times. |
| > BIF 1 ; EIF 2 C_R | to keep both IFs |
| > FREQID 1 C_R | to set the one FQ value to use. |
| > DOCALIB 1 C_R | to apply calibration to the data and the weights. |
| > GAINUSE 0 C_R | to use the highest numbered CL table. |
| > DOPOL TRUE C_R | to correct for feed polarization. |
| > DOBAND 3 C_R | to correct bandpass with time smoothing. |
| > BPVER 1 C_R | to select BP table to apply. |
| > STOKES ' ' C_R | to write the input Stokes type. |
| > DOUVCOMP FALSE C_R | to write visibilities in uncompressed format. |
| > APARM 0 C_R | to avoid channel averaging and autocorrelation data. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when inputs set correctly. |

The files produced by this process should be completely calibrated and edited and ready to be imaged or further processed as described in later chapters.

It is not necessary to run SPLIT to make images with IMAGR and it is probably a good idea to make a couple of quick images to make sure that the calibration is okay. However, for serious imaging, it is probably best to run SPLIT and then use the single-source output files. See § 5.2 for details of the imaging process.

### 4.9.3 Making images from multi-source data with IMAGR

IMAGR can be used to make images from multi-source data files. It is probably a good idea to make a couple of quick images to make sure that the calibration is okay. An example set of inputs to IMAGR is:

| | |
|---|---|
| > TASK 'IMAGR' ; DEFAULT C_R | to select task and initialize all its parameters. This selects the usual convolution and weighting functions among other things. |
| > IND $m$ ; GETN $n$ C_R | to specify the multi-source data set. |
| > SOURCE '*sou1*' , ' ' C_R | to choose one source to image. |
| > STOKES 'I' ; TIMERANG 0 C_R | to image total intensity from all times. |
| > FREQID 1 C_R | to select FQ value to image. |
| > BIF 1 ; EIF 0 C_R | to image all IFs — multi-channel mode images only one IF. |
| > BCHAN $n$ ; ECHAN $m$ C_R | to combine a range of channels. |

| | |
|---|---|
| > NCHAV *N* C_R | to include *N* spectral channels in each image where $N \leq (m - n + 1)$; for each spectral channel, IFs *bif* through *eif* are also included. Note that each channel and IF included in the "average" image is handled individually at its correct frequency. |
| > DOCALIB 1 C_R | to apply calibration. Use DOCAL 100 C_R if the weights should *not* be calibrated. |
| > GAINUSE 0 C_R | to use highest numbered CL table. |
| > FLAGVER 1 C_R | to edit data. |
| > DOPOL TRUE C_R | to correct for feed polarization. |
| > DOBAND 3 C_R | to correct bandpass with time smoothing. |
| > BPVER 1 C_R | to select BP table to apply. |
| > OUTNAME '*sou1*' C_R | to set the output file name to the source name. |
| > OUTDISK 0 C_R | to use any output disk with enough space. |
| > IMSIZE 512 512 C_R | to set the size in cells of image. |
| > CELLSIZE 0.25 , 0.25 C_R | to set the size of each image cell in arc-seconds. |
| > RASHIFT 0 ; DECSHIFT 0 C_R | to (not) shift image center. |
| > NFIELD 1 ; NGAUSS 0 C_R | to make only one image at high resolution. |
| > UVWTFN ' ' C_R | to use uniform weighting. |
| > ZEROSP 0 C_R | to introduce no zero-spacing flux. |
| > NITER 0 C_R | to do no Cleaning. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run IMAGR when the inputs are set correctly. |

## 4.10 Additional recipes

### 4.10.1 Banana-pineapple bread

1. Mix together 1 cup chopped **nuts**, 2-1/2 cups **sugar**, 5 cups **flour**, 1 teaspoon **salt**, 1 teaspoon **baking powder**, and 1 teaspoon **cinnamon**.
2. Mix together 1-1/2 cups **vegetable oil**, 3 **eggs**, 3 mashed **bananas**, 1 teaspoon **lemon juice**, and 1 can **crushed pineapple** (drained).
3. Combine. Bake at 350° F for one hour.

Thanks to Tim D. Culey, Baton Rouge, La. (`tsculey@bigfoot.com`).

### 4.10.2 Banana relish

1. Cut 12 **bananas**, 1 pound **dates**, and 2 pounds **Bermuda onions** into small pieces.
2. Add 2/3 cup **molasses**, 1/2 teaspoon ground **ginger**, 1 teaspoon **salt**, 1 teaspoon **allspice**, 1 cup **water**, and 2 cups **vinegar**; mix well.
3. Turn into a large stone jar or crock, bake in a slow oven till rich brown, seal in jars while hot.

# 5 MAKING IMAGES FROM INTERFEROMETER DATA

This chapter is devoted to the use of $\mathcal{AIPS}$ to make and improve images from interferometer visibility data. It begins with a brief description of the routes by which such data arrive in $\mathcal{AIPS}$. The basics of weighting, gridding, and Fourier transforming the data to make the so-called "dirty" image are described, followed by a discussion of deconvolution, particularly Clean. The output of Clean is a model of the sky which, in cases of good signal-to-noise, can be fed back to improve the calibration of the interferometer data, a process called "self-calibration." How this is done in $\mathcal{AIPS}$ is described. This entire process often isolates bad data samples, not previously removed from the data set. An interactive, baseline-based data editor called EDITR is described at the end of the chapter. You may find it more useful than TVFLG (§ 4.4.3) for removing data at this stage in the processing. This chapter has been revised for the 31DEC07 release of $\mathcal{AIPS}$ and some portions of it do not apply to really old releases. In particular, task IMAGR now does "3-dimensional" imaging, SCMAP contains an editing option at each self-calibration cycle, and EDITR has replaced IBLED as the baseline-based editor of choice.

Lists of $\mathcal{AIPS}$ software appropriate to this chapter can be obtained at your terminal by typing ABOUT UV C_R, ABOUT CALIBRATION C_R, ABOUT EDITING C_R, and ABOUT IMAGING C_R. Relatively recent versions of these lists are also given in Chapter 13 below. Basic data calibration is discussed in Chapter 4, editing is discussed in § 4.4 and § 8.1, and imaging and self-calibration are also discussed in § 8.4 for spectral-line data and in § 9.6 for VLBI data.

## 5.1 Preparing *uv* data for imaging

$\mathcal{AIPS}$ requires visibility data to be calibrated before imaging. If your data are not yet calibrated, return now to Chapter 4, read in your data, and carry out the steps necessary to determine calibration corrections for your data. Note that the main imaging task, IMAGR, does not require you to run SPLIT to apply the calibration in advance. IMAGR can do that for you. Nonetheless, for simplicity and speed — if you are running IMAGR multiple times — it may be best to SPLIT and perhaps even UVSRT the data in advance of running IMAGR. When used for self-calibration, tasks CALIB and SCMAP normally work on data that have been SPLIT in advance.

If your calibrated data are not already on disk in $\mathcal{AIPS}$ cataloged files, then you will need to import them. These data will normally arrive in $\mathcal{AIPS}$ from FITS format tapes or disk files. FITS is the internationally recognized standard for moving astronomical data between different types of computers and different software packages. Pre-1990 VLA data may also be stored on EXPORT format tapes. This format was written by the now-deceased VLA DEC-10 and as an option by old versions of $\mathcal{AIPS}$.

### 5.1.1 Indexing the data — PRTTP

Bring your data tape to the $\mathcal{AIPS}$ processor and follow the tape mounting instructions in § 3.9. The program PRTTP reads a full tape and prints out a summary of all the *uv* and image data on tapes written in any of the supported formats. Type:

| | |
|---|---|
| > TASK 'PRTTP' ; INP C_R | to list the required inputs on the terminal. |
| > INTAPE *m* C_R | to specify the tape drive number (*m*). |
| > NFILES 0 C_R | to print information for all the files. |
| > DOCRT -1 C_R | to print output on your system printer. |

| | |
|---|---|
| > PRTLEV 0 C_R | to select the level of reporting. |
| > GO C_R | to run the program. |

The tape will be rewound if necessary and will then begin to move forward. All files will be read. A printout will appear on the system printer with a valuable summary of header information for each file on the data tape. The printout may be routed, instead, to your terminal by specifying DOCRT 1 C_R before running PRTTP or it may be saved in a disk file by setting OUTPRINT (see § 3.10.1).

As PRTTP starts executing, look for the message PRTTP BEGINS on the *AIPS* "monitor" (the MSG_SERVER window on your workstation or, in its absence, your own *AIPS* window or some nearby terminal on antique systems). If you can see the active tape drive from your terminal, look also for movement of the tape. The AIPS prompt > should have already returned on your terminal, however, since PRTTP is running as a detached "task." As described in Chapter 3, tasks are the more complicated *AIPS* programs, run by the GO command after setting the task name with TASK '*taskname*'. They are shed from the terminal, as PRTTP has been here, allowing you to use AIPS for further processing (except running the same task at the same time).

The file at which the tape is currently positioned can also be "indexed" by the AIPS verb TPHEAD. This verb, which also works on FITS-disk files (§ 3.10.3), displays the data header to let you decide if you are pointing at the desired data file.

### 5.1.2 Loading the data — FITLD and UVLOD

FITLD copies FITS-format images and *uv* data from tape (or from an external FITS-format disk file) into your *AIPS* catalog on disk. The following shows inputs to FITLD for reading data from the third and fourth files on a tape mounted on tape unit number 2:

| | |
|---|---|
| > TASK 'FITLD' ; INP C_R | to set the task name and review the required inputs. |
| > INTAPE 2 C_R | to specify the tape drive number; the tape must already be mounted as in § 3.9. |
| > NFILES 2 C_R | to skip to the third file on the tape. |
| > CLRONAME C_R | to use the file names on the tape. |
| > OUTDISK 3 C_R | to specify writing to disk 3, *e.g.*, to select a disk with sufficient free space. (See § 3.6 for help in monitoring free disk space). |
| > DOUVC 1 C_R | to use compressed *uv* disk format to save space. |
| > NCOUNT 2 C_R | to read 2 consecutive tape files. |
| > OPTYPE 'UV' C_R | to restrict reading to *uv* files. |
| > REWIND C_R | to rewind tape before skipping files. |
| > GO C_R | to run FITLD.. |

The tape will begin to move and appropriate messages should appear on the *AIPS* monitor. When the prompt > appears on your terminal, you are free to use AIPS for other purposes.

FITLD may also be used to read a FITS-disk file as:

| | |
|---|---|
| > DATAIN 'FITS:*filename* C_R | to read the FITS-disk file in the public area known as $FITS of name *filename*. |
| > GO C_R | to run FITLD with the adverbs set above — NFILES and NCOUNT are ignored when DATAIN is not blank. |

Multiple FITS-disk files may be read in one run of FITLD; set NFILES and name the files with sequential post-pended numbers beginning with 1 (*e.g.*, FITS-file_1, FITS-file_2, ..., FITS-file_*n*). See § 3.10.3 for a discussion of FITS disk files.

If your data are in the old EXPORT format, you must use UVLOD instead. This task is restricted to *uv* files, but can read both FITS and EXPORT formats. Since the latter may have multiple sources, frequencies, and the like in each file, UVLOD has extra adverbs to let you specify source name, frequency band, source qualifier number, and, if all others fail, position within the file. See HELP UVLOD C_R for details.

Once FITLD has finished, check that your disk catalog now contains the *uv* data you have just tried to load by:

> INDI OUTDISK ; UCAT C_R

which will list all *uv* data sets in your disk catalog. This list should look something like:

```
CATALOG ON DISK   3
CAT USID MAPNAME      CLASS    SEQ  PT     LAST ACCESS      STAT
  1   76 3C138 A C   .UVDATA .    1 UV 22-MAR-1995 12:33:34
```

Alternatively, get terminal *and* hard-copy listing of your catalog by:

| | |
|---|---|
| > CLRNAME ; INTY 'UV' C_R | to list all disks, *uv* files only. |
| > CATALOG C_R | to put the catalog listing in the message file. |
| > PRTMSG C_R | to print the message file. |

This sequence takes a little longer to execute, but the hard-copy list (sent to the appropriate printer) may be useful if your catalog is a long one. Note that the catalog has assigned an ordinal number to the data set in the first (CAT) column of the listing. This number and the disk number (3) should be noted for future reference as they are useful when selecting this data set for further processing. See § 3.3 and § 3.3.1.

### 5.1.3 Sorting the data — UVSRT

Some of the AIPS imaging tasks, such as UVMAP, require the *uv* data to be in "XY" sort order (decreasing $|u|$). The recommended IMAGR is able to sort the data for you and will do so only if it has to. If you are planning to run IMAGR a number of times, you can help things along by sorting the data in advance. Note, however, that self-calibration requires data in TB (time-baseline) order. Thus, if you are planning to use self-calibration, you should probably sort the data to — or leave them in — TB order. To sort a data set:

| | |
|---|---|
| > TASK 'UVSRT' ; INP C_R | to set the task name and list the input parameters. |
| > INDI *n* ; GETN *ctn* C_R | to select the input file, where $n$ is the disk number with the *uv* data and *ctn* is its catalog number on that disk. ($n = 3$ and $ctn = 1$ from our UCAT example). |
| > OUTN INNA ; OUTCL 'UVSRT' C_R | to set the output file name to the same as the input file name and the output file class to UVSRT; these are actually the defaults. |
| > SORT 'XY' C_R | to select the "XY" sort type required for image making. |
| > INP C_R | to review the inputs you have selected. *N.B.,* check them carefully since the sort can be time consuming for large data sets. |
| > GO C_R | to run the task UVSRT. |

The task MSORT may be faster for data sets with large numbers of spectral channels and for data sets that are nearly in the desired order. Task OOSRT is yet another option.

Once UVSRT has finished, check that a *uv* database with the "class" .UVSRT has appeared in your disk catalog by:

> INDI 0 ; UCAT C_R

The catalog listing might now look like:

```
CATALOG ON DISK  3
CAT USID MAPNAME      CLASS   SEQ  PT     LAST ACCESS      STAT
  1   76 3C138 A C   .UVDATA .   1 UV 22-MAR-1995 12:33:34
  2   76 3C138 A C   .UVSRT  .   1 UV 22-MAR-1995 12:56:50
```

Note that the catalog number of the sorted file need not be contiguous with that of the unsorted file. All *AIPS* installations now have "private" catalog files containing only your data. Your *uv* files will have contiguous catalog numbers starting from 1 when you first write *uv* data to disk. See also § 3.3.3.

Deep integrations often involve multi-day observations of the same source position in the same antenna configuration. After calibration (and usually at least one round of self-cal), such data may be combined and compressed by the RUN file STUFFR. This compiles a procedure that will convert times to hour angles (TI2HA), sort, and concatenate the data from all days, and then do a baseline-length dependent time averaging (UBAVG). This produces a data set which is more manageable in size and which can still be self-calibrated at some level, although the days are now fully merged.

## 5.2 Basic image making — IMAGR

*AIPS* had several imaging tasks, each with distinctive capabilities, BUT they have all been superseded by IMAGR. The abilities of IMAGR include:

1. data calibration application for multi-source or self-calibrated single-source data sets.
2. data sorting if needed to fit the weighting, gridding, or Cleaning.
3. time averaging of data in a baseline-dependent fashion based on field of view.
4. data weighting options far more general than those in any other task and including all those used in previous tasks.
5. data imaging in up to 4096 simultaneous fields, each up to 16384x16384 in size.
6. Cleaning of all fields simultaneously with subtraction of the Clean components from the data at each major cycle followed by re-computation of the residual images — avoiding aliasing of sidelobes and allowing components almost to the edges of each field.
7. re-projection of the $(u, v, w)$ baseline coordinates to make each field tangent to the Celestial sphere at its center thereby making a larger area of each field free of projection defects.
8. correction of Clean components for various wide-field and wide-bandwidth effects.
9. truly interactive TV display of residual images allowing you to alter the areas over which Clean components are sought.
10. sensible Cleaning strategies for, and restoration to, overlapped image fields.
11. choice of Clark or Steer-Dewdney-Ito methods of component selection.
12. filtering of weak, isolated Clean components to reduce the Clean bias.
13. simultaneous Cleaning with multiple component widths.
14. automatic selection of the areas to be Cleaned based on image statistics and peak values.

This section will concentrate on how to use IMAGR to weight, grid, and Fourier transform the visibility data, making a "dirty beam" and a "dirty map." We will begin with a simple example and then discuss a number of matters of image-making strategy to help make better images. Deconvolution will be discussed in the next section. This separation reflects our belief that you should first use IMAGR to explore your data to make sure that there are no gross surprises — emission from unexpected locations, "stripes" from bad calibration or interference, and the like. If you begin Cleaning immediately, you may find that you are using Clean to convert noise and sidelobes into sources while failing to image the real sources, if any. It is a good idea to make the first images of your field at the lowest resolution (heaviest taper) justified by your data. This will allow you to choose input parameters to combine imaging and Cleaning steps optimally.

We do not discuss imaging theory and strategy in much detail here because it is discussed fully in numerous lectures in *Synthesis Imaging in Radio Astronomy*[1].

### 5.2.1 Making a simple image

The most basic use of IMAGR is to make an image of a single field from either a single-source data set or, applying the calibration, from a multi-source data set. Do not be discouraged by the length of the INPUTS list for IMAGR. They boil down to separate sets for calibration (with which you are familiar from Chapter 4), for basic imaging, for multi-field imaging, and for Cleaning. We will consider the second set here, the third in the next sub-section, and the last in § 5.3. A standard procedure MAPPR provides a simplified access to IMAGR when calibration, polarization, multiple fields, and other more complicated options are not needed.

A typical use of IMAGR at this stage is to construct an unpolarized (Stokes I) image at low resolution and wide field to search for regions of emission or at full resolution for deconvolution by image-plane techniques discussed in § 5.3.7. The following example assumes the use of an already calibrated, single-source data set:

| | |
|---|---|
| > DEFAULT IMAGR ; TASK 'MAPPR' C_R | to set the "task" name and set all IMAGR's adverbs to initial values. |
| > INP C_R | to see what parameters should be set. |
| > INDI *m*; GETN *n* C_R | to select the desired *uv* database. |
| > IMSIZE 1024 C_R | to make a square image 1024 pixels on each side. |
| > CELLSIZ 1 C_R | for 1 arc-second cells. |
| > UVTAP *utap vtap* C_R | to specify the widths to 30% of the Gaussian taper in *u* and *v* in k$\lambda$ (kilo-wavelengths). |

Other inputs are defaulted sensibly, which is why we started with a DEFAULT and are using the MAPPR procedure. In particular, Clean is turned off with NITER = 0, other calibrations are turned off, and all of the data (all IFs, channels, sub-arrays) will be used. Data weighting will be somewhere between pure "uniform" and pure "natural" (see § 5.2.3). Note that task SETFC can be requested to examine your data file and make recommendations on the best combination of CELLSIZE and IMSIZE. Consider also both:

| | |
|---|---|
| > DOCRT = -1 ; EXPLAIN IMAGR C_R | to print the long explain file, and |
| > HELP *xxx* C_R | |

where *xxx* is a parameter name, *e.g.*, IMSIZE, UVWTFN, etc., to get useful information on the specific parameter. The default *uv* convolution function is a spheroidal function (XTYPE, YTYPE = 5) that suppresses aliasing well. Check that you are satisfied with the inputs by:

> INP C_R

then:

| | |
|---|---|
| > MAPPR C_R | to run IMAGR. |

[1] *Synthesis Imaging in Radio Astronomy*, A Collection of Lectures from the Third NRAO Synthesis Imaging Summer School, eds. R. A. Perley, F. R. Schwab and A. H. Bridle, Astronomical Society of the Pacific Conference Series Volume 6 (1989)

In IMAGR, you may limit the data used to an annulus in the *uv* plane with UVRANGE, given in kilo-wavelengths. This is a useful option in some cases, but, since it introduces a sharp edge into the data sampling and otherwise discards data that could be improving the signal-to-noise, it should be used with caution and is not available in MAPPR. Taper and other data weighting options may accomplish much the same things, but do not introduce sharp edges and do not entirely discard the data.

In the example above, we chose to make the image and each cell square. This is not required. Images can be any power of two from 64 to 16384, *e.g.*, 2048 by 512 or 128 by 8192, if you want, and the cells may also be rectangular in arc-seconds. There may be good reasons for such choices, such as to avoid imaging blank sky (saving disk, time ...) and to make the synthesized beam be roughly round when measured in pixels. Rectangularity may complicate rotating the image later with *e.g.*, LGEOM, but the problem can be handled with the more complex HGEOM. IMAGR has the ROTATE adverb to allow you to rotate your image with respect to the usual right ascension and declination axes to align elongated source structure with the larger axis of your image.

IMAGR will create both "dirty" beam and map images. The AIPS monitor provides some important messages while IMAGR is running. When you see IMAGR*n*: APPEARS TO END SUCCESSFULLY on this monitor, you should find the requested images in your catalog using:

> INDI 0 ; MCAT C_R

This would produce a listing such as:

```
CATALOG ON DISK  2
CAT USID MAPNAME       CLASS   SEQ  PT      LAST ACCESS      STAT
 42   76 3C138 A C    .IIM001.    1 MA 22-MAR-1999 13:50:10
 43   76 3C138 A C    .IBM001.    1 MA 22-MAR-1999 13:59:58
```

Note that the default beam class is IBM001; the default image class will be IIM001. The images produced with NITER = 0 by IMAGR can be deconvolved by various image-plane methods (§ 5.3.7).

### 5.2.2 Imaging multiple fields and image coordinates

There is little real need for the multi-field capability of IMAGR unless you are Cleaning. In that case, the ability to remove components found in each field from the *uv* data and, thereby, to remove their sidelobes from every field, is practically a necessity. Nonetheless, it may be more efficient to make multiple fields in one GO and a good idea to check the field size and shift parameters while looking for emission sources before investing significant resources in a lengthy Clean. Task SETFC can recommend cell size, image size, and field locations to cover the central portion of the single-dish beam.

You specify the multiple-field information with:

> NFIELD $n$ C_R — to make images of $n$ fields.

> IMSIZE $i, j$ C_R — to set the *minimum* image size in $x$ and $y$ to $i$ and $j$, where $i$ and $j$ must be integer powers of two from 64 to 8192.

> FLDSIZ $i_1, j_1, i_2, j_2, i_3, j_3, \ldots$ C_R — to set the area of interest in $x$ and $y$ for each field in turn. Each $i_n$ and $j_n$ is rounded up to the greater of the next power of 2 and the corresponding IMSIZE. FLDSIZE controls the actual size of each image and sets an initial guess for the area over which Clean searches for components. (That area is then modified by the various box options discussed later.)

> RASHIFT $x_1, x_2, x_3, \ldots$ C_R — to specify the $x$ shift of each field center from the tangent point; $x_n > 0$ shifts the field center to the East (left).

> DECSHIFT $y_1, y_2, y_3, \ldots$ C_R — to specify the $y$ shift of each field center from the tangent point; $y_n > 0$ shifts the field center to the North (up).

> DO3DIMAG TRUE C_R — to specify that the $(u, v, w)$ coordinates are re-projected to the center of each field. In 31DEC09, DO3DIMAG FALSE also re-projects $(u, v, w)$ to correct for the sky curvature while keeping all fields on the same tangent plane. The two choices now produce very similar results.

If ROTATE is not zero, the shifts are actually with respect to the rotated coordinates, not right ascension and declination. There may be good reasons to have the fields overlap, but this can cause some problems which will be discussed in § 5.3. IMAGR has an optional BOXFILE text file which may be used to specify some or all of the FLDSIZE, RASHIFT, and DECSHIFT values. To simplify the coordinate computations, the shift parameters may also be given as right ascension and declination of the field center, leaving IMAGR to compute the correct shifts, including any rotation. BOXFILE may also be used to specify initial Clean boxes for some or all fields, values for BCOMP, and spectral-channel-dependent weights.

The OUTCLASS of the fields is controlled by IMAGR with no user assistance. For dirty images it is IIM001 for the first field, IIM002 for the second, and so forth. The I is replaced by Q, U, *et al.* for polarized images and the IM is replaced by CL when Cleaning. When ONEBEAM is true, one beam of class IBM001 is used for all fields. When ONEBEAM is false, a beam of class IBM*nnn* is used for fields of class IIM*nnn* or ICL*nnn*, with similar substitutions for other Stokes parameters.

Users are often confused by the fact that radio synthesis images are made in a rectangular coordinate system of direction cosines that represents a *projection* of angular coordinates onto a tangent plane. Over wide fields of view, the image coordinates are not simple scalings of right ascension and declination. For details of all coordinate systems supported by AIPS, please consult AIPS Memos No. 27, "Nonlinear Coordinate Systems in AIPS," and No. 46, "Additional Non-linear Coordinates," by E. W. Greisen (available via the World-Wide Web § 3.8 and § 3.10.3).[2] The coordinate system for VLA images is the SIN projection, for which the image coordinates $x$ and $y$ relate to right ascension $\alpha$ and declination $\delta$ as

$$
\begin{aligned}
x &= \cos\delta \sin\Delta\alpha \\
y &= \cos\delta_0 \sin\delta - \sin\delta_0 cos\delta \cos\Delta\alpha
\end{aligned}
$$

where $\Delta\alpha = \alpha - \alpha_0$ and the coordinates with subscript "0" are those of the tangent point that serves as the origin of the image coordinate system. When DO3DIMAG is false, all fields have a single coordinate origin, but, when DO3DIMAG is true, each field has a different coordinate origin (at its center). RASHIFT and DECSHIFT are now "simple" shifts, specified with respect to the reference coordinate of the input *uv* data set, rather than SIN projection shifts. Thus

$$
\begin{aligned}
\texttt{RASHIFT} &= (\alpha - \alpha_0)\cos\delta_0 \\
\texttt{DECSHIFT} &= \delta - \delta_0
\end{aligned}
$$

For many practical purposes, it is sufficiently accurate to suppose that imaging parameters do correspond to simple angular shifts of the image on the sky. *AIPS input terminology* reflects this simplification, although *actual coordinate shifts and transformations* in all AIPS tasks and verbs *are accomplished rigorously using the full non-linear expressions*. If you want to relate shifts in pixels (image cells) to shifts in sky coordinates ($\alpha$, $\delta$) *manually*, you must understand, and take account of, the non-linear coordinate system yourself. The verb IMVAL can help by displaying the non-linear coordinates for the specified input pixel. This is rarely necessary, however.

### 5.2.3 Data weighting

The minimum noise in an image is produced by weighting each sample by the inverse square of its uncertainty (thermal noise). AIPS assumes that the input weights are of this form, namely $W \propto 1/\sigma^2$. FILLM offers

[2] See also AIPS Memo No. 113, "Faceted Imaging in AIPS" by Kogan and Greisen for details of the DO3DIMAG = **false** geometry now used.

the option, for VLA data, of weighting data in this fashion using recorded system temperatures (actually "nominal sensitivities"). They are reasonably accurate for this use *after calibration.* In some cases, weights are simply based on integration times and the assumption that each antenna in the array had the same system temperature. If the weights are not of the correct form, run FIXWT on the *uv* data set to calculate weights based on the variances in the data themselves. Then to get the minimum-noise image, specify

> UVWTFN 'NA' C_R — to get "natural" weighting.

to have all samples simply weighted by their input weights. Unfortunately, most interferometers do not sample the *uv* plane at all uniformly. Typically, they produce large numbers of samples at short spacings with clumps of samples and of holes at longer spacings. Thus, the beam pattern produced by natural weighting tends to have a central beam resembling a core-halo source with the broad halo (or plateau) produced by all the short spacing data and also to have rather large sidelobes due to the clumps and holes. In some VLBI arrays, data from some baselines have weights much much greater than from other baselines due to differences in antenna size and receiver temperature. Only the high-weight baselines contribute significantly to a natural-weighted image in this case.

To reduce the effects of non-uniformity in data sampling, the concept of "uniform" weighting was devised. In its purest form, uniform weighting attempts to give each cell in the *uv*-plane grid the same weight. Thus, the weight given each sample, is its weight divided by the sum of weights of all samples in the cell in which it occurs. In this case, in some cells a sample will count at full weight while in another, possibly adjacent, cell a sample will count at only a small fraction of its weight. To obtain this classic weighting in IMAGR enter:

> UVSIZE 0 ; UVWTFN ' ' C_R — to specify a weight grid the size of the image grid and the default weighting scheme.

> ROBUST = -7 C_R — to turn off all weight tempering.

IMAGR actually implements a far more flexible (and therefore more complicated) scheme to give you a wide range of weighting choices. The intent of uniform weighting is to weight a sample inversely with respect to the local density of data weights in a wider sense than the default cell boundaries. IMAGR allows you to choose the size of cells in the *uv* plane with UVSIZE, the radius in units of these cells over which each sample is counted with UVBOX, and the way in which each sample is counted over this radius with UVBXFN. The weighting grid can be smaller or larger than the image grid. You can even make the *uv* cells be very small by specifying a very large UVSIZE; you are limited only by the available memory in your computer and the time you wish to spend weighting the data. Note, of course, that uniform and natural weighting are the same if the cells are small enough unless you specify a significant radius over which to count the samples. IMAGR does not stop here, however. It also allows you to alter the weights before they are used, to count samples rather than weights, and to temper the uniform weights with Dan Briggs' "robustness" parameter. Thus

$$W_{out} = \frac{TW_{in}^{p}}{\sum_{(i)} W_{in}^{pq} + R\overline{\sum_{(i)} W_{in}^{pq}}}$$

where $W_{in}$ is the input weight, $W_{out}$ is the weight used in imaging, $T$ is any tapering factor, $p$ is an input weight modification exponent, $q$ separates uniform weights ($q = 1$) and uniform counts ($q = 0$), the sum is actually

$$\sum_{(i)} W_{in}^{pq} \equiv \sum_{j}^{N} W_{in}^{pq}(j)\,\mathrm{fun}(\sqrt{(u_i - u_j)^2 + (v_i - v_j)^2})$$

with fun being some function of the separation between sample $i$ and all samples $j$, the overline represents the average over all samples, and

$$R \equiv \frac{10^{\mathtt{ROBUST}}}{5}.$$

The exponents are set by UVWTFN as: $q = 1$ except $q = 0$ when the first character of UVWTFN is 'C' and $p = 1$ except $p = 0.5, p = 0.25$ and $p = 0$ when the second character of UVWTFN is 'S', 'V', and 'O' (the letter), respectively.

At this point you should be totally confused. To some extent, we are. While IMAGR has been around for a while, the impact of all of these parameters on imaging is not well understood. You may wish to experiment since it *is* known — see figures on next page — that weighting can make a significant difference in the signal-to-noise on images, can alter the synthesized beam width and sidelobe pattern, and can produce bad striping in the data when mildly wrong samples get substantially large weights. The default values do seem to produce desirable results, fortunately. The beam width is nearly as narrow as that of pure uniform weighting, but the near-in sidelobes are neither the positive "shelf" of pure natural weighting nor the deep negative sidelobes of pure uniform weighting. The expected noise in the image is usually rather better than for pure uniform weighting and sometimes approaches that of natural weighting. Deconvolution should be improved with reduction of erroneous stripes, noise, and sidelobe levels. You should explore a range of UVTAPER and ROBUST (at least) in a systematic way in order to make an informed choice of parameters.

The new (31DEC09) option to average the input data in time over a baseline-length dependent interval adds further complications. It has the desirable effect of reducing the size of your work file, thereby speeding the imaging process. But it changes the distribution of data samples ahead of uniform weighting since it averages the short-spacing samples a great deal more than the long-spacing samples. This makes natural weighting less undesirable and causes uniform weighting to be less sensitive to extended source structures. Set IM2PARM(11) and (12) to request this option.

If your source has complicated fine structure and has been observed with the VLA at declinations south of about $+50^{\circ}$, there may be important visibility structure in the outer regions of the *uv* plane that is sampled sparsely, even by "full synthesis" imaging. In such cases, Clean may give images of higher dynamic range if you are not too greedy for resolution at the imaging stage. Use UVTAPER to down-weight the poorly sampled outer segments of the *uv* plane in such cases. (UVRANGE could be used to exclude these data, but that introduces a sharp discontinuity in the data sampling with a consequent increase in sidelobe levels.) Tapering is, to some extent, a smooth inverse of uniform weighting; it down-weights longer spacings while uniform weighting down-weights shorter spacings in most arrays. The combination can produce an approximation to natural weighting that is smooth spatially.

IMAGR does all weighting, including tapering, in one place and reports the loss in signal-to-noise ratio from natural weighting due to the combination of weighting functions. This reported number does *not* include the loss due to discarding data via UVRANGE, GUARD, the finite size of the *uv*-plane grid, data editing, and the like.

### 5.2.4 Cell and image size, shifting

Other things being equal, the accuracy of beam deconvolution algorithms (§ 5.3) generally improves when the shape of the dirty beam is well sampled. When imaging complicated fields, it may be necessary to compromise between cell size and field of view, however. If you are going to Clean an image, you should set your imaging parameters so that there will be at least three or four cells across the main lobe of the dirty beam.

Actually, this is not the full story. If you have a large number of samples toward the outer portions of the *uv*-data grid, then the width of the main lobe of the dirty beam will not be correctly measured. Making the cell size smaller — raising the size of the *uv*-data grid (in wavelengths) — will change the apparent beam width even if no additional data samples are included. Even when you have a cell size small enough to accurately represent the dirty beam, the presence of samples in the outer portion of the *uv*-data grid can confuse high dynamic-range deconvolution. The high-resolution information contained in these outer samples cannot be represented with point sources separated by integer numbers of too-large cells. The result is a sine wave of plus and minus intensities, usually in the $x$ or $y$ direction, radiating away from bright point objects and a Clean that always finds a component of opposite sign at a virtually adjacent pixel whenever a component is taken at the bright point sources. This is often a subtle effect lost in the welter of long Cleans,

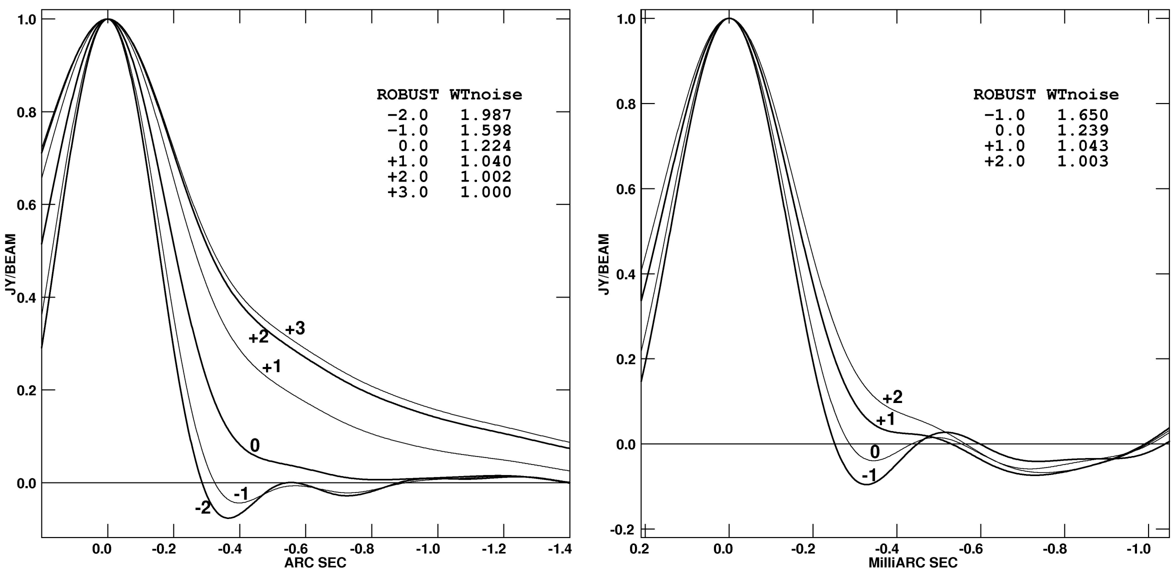



Figure 5.1: Slices taken through the centers of synthesized beams for various values of the ROBUST parameter. Plot at left for a VLA A- and B-array data set, while the plot at right is for a VLBA data set. Do not assume that these plots apply to your data sets, however. Tables give noise increase over natural weighting (ROBUST large).

but has led to the concept of a "guard" band in the *uv*-data grid. The adverb GUARD in IMAGR and friends, controls the portion of the outer *uv*-data grid which is kept empty forcibly by omitting any data that would appear there. The default is the outer 30% of the radius (or less if there is taper), which is a compromise between the 50% that it probably should be and the epsilon that some vocal individuals believe is correct. All imaging tasks will tell you if they omit data because they fall off the grid or outside the guard band and will warn you of possible Cleaning problems if data lie inside the guard band but outside a more conservative guard band.

Because Clean attempts to represent the brightness distribution of your source as an array of $\delta$-functions, the deconvolution will have higher dynamic range if the brightest point-like features in your images have their maxima exactly at pixel locations. In this case, the brightest features can be well represented by $\delta$-functions located at image grid points. If you are pursuing high dynamic range, it may therefore be worth adjusting the image shift and cell-size parameters so that the peaks of the two brightest point-like features in your image lie exactly on pixels.

If you are going to use image-plane deconvolutions such as APCLN, SDCLN, or VTESS, you must image a large enough field that no strong sources whose sidelobes will affect your image have been aliased by the FFT and so that all real emission is contained within the central quarter of the image area. With IMAGR, you should make a small image field around each confusing source (or use Clean boxes within larger fields).

### 5.2.5 Zero-spacing issues

You help Clean to guess what may have happened in the unsampled "hole" at the center of the *uv* plane by including a zero-spacing (usually single-dish) flux density when you make the image. This gives Clean a datum to "aim at" in the center of the *uv* plane. Extended structure can often be reconstructed by deep Cleaning when the zero-spacing flux density is between 100% and ∼125% of the average visibility amplitude at the shortest spacings (run UVPLT to estimate this average for your data set). If your data do not meet this criterion, there may be no reliable way for you to image the extended structure of your source without adding further information to your observations (*e.g.*, by adding *uv* data from a more compact array, by Fourier transforming a suitably tapered and deconvolved single dish image of the VLA primary beam, or by using such an image as the default image for a maximum entropy deconvolution as in § 5.3.7). See § 10.5 for further discussion. IMAGR treats the zero spacing differently from previous tasks. The adverb ZEROSP gives five values, the I, Q, U, V fluxes, and a weight. This weight should be in the same units as for your other data, since the ZEROSP sample is simply appended to your data set and re-weighted and gridded just like any other data sample. To have the zero spacing be used, both ZEROSP(1) and ZEROSP(5) must be greater than zero, even when you are imaging some other polarization. Previous "wisdom" held that the weight should be "the number of cells that are empty in the center of the *uv* plane," but this does not appear to be correct with IMAGR.

If UVPLT shows a rapid increase in visibility amplitudes on the few shortest baselines in your data, but not to a value near the integrated flux density in your field, you may get better images of the *fine* structure in your source by excluding these short baselines with the UVRANGE parameter. There is no way to reconstruct the large-scale structure of your source if you did not observe it, and the few remnants of that structure in your data set may just confuse the deconvolution. Be aware that, in this circumstance, you cannot require your image of total intensity to be everywhere positive. The fine-scale structure can consist of both positive and negative variations on the underlying large-scale structure.

## 5.3 Deconvolving images

The most widely used deconvolution method is Clean, originally described by Högbom. All AIPS Clean tasks implement a Clean deconvolution of the type devised for array processors by Barry Clark (*Astron. & Astrophys.* **89**, 377 (1980)). (Your computer does not need not to have an array processor or other special vector hardware to run them, however.) The recommended task IMAGR implements Clark's algorithm with enhancements designed by Bill Cotton and Fred Schwab. These enhancements involve going back to the original *uv* data at each "major cycle" to subtract the current Clean-component model and re-make the images. This allows for more accurate subtraction of the components, for Cleaning simultaneously multiple (perhaps widely spaced) smaller images of portions of the field of view, for Cleaning of nearly the full image area, for more accurate removal of sidelobes, and for corrections for various wide-field and wide-bandwidth effects. Of course, all these extras do come at a price. For large data sets with fairly simple imaging requirements, image-based Cleans, particularly APCLN, may be significantly faster.

The next section describes the basic parameters of Cleaning with IMAGR. The second section describes the use and limitations of multiple fields in IMAGR; the third section describes the setting of Clean "boxes" and the TV option in IMAGR; the fourth section describes some experimental extensions to standard Clean; and the fifth section describes various wide-field and wide-bandwidth correction options. Clean component files are tables which can be manipulated, edited, and plotted both by general-purpose table tasks and by tasks designed especially for CC files. Some aspects of this are discussed in the fifth section. Images may also be deconvolved by other methods in AIPS. § 5.3.7 mentions several of these and describes the most popular alternatives, image-based Clean with APCLN and SDCLN and a Maximum Entropy method embodied in the task VTESS.

### 5.3.1 Basic Cleaning with IMAGR

IMAGR implements a Clean deconvolution of the type devised by Barry Clark and enhanced by Bill Cotton and Fred Schwab. Clean components — point sources at the centers of cells — are found during "minor" iteration cycles by Cleaning the brightest parts of the residual image with a "beam patch" of limited size. More precise Cleaning is achieved at the ends of "major" iteration cycles when the Fourier transform of the Clean components is computed, subtracted from the visibility data, and a new residual dirty image computed. The rule for deciding when a major iteration should end in order to achieve a desired accuracy is complicated (see the Clark paper). IMAGR lets you vary the major iteration rule somewhat to suit the requirements of your image. Type DOCRT FALSE; EXPLAIN IMAGR C_R, if you haven't already, to print out advice on imaging and Cleaning.

IMAGR both makes and Cleans images. See § 5.2 for the inputs needed to make the images. The inputs for basic Cleaning are:

| | |
|---|---|
| > OUTS 0 C_R | to create a new output file. If OUTSEQ $\neq 0$, the specified value is used. OUTSEQ must be set to restart a Clean (see below). |
| > GAIN 0.1 C_R | to set the loop gain parameter, defaults to 0.1. Values of 0.2 or more may be suitable for simple, point-like sources, while even smaller values may be required for complex sources with smooth structure. |
| > FLUX *f* C_R | to stop Cleaning when the peak of the residual image falls to *f* Jy/beam. |
| > NITER *n* C_R | to stop Cleaning when *n* components have been subtracted. There is no default; zero means no Cleaning. |
| > BCOMP 0 C_R | to begin a new Clean — see below for restarting one. |
| > NBOXES 0 ; BOXFIL ' ' C_R | to specify no Clean search areas in advance; see § 5.3.3. |
| > CMETHOD ' ' C_R | to allow IMAGR to use DFT or gridded-FFT component subtraction at each major cycle, depending on which is faster. 'DFT' forces DFT and 'GRID' forces gridded subtraction at all iterations. Use the default. DFT is more accurate, but usually much slower; see the explain file for details. |
| > FACTOR 0 C_R | to use the "normal" criteria for deciding when to do a major cycle; see below. |
| > BMAJ 0 C_R | to have IMAGR use a Clean beam which is a fit to the central lobe of the dirty beam. |
| > DOTV 1 C_R | to have dirty and residual images displayed on the TV; see § 5.3.3. |
| > INP C_R | to review the inputs — read carefully. |
| > GO C_R | to start IMAGR. |

The procedure MAPPR may be used for single-field Cleaning.

The FACTOR parameter in IMAGR can be used to speed up or to slow down the Cleaning process by increasing or decreasing the number of minor cycles in the major cycles. The default FACTOR 0 causes major cycles to be ended using Barry Clark's original criterion. Setting FACTOR in the range 0 to +1.0 will speed up the Clean, by up to 20% for FACTOR 1.0, at the risk of poorer representation of extended structure. Setting FACTOR in the range 0 to −1.0 will slow it down, but gives better representation of extended structure.

Two other subtle parameters which help to control the Clean may need to be changed from their defaults. MINPATCH controls the minimum radius in the dirty beam (in pixels) used during the minor cycles to subtract sidelobes of one component from other nearby pixels. If your dirty beam is complicated, with significant near-in sidelobes and your source extended, then the default 51 cells may be too small. IMAGR uses a larger patch during the first few major cycles, but will be reduced eventually to a MINPATCH patch. IMAGR normally creates a dirty beam twice the size of the largest field (or 4096 pixels whichever is smaller). This allows for a very large beam patch in the early cycles, letting widely spaced bright spots be Cleaned more accurately. If your image does not have widely spaced bright spots, you can save some compute time by reducing this beam size with IMAGRPRM(10); see the help file. MAXPIXEL controls the maximum number of image pixels searched for components during any major cycle. If MAXPIXEL were very large, IMAGR would spend all of its time examining and subtracting from pixels it is never going to use for components. If it is too small, however, then pixels that should be used during a major cycle will not be used and major cycles may end up using only a few components before doing another (expensive) component subtraction and re-imaging. Again, we do not know what to recommend in detail. The default (20050) seems good for normal 1024x1024 images, smaller values are better for smaller images of compact objects, and rather larger values may be good for extended objects or large numbers of fields. If the first Clean component of a major cycle is significantly larger than the last component of the previous cycle (and the messages let you tell this), then too few cells are being used.

If you do not specify the parameters of the Clean beam, a Gaussian Clean beam will be fitted to the central portion of the dirty beam. The results may not be desirable since the central portions of many dirty beams are not well represented by a single Gaussian and since the present fitting algorithm is not very elaborate. If you use the default, check that the fitted Clean beam represents the central part of the dirty beam to your satisfaction. Use task PRTIM on the central part of the dirty beam to check the results — another reason to make an un-Cleaned image and beam first. To set the Clean beam parameters:

> BMAJ *bmaj* C_R — to set the FWHM of the major axis of the restoring beam to *bmaj* arc-sec. BMAJ = 0 specifies that the beam is to be fitted.

> BMIN *bmin* C_R — to set the FWHM of the minor-axis of the restoring beam to *bmin* arc-sec; used if BMAJ $> 0$.

> BPA *bpa* C_R — to set the position angle of beam axis to *bpa* degrees measured counter-clockwise from North (*i.e.*, East from North); used if BMAJ $> 0$.

Use BMAJ < 0 if you want the *residual* image, rather than the Clean one, to be stored in the output file.

Note that the number of Clean iterations, and many of the other Cleaning parameters, may be changed interactively while IMAGR is running by use of the AIPS SHOW and TELL utilities. Type SHOW IMAGR C_R while the task is running to see what parameters can be reset, and their current values. Then reset the parameters as appropriate and TELL IMAGR C_R to change its parameters as it is running. (The changes are written to a disk file that IMAGR checks at appropriate stages of execution, so they may not be passed on to the program immediately — watch your AIPS monitor for an acknowledgment that the changes have been received, perhaps some minutes later if the iteration cycles are long or your machine is heavily loaded. AIPS verb STQUEUE will show all queued TELLs.) Of particular interest is the ability to turn the TV display back on and to extend the Clean by increasing NITER. There are two ways to tell IMAGR that it has done enough Cleaning: by selecting the appropriate menu item in the TV display or by sending a OPTELL = 'QUIT' with TELL. The former can only be done at the end of a major cycle and only if the TV display option is currently selected, while the latter can be done at any time (although it will only be carried out when the current major cycle finishes).

IMAGR makes a *uv* "workfile" which is used in its Clean step to hold the residual fringe visibilities. Its name is controlled with the IN2NAME, IN2CLASS, IN2SEQ, and IN2DISK parameters. If the first three are left blank and 0, the workfile will be deleted when IMAGR terminates. Even if the workfile already exists, IMAGR assumes that its contents must be initialized from the main *uv* file unless the ALLOKAY adverb is set $\geq 2$.. This file is useful if you suspect that there are bad samples in your data. Use LISTR (§ 4.4.1) UVFND (§ 6.2.1), PRTUV (§ 6.2.1), UVPLT (§ 6.3.1) or even TVFLG (§ 4.4.3) to examine the file. If you find data which you think are corrupt, remove them from the *input uv* data set with UVFLG. These workfiles may eventually use an annoying amount of disk if IN2SEQ is left 0. Be sure to delete old ones with ZAP in this case.

IMAGR may be restarted to continue a Clean begun in a previous execution. To do this, you must set the OUTSEQ to the sequence number of file you are restarting. A good way to do this is

> OUTDISK *d* ; GETONAME *ctn* C_R — to set the output name parameters to the name parameters of catalog entry *ctn* on disk *d*.

The other parameters that must be set to restart a Clean are OUTVER, the output Clean Components version number, and BCOMP, the number of Clean components to take from the previous Cleans. A restart saves you much of the time it took IMAGR to do the previous Clean, although it will make new beam images and a new file of residual visibilities unless you specify that it should not using ALLOKAY. An image can be re-convolved by setting NITER = the sum of the BCOMPs and specifying the desired (new) Clean beam. Images can be switched between residual and Clean (restored) form in the same way, setting BMAJ = -1 to get a residual image. (For single fields, tasks RSTOR and CCRES may be used for this purpose.) IMAGR writes over the Clean image file(s) as it proceeds to Clean deeper. You can preserve intermediate Clean images, however, either by copying them to another disk file with SUBIM or by writing them to tape with FITAB or FITTP.

### 5.3.2 Multiple fields in IMAGR

IMAGR can also deconvolve components from up to 4096 fields of view simultaneously, taking correct account of the $w$ term at each field center (DO3DIMAG false) or even re-projecting the $(u, v, w)$ coordinates as well as the phases to each field center (DO3DIMAG true). This is a vital advantage if there are many localized bright emission regions throughout your primary beam; only the regions containing significant emission need to be imaged and cleaned, rather than the entire (mainly empty) area of sky encompassing them all. It may even be necessary to image regions well outside the primary beam, not because you will believe the resulting images, but to remove the sidelobes of sources in those distant fields from the primary fields. To take advantage of this option, you must have prior knowledge of the location and size of the regions of emission that are important — yet another reason to make a low resolution image of your data first. Task SETFC helps you prepare multi-field input to IMAGR using the NRAO VLA Sky Survey (NVSS) source catalog and even the current coordinate of the Sun. It can also recommend cell and image sizes. After Cleaning, multiple fields (and even multiple pointings of a mosaic) from IMAGR may be put into a single large image on a single geometry by FLATN. Task CHKFC may be used with FLATN to check that a given BOXFILE covers the desired portion of sky with fields and Clean boxes. The BOXFILE may be edited by task BOXES to put Clean boxes around sources from a source list such as the NVSS or WENSS. The task FIXBX may be used to convert the Clean boxes from the facets and cell sizes of one box file to those of another.

The use of IMAGR to make images of multiple fields was described in § 5.2.2. To repeat some of the description, you specify the multiple-field information with:

| | |
|---|---|
| > NFIELD $n$ C_R | to make images of $n$ fields. |
| > IMSIZE $i, j$ C_R | to set the minimum image size in $x$ and $y$ to $i$ and $j$, where $i$ and $j$ must be integer powers of two up to 8192. |
| > RASHIFT $x_1, x_2, x_3, \ldots$ C_R | to specify the $x$ shift of each field center from the tangent point; $x_n > 0$ shifts the map center to the East (left). |
| > DECSHIFT $y_1, y_2, y_3, \ldots$ C_R | to specify the $y$ shift of each field center from the tangent point; $y_n > 0$ shifts the map center to the North (up). |
| > FLDSIZ $i_1, j_1, i_2, j_2, i_3, j_3, \ldots$ C_R | to set the area of interest in $x$ and $y$ for each field in turn. Each $i_n$ and $j_n$ is rounded up to the greater of the next power of 2 and the corresponding IMSIZE. FLDSIZE controls the actual size of each image and sets an initial guess for the area over which Clean searches for components. (That area is then modified by the various box options discussed in § 5.3.3.) |

If ROTATE is not zero, the shifts are actually with respect to the rotated coordinates, not right ascension and declination. The actual $x$ shift will be RASHIFT which is $(\alpha - \alpha_0)\cos(\delta)$. IMAGR has an optional BOXFILE text file which may be used to specify some or all of the FLDSIZE, RASHIFT, and DECSHIFT values. It is the only way to specify these parameters for fields $> 64$. To simplify the coordinate computations, the shift parameters may also be given as right ascension and declination of the field center, leaving IMAGR to compute the correct shifts, including any rotation. BOXFILE may also be used to specify initial Clean boxes for some or all fields, values for BCOMP, and spectral-channel-dependent weights.

The manner in which the multi-field Clean is conducted requires some discussion. When ONEBEAM is true, there is a single dirty beam for all fields. For either value of DO3DIMAG, the dirty beams for each facet are, at least subtly, different. Using a single dirty beam allows the task to run faster at some compromise to accuracy. Since the Clean component models are subtracted from the *uv* data at each major cycle, Clean will correct much of this compromised accuracy. In OVERLAP $< 2$ mode with one beam, all pixels within Clean windows above the current threshold from all fields are selected for the Clark Clean at the same time. The component flux at which the major cycle terminates is adjusted by the number of iterations before and during that major cycle. All components found from all fields in the major cycle are subtracted at once from the residual data and a new set of residual images is constructed. When ONEBEAM is false, there is a different dirty beam for each field. Thresholds are set by reviewing the data in all fields as above. However, a major cycle is then conducted for each field individually in order of decreasing peak residuals (within the Clean boxes). The first field alone determines the flux at which the major cycle terminates for all fields. Components are subtracted from the residual data one field at a time.

There is a third arrangement, selected by specifying OVERLAP $\geq 2$, which is useful if the multiple fields overlap. All fields are imaged at the beginning to allow the user to set the initial Clean boxes. Then, at each cycle, the one field thought to have the highest residual with its Clean boxes is imaged, a major cycle of Clean performed, and the components found subtracted from the residual *uv* data. The process is repeated using the previous estimates of the maxima (with a revised value for the field just Cleaned). This arrangement requires some extra imaging at the beginning (and occasionally during Cleaning), has some uncertainties about the setting of thresholds and major cycle flux limits, and will invoke the DOTV option for every field individually except at the beginning. It has the benefit of removing the strongest sources (if there is overlap) and their sidelobes from the later fields before they are imaged. This arrangement removes the instabilities that arise if the same spot is Cleaned from 2 fields. In 31DEC09, IMAGR carefully checks the Clean boxes in OVERLAP $< 2$ mode and eliminates one of any two overlapping boxes.

It appears that the most reasonable approach would be to use `ONEBEAM FALSE ; OVERLAP 2` at the beginning of a deep Cleaning in order to deal carefully with the brightest source components, avoiding putting erroneous components on their sidelobes. But when the dynamic range of the residual image is reduced, `ONEBEAM TRUE ; OVERLAP 1` will be accurate enough and much faster. In 31DEC09, IMAGR has an OVRSWTCH option to control switching from the former to the latter without having to restart the Clean.

There are a number of aspects of multi-field Clean that can trip up the unwary. The first is that the sidelobes of an object found in one field are *not* subtracted from the other fields in the minor Clean cycle. In fact, they are not even subtracted from pixels more than the beam patch size away in the same field. This can cause sidelobes of the strongest sources to be taken to be real sources during the current major cycle. (The OVERLAP $\geq 2$ sequence reduces this effect significantly.) At the end of the major cycle, all components from all fields are subtracted from the *uv* data. At this point, all sidelobes of the components are gone from all fields, but the erroneously chosen "objects" with their sidelobes will appear (in negative usually). This is normally not a problem. During the next cycle, Clean will put components of the opposite sign on the erroneous spots and they will eventually be corrected. Nonetheless, it is a good idea to restrict the Cleaning to the obvious sources to begin with, saving Clean the trouble of having to correct itself, and to open up the search areas later in the Clean. The TV options make this easy to do in IMAGR; see § 5.3.3.

The situation is more complex if the multiple fields overlap. If a sidelobe in the overlap area is taken as a source in one major cycle, it will appear as a negative source in both fields at the start of the next major cycle (*only when* OVERLAP $< 2$). Clean will then find negative components in both fields and correct its original error twice, producing a positive "source" at the next major cycle. Such errors never get fully corrected. A simple rule of thumb is never to allow the search areas of one field to overlap with the search areas of another field — or use OVERLAP $\geq 2$.. Even then, there is one other "gotcha." In the restore step, Clean only restores components to the fields in which they were found (again, unless OVERLAP $> 0$). Thus, a real source visible in two fields will be found in only one after Clean; your two images of the same celestial coordinate will be in substantial disagreement. Therefore, you must be careful about which parts of which images you believe to represent the sky. Instead, use OVERLAP $\geq 1$ to have Clean components from all fields restored to all fields as needed. If OVERLAP $\geq 2$ , the Clean and imaging are done in a fashion which greatly reduces the instabilities arising from Cleaning the same source (or sidelobe) from more than one field.

### 5.3.3 Clean boxes and the TV in IMAGR

Clean works better if it is told which pixels in an image are allowed to have components. The initial information on this is provided by the FLDSIZE adverb which gives the pixel dimensions of a rectangular window centered in each field in which Clean looks for components. This window can be nearly the full size of the image because the components are subtracted from the ungridded *uv* data. Cleaning windows or "boxes" can be specified with the adverbs:

> NBOXES *n* C_R — to set the number of boxes in which to search for Clean components. Must be $\leq$ 50; if 0, one Clean box given via FLDSIZE is used and CLBOX is ignored.

> CLBOX $lx1, by1, rx1, ty1, lx2, by2, rx2, ty2, \ldots$ C_R — to specify the pixel coordinates of the Clean windows as leftmost $x$, bottommost $y$, rightmost $x$, topmost $y$ for boxes 1 through NBOXES. Circular boxes may also be specified as $-1$, radius, center $x$, center $y$ interspersed in any order with the rectangular boxes. Default is given by FLDSIZE(1).

> BOXFILE '*area : infilename*' C_R — to specify the name of a text file listing the Cleaning windows. Blank means no file.

> OBOXFILE '*area : outfilename*' C_R — to specify the name of an output text file to list the Cleaning windows after any modifications made while running IMAGR. Blank means no file. Can be the same as BOXFILE.

The BOXFILE text file is an optional means by which Clean windows may be entered at the start of a run of IMAGR for all fields, not just the first. It is also the only way to enter more than 50 boxes for the first field; the limit is min (2048, 131072/NFIELD) (!) boxes per field with this option. The format of the file is one box per line beginning with the field number followed by the four numbers describing the box as in CLBOX above. Any line in which the first non-blank character is not a number is taken as a comment, a field definition (see § 5.2.2), a BCOMP value or a channel weight. NBOXES and CLBOX are overridden if any boxes for the first field are given in the file.

You can use the TV cursor in advance of running IMAGR to set the Cleaning boxes. First, load the TV display with either the dirty image or a previous version of the Clean image of the first field; see § 6.4.1. Then type:

> TVBOX C_R — to begin an interactive, graphical setting of up to 50 boxes, or

> REBOX C_R — to do a similar setting of the boxes, beginning with the NBOXES boxes already in CLBOX.

Position the TV cursor at the bottom left corner of the first Cleaning box and press a trackball or mouse button. Then position the cursor at the top right corner of the box and press Button B. Repeat for all desired boxes. This will fill the CLBOX array and set NBOXES for the first field. Note that the terminal will display some additional instructions. These will tell you how to switch to a circular box and how to reset any of the previously set corners or radii/centers should you need to do so. HELP REBOX C_R will provide rather more details. In 31DEC06 the verb DELBOX allows you to delete boxes from CLBOX interactively.

You can also use the TV cursor in a very similar way to build and modify the BOXFILE text file. (You can also use your favorite text editor of course; see § 3.10.1 for general information about specifying and using external text files.) The verb FILEBOX reads the text file (if any) given by BOXFILE selecting those boxes (if any) already specified for the specified field number which fit fully on the current image on the TV. Which field number you want is given with the NFIELD adverb, or, if that is zero, deduced from the Class name of the image on the TV. (Be careful to load the TV with the desired image before running FILEBOX!) You then carry out a graphical setting or resetting of boxes in exactly the same manner as with REBOX. The new and changed boxes are then added to the end of the text file. Different portions of the current field and other fields may be done and redone as often as needed. In 31DEC06, verb DFILEBOX may be used like DELBOX to delete boxes interactively from a BOXFILE. The BOXFILE may be edited by task BOXES to put Clean boxes around sources from a source list such as the NVSS or WENSS. The task FIXBX may be used to convert the Clean boxes from the fields and cell sizes of one box file to those of another.

For 31DEC09, a new task called FILIT was written. It does something like FILEBOX but it does the TV load for you, using a roam mode if the image is larger than the TV display area. From a TV menu, you may then add boxes, change boxes, and delete boxes and even use an auto-boxing feature to add boxes automatically based on the peak values and noise in the image. FILIT will work on a set of facet images and should become the task of choice for examining multi-facet images and their Clean boxes. The non-interactive task SABOX will find boxes to use for a set of facet images, prepared, for example, by a shallow un-boxed Clean.

In 31DEC09, IMAGR will also create Clean boxes for you automatically. The adverbs IM2PARM(1) through IM2PARM(6) control the process, selecting the maximum number of boxes to be found at any one time, the cutoff levels as factors times the residual image robust rms, and more. IM2PARM(7) controls the starting list of Clean boxes for the next spectral channel - do they start with those input to IMAGR or also include those found in the current channel. See HELP IM2PARM C_R for information and AIPS Memo No. 115 "Auto-boxing for Clean in AIPS" by Greisen for a detailed explanation of this new option.

The real power of IMAGR becomes apparent if you set DOTV = $n$, where NFIELD $\geq n > 0$ is the field number first displayed on the TV. Before each major cycle, the current residual image is displayed on the TV and a menu of options is offered to you. (Note that the residual image before the first major cycle is the un-Cleaned dirty image.) The image displayed is interpolated up or decremented down (by taking every $n^{\rm th}$ pixel in each direction) to make it fit on the display and the current Clean boxes are shown. If you do not select a menu option, IMAGR proceeds after 30 seconds.

The interactive options appear in two columns. To select an option, move the TV cursor to the option (remember the left mouse button — see § 2.3.2) and press buttons A, B, or C. Button D will get you some on-line help about the menu option. The basic options, in the order in which they are displayed, are:

| | |
|---|---|
| ABORT TASK | to stop the task abruptly, destroying the output images and exiting as quickly as possible. |
| TURN OFF DOTV | to resume the Cleaning now and stop using the TV to display the residual images. To turn the TV display back on, if needed, use the TELL IMAGR verb with suitable adverbs, including DOTV TRUE. |
| STOP CLEANING | to stop the Clean at this point, restore the components to the residual images, write them on disk, and exit. |
| OFFZOOM | to turn off any zoom magnification |
| OFFTRANS | to turn off any black & white enhancement |
| OFFCOLOR | to turn off any pseudo-coloring |
| TVFIDDLE | to interactively zoom and enhance the display in black & and white or pseudo-color contours as in AIPS |
| TVTRAN | to enhance in black & white as in AIPS |
| TVPSEUDO | to select many pseudo-colorings as in AIPS |
| TVFLAME | to enhance with flame-like pseudo-colorings as in AIPS |
| TVZOOM | to set the zoom interactively as in AIPS |
| CURVALUE | to display the pixel value and $x, y$ pixel coordinates at the TV cursor position as in AIPS |
| SET WINDOW | to select a sub-image of the whole to be reloaded with better resolution — all boxes must be included. |
| RESET WINDOW | to select the full image and reload the display |
| TVBOX | to set the Clean boxes for this field beginning at the beginning as in AIPS |

| | |
|---|---|
| REBOX | to reset the current Clean boxes and create more as in AIPS |
| DELBOX | to delete some of the current Clean boxes as in AIPS |
| CONTINUE CLEAN | to resume Cleaning now rather than wait for the time out period. |

If OBOXFILE was specified and TVBOX, REBOX, or DELBOX used, the new Clean boxes will be written to the text file, replacing any previously in that file. (All non-box cards in that file are preserved unchanged; a new OBOXFILE will be filled with the non-box cards from BOXFILE.)

If NFIELD > 1, a sufficient number of additional options appear of the form

| | |
|---|---|
| SELECT FIELD $n$ | to display field $n$, allowing its Clean boxes to be altered or |
| SELECT NEW FIELD | to prompt on the terminal for a new field number to be displayed, allowing its Clean boxes to be altered (when $> 64$ fields). |

Thus you can look interactively at the initial dirty images, place boxes around the brightest sources, and start the Clean. As it proceeds and weaker source become visible, you can expand the boxes and add more to include other sources of emission. Do be careful, however. Boxes that are too tight around a source can affect its apparent structure. The author once made Cas A into a square when stuck with a too-tight box. If OVERLAP = 2, the SELECT FIELD options are displayed when all residual images are current, *i.e.*, at the beginning, but are replaced by the options

| | |
|---|---|
| REMAKE IMAGES | to re-compute all fields using the current residual *uv* data and then to display all fields on the TV. |
| THIS IS FLD $n$ | to indicate that only field $n$ is displayed and available to have its boxes altered. |
| FORCE A FIELD | to prompt on the terminal for a field number, exit TV, re-compute and display that field with current residual data (if needed) and then Clean that field (only available if NFIELD $> 64$ or DOWAIT true). |
| STOP FLD $n$ | to mark field $n$ as Cleaned sufficiently. |
| ALLOW FLD $n$ | to allow further cleaning of previously stopped field $n$. |
| CHECK BOXES | to see if Clean boxes in one field overlap with Clean boxes in other fields and drop some to avoid this situation. |

We encourage use of DOTV TRUE C<sub>R</sub> when you are Cleaning an image, especially for the first time or when using the options described in the next section. Watching the TV display as the Clean proceeds will help you to gauge how to set up control parameters for future Cleans and how long to iterate. It may also warn you about instabilities in the deconvolution if you compare the appearance of extended structures early and late in the Cleaning process. The instabilities referred to in § 5.2.4 were first seen while Cleaning with the TV option.

### 5.3.4 Experimental variations on Clean in IMAGR

In the 15OCT99 and 31DEC00 versions of IMAGR, new experimental variations of the familiar Cleaning methods have been introduced. One deals with the so-called "Clean bias" which causes the fluxes of the real sources to be underestimated. The other two deal with the inadequacies of Clean in modeling extended sources.

#### 5.3.4.1 Clean-component filtering

It has been found that Clean will eventually assign some components to noise spikes in regions which do not have real sources, producing the "Clean bias." Real source flux is underestimated, presumably because "sidelobes" of the noise "sources" get subtracted from areas of real sources. The magnitude of the effect is rather variable and is not understood. There are two older tasks discussed in § 5.3.6 which deal with the problem. However, it would be better to remove "weak, isolated" (presumably spurious) Clean components as Clean proceeds rather than only after the fact. One cannot do this at every Clean major cycle, since all components are likely to be weak and isolated initially. But it is a good idea to do it a few times while *uv*-plane based Cleans still have the ability to respond to the filtering. Note that this option may be used to remove negative "bowls" surrounding sources imaged with too little short-spacing data. However, it does not remove the bowl that sits on the source itself and so the final flux will be too low. You should consider the multi-scale Clean instead.

To have `IMAGR` filter Clean components set `IMAGRPRM(8)` $\neq 0$. Then `IMAGR` will select only those Clean components having > abs(`IMAGRPRM(8)`) Jy within a radius of abs(`IMAGRPRM(9)`) cells of the component. Note that this rejects all areas of negative flux, unless `IMAGRPRM(8)`$< 0$, in which case the absolute value of the flux near the component is used. You can change these parameters with `TELL`, but only if `IMAGRPRM(8)` was non-zero to begin with. A copy of the input data has to be made for this option and it is only made if `IMAGRPRM(8)` is non-zero. If this option is selected, the output CC files will have been merged. Note that `IMAGRPRM(8)` should always be $\leq 0$ for images of Q, U, and V Stokes parameters since negative brightnesses are valid. Filtering is done on restarts, when requested from the TV, on certain Cleaning failures, and near the exit. Clean is continued after this last filtering if `IMAGRPRM(9)`$< 0$, but usually terminates fairly quickly. When this option is available, an addition TV option will appear:

FILTER COMPS — to exit TV, filter all Clean components, and then re-compute all fields using new residual data.

This is the only way to filter before the end of the current Clean.

#### 5.3.4.2 SDI modification of Clean in `IMAGR`

A modified Clean algorithm that attempts (often successfully) to suppress the striping and bumpiness in Cleans of extended sources has been developed by Steer, Dewdney and Ito (1984, *Astron. & Astrophys.* **137**, 159). In the *AIPS* modification of the algorithm, Clean proceeds normally until the residual image becomes rather smooth. It then takes many components at once from all high-residual cells rather than trying to decide exactly which *one* cell is the highest. This algorithm attempts to cut the top off the plateau of emission found in the residual image(s) in a relatively uniform way. Unfortunately, it is very expensive to determine the correct weights to use for each pixel in this algorithm. The technique used by `IMAGR` does apply larger weights to isolated pixels and pixels at the edges of the "plateau" but these weights are still not quite large enough to avoid a tendency to make a slight rim around the plateau. The next cycle of SDI Clean does trim this down and the method converges well for the extended sources for which the algorithm was designed. `IMAGR` allows you to switch back and forth automatically between BGC and SDI depending on the contrast between the brightest and median residual pixel in the Clean windows. (SDI is used when the contrast is low.)

To allow `IMAGR` to use the SDI algorithm, specify `IMAGRPRM(4)` $> 0$. SDI Clean will be used when the fraction of pixels in the Clean windows exceeding half of the peak residual exceeds `IMAGRPRM(4)`. `IMAGRPRM(19)` is used to limit the depth of an SDI Clean cycle. When this option is used, additional TV options appear:

FORCE SDI CLEAN — to force the next Clean cycle to use SDI method.

FORCE BGC CLEAN — to force the next Clean cycle to use Clark method.

These allow you to force the choice of SDI or BGC methods for the next Clean major cycle. After that, it reverts to selecting the method based on `IMAGRPRM(4)` and the histogram of residual values.

#### 5.3.4.3 Multi-scale modification of Clean in IMAGR

Clean has problems with extended sources because the point-component model is so far from the reality for them. Greisen experimented in the 1970s with modeling sources as Gaussians rather than points, but found that there are always point sources in the image which cannot be modeled sensibly with an extended component. ("Bull's eyes" get painted around every point object.) Wakker and Schwarz (1998, *Astron. & Astrophys.* **200**, 312) proposed a scheme in which a smoothed image and a difference image were Cleaned. This still used point-source models although the Clean beam used for restoring the smoothed-image components was extended. Cornwell and Holdaway (July 1999, Socorro imaging conference) described a scheme in which an image is Cleaned simultaneously at several scales.

31DEC00 has a *uv*-based variation of this last algorithm. The multi-field capability of IMAGR is used to image for each of NFIELD fields, images at NGAUSS scales specified in the array WGAUSS in arcsec. The full-resolution image is convolved with a Gaussian of width WGAUSS($i$) while a dirty beam appropriate to a component of that width is constructed. One of the WGAUSS must be zero if a point-source model is desired; a warning is issued if none of the resolutions is zero. OVERLAP = 2 mode is used. See EXPLAIN IMAGR for details of this new option. Users have found that WGAUSS values increasing by factors of $\sqrt{(10)}$ are frequently optimal. The most important additional control parameter is IMAGRPRM(11) which down-weights higher scales to allow Clean to work on the higher-resolution images with roughly equal probability. FGAUSS is used to select the minimum brightness to be cleaned at each scale; higher values at higher scales are usually desired. Reasonable values of these three parameters will require running IMAGR to determine the point-source resolution and then to determine the peak brightnesses in each scale and the apparent noise levels after some Cleaning. The other available "knobs" for this algorithm may safely be left at zero.[3]

#### 5.3.4.4 Spectral-index corrections

When using wide-band, multi-channel data to image continuum sources, serious effects are seen if the source intensities change as a function of frequency. If these changes can be modeled as spectral index images with or without "curvature," then the 31DEC06 version of IMAGR will allow the spectral-index effects to be compensated during Cleaning. First image each spectral channel (or group of closely-spaced channels) separately. Combine them into a cube with FQUBE, transpose the cube with TRANS, and solve for spectral index images with SPIXR. To use these images, set IMAGRPRM(17) to a radius ($> 0$) in pixels of a smoothing area and put the image name parameters in the 3rd and 4th input image names. Note that this algorithm is expensive, but that it can be sped up with judicious use of the FQTOL parameter.

### 5.3.5 Data correction options in IMAGR

There are a number of effects which degrade the usual image deconvolution, but which are, optionally, handled differently by IMAGR. These corrections are primarily for observations made with widely spaced frequencies over fields comparable to the single-dish field of view. If you have such data and hope to achieve high dynamic range images, then these corrections are for you. Otherwise skip to the next section.

#### 5.3.5.1 Frequency-dependent primary-beam corrections

The primary-beam pattern of the individual telescopes in the interferometer scales with frequency. Therefore, each channel of multi-frequency observations of objects well away from the pointing center effectively observes

[3]See "Aperture Synthesis Observations of the Nearby Spiral NGC 6503: Modeling the Thin and Thick Disks" 2009, AJ, 137, 4718, by Greisen, E. W., Spekkens, K. and van Moorsel, G. A. for a detailed description of this algorithm and an example of its use.

a different sky. When a combined source model is produced, there will be residuals in the visibility data that cannot be Cleaned as the data does not correspond to a possible sky brightness distribution. If IMAGRPRM(1) is larger than 0, then a correction is made in the subtraction of Clean components from the *uv* data to remove the effects of the frequency dependence of the primary beam. The primary beam is assumed to be that of a uniformly illuminated disk of diameter IMAGRPRM(1) meters. This correction is made out to the 5% power point of the beam with a flat correction further out. Note: this correction is only for the relative primary beam to correct to a common frequency and *does not* correct for the primary beam pattern at this frequency. Note that this algorithm is expensive, but that it can be sped up with judicious use of the FQTOL parameter. It adds essentially no cost when doing the spectral-index corrections, however.

#### 5.3.5.2 Frequency-dependent correction for average spectral index

If the sources observed do not have a flat spectrum, then the source spectrum will have channel-dependent effects on the Cleaning of a similar nature to the primary beam effects described above. This problem does not depend on position in the field except, of course, that the spectral index usually varies across the field. Normally, however, it varies around $-0.8$ rather than about 0. To the degree that the structure in the field can be characterized by a single spectral index, the amplitudes of the data can be scaled to the average frequency. This is done, before imaging, by scaling the amplitudes of the *uv* data to the average frequency using a spectral index of IMAGRPRM(2). For optically thin synchrotron sources, this spectral index is typically between -0.6 and -1.0. This correction cannot remove the effects of variable spectral index but allows a single correction which should usually be better than no correction at all. Note that a much more expensive correction and more accurate may now be made (see above).

#### 5.3.5.3 Error in the assumed central frequency

If the frequency used to compute the $u$, $v$ and, $w$ terms is in error, there will be a mis-scaling of the image by the ratio of the correct frequency to that used. Since central frequencies are frequently computed on the basis of unrealistic models of the bandpass shape, the "average" frequency given in data headers is frequently in error. If IMAGRPRM(3) is larger than 0, it is assumed to be a frequency scaling factor for the $u$, $v$, and $w$ that is to be applied before imaging. Again, this can only correct for some average error. Since individual antennas will have different bandpass shapes, no single factor can correct all of the error.

#### 5.3.5.4 Array mis-orientation effects

Images made with a coplanar array not oriented towards the instrumental zenith will have a distortion of the geometry which increases in severity away from the phase tracking center. For non-coplanar arrays, the image is distorted rather than just the geometry. VLA snapshots are misaligned coplanar arrays, whereas VLA synthesis images cannot be considered to have been made with a coplanar array. Images made with mis-aligned coplanar arrays can be corrected using task OHGEO to remove the effects of this misalignment. Since this correction requires the knowledge of the observing geometry, in particular, the average parallactic and zenith angles, IMAGR computes these values and leaves then as header keywords for OHGEO to use.

#### 5.3.5.5 Non-coplanar effects

IMAGR has a IMAGRPRM(4) option to attempt to correct for non-coplanar effects in imaging. If this worked, it would be very very slow. At this writing, it is not believed to work at all and is disabled in the code. See the explain information for further details. The DO3DIMAG option removes a good part of the non-coplanar effects by rotating the projected baselines to make each field tangent at its center.

#### 5.3.5.6 Units mismatch of residuals and Clean components

In principle, the units of the residuals are different from those of the restored components. Both are called Jy per beam area, but the beam areas differ; that of a dirty image is — in principle — zero. If the area of the central lobe of the dirty beam is similar to the restoring beam area, then this effect is negligible. Similarly, if the Clean has proceeded well into the noise then this difference is of little consequence. However, if there is significant flux left in the residual image, then this difference may be important. If IMAGRPRM(5)$>0$, IMAGR will attempt to scale the residuals to the same units as the restored components. The principal difficulty is determining the effective area of the dirty beam. Operationally, this is done inside a box centered on the peak in the beam with half-width IMAGRPRM(6) in $x$ and IMAGRPRM(7) in $y$. It may be better, in this regard, to use the default Clean beam and this option at this stage and change resolution and units later with CCRES; see § 7.6.4.

### 5.3.6 Manipulating Clean components

The list of Clean components associated with a Clean image can be printed with:

| | |
|---|---|
| > TASK 'PRTCC' ; INP | to select the task and review its inputs. |
| > INDI $n$ ; GETN $ctn$ C_R | to select the Clean image, where $n$ and $ctn$ select its disk and catalog numbers. |
| > BCOUNT $n_1$ ; ECOUNT $n_2$ C_R | to list Clean components from $n_1$ to $n_2$. |
| > XINC $n_3$ C_R | to list only every $n_3^{\text{th}}$ component. |
| > DOCRT FALSE C_R | to route the list to the line printer, or use TRUE to route the display to your workstation window. |
| > GO C_R | to execute the task. |

Some users of the CC file for self-calibration suggest that only the components down to the first negative, or down to some factor times the flux at the first negative, should be used. The justification for this advice is the assumption that negative components occur near the noise level. This is not always the case. They also occur to correct for previous over-subtraction or for an object which does not lie on a cell. In any case, PRTCC will display the first negative component if it is found during the printing (*i.e.*, before or during the range printed). The task CCFND is designed solely to find the component number of the first negative and the number of the component having FACTOR times the component flux of that first negative. The total fluxes at these two positions in the file are also displayed.

You can plot the list of Clean components associated with a Clean image in various ways with TAPLT. For example, to plot the sum of the components as a function of component number enter:

| | |
|---|---|
| > APARM 0 ; BPARM 0 ; CPARM 0 C_R | to clear input parameters. |
| > APARM(6) 1; APARM(10) 1 C_R | to have the component flux summed and plotted on the $y$ axis. |
| > GO TAPLT C_R | to create the plot file. |
| > GO LWPLA C_R | to display the plot file on the laser printer. |

TAPLT offers many options for plotting functions of table columns against each other. Enter EXPLAIN TAPLT C_R for details.

You can compare the source model contained in the CC file with the visibility data in a variety of ways. UVSUB allows you to subtract the components of some or all fields from the data, producing a residual visibility data set. OOSUB is similar, but allows for the frequency-dependent corrections performed in IMAGR and for limiting the components subtracted to those inside or outside of the primary beam. Of course, IMAGR's workfile already contains these residuals with the CC files of all fields subtracted. Various display options can be used on these *uv* files; see § 5.3.1. VPLOT, described in § 9.3.3, will plot a CC model against visibility data, one baseline at a time, $n$ baselines per page.

The algorithm used by all *AIPS* Cleans assigns to a component only a fraction (GAIN) of the current intensity at the location of that component. As a result, the list of components contains many which lie on the same pixels. CCMRG combines all components that lie on the same pixel. This can reduce the size of the list greatly and, hence, the time required for model computations in tasks such as CALIB (§ 5.4) and UVSUB. Do this with

| | |
|---|---|
| > TASK 'CCMRG' ; INP | to select the task and review its inputs. |
| > INDI *n* ; GETN *ctn* C_R | to select the Clean image, where *n* and *ctn* select its disk and catalog numbers. |
| > INVERS *m* ; OUTVER *m* C_R | to select the input version of the Clean components and to replace it with the compressed version. |
| > GO C_R | to execute the task. |

Under a variety of conditions, the Clean component files produced by IMAGR will already be merged.

There should seldom be a need to edit Clean component files in detail. However, task TAFLG allows editing based on comparison of a function of one or two table columns with another function of another one or two columns. One interesting use for TAFLG would be to delete all components below some cutoff before running CCMRG. Enter EXPLAIN TAFLG C_R for details.

It has been found that Clean will eventually assign some components to noise spikes in regions which do not have real sources and that this produces the so-called "Clean bias" which causes the fluxes of the real sources to be underestimated. This is presumably because "sidelobes" of the noise "sources" get subtracted from areas of real sources, but the magnitude of the effect is rather variable and is not understood. There are two tasks which can help. CCEDT copies a CC file keeping only those components which occur in specified windows. Then it merges the file (like CCMRG) and discards all merged components of flux below a specified cutoff. Under some circumstances, such filtering of Clean components before self-calibration can be a more effective way of obtaining convergence of hybrid mapping (mostly for VLBI) than restricting Clean windows in IMAGR.

The second task, CCSEL, explicitly addresses the Clean bias problem. It sums the flux of all components within a specified distance of each component and then discards those components for which this sum is less than a specified threshold. The idea is to eliminate "weak isolated" components which are likely to be those on noise points. You should run CCMRG before using CCSEL since the compute time increases quadratically with the number of components. IMAGR's internal algorithm for filtering is much more efficient.

### 5.3.7 Image-plane deconvolution methods

The previous sections have described the task IMAGR which implements Clean by subtracting model components in groups from the ungridded *uv* data and re-imaging. This can be rather expensive. If you have a significant number of visibilities contributing to a fairly small image, it may be faster to use an image-plane deconvolution method. The venerable APCLN implements the Clark Clean in the image plane. Clean components are found during "minor" iteration cycles by Cleaning the brightest parts of the residual image with a "beam patch" of limited size, just as in IMAGR. More precise Cleaning is achieved at the ends of "major" iteration cycles when the Fourier transform of the Clean components is computed, multiplied by the transform of the beam, transformed back to the image plane, and then subtracted from the dirty image. This method does a good job Cleaning the inner quarter of the image area, but artifacts of the Cleaning and aliasing of sidelobes do interesting things to the remaining 75% of the image. Make the dirty image using IMAGR and be sure to make it large enough to include all of the source in the inner quarter of the area. APCLN uses many of the now-familiar adverbs of IMAGR, including GAIN, FLUX, NBOXES, CLBOX, FACTOR, MINPATCH, MAXPIXEL, BMAJ, and more. APCLN recognizes only rectangular boxes and its DOTV option only displays the residual image with a pause for you to hit button D to end the Cleaning early.

The subject of image deconvolution has been widely studied and many methods have been proposed for tackling it. Clean is renowned for yielding images that contain many artificial beam-sized lumps or stripes in smooth low-brightness regions. Point sources are a poor model for such regions. You should compare heavily Cleaned images with dirty, or lightly Cleaned, images to test that any features you will interpret physically have not been introduced by these Clean "instabilities." The *AIPS* Clean tasks have an optional parameter PHAT that will add a small-amplitude $\delta$-function to the peak of the dirty beam in an attempt to suppress these instabilities as described by Cornwell (*Astron. & Astrophys.* **121**, 281 (1983).)

A modified Clean algorithm that attempts (often successfully) to suppress these instabilities has been developed by Steer, Dewdney and Ito (*Astron. & Astrophys.* **137**, 159 (1984)). In this algorithm, Clean proceeds normally until the residual image becomes rather smooth. It then takes many components at once from all high-residual cells rather than trying to decide exactly which *one* cell is the highest. The algorithm is embodied in the well-tested *AIPS* task SDCLN, which is actually an enhanced version of APCLN. The source must be contained in the inner quarter of the image area as in that task. Type EXPLAIN SDCLN C<sub>R</sub> for information. SDCLN gives excellent results on extended sources, but is exceptionally CPU-intensive.

The most widely used, best understood, and probably most successful alternative to Clean is the Maximum Entropy Method ("MEM"). This is implemented in *AIPS* by the task VTESS. This requires a dirty image and beam, such as those produced by IMAGR with NITER set to 0, each twice the (linear) size of the region of interest (as for APCLN and SDCLN). The deconvolution produces an all-positive image whose range of pixel values is as compressed as the data allow. The final VTESS image is therefore stabilized against Clean-like instabilities while providing some "super-scale" wherever the signal-to-noise ratio is high. VTESS can also deconvolve multiple images simultaneously; see below.

There are three main reasons to prefer MEM deconvolution over all of the Clean deconvolution methods:

1. MEM can be much faster for images which have strong signals in many pixels. "Many" seems to be $\geq 512^2$ or so.
2. MEM produces smoother reconstructions of extended emission than does Clean.
3. MEM allows introduction of *a priori* information about the source in the form of a "default" image.

Because VTESS can produce excellent deconvolutions of extended sources in much less computation time than Clean, but requires careful control, we recommend studying the output of EXPLAIN VTESS C<sub>R</sub> before using the task. The NOISE parameter is particularly important; some have claimed that VTESS requires this to be within 5% of the correct value in order to deconvolve fully without biasing the total flux. (Use IMEAN (§ 7.3) to estimate the true rms.) Chapters 8 and 15 of the NRAO Summer School on *Synthesis Imaging in Radio Astronomy* also provide useful general background.

MEM can be used for quantitative work on regions of good ($> 10$) signal-to-noise ratio, if the dirty image is convolved with a Clean beam prior to deconvolution. Use the *AIPS* task CONVL for this purpose. The images may also be post-convolved, and added to the residuals, within VTESS. In many cases, the images of extended sources produced by SDCLN and VTESS are functionally identical. VTESS usually converges in *much less* CPU time, however, at the expense of leaving significantly larger residual sidelobes close to bright compact (point-like) features. To get around this deficiency of VTESS, first use Clean to remove the peaks of bright point-like features, then run VTESS on the residual image produced by this restricted Clean. (The *AIPS* Clean tasks will output a residual image if you set BMAJ $< 0$.) The Clean components may be restored to the final image with tasks CCRES or RSTOR.

VTESS can also combine information from different types of data. For example, single-dish data can be used to constrain the imaging of interferometer data, or many pointings covering one large object can be processed together. VTESS takes up to 4087 pairs of images and beams, together with some specification of the primary beam for each, either a circular Gaussian model or the VLA primary beam, and performs a joint maximum entropy deconvolution to get an image of one field. The images must all be in the same coordinate system, and a noise level must be known for each. The time taken is approximately the time VTESS would take for one input map and beam, multiplied by the number of map/beam pairs.

VTESS cannot be used on images which are not intrinsically positive, such as images of the Stokes Q, U, and V parameters. UTESS is a version of VTESS designed to deconvolve polarization images, for which a positivity constraint cannot be applied. For further information type EXPLAIN UTESS C_R

Two further alternatives to Clean have been implemented in *AIPS* as *experimental* tasks. These are algorithms due to Gerchberg and Saxton (APGS) and van Cittert (APVC). Type EXPLAIN APGS C_R, EXPLAIN APVC C_R for further information on these tasks.

## 5.4 Self-calibration

The task CALIB was described in some detail in Chapter 4 as the tool to determine the instrumental gains on calibrator sources which were then interpolated in time and applied to your program sources. If you have sufficient signal to noise in the latter, you may now use CALIB to improve the dynamic range of your images. The assumption is made that your images have been degraded by antenna-based (complex) gain errors which vary too rapidly with time or direction to have been fully calibrated with the calibrator sources. CALIB compares the input *uv* data set with the predictions of a source model — a point-source initial guess or your current best set of Clean components — in order to compute a set of antenna-based amplitude and phase corrections as a function of time which would bring the data into better agreement with your current model. For an $n$-element array, there are $(n-1)/2$ times more observations than unknown antenna gains at any time, so the process is well-determined when $n$ is reasonably large. Since this process uses the data to calibrate themselves, it is called self-calibration.

Do not use CALIB unless your data have enough signal-to-noise to warrant improvement. Ask yourself whether your externally-calibrated Clean images contain un-Cleanable artifacts well above the noise, and whether your source meets the criteria for self-calibration given by Tim Cornwell and Ed Fomalont in Lecture 9 of *Synthesis Imaging in Radio Astronomy*. Note that if your images are limited by receiver noise, self-calibration may produce erroneous results, including the fabrication of weak sources!

### 5.4.1 Self-calibration sequence and SCMAP or SCIMG

If you decide to use self-calibration, a good sequence of steps is:

1. Use UVPLT to make a plot file showing the shape of the visibility function as a function of baseline length in the externally-calibrated data set. (See § 6.3, especially § 6.3.1, for information about plotting in *AIPS*.) *N.B.,* for large data sets, use XINC to reduce the number of points plotted to no more than a few thousand; otherwise it will take too long to make and plot the plot file. Use LWPLA to get hard copy of the plot file.

2. If you can use a point-source model for the first iteration, *i.e.*, if a range of baselines sufficient to calibrate all antennas is dominated by a single component (flat visibility function well above the noise), go to step 6 directly. This is frequently done with VLBI data, but is less common with arrays for which the initial calibrations are better such as the VLA.

3. If you must use a more complicated model, obtain a Clean-component representation of it by making and Cleaning an image of the externally-calibrated data using IMAGR. Leave the *uv* data in "TB" sort order for CALIB; IMAGR will sort them if it has to. Note that you may want to use a somewhat higher loop GAIN in a Clean to be used as an input model for an early iteration of self-calibration than you

would for final deconvolution of a very extended structure. Task FACES can prepare an initial model for wide-field observations particularly at long wavelength.

4. Consider running CCMRG to reduce the number of components in the model. This improves the speed of the calibration and makes the first negative component be a real negative rather than a minor correction to previous positive components. Remember that merging the components does alter the model which is used to compute the gains unless you were going to include all components anyway. Note that IMAGR often merges the components automatically.

5. Use PRTCC or TAPLT (as in the example in § 5.3.6) to help you decide how many components from this Clean to include in the CALIB model. CCFND is also helpful. When you have decided this, determine the appropriate *uv*-limits for the gain solution by referring to the hard copy of the visibility function you made at step 1.

6. Plan your CALIB inputs using the information given in the following two sections. The first few iterations are usually used to correct only phases; amplitude is normally corrected only in the last one or two iterations.

7. Use CALIB to calculate the gain corrections. It will apply them to produce a new, (hopefully) improved data set, and will also catalog the gain corrections as an SN extension to the *input uv* data file. In the 31DEC04 version, you may set DOFLAG to produce and use new data flags based on closure failures.

8. Use SNPLT on the input data file with DOTV = TRUE to review the gain corrections before proceeding further. Use DOBLANK = 1 to plot failed solutions as well as good ones. To take hard copy for future reference, run SNPLT with DOTV = FALSE and then run LWPLA on the plot files (usually more than one) produced. To plot the extrema of the gains use OPTYPE = 'SUM' in SNPLT.

9. Ask whether the gain corrections were believable — were they smaller than at the previous iteration of CALIB, if any? If not, is there a good reason why not? Did you change input parameters such as the model, the type of solution, or the solution interval, in a way that may have forced larger corrections than before? Proceed only if you are reasonably sure you understand what is happening at this point — otherwise consult a local expert at your site.

10. If the corrections were believable, run IMAGR to produce a new Clean image. Lower GAINs and higher NITER to produce deeper and more careful Cleans are appropriate as the self-calibration progresses.

11. Go back to step 4 and repeat the whole process if your new Clean image is a significant improvement over the previous one (with comparable Cleaning parameters on both occasions). You may want to go back to step 1 and repeat the process from there if you have been using amplitude self-calibration and wish to check that your amplitude calibration has not drifted significantly. If the new Clean image differs little from the previous one, do not continue on with further iterations of steps 4 through 10 unless you feel you can make an informed change to the CALIB input parameters at step 6. Task UVDIF (§ 6.2.1) may help you to decide whether there have been significant changes to your data due to the previous iteration of CALIB.

The tasks SCMAP and SCIMG attempt to implement this sequence inside a single task. SCIMG contains almost all of IMAGR and all of CALIB. SCMAP is similar, but limited to a single field for simplicity. They attempt to make the decision about the number of merged components and the range of *uv* spacings to use in each self-calibration based on $\sigma$ times the rms in the residual image of the current Clean, where you provide the $\sigma$. The process is somewhat less flexible, but also less painful, than running CALIB and IMAGR multiple times. They do not let you change imaging parameters while they are running, but they do provide interactive methods to change Clean boxes and to set a variety of Cleaning and self-calibration parameters including loop gain, solution interval and solution smoothing interval. They let you switch from phase-only to amplitude and phase self-calibration or they will do it automatically when the phase only stops converging. Both tasks offer the full editing options of task EDITR (see § 5.5.2) displaying the input and current residual *uv* data with a wide variety of data selection and editing options. The CALIB, IMAGR, and EDITR process is similar, but conceptually simpler, so it is the one described here.

### 5.4.2 Self-calibration with CALIB

CALIB is the heart of the *AIPS* calibration package. The inputs to CALIB are extensive and spread over several screen pages. This is because the routines in CALIB are used in many situations — general calibration, real-time interferometry and VLBI. The task solves for antenna-based complex gains *i.e.*, "self-calibration," whether the source being calibrated is a "calibrator" source (usually taken to be a point) or a "program" source (usually taken to be complex). The solutions that CALIB generates are stored in SN "solution" tables which are attached to the *input* data file. The SN tables can be plotted with SNPLT and listed with LISTR. They can be edited themselves with SNEDT or be used to edit the *uv* data with EDITA.

The following input parameters are used by CALIB for self-calibration of a single-source *uv* data set:

| | |
|---|---|
| > TASK 'CALIB' ; INP C_R | to specify the task and review the inputs. |
| > INDI *n1* ; GETN *ctn1* C_R | to select the 'TB' sorted *uv* database. |
| > IN2D *n2* ; GET2N *ctn2* C_R | to select the Clean model image(s) to use. |
| > NMAPS *q* C_R | to specify the number of images with CC files to use for the model. If $q > 1$, the image class names are assumed to have the first three characters of IN2CLASS with the field number one given in the last three characters as is done by IMAGR. |
| > NCOMP = $n_1, n_2, \ldots$ C_R | to cut off the model at the $n_i^{\rm th}$ Clean component in the $i^{\rm th}$ image. |
| > INVERS *m* C_R | to specify the CC file version number to use from *every* model image; 0 means the highest. |
| > SMODEL $S, x, y, m$ C_R | to specify a point-source (or Gaussian or uniform spherical) model rather than a Clean component model. CALIB uses a source model (type *m*) of *S* Jy located at *x, y* arc-sec with respect to the pointing center. For a point model *m* = 0; see the help for details of the other types. |
| > SUBARRAY *s* C_R | to select the appropriate sub-array — SUBARRAY = 0 implies all sub-arrays. |
| > UVRANGE = $x_1$, $x_2$ C_R | to give full weight (in doing the gain solutions) only to data from projected baselines between $x_1$ and $x_2$ in kilo wavelengths. |
| > WTUV *w* C_R | to set the weight for projected baselines outside the range UVRANGE(1) → UVRANGE(2). WTUV = 0 is interpreted as zero weight and should *not* be used. |
| > REFANT $n_r$ C_R | to select the reference antenna; for best results, choose one known to be good over most of the time range. |
| > SOLMODE 'A&P' C_R | to solve for amplitude and phase corrections simultaneously. |
| > SOLMODE 'P' C_R | to solve for phase weighted by amplitude, the default for single-source files. |
| > SOLMODE 'P!A' C_R | to solve for phase ignoring amplitude. |
| > SOLTYP ' ' C_R | to use a normal (non-linear) least squares solution. |
| > SOLTYP 'L1' C_R | to use an "L1" solution method in which a weighted sum of the moduli of the residuals is minimized. The computed gain solutions are less influenced by wild data points, but there is some loss of statistical efficiency and a modest increase in compute time. See F. R. Schwab, VLA Scientific Memo #136 for further details. |
| > SOLTYP 'GCON' ; SOLMOD 'GCON' C_R | to solve for amplitude and phase using least squares with a gain constraint — this requires GAINERR and SOLCON as well; see the help file. |

| | |
|---|---|
| > ANTWT $w_1, w_2, w_3, \ldots$ CR | to apply additional weights to each antenna (in order) in generating the solutions; 0 implies 1. |
| > APARM(1) = $x_5$ CR | to reject solutions from fewer than $x_5$ antennas; default is 6. |
| > APARM(2) = $x_6$ CR | to tell CALIB whether the data have already been divided by a model ($x_6 > 0$) or not. |
| > APARM(3) = $x_7$ CR | to solve for RR and LL separately ($x_7 \leq 0$) or to average RR and LL correlators before solving ($x_7 > 0$). |
| > APARM(5) = $x_8$ CR | to make separate solutions for each IF ($x_8 \leq 0$) or to average all IFs to make a single solution ($x_8 > 0$). It is better to do separate solutions unless you are desperate for signal to noise. |
| > APARM(6) = $x_9$ CR | to set the level of diagnostic information as 0 (very little), 1 (some including time and closure error statistics), 2 (more including individual closure failures), 3 (even more including S/N ratio), or more (too much or much too much). |
| > APARM(7) = $x_{10}$ CR | to discard solutions having S/N ratios $< x_{10}$; default is 5. |
| > SOLINT = $x_{11}$ CR | to set the length of the solution interval (in minutes); default is 10 seconds for single-source files. |
| > CPARM(2) = 1 CR | to scale the gain corrections by the mean modulus of all gains to keep the flux density scale from drifting; $\leq 0$ lets the gains float free. Other normalizations are also offered. |
| > MINAMPER $a_1$ CR | to set the level of amplitude closure error regarded as "excessive" to $a_1$ per cent. If APARM(6)$\geq$ 1, summaries of the number of excessive errors by antenna are printed and, if APARM(6) $> 1$, up to 1000 of the individual failures are printed. 0 means do not check or report amplitude closure errors of any sort. Note that amplitude closure errors are accumulated using logarithms so that gains of 0.5 and 2.0 are both errors of 100%. errors are reported only if thy are "significant" following CPARM(7). |
| > MINPHSER $p_1$ CR | to set the level of phase closure errors regarded as "excessive." APARM(6) controls the display as for MINAMPER. |
| > CPARM(3) = $a_2$ CR | to display a line when the average absolute value of amplitude closure errors is $> a_2$ % if $a_2 > 0$ and APARM(6) $\geq 1$. |
| > CPARM(4) = $p_2$ CR | to display a line when the average absolute value of phase closure errors $> p_2$ degrees if $p_2 > 0$ and APARM(6) $\geq 1$. |
| > CPARM(5) = 1 CR | to form scalar averages of amplitudes before doing solutions. This is useful only if the phases are bad, but the amplitudes have high signal to noise. |
| > CPARM(7) = $N_\sigma$ CR | to display excessive amplitude and phase errors individually only if they exceed MINAMPER or MINPHSER) and if their significance exceeds $N_\sigma$ times the uncertainty implied by the data weights. |

Other parameters are defaulted sensibly — type EXPLAIN CALIB CR for further information. In general, the *AIPS* philosophy is such that if you don't know what value to set for an adverb, leave it at the default — this will usually give you what you want, or at least something reasonable!

### 5.4.3 Considerations in setting CALIB inputs

In many cases, only a few input parameters to CALIB need be set, other than those selecting the *uv* data and the input model. The key parameters are NCOMP, UVRANGE, SOLINT and, if you are interested in polarization, REFANT.

It pays to be conservative when using NCOMP to select the number of Clean components which will comprise the input source model. Setting NCOMP too high will fossilize errors from the earlier calibrations in the model for the next one; after this, you are stuck with them as long as you continue feeding CALIB a model with as much Cleaned flux density. When calibrating Stokes I images, consider setting NCOMP in CALIB so that few negative Clean components are included. The first few iterations of CALIB should be phase-only calibration, since the tropospheric and ionospheric phase errors will almost always dominate amplitude errors due to the atmosphere or to system drifts. In these first iterations, it is prudent to be even more conservative, setting NCOMP so that the total Cleaned flux included in the model is between 50% and 80% of that at which the first negative Clean component appeared. CCFND will help you with this (§ 5.3.6). If your field is dominated by a few very strong, small-diameter regions, it is a good idea to make the first iterations of CALIB work on Clean components from these regions alone, restricting the range of baselines suitably by setting UVRANGE(1). Setting Clean windows in IMAGR or using CCEDT (§ 5.3.6) suitably will help you do this. Even later in the self-calibration cycle, it is probably still a good idea to eliminate weak, isolated Clean components. Try CCSEL for this.

It is always important to restrict the high-weight domain of the CALIB solution to the part of the *uv* plane that is described well by the model. In the early stages of self-calibration, the trustworthy part of your Clean model will almost always contain less flux density than was measured in the visibility function at the shorter baselines. Another way of putting this is that the large-scale structure of the source will be poorly represented by the model. You should therefore set UVRANGE(1) so that the total flux density in the input model (the sum of the Clean components up to the Clean iteration selected by NCOMP) exceeds the peak visibility amplitude in your data at a baseline of UVRANGE(1) kilo wavelengths (read this off a plot file output from UVPLT). It is also important to give some slight weight to the rest of the *uv* plane so that some solution may be found for most all antennas including those having no baselines in the high-weight region.

SOLINT sets the length of the time interval, in minutes, over which the model and the data are averaged when computing the gain corrections. This must be *short* enough that the gain corrections can track the fluctuations produced by the atmosphere over the longer baselines with sufficient accuracy. It must be *long* enough that the variances of the computed gain corrections (which depend on the signal-to-noise ratios in the data over the *uv* range in which the model is being compared with the data) are acceptably small. These constraints vary from source to source, frequency to frequency, and (because of the "weather") from day to day. They may not in fact be reconcilable for weak sources, especially in the wider VLA configurations and/or at the higher frequencies. In many combinations of these circumstances, you may not be able to self-calibrate your data. See Lecture 9 in *Synthesis Imaging in Radio Astronomy* for details of how to make this assessment. In VLBI imaging, it may be helpful to use a point-source model and quite small SOLINT for the first iteration of self-calibration to remove the gross and rapid changes due to atmospheric fluctuations. With that problem removed, it may then be possible to use longer SOLINTs and more complicated models.

REFANT selects the number of the reference antenna for the gain solutions. For total intensity continuum calibration, the choice of this CALIB input is unimportant. It is always best, however, to choose a reference antenna that was stable and present in all data throughout the run, if only because this prevents propagation of noise or glitches in the reference antenna through the gain solutions (and plots of them) for the other antennas. For polarization work, it is important to select an antenna for which both polarizations were always present; otherwise any polarization calibration which preceded CALIB may be seriously compromised.

Note that CALIB should almost always be run with SOLMODE set to phase-only calibration for the first iteration or two. Consider turning on amplitude calibration by setting SOLMODE 'A&P' only when either the phase adjustments being made are generally small (*i.e.*, the worst cases being a few tens of degrees) or the new re-Cleaned image is clearly dominated by amplitude errors — which will give symmetric Y-shaped patterns around strong point sources for VLA observations. In general, you will want to set CPARM(2) = 1 when using SOLMODE 'A&P', to prevent drifting of the flux-density scale during amplitude self-calibration.

In the 31DEC04 release, CALIB has a number of new options to deal with difficult data. The adverb WEIGHTIT controls how the data are weighted when being processed by the gain-fitting routines. The default is $w = 1/\sigma^2$ which may cause too much contrast between the highest weighted points and the lowest. This problem is much worse when self-calibrating extended sources than when doing the primary calibration on point sources. If you encounter many failed solutions, try WEIGHTIT = 1 which uses $w = 1/\sigma$. If you have trouble with bad data and failed solutions, consider trying the "robust" forms of SOLTYPE selected with 'R', 'L1R', and 'GCOR'. A robust solution is one in which a solution is found, outlier data are temporarily flagged, a new solution found, and the process repeated while gradually tightening the omission criteria. This should make for more reliable solutions when there are bad correlators or antennas and, as a side benefit, allows more permanent flagging of the data under control of adverb DOFLAG.

CALIB will also edit out bad data according to the following criteria:

1. there are too few antennas (APARM(1)) to form a solution,
2. the solution does not converge, or
3. the signal-to-noise ratio for a given antenna (APARM(7)) is too low.

The signal-to-noise ratio is calculated from the post-fit scatter of the residuals from the gain model. Note that the scatter will contain contributions from thermal noise *and* unmodeled source structure. This is a good reason to restrict the *uv* range of the data. For further guidance and information on other CALIB inputs, type EXPLAIN CALIB C<sub>R</sub> and/or read Lectures 9 and 16 in *Synthesis Imaging in Radio Astronomy.*

### 5.4.4 Experimental extension of multi-field self-calibration

High-quality, multi-field images often suffer from position-dependent calibration effects. At lower frequencies, the strongest sources may well lie outside the main portion of the primary beam and so be effected by different instrumental gains including pointing errors, differences in atmosphere or ionosphere, etc. In 31DEC06, an experimental RUN file PEELR compiles a procedure by that name. One "interfering" field at a time, it performs a self-cal to improve that facet. After a list of fields is processed, it restores the original multi-field model to the corrected residual *uv* data. See HELP PEELR for details. It seems almost magical, but it really does improve the final images. A slight increase in the image rms is the price one pays for removing larger, more systematic problems.

## 5.5 More editing of *uv* data

### 5.5.1 General remarks on, and tools for, editing

There are many programs which aid in the processing, display, and editing of *uv* data. Summaries of this software may be listed on your terminal with:

| | |
|---|---|
| > ABOUT UV C_R | to list all *uv*-related software. |
| > ABOUT EDITING C_R | to list all editing software. |
| > ABOUT PLOT C_R | to list all plotting software. |

and are also in Chapter 13 of this *CookBook*. Type

> DOCRT -1 ; EXPLAIN *taskname* C_R    to print information about task *taskname*.

to get more information about any of the tasks mentioned below. The discussion below assumes that you have deduced that there are suspect samples in your data set and that you want to remove them. Read § 4.4 before investing large amounts of time in editing even at this stage.

There are facilities in CALIB, FLAGR, CLIP, CORER, UVMLN, FLGIT, DEFLG, and SNFLG to flag *uv* data in AIPS based on deviations from specified norms. There is also the task UVFLG to flag and unflag by antenna-IF or by correlator. The task UVPLT plots various combinations of *uv* data; see § 6.3.1. The task WIPER makes a similar plot on the TV and allows you to wipe away offending data. The task UVFND is also recommended for printing out suspicious portions of the database; see § 6.2.1. Note that CLIP examines the data correlator by correlator, but UVFND normally converts the data to Stokes components (using the same criteria as UVMAP) before checking that the amplitudes and/or phases are in range. To examine the correlators individually, use STOKES 'CORR' in UVFND, or to flag the data based on their values after conversion to true Stokes use STOKES = 'IQUV' in CLIP. Task FINDR is a companion to FLAGR intended to assist you in determining what is normal within your data.

CLIP is also useful for flagging discrepant data (*e.g.*, due to interference or malfunctions) on the basis of their deviations from the visibility predicted by a set of Clean components. Tasks OOSUB or UVSUB will subtract the Fourier transform of a set of Clean components from visibility data. You may then use UVPLT to display the residual *uv* data set and CLIP to flag abnormally high points. You may wish to be cautious, and run UVFND to display such points before running an automatic CLIP task — be especially careful not to CLIP away evidence for real extended structure near the center of your *uv* plane! Before re-imaging, you must copy, with TACOP, the flag table produced by CLIP to the data set used for imaging. Note that IMAGR's workfile is also a *uv* data set from which the current Clean component model has been subtracted. It may also be used with UVPLT to help you to diagnose problems. If you run CLIP on it, you will need to append the resulting FG table to one on the imaging data set; in 31DEC07, use TAPPE.

FFT is another useful tool for finding suspicious data. Transform your image back into the *(u,v)* plane by running FFT and then display the results on the TV. Use image read-back verbs like CURVALUE and IMPOS (§ 6.4.5) to find the $u$ and $v$ values for abnormally high cells. Then use UVFND with OPCODE 'UVBX' to print the data surrounding these cells and UVFLG to delete any bad data. This method is particularly effective when applied to residual images from Clean. (You can instruct IMAGR to put out a residual image by setting BMAJ $<0$. CCRES can also make a residual image from a single-field normal image.)

In 31DEC04, there is a new task called FLAGR which goes through a data set determining what are normal rmses and weights and then flagging those that deviate excessively including clipping all those that have amplitudes or weights outside specified normal ranges. FLAGR is intended for use eventually in pipeline data-reduction procedures, but at present should be considered experimental, but potentially very valuable. Before calibration, try it on your calibration sources using default values for most adverbs plus SOLINT set to 2.5 times the basic integration time and VECTOR set to 0. Task FINDR is a companion intended to determine what is normal in the data and then to print those values and return selected adverb values to AIPS for use by procedures.

TVFLG, SPFLG, WIPER, IBLED and EDITR are TV-based, interactive editors. TVFLG is most suitable for data sets with large numbers of baselines, *e.g.*, the VLA, but it can be used usefully for VLBI data experiments with 10 or more antennas. TVFLG allows you a global overview of your data and can display the data for all baselines simultaneously as a function of time. This task is documented extensively in § 4.4.3 of the *CookBook*. SPFLG is a very useful task for data with a significant number of spectral channels. It is effective in examining data for frequency-dependent errors and interference and can be an effective data editor for interferometers with a small number of baselines; see § 10.2.2 and § 8.1. IBLED has a different philosophy; it plots one baseline at a time in a graphical rather than gray-scale (image) fashion. It is able to average data over time, spectral channels, and/or IFs to make a more manageable amount of data and to measure the "decorrelation index" which is a measure of how variable the phase is over the averaging intervals. The capability of averaging IFs and displaying decorrelation may be of special interest for VLBI data sets. Otherwise, IBLED has been replaced in 15APR98 by EDITR, which also uses the graphics planes rather than gray-scale images but which can plot multiple baselines to a chosen antenna and can display two data sets at the same time. This is obviously more useful for smaller arrays — *e.g.*, VLBI, MERLIN, and the Australia Telescope. This task is described below.

The editing task WIPER should be used with caution. It makes a plot like UVPLT of almost any parameter of a *uv* dataset against any other parameter. The plot is displayed on the TV and you may "wipe away" any points you do not like one point at a time or many at a time with a "fat brush." The task will be very useful for fields with a well-behaved visibility function seen with good signal-to-noise. It may also be useful with data sets from which a fairly good IMAGR model has been subtracted with UVSUB. It allows you to plot and edit any reasonable STOKES polarizations in one execution and displays which baselines enter into each plotted point.

### 5.5.2 Baseline-based *uv*-data editing — EDITR

EDITR is a very effective editing tool from the beginning of data analysis on data sets with modest numbers of antennæ. Since it can display two data sets at the same time for comparison purposes, EDITR may also be used to good purpose with larger data sets during the self-calibration and imaging stage. The visibility amplitude or phase or the amplitude of the visibility with a running vector average subtracted may be displayed. The data for the selected baseline are shown in an edit window at the bottom of the display. Optionally, a second observable (*e.g.*, phase) from the selected baseline is shown in the same color in a window directly above the edit window. This option is controlled by the DOTWO adverb. Data for 0 to 10 other baselines to the selected antenna may be displayed in a different color in windows above these. A second *uv* data set may also be displayed along with the first. These data are not used for editing but may help you to select the data to be deleted. A "normal" choice for the second data set would be the residuals after Cleaning or UVSUB. A menu-like control interface is available to select the data antenna and time range to be edited and to select various forms of editing. Instructions, explanations, informative messages, and the results of various functions appear in the standard AIPS message window. When prompted for information, such as an antenna number, type it into your normal AIPS input window (which is where the prompt message should have appeared).

EDITR is for editing continuum data from one or more IFs. Multiple spectral channels may be averaged on input with the vector average used for display and editing; multiple IFs are kept separate. The data may also be averaged over time as they are read into memory. This is useful for improved signal-to-noise, but will cause the data flags to be less selective in time. Beginning with 31DEC07, the program will allocate sufficient dynamic memory to hold the selected data. If you have a very large data set and a modest computer, it would probably improve efficiency to limit the time range and run the task more than once to cover all time ranges.

To run it, enter:

| | |
|---|---|
| > TASK 'EDITR ; INP C<sub></sub>R | to select the task and review the inputs. |
| > INDI *n1* ; GETN *ctn1* C<sub></sub>R | to select the 'TB' sorted *uv* single- or multi-source data set. |
| > DOCAL FALSE C<sub></sub>R | to apply no calibration. The SN or CL table from previous calibrations can be applied. |
| > FLAGVER *fg1* C<sub></sub>R | to apply flag table *fg1* to the data on input. |
| > OUTFGVER 0 C<sub></sub>R | to write a new flag table containing version *fg1* and all new flag commands generated. |

| | |
|---|---|
| > SOLINT = $\Delta t$ C_R | to have the data averaged over a time interval $\Delta t$ minutes. If you do not want averaging, set this parameter to a small value; the default is $1/6000 = 0.01$ second. Editing times are recorded with an offset of SOLINT/2 which may cause confusion when no averaging was actually done. |
| > DETIME $T$ C_R | to set the initial scan length estimate to $T$ minutes (which can be changed later interactively) and to set the interval regarded as a break in the regular time sequence of the data. Setting this parameter suitably helps the program do a better display, but its exact value is not critical. |
| > CLR2NAME C_R | to display only one data set. |
| > DOTWO TRUE C_R | to display a second observable from the main baseline. |
| > CROWDED TRUE C_R | to allow all IFs and all polarizations to be displayed and edited at one time. |
| > INP C_R | to review the other parameters, which we assume here to be set to their null values. |
| > GO C_R | to run the task. |

You can average the data over spectral channels (the default will average all channels present). IFs are edited separately; the default will include all IFs after which you can choose the one to edit interactively.

Since the display used by EDITR is very similar to the one used by EDITA displayed in § 4.4.2, we do not include a figure here; see Figure 4.2. The upper left corner of the display is reserved for displays of the selected data sample during editing while the bottom left corner is used for status information including flagging options. Menus, discussed below, appear down the left and right sides of the screen. The data are displayed in a stack of plots in the center of the screen. At the bottom are the data from the selected baseline in the primary observable; then the data from the primary baseline in a second observable (if DOTWO is true), and finally the data in the primary observable from 0–10 other baselines to the primary antenna. Data which have been flagged are shown in a different color. The data are plotted on a linear axis vertically, while the horizontal axis is monotonic but irregular in time. Tick marks are plotted at integer hours and the time interval of the edit area is indicated by times at the left and right ends of the axis. The time range displayed in all plots may be selected interactively and editing may therefore be done in crowded full time-range plots or in well separated short time-range plots. Surrounding the plot are various annotations describing the data plotted and the status of the various flags which control which data will be deleted on the next flagging command. If a second data set was specified, then data from that file are displayed in a different color in the same plot areas used for the primary data set.

The interactive session is driven by a menu which is displayed on the same screen as the data. Move the cursor to the desired operation (noting that the currently selected one is highlighted in a different color on many TVs) and press button A, B, or C to select the operation. Press button D for a short explanation of the selected operation. The right-hand column contains options to select which data are displayed and to select which data are flagged on the next flag command. The menus are changed to adapt to the input data in order to avoid, for example, offering options to select IF in a one-IF data set. The left-hand column contains 7 interactive modes for editing the data plus options to set the display ranges and scan averaging length, to turn on error bars in plotting samples, to review, alter, and re-apply the existing flag commands, to defer or force a TV display, to switch to entering commands from the keyboard instead of the menu, and to exit with or without applying the current flag commands.

The right-hand menu can contain

| | |
|---|---|
| NEXT CORRELATOR | To switch to viewing the next correlator, switching to the other polarization and, if needed, incrementing the IF. |
| SWITCH POLARIZ | To switch to viewing and editing the other polarization, cycles through both if CROWDED was true. |

| | |
|---|---|
| SWITCH ALL POL | To switch functions from applying to one polarization to applying to both polarizations or vice versa. |
| ENTER IF | To select which IF is viewed and edited. When CROWDED is true, zero means all. |
| SWITCH ALL IF | To switch functions from applying to one IF to applying to all IFs or vice versa. |
| SWITCH ALL TIME | To switch FLAG ABOVE and FLAG BELOW between all times and the time range of the frame. |
| ROTATE ALL ANT | To rotate functions from applying to (a) one baseline, (b) all baselines to the main antenna, and (c) all baselines. |
| SWITCH ALL SOURC | To switch between flagging only the current source and flagging all sources. |
| ENTER ANTENNA | To select the main antenna, baselines to which are displayed on the screen. |
| ENTER OTHER ANT | To select up to 11 other antennas to define the baselines to be displayed; enter 11 numbers, 0's are then ignored (to plot 5 enter the 5 plus 6 0's). The first one is used for the edit area. |
| NEXT BASELINE | To advance the list of other antennas, selecting the next one for the edit area. |
| NEXT ANTENNA | To select a new main antenna, one higher than the current main antenna. The "others" will also be adjusted if appropriate. |
| PLOT ALL TIMES | To display all data for the selected baselines. |
| SELECT FRAME | To select a window into the current data interactively. |
| NEXT FRAME | To select the next time range window of the same size as the current frame. |
| PREVIOUS FRAME | To select the previous time range window of the same size as the current frame. |
| SHOW AMPLITUDE | To display and edit amplitudes. |
| SHOW PHASE | To display and edit phases. |
| SHOW DIFF AMPL | To display and edit the amplitudes of the vector difference between the sample and its running mean. |
| SHOW ALSO AMPL | To display amplitudes of the edit baseline for reference with the phase or difference amplitude edit window. |
| SHOW ALSO PHASE | To display phases of the edit baseline for reference with the amplitude or difference amplitude edit window. |
| SHOW ALSO DAMP | To display difference amplitudes of the edit baseline for reference with the phase or amplitude edit window. |
| TV ZOOM | To alter the display zoom used while in the flag functions. |
| OFF ZOOM | To turn off any zooming. |
| 2ND UV OFF | To disable the display of the $2^{nd}$ *uv* data set. |
| 2ND UV ON | To enable the display of the $2^{nd}$ *uv* data set. |

The data displayed are of a single polarization, single IF, and 1–11 baselines to a single antenna. If CROWDED is true, then you may also choose to display and edit both polarizations and/or all IFs at the same time. The NEXT CORRELATOR cycles through all polarizations and IFs, show one at a time. The SWITCH POLARIZATION option switches the displayed polarization, the ENTER IF option prompts you if necessary for a new IF number, the ENTER ANTENNA option prompts you for a new primary antenna number, and the ENTER OTHER ANT prompts you for up to 11 other antenna numbers to select the main editing baseline and up to 10 secondary baselines to the primary antenna. (Note that you have to type in 11 numbers, but zeros are then ignored.) A flag command can apply to one or both polarizations and to one or all IFs. It can apply to one baseline, to all baselines to the primary antenna, or to all baselines. The FLAG ABOVE and FLAG BELOW commands can apply only to the time range displayed in the data "frame" or they can apply to the full time range in the data set. The SWITCH ALL POL, SWITCH ALL IF, ROTATE ALL ANT and SWITCH ALL TIME options control these choices and the current state of these switches is displayed at the lower left of the TV screen. The task is able to zoom the display during interactive editing operations if you should need magnification to see what you are doing. The TV ZOOM and OFF ZOOM options let you control this. In larger data sets, however, a more useful display is obtained by interactively selecting a narrower time range with the SELECT FRAME option. To step forward and back through the frames, use the NEXT FRAME and PREVIOUS FRAME options, respectively. To display *uv* data amplitude, select SHOW AMPLITUDE and to display *uv* data phase, select SHOW PHASE. You may also display the difference between the current data sample and a running vector average of the data centered on the current sample and extending no more than plus or minus the "scan length" divided by two. To display the amplitude of the vector difference, select SHOW DIFF AMPL. Such displays are particularly sensitive to short-term problems while ignoring longer-term changes due to source structure. Since it takes time to compute things for, and display, the second data set, you may wish to turn it off part of the time. The 2ND UV OFF and 2ND UV ON options control this choice.

The left-hand menu can contain

| | |
|---|---|
| FLAG TIME | To delete one time at a time. |
| FLAG TIME RANGE | To delete one or more time ranges. |
| FLAG BELOW | To delete all displayed times with data below a cutoff value. |
| FLAG ABOVE | To delete all displayed times with data above a cutoff value. |
| FLAG AREA | To delete one or more areas in the data-value *vs* time plane. |
| FLAG POINT | To delete one sample at a time using both horizontal and vertical cursor position. |
| FLAG QUICKLY | To delete samples using only mouse clicks |
| ENTER AMPL RNG | To select the display range for amplitude plots. Use $0 - 1$ for zero to maximum, 00 for minimum to maximum. |
| ENTER PHASE RNG | To select the display range for phase plots. |
| ENTER DAMP RNG | To select the display range for plots of the amplitude of the visibility minus a running vector average visibility. |
| PLOT ERROR BARS | To plot error bars based on data weights. |
| SET SCAN LENGTH | To set the averaging time used to determine the running average in seconds. |
| LIST FLAGS | To list all flags now in the Flag Command table. |
| UNDO FLAGS | To undo one of the flag operations in the FC table |
| REDO FLAGS | To reapply all remaining flags after one or more have been undone |
| SET REASON | To set the "reason" string to be put in the *uv*-data flag table. |
| USE EXPERT MODE | To control the task from the keyboard instead of the menu. |
| HOLD TV LOAD | To stop updating the TV display with every change of parameter; change several, then select |
| DO TV LOAD | To update the TV display now and with each change of display parameter. |
| REPLOT | To do the current plot over again, recomputing the differences from the running mean if appropriate. |
| EXIT | To exit EDITR, moving the FC table to a *uv*-data FG table. |
| ABORT | To exit EDITR, deleting the FC table. |

The first seven items select interactive flagging modes to delete all selected data at a single time, over a range of times, over all values below or above a specified value, or within a range of times and values (respectively). When one of these options is invoked, the screen zooms (if set to do so), a line or box appears in the editing window, and a display of the sample (source, time, value) under the cursor appears at the upper left. Follow the instructions in the message window to select and edit data. Note that this is a very good way to look at your data values even if you do not want to delete anything. The FLAG QUICKLY method is very efficient, but it requires caution in its use. Whenever the left mouse button is depressed, the sample closest to the cursor position is flagged. The next three options set the range of amplitudes, phases, and difference amplitudes displayed. These default to the full range in the data (separately and differently for each baseline) and can be set back to default by entering 0 0. The SET SCAN LENGTH option prompts you for a "scan" length in seconds used as the averaging interval for computing the running mean used in the difference displays. A longer scan length takes longer to compute, but is likely to be less noisy and more meaningful as an editing tool. If you are not using the difference display, set the scan length to a short interval. The running mean is not carried between sources and, as a result, is not normally carried across actual scan boundaries.

When you execute a flagging option, one or more lines are written to a flag command (FC) table attached to the input data set. If EDITR dies abnormally, this FC table can even be used in a later session. To list all of the flagging commands now in the table select the LIST FLAGS option. If you decide that you no longer want one of these flags, select UNDO FLAGS and enter the number (from LIST FLAGS) of the undesirable flag command. More than one flag command may apply to the same datum. After undoing flags, it is probably a good idea to select REDO FLAGS first to undo all remaining flags and then to reapply them to the data to make sure that everything is consistent. When the flag commands in the FC table are entered into a normal flag table, a 24-character "reason" is attached which is both descriptive and can even be used in UVFLG when removing entries in the FG table. The SET REASON command prompts you for the reason to be attached to subsequent flag commands. The default reason is the task name, time and date. Normally, EDITR updates the display whenever anything is changed. If you are about to change more than one display parameter (*i.e.*, polarization, IF, antenna, other antennæ, frame) before doing more editing, select HOLD TV LOAD to defer the display update until you select the DO TV LOAD option. If the display appears not to be current, select the REPLOT option. Finally, you may exit the program with the EXIT or ABORT options. The former applies your editing to a flag (FG) table attached to the input data set, while the latter discards any editing commands you may have generated.

Note that value-dependent flagging (FLAG BELOW, FLAG ABOVE, and FLAG AREA) use the values currently plotted to make a list of value-independent flag commands, namely a single time for the specified antennæ, IFs, polarizations, etc. When a value-dependent flag operation is undone with UNDO FLAGS or redone with REDO FLAGS, it is these value-independent flags which are undone or redone. You may have to undo more commands and then repeat flag commands to get the results you could have gotten by doing the now desired value-dependent command in the first place. You need also to be careful with the ROTATE ALL ANT setting with these value-dependent commands. If one baseline is set, then the commands only apply to the current baseline. If one antenna is set, the commands apply to all baselines to the current main antenna, while if all antennas is set, the commands apply to all baselines. The first two set a clip level, below or above which data are deleted, based on the value of the observable in each baseline independently. The FLAG AREA command, however, only looks at the values of the observable in the main edit baseline and flags those samples from all applicable baselines.

Be careful when choosing EXIT versus ABORT. The former applies the flag commands to a flag table attached to the input uv data, the latter causes the flag commands to disappear without a trace. After EXIT, of course, one may use, edit, or ignore the output flag (FG) table. For single-source files, it may be necessary to run SPLIT to apply the FG table to the data since only some tasks know how to apply FG tables (those with FLAGVER as an adverb).

The colors used by EDITR are those of the various graphics planes when it begins to run. You may change them with the AIPS verb GWRITE to more desirable colors. The planes are:

| Plane | Default RGB | | | Use |
|---|---|---|---|---|
| 1 | 1.00 | 1.00 | 0.00 | Main editing and secondary windows |
| 2 | 0.06 | 1.00 | 0.00 | Comparison baseline data windows |
| 3 | 1.00 | 0.67 | 1.00 | Menu highlight |
| 4 | 0.00 | 1.00 | 1.00 | Edit and frame window boundaries |
| 5 | 1.00 | 0.18 | 0.18 | Flagged data in all windows |
| 6 | 0.60 | 0.60 | 1.00 | Menu foreground |
| 7 | 1.00 | 0.80 | 0.40 | Second uv data set if present |

You may wish to change the colors to ones that you can see better.

## 5.6 Additional recipe

### 5.6.1 Banana-chocolate tea bread

1. Cream 1/2 cup softened **butter**, gradually add 1 cup **sugar**, beating until light and fluffy. Add 2 **eggs**, one at a time, beating well after each addition.
2. Combine 1 1/2 cups all-purpose **flour**, 2 tablespoons **cocoa**, 1 teaspoon **baking soda**, 1 teaspoon **salt**, and 1/2 teaspoon `cinnamon`; sift together.
3. Stir flour mixture into egg mixture, blending well.
4. Add 1 teaspoon **vanilla extract**; stir in 1 cup mashed **banana**, 1/2 cup **sour cream**, 1/2 cup chopped **walnuts**, and 1/3 cup miniature **semi-sweet chocolate chips**.
5. Spoon batter into two greased and floured 7-1/2 x 3 x 2-inch loaf pans. Bake at 350° F for 55 minutes or until a wooden pick inserted in center comes out clean. Cool in pans 10 minutes, remove from pans and cool completely on a wire rack.

Thanks to Tim D. Culey, Baton Rouge, La. (`tsculey@bigfoot.com`).

### 5.6.2 Banana July cocktail

1. Sprinkle 3 sliced **bananas** with 1 tablespoon **lemon juice**.
2. Mix with 1 1/4 cans drained and flaked **tuna**, 1/2 **onion** chopped, and 2 tablespoons chopped **gherkins** or **olives**.
3. Spoon into 7 cocktail shells.
4. Melt 2 tablespoons **butter** in a saucepan. Add 2 tablespoon **cake flour** and salt and pepper to taste.
5. Add 1/4 cup **chicken stock** and 1/4 cup dry **white wine**. Simmer for one minute stirring constantly.
6. Add 1/3 cup grated **cheddar cheese** and allow to cool.
7. Add 1/4 cup fresh cream to sauce and pour over banana-tuna mixture.
8. Sprinkle with 1 tablespoon grated **cheese** and **paprika**. Decorate with a slice of **gherkin** pr **olive**.
9. Bake 15–20 minutes at 350° F; serve warm.

Thanks to Turbana Corporation (`www.turbana.com`).

### 5.6.3 Banana sweet potato puff casserole

1. In a large bowl, combine 2 cups mashed **sweet potatoes**, 1 cup mashed ripe **bananas** (3 medium), 3/4 teaspoon **curry powder**, 1/3 cup **sour cream**, 1/2 teaspoon **salt**, and 1 **egg**.
2. Beat with electric mixer until light and very fluffy. Turn into 1 quart casserole dish.
3. Bake at 350° F for 20 minutes or until puffed and lightly browned.

Thanks to Turbana Corporation (`www.turbana.com`).

### 5.6.4 Churros de Plátano

1. Heat about 1 inch of salad (or part salad and part olive) **oil** in a large frying pan.
2. Peel and split 3 large, green-tipped **bananas** lengthwise. Then cut each piece in half and dip in **lemon juice**.
3. Separate 4 **eggs**. Beat the egg yolks until thick and light. Then add 1/4 cup **flour** and 1/2 teaspoon **salt**.
4. Beat the egg whites until stiff, but not dry, and fold into yolk mixture.
5. Drop the drained banana pieces one at a time into the batter. Pick up with a spoon and slide into the hot oil.
6. Cook over medium heat, turning almost at once, until brown on both sides. Drain on paper towels.

### 5.6.5 Hawaiian banana cream pie

1. Preheat oven to 375° F.
2. In a bowl, combine 1 cup chopped cashew or macadamia **nuts**, 1/2 cup flaked **coconut**, and 2 tablespoons **brown sugar**.
3. Beat 1 **egg white** until stiff; fold into nut mixture.
4. Press mixture evenly into an 8-inch pie plate, building up the sides slightly. Bake for 7 minutes or until crust is lightly browned. Crust will tighten as it cools (use a rack).
5. In a medium-sized saucepan, beat 3 **egg yolks**. Mix in 5 tablespoons **cornstarch** and 3/4 cup granulated **sugar**. Stir in 1.5 cups **milk**, 1/4 teaspoon **salt**, and 1 tablespoon unsalted **butter**.
6. Cook mixture slowly over medium heat, stirring constantly, for 5 to 7 minutes. Filling should be bubbling and thick.
7. Remove from heat and stir in 1 teaspoon **vanilla extract**. Transfer this custard to a glass bowl, cover with plastic wrap, and refrigerate for 2 hours.
8. Two hours before serving, whip 1/2 cup heavy **whipping cream** to stiff peaks and fold into custard. Peel and slice one **banana**, arranging evenly on bottom of crust. Spoon custard filling into crust. Cover again with plastic wrap and chill for 2 more hours.
9. Sprinkle 1/2 cup finely chopped cashew or macadamia **nuts** evenly over the filling. Peel, slice and arrange a second **banana** in a circular fashion around the outside top of the pie, placing a few slices decoratively in the center.

# 6 DISPLAYING YOUR DATA

This chapter is concerned with the ways in which you may display your data. There are a number of tasks for generating "plot files" which contain graphics commands for the making of various displays of your *uv* and image data. All of these now offer a "preview" option to draw the plot directly on the *AIPS* TV, rather than putting the commands into a file. Once the files are created, a variety of tasks may be used to translate them into displays on various devices, such as the *AIPS* TV and graphics windows and PostScript printers. There are also verbs to display and manipulate your images on the *AIPS* TV and a single task TVCPS to capture that display, if desired, into a PostScript file for printing, recording on film, or even including in your scientific papers.

Several indices of the *AIPS* software are relevant to this discussion. To generate current lists of *AIPS* functions on your workstation window (or terminal) use ABOUT HARDCOPY C_R, ABOUT INTERACT C_R, ABOUT PLOT C_R, ABOUT TV-APPL C_R, and ABOUT TV C_R. Recent versions of these indices are reproduced in Chapter 13 of this *CookBook*.

## 6.1 Getting data into your *AIPS* catalog

By the time you reach this chapter, most of your data will probably already be loaded into your *AIPS* catalog either by reading an external tape or disk or by being generated by some *AIPS* task. Visibility data which are not presently on disk may be read by the *AIPS* tasks FILLM, UVLOD and FITLD; see § 4.1 and § 5.1 for details. Images that are generated by other imaging systems, (*e.g.*, images from non-NRAO radio telescopes or non-radio images) can be transported to *AIPS* by writing them out of the other imaging system on tape or disk in the standard FITS format. The tasks IMLOD and FITLD can then be used to read them into *AIPS*. These tasks are also used to read images saved with FITTP and FITAB from previous *AIPS* sessions.

### 6.1.1 IMLOD and FITLD from tape

IMLOD and FITLD will position tapes for you using the NFILES adverb. It is safer to use AIPS verbs instead to position the tape and to check that positioning. First, mount your tape in hardware and software as described in § 3.9. To move the tape forward by *nf* file marks to position it at the first interesting image, enter:

| | |
|---|---|
| > INTAPE *n* C_R | to specify the tape drive labeled *n*. |
| > NFILES *nf* C_R | to specify the number of file marks to move the tape. |
| > AVFILE C_R | to move the tape. |

If $nf > 0$, AVFILE will advance the tape the specified number of file marks. If $nf = 0$, the tape is moved backward to the beginning of the current file. Once you have moved part-way into a tape, you may use $nf < 0$ to move backwards to the $|nf|$ previous file. In all cases, the tape is left at the beginning of a file. Task PRTTP is an invaluable aid to determine what is on your tape and where it is; see § 3.9.4 and § 5.1.1. If you happen to come across a CV-IBM format tape from some astronomical museum, the verb AVMAP may also be needed. Type HELP AVMAP C_R for details. You must use IMLOD not FITLD for such antiques.

To check that the tape is positioned where you expect, type:

> TPHEAD C_R

Your terminal will then list information about the image header at which the tape is positioned. The tape position is not altered. Once the tape has been positioned at the desired image, enter:

| | |
|---|---|
| > OUTDI *n* C_R | to specify writing the image to your AIPS catalog on disk *n*. |
| > OUTNAME '*your-chosen-name*' C_R | to specify the output disk file name in AIPS; the default is the image name on tape if FITTP was used to write the image to tape. |

The string *your-chosen-name* can be any (≤ 12-character) title that you want to use as the image name within AIPS and should be specified for images from other image-processing software systems. FITLD also allows you to specify the 6-character image "class" parameter. Use OUTCLASS '*abcdef*' C_R, if you wish to change the class from that on your input tape as the image is read or if the image comes from a "foreign" system.

| | |
|---|---|
| > OUTS -1 C_R | to keep the sequence number the same as that on tape; the default is the highest unique number for images with this name and class in your current AIPS catalog. |
| > NFILES 0 C_R | to have no further files skipped — **important** if you have just used AVFILE to position the tape! |
| > NCOUNT *m* C_R | to load *m* images consecutively starting with the image at the current tape position; default is $m = 1$. If you use this option, do *not* specify the OUTNAME unless you want the same name for all the new images in your catalog. |
| > GO FITLD C_R | or IMLOD, to run the task. |

If OUTNAME is left unspecified, it defaults to the "name" of the image read from the FITS header — either the name previously used in earlier image processing or the source name. If OUTCLASS is unspecified, it defaults to the Class previously used in earlier image processing or to a compound name (*e.g.*, IMAP, IBEM, QMAP, ICLN) which attempts to describe the image. These defaults are frequently good ones when you are loading multiple consecutive images with NCOUNT $> 0$. You may of course change the AIPS image and class names later by using RENAME (see § 3.3.3 of this *CookBook*).

To load *m* consecutive further images from the same tape using the default OUTNAME (the names from their FITS header), skipping *n* from the sequence:

| | |
|---|---|
| > OUTNAME ' '; OUTCL ' ' C_R | to ask for the system defaults. |
| > NFILES *n* C_R | to skip *n* file marks. |
| > NCOUNT *m* C_R | to specify loading *m* consecutive images after the skip. |
| > GO FITLD C_R | or IMLOD, to run the program. |

To dismount the tape when FITLD is done:

> DISMOUNT C_R

### 6.1.2 IMLOD and FITLD from FITS-disk

FITLD and IMLOD can also read FITS-format images from external disk files into your AIPS catalog. This option is indicated by setting the adverb DATAIN to a non-blank value. The control parameters are the same as described above for reading FITS tapes, except that INTAPE and NFILES are ignored and NCOUNT applies only in FITLD.. Disk image files must therefore be read in only one at a time per execution of IMLOD. FITLD can read more than one FITS-disk file if the file names are identical except for sequential post-pended numbers beginning with 1. DATAIN is a string of up to 48 characters that must completely specify the disk, directory, and name of the input disk file to your computer's operating system. See § 3.10.3 for a discussion of FITS-disk files.

One "feature" of AIPS complicates this otherwise straightforward disk analog of FITS tape reading. AIPS translates all of your alphabetic inputs to upper case (this was demanded by users who otherwise became confused between upper and lower cases).[1] So if your computer distinguishes upper and lower cases for disk, directory, or file names, you must do two things to prepare for this before running AIPS. First, you must restrict your external disk file names to upper-case characters and numbers. Second, you must set an upper-case "environment variable" or "logical" to point to the disk and directory where your FITS-disk images are stored before you run AIPS. You may need help from your System Manager when doing this for the first time. A common strategy on UNIX machines is to create an upper-case logical name after logging in but before starting up AIPS:

% setenv MYLOGICAL *myarea* C_R if using C-shell, or

$ export MYLOGICAL=*myarea* C_R if using korn, bourne, or bash shells,

where MYLOGICAL is an all-upper-case string of your choice and *myarea* is the full path name of the disk directory that contains your FITS-disk data. AIPS usually provides a public disk area known as FITS which you may use.

Then, once inside AIPS, tell FITLD or IMLOD:

> DATAIN 'MYLOGICAL:IMAGE.DAT' C_R to read in the FITS-disk file *myarea*:IMAGE.DAT.

## 6.2 Printer displays of your data

The most old fashioned way to look at your data — and the most exact — is simply to print it out and read the numbers. AIPS provides a variety of tasks and verbs to print visibility data, image data, tabular data, and miscellaneous other information. All of these tasks and verbs allow you to specify where the printed output goes using two adverbs, DOCRT and OUTPRINT. If DOCRT $\leq 0$ and OUTPRINT is blank, then the output is placed in a temporary file and queued to the printer you selected when starting AIPS; see § 2.2.3. (Type PRINTER $n$ C_R to change the line printer selection to that numbered $n$; type PRINTER 999 C_R to see the devices available to you and their assigned numbers.) If DOCRT $\leq 0$, a non-blank OUTPRINT specifies a text file into which the output is to be written; see § 3.10.1. The current output is appended to the file if it already exists. Thus, you can combine a number of printed outputs for later editing and/or printing. When DOCRT = -1, the output print file will contain full paging commands and headers. To suppress some of this, use DOCRT = -2 or to suppress almost all of it, use DOCRT = -3. This last is especially helpful when writing programs to read the text file. If DOCRT $> 0$, the output is directed to your workstation window or terminal. All printer verbs and tasks are able to respond to both the width and height of your workstation window. Set DOCRT = 1 to use the current width; set DOCRT $= n \geq 72$, to use $n$ as the width of the display window. Since most print tasks display more information on wider windows, we recommend widening your window to 132 characters and specifying DOCRT = 1. The print routines will pause whenever the screen is full and offer you the choice of continuing or quitting. Thus, you can start what might be a very long print job, find out what you wanted to know after a few screens full, and quit without using up any trees.

### 6.2.1 Printing your visibility data

Before beginning calibration, it is a very good idea to make a -summary list of the contents of your data set. LISTR with OPTYPE = 'SCAN' will list the contents of each scan in the data set. DTSUM also produces a listing summarizing the data set in either a condensed or full form.

The most basic display of your visibility data is provided by PRTUV which lists selected correlators in the order they occur in the data set:

> TASK 'PRTUV' ; INP C_R to review the inputs.

[1] If you omit the close quote on the character string, it is not converted to upper case, allowing you to circumvent this AIPS limitation. The string without a close quote must, of course, be the last thing on the line.

| | |
|---|---|
| > INDI *n* ; GETN *ctn* C_R | to select the disk and data set to print. |
| > CHANNEL *c* ; BIF 1 C_R | to print starting with channel *c* from IF 1. |
| > BPRINT *m*; XINC *i* C_R | to print every $i^{\text{th}}$ visibility starting with the $m^{\text{th}}$ visibility in the data set. |
| > DOCRT 1 ; GO C_R | to run the task with display on the terminal. |

When you have seen enough, enter q C_R or Q C_R at the page-full prompt.

You may limit the sources, range of projected baselines, and times displayed and may select only one baseline or one antenna. PRTUV does not apply calibration or flagging tables. To get a similar display with all "standard" calibration, flagging, and data selection (optionally) applied, use the task UVPRT. LISTR also uses all of the calibration options to list the data in simple lists or in a display showing all the baselines at each time in a matrix form. SHOUV also lists calibrated visibility data with options to average all channels in each IF and to display closure rather than observed phases. ANBPL converts baseline-based amplitudes, phases, or weights into antenna-based values and prints and/or plots them. The display of antenna-based weights before and after amplitude self-calibration is a particularly useful tool for spotting calibration/instrumental problems.

There are a number of tasks used to diagnose possible problems in your data and to print information about them. UVFND examines a data set for excess fluxes, excess apparent V-polarization, or simply any data with a specified fringe spacing and position angle or a specified range in $u$ and $v$. As it does this, it also checks for bad antenna numbers, bad times, and (optionally) bad data weights. CORER examines a data set for excessive mean values and rms in each correlator (after, in 31DEC07, applying calibration and flagging and then subtracting a point source at the origin). RFI examines the rms fluctuations in the real and imaginary visibilities of each correlator looking for (and reporting) periods of apparent RF interference. UVDIF directly compares two data sets reporting any excess differences. It is useful for determining whether your latest operations (flagging, self-cal) have made a significant (or any) difference.

### 6.2.2 Printing your image data

The most basic display of an image is a print out of the numbers it contains. Such a display is provided by PRTIM:

| | |
|---|---|
| > TASK 'PRTIM' ; INP C_R | to review the inputs. |
| > INDI *n* ; GETN *ctn* C_R | to select the disk and image to print. |
| > NDIG 3 C_R | to use 3 digits, printing numbers between -99 and 999 with appropriate power of 10 scaling. |
| > FACTOR 10 C_R | to raise the default scaling by a factor of 10, overflowing regions of high values to see low valued regions better. |
| > BLC 0 ; TRC 0 C_R | to see the whole image. |
| > XINC 2 ; YINC 2 C_R | to see every other column and every other row. |
| > DOCRT FALSE ; GO C_R | to print the image on the selected printer. |

Other imaging tasks which use the printer are BLSUM and ISPEC, which compute and print spectra by summing over regions of each plane in a data cube (see § 8.6), and IMFIT, JMFIT, and SAD, which fit one or more Gaussians to an image (see § 7.5). IMTXT writes an ASCII-formatted file containing an image.

### 6.2.3 Printing your table data

If you have any doubts about the contents of tables in AIPS, it is best to resolve them by looking at the contents of the tables involved. PRTAB is a very general task which will print the contents of any AIPS table file. For example, to print flag table version 1:

| | |
|---|---|
| > TASK 'PRTAB' ; INP C_R | to review the inputs. |
| > INDI *n* ; GETN *ctn* C_R | to select the disk and catalog entry to print. |
| > INEXT 'FG' ; INVERS 1 C_R | to select flag table version 1. |
| > BPRINT 0 ; EPRINT 0 ; XINC 1 C_R | to print everything. |
| > DOHMS TRUE C_R | to print times in sexagesimal notation. |
| > DOCRT 1 ; GO | to print the flag table on the terminal. |

When you have seen enough, enter q C_R or Q C_R at the page-full prompt. For a table with a significant number of columns, PRTAB shows all rows for the first columns and then loops for the next set of columns. To see all columns for some rows, set a low EPRINT value or be very patient. Enter a list of column numbers in BOX to see only some of the columns. NCOUNT, BDROP and EDROP control which values are displayed in those columns having more than 1 value per row. Enter NDIG = 4 to have floating-point columns displayed with greater accuracy.

Some of the tables have specialized printing programs. These include PRTAN for antenna tables, PRTCC for Clean component tables, and LISTR with OPTYPE = 'GAIN' for calibration, solution, and system temperature tables. The verb EXTLIST will list information about various extension files, particularly plot files (see below), which may be printed with PRTMSG. OFMLIST is a verb to print the contents of an *AIPS* TV color table. Finally, task TBDIF will compare columns of two tables and print information about their differences.

### 6.2.4 Printing miscellaneous information

There is a variety of miscellaneous information which may also be sent to the printer in the same way. Verb PRTMSG prints selected contents of the *AIPS* message file; see § 3.2. Verb PRTHI prints selected lines from a history file; see § 3.4. Pseudoverb ABOUT prints lists of *AIPS* symbols by category while pseudoverbs HELP and EXPLAIN print information about a selected symbol; see § 3.8. Task PRTTP prints the contents of magnetic tape volumes and pseudo-tape disk files; see § 5.1.1 and § 3.9.4. Task PRTAC, which may also be run in a stand-alone mode, prints information selected from the *AIPS* accounting file.

Task TXPL will attempt to represent an *AIPS* plot file (see below) on the printer. This will not work well for complicated plots, but, for simple plots, it may be the only way someone running over a slow telephone line can see his/her data in plot form.

## 6.3 Plotting your data

The basic concept in *AIPS*' plotting is to use some task to create and write a device-independent plot file as a PL extension file to a cataloged image or visibility data set and then to use some device-dependent task to interpret that file for the desired output device. Plot files are not overwritten by subsequent plot tasks. Instead they make new plot files with higher "version" numbers. The device-dependent tasks include TVPL (*AIPS* TV devices including XAS), TKPL (Tektronix graphics devices including *AIPS*' TEKSRV server), TXPL (line printers), and LWPLA (PostScript printer/plotters). Tasks called PRTPL, QMSPL, and CANPL support antique Versatec, QMS, and Canon printer/plotters. To plot on a PostScript printer/plotter:

| | |
|---|---|
| > TASK 'LWPLA' ; INP C_R | to review the inputs. |
| > INDI *n* ; GETN *ctn* C_R | to select the disk and catalog entry to print. |
| > PLVER *m* ; INVERS 0 C_R | to plot the $m^{\text{th}}$ plot file only. |
| > OUTFILE ' ' ; GO C_R | to do the plot immediately. |

LWPLA offers the option to save the file for later plotting or inclusion as encapsulated PostScript in other documents. It also has options to control scaling, output paper size, width and darkness of lines, and transformation of grey-scale intensities. It can write more than one plot file at a time and can append new plots to existing output files. Multi-plot files are not "encapsulated" but may be printed and viewed with tools such as gv or ghostview. Note that PostScript files are text files and AIPS writes particularly simple PostScript so that it can be modified by the users. See HELP POSTSCRIPT for suggestions including information on deleting and adding labels and arrows and on converting the PostScript to other formats like jpg without loss of resolution.

Beginning with the 31DEC02 release, LWPLA and all plot tasks offer some "coloring" options. These are illustrated in the color pages at the end of this chapter. The grey-scale plotting tasks, including GREYS, PCNTR, and KNTR, can now enhance the grey-scales with a transfer function and then pseudo-color them with a color table. See § 6.4.3 for a short discussion of "output-function memory" tables which may be read into the above tasks or to LWPLA using the adverb OFMFILE. Lines plotted on top of grey scales (*e.g.*, contours, polarization vectors, stars) may be "dark" when the grey scale intensity is high. LWPLA may be instructed to plot these as bright if adverb DODARK is false. All plot programs can draw lines of different types in both bright and dark forms. In LWPLA, if DOCOLOR is true, the array adverb PLCOLORS$(i, j)$ controls the red, green, and blue colors ($i = 1, 2, 3$, resp.) of line types $j = 1 - 10$. The normal meanings of these types are:

1. Bright labeling, tick marks, surrounding lines
2. Bright lines, usually contours or model curves
3. Bright lines, usually polarization vectors
4. Bright lines, usually symbols such as stars, visibility samples
5. Dark labeling text inside plot area
6. Dark lines, usually contours
7. Dark lines, usually polarization vectors
8. Dark lines, usually symbols such as stars
9. Bright labeling outside the main plot area, e.g. titles, tick values and types, documentation
10. Background for the full plot

In 31DEC03, some plot tasks have the ability to control the colors of their line drawing independent of these line types. These colors may be controlled only when making the plot file with the particular task. In 31DEC06, PCNTR and KNTR acquired the ability to color each contour level under control of the adverb RGBLEVS. Using system RUN file SETRGBL, procedures CIRCLEVS, RAINLEVS, FLAMLEVS, and STEPLEVS are available to help you set the values of RGBLEVS. Examples are shown on the color pages at the end of this chapter. With LWPLA and these options one may prepare extremely effective displays — or hopelessly bad ones — for use in talks and, since the prices have become reasonable, even in journals. Note that most journals want color images in CMYK (cyan-magenta-yellow-black) rather than RGB; use DPARM(9) = 1 in LWPLA to get PostScript files with this color convention. Note that these two color representations usually require different "gamma" corrections; the adverb RGBGAMMA allows this control in LWPLA.

All AIPS plot tasks now offer a "preview" option. If you set DOTV = TRUE when running any plot task, then the plot appears immediately on the AIPS TV display and no plot file is generated. This option allows you to make sure that the parameters of the plot are reasonable and lets you avoid making files and wasting paper for quick-look plots. Additional options allow you to control which graphics channel is used for the line drawing (GRCHAN) and to select pixel scaling of the plot at your specified location on the TV screen (TVCORN). These two options allow you to view more than one plot at a time on the TV, usually for purposes of comparison. Each graphics channel on the TV has a different color and a complementary color is used when two or more channels are on at the same point. This allows for a fairly detailed and effective comparison of plots, all of which may be captured with task TVCPS (see below). Be aware that most tasks now interpret GRCHAN = 0 as an instruction to use graphics channels 1 through 4 for line types 1 through 4 and graphics channel 8 for dark vectors. The comparison function is only achieved by specifying GRCHAN. (Since the DOTV option can be fairly slow on complicated plots, you may prefer to use TKPL on plot files produced with DOTV FALSE.) Tasks that produce multiple plot files pause for 30 seconds at the end of each plot when DOTV = TRUE. This allows you to stop the task (TV button D), hurry it along (TV buttons B or C), or make it pause indefinitely (TV button A) until another TV button is pressed.

You can review the parameters of the plot files associated with a given image or visibility data set by typing:

| | |
|---|---|
| > INDI *n* ; GETN *ctn* C_R | to select the disk and catalog entry to print. |
| > INEXT 'PL' ; EXTLIST C_R | to list summaries of the plot file contents. |
| > PLVER *m* ; PLGET C_R | to recover all adverb values used when making the specified plot file. |

Plot files (and other "extension files") are automatically deleted when an image is deleted by ZAP. However, large plot files should be deleted as soon as they are no longer needed:

| | |
|---|---|
| > INP EXTDEST C_R | to review the inputs required. |
| > INEXT 'PL' ; INVERS *m* C_R | to set the type to PL (plot) and the version number to be deleted to $m$. $m = -1$ means all and $m = 0$ means the most recent (highest numbered). |
| > EXTDEST C_R | to do the deletion. |
| > INVERS 0 C_R | to reset the version number to its default — usually advisable. |

Plot files are not amenable to the FITS format and so are not written by FITTP and FITAB. They may be copied from one catalog entry to another with TACOP.

### 6.3.1 Plotting your visibility data

The most basic plot program for visibility data is called UVPLT. It allows you to select the $x$ and $y$ axes of the plot from real, imaginary, amplitude, log of amplitude, phase and weight of the visibility, time, hour angle, elevation, azimuth, and parallactic angle, and projected baseline length, position angle, $u$, $v$, and $w$. It offers all of the usual calibration and data selection options and it plots the selected points individually and/or in a controlled number of bins along the $x$ axis. In can display multiple IFs and spectral channels at once, including averaging groups of spectral channels. For example, to plot calibrator phases as a function of time for all baselines to one antenna:

| | |
|---|---|
| > TASK 'UVPLT' ; INP C_R | to review the inputs. |
| > INDI *n* ; GETN *ctn* C_R | to select the disk and catalog entry of the data set. |
| > BPARM = 11 , 2 C_R | to plot time in hours on the $x$ axis and phase in degrees on the $y$ axis. |
| > SOURCES ' ' ; CALCODE '*' C_R | to select all calibrator sources. |
| > XINC 4 C_R | to plot only every fourth selected sample. |
| > ANTENNA 2,0 ; BASELINE 0 C_R | to do all baselines with antenna 2. |
| > DOCRT = -1 ; GO C_R | to make a plot file of these data. |

After UVPLT is running, or better, after it has finished:

| | |
|---|---|
| > PLVER 0 ; GO LWPLA C_R | to plot the latest version on a PostScript printer/plotter. |

There are several other tasks to plot your visibility data. VPLOT plots all of the parameters offered by UVPLT, but one baseline at a time with multiple baselines per page (*i.e.*, per plot file) and multiple pages per execution. CLPLT is a similar task but restricted to plotting closure phases around baselines involving 3 antennas as a function of time. CAPLT is a similar task but restricted to plotting closure amplitudes around groups of 4 baselines as a function of time. All three of these can also plot a source model (based on Clean

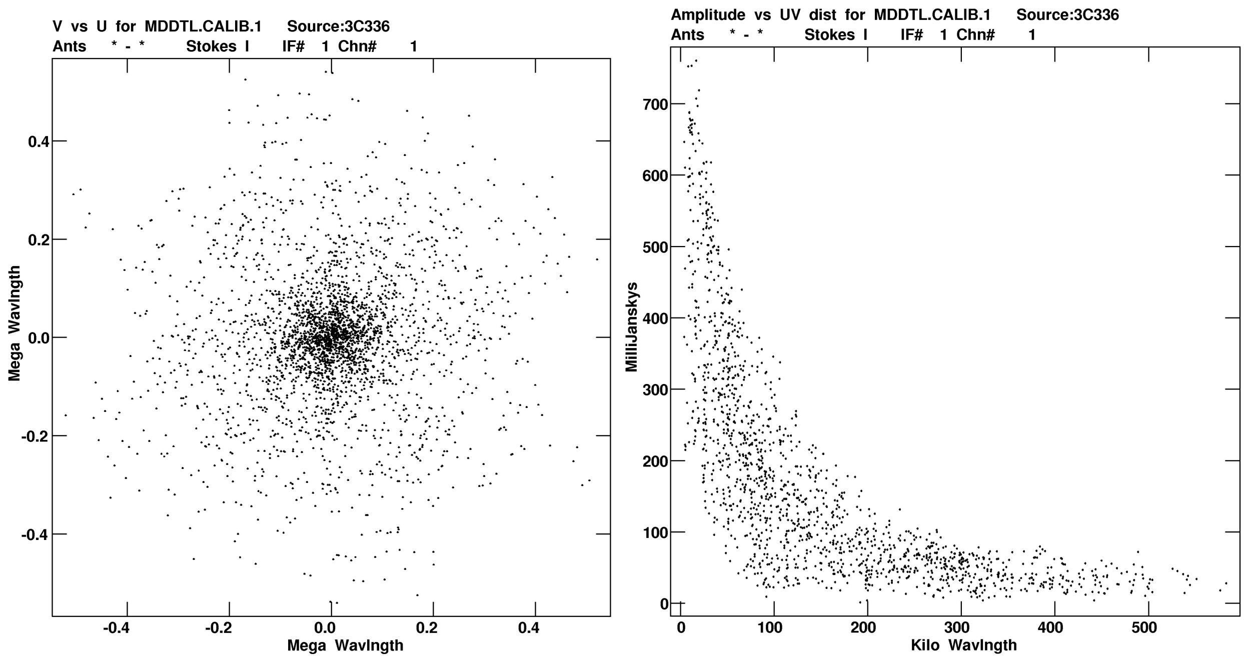



Figure 6.1: `UVPLT` displays of where the data were observed in the *uv* plane (left) and of the visibility amplitudes as a function of baseline length (right). The data on 3C336 were provided by Alan Bridle from observations made with the VLA on 6 December 1987.

components) as well as the observations. `ANBPL` can create a similar plot of amplitudes, phases, or weights converted to antenna-based quantities; this function is helpful in diagnosing problems with your data. For spectral-line users, `POSSM` plots visibility spectra averaged over selected baselines and time intervals. It can also plot bandpass calibration tables and the Fourier transform of visibility spectra (the auto- and cross-correlation functions). For VLBI users (primarily), `FRPLT` plots visibilities versus time or, more importantly, the fringe rate spectrum. To examine the statistical distribution of your data, try `UVHGM` which plots histograms showing the number of samples or weights versus a wide variety of parameters. Optionally, it will fit a Gaussian to the histogram and plot the result. New in `31DEC06`, the task `UVHIM` will make an image of a two-dimensional histogram of your *uv* data. All image display functions below may then be used to view the result. For example, if the axes of the histogram image are the real and imaginary parts of your data, then the image will demonstrate the amplitude and phase stability present (or missing) in your data.

Two plot programs actually convert visibility data to the image plane for plotting. Observers of point objects which might vary with time either intrinsically or by scintillation (*e.g.*, stars, masers) might wish to try `DFTPL`, which plots the Fourier transform of the data shifted to a selected position as a function of time. VLBI spectral-line observers may need to use `FRMAP`, which performs imaging via fringe-rate inversion and plots the loci of possible source positions.

### 6.3.2 Plotting your image data

Image data may be drawn in a variety of ways including contours, grey or color levels, row tracing, and statistical. All plots are drawn with labeled tick marks although these may be suppressed with the `LTYPE` parameter. For plots having significantly non-linear coordinate axes, *e.g.*, wide-field images, it is useful to draw a full, non-linear coordinate grid rather than just short lines at the edges of the plot. Tasks like `CNTR` and even the verb `TVLABEL` offer this option; enter `DOCIRC TRUE` $C_R$.

Plot symbols (*e.g.*, plus signs) may be drawn on the plots produced by CNTR, PCNTR, GREYS, KNTR and several of the other tasks mentioned below. In these tasks, the parameter which controls the plotting is STFACTOR, a scale factor for the symbols. When using this option, there must be a table of "star" positions associated with the image being plotted. To create one, enter EXPLAIN STARS C_R to learn the format of the input data file and the parameters for the task. See also Appendix Z or your local equivalent for instructions on editing text files. A star file may also be created by MF2ST from a model fit file produced by task SAD (see § 7.5.3 and § 10.4.4).

Example outputs of the following three tasks are given in Figure 6.2.

#### 6.3.2.1 Contour and grey-scale plots

The most basic contour drawing task is CNTR. In addition to the usual image selection parameters, you may specify:

| | |
|---|---|
| > TASK 'CNTR' ; INP C_R | to tell you what you may specify. |
| > BLC 250 , 230 C_R | to set the bottom left corner of plot at 250, 230 (in pixels with 1,1 at extreme bottom left of the image). |
| > TRC 300, 330 C_R | to set the top right corner of plot at 300, 330. |
| > CLEV 0 ; PLEV 1 C_R | to get contour levels at 1% of the peak image value. |
| > PLEV 0 ; CLEV .003 C_R | to get contour levels at 3 mJy. |
| > LEVS -1, 1, 2, 4, 6 C_R | to get actual contours at -1, 1, 2, 4, and 6 times the basic level set by PLEV or CLEV. LEVS need not be integers, but very fine subdivisions cannot be represented accurately on the plot. |

*N.B.,* if you request more than one negative level with the LEVS input, you *must* use commas between the negative levels. Otherwise the minus sign(s) will be treated as subtraction symbols and the desired levels will be combined into a single negative level by the AIPS language processor. BLC and TRC can be initialized conveniently from the TV display using the cursor with the TVWIN instruction (see § 6.4.4). Then check:

| | |
|---|---|
| > INP C_R | to review what you have specified. |
| > GO C_R | to run the task when you're satisfied with the inputs. |

This generates a plot file as an extension to your image file, with the parameters you have just specified. Watch the *AIPS* monitor (which, on some systems, is your terminal) to see the progress of this task. If the "number of records used" in the plot file is over 200, the contour plot will be messy (unless the field is also large). In this case, check that you have not inadvertently set PLEV or CLEV, for example, to unrealistically low values. Printing a large, messy plot file on the printer can take a considerable length of time and will inconvenience other users. Consider plotting directly on the TV first (DOTV = TRUE) to check on your selection of contours.

PCNTR plots polarization vectors on top of contours and/or grey-scales. You may make a polarized-intensity image and a polarization position-angle image from the Q and U images (see § 7.1.2) or use the Q and U images themselves. Then:

| | |
|---|---|
| > TASK 'PCNTR' ; INP C_R | to review the input parameters. |
| > INDI *n1* ; GETN *ctn1* C_R | where *n1* and *ctn1* select the disk and catalog numbers of the image to be contoured. |
| > IN2DI *n2* ; GET2N *ctn2* C_R | where *n2* and *ctn2* select the Q or polarized intensity image. |
| > IN3DI *n3* ; GET3N *ctn3* C_R | where *n3* and *ctn3* select the U or position-angle image. |
| > IN4DI *n4* ; GET4N *ctn4* C_R | where *n4* and *ctn4* select the grey-scale image. |
| > PCUT *nn* C_R | to blank out vectors less than *nn* in the units of polarized intensity. |
| > ICUT *mm* C_R | to blank out vectors at pixels where the total intensity (image 1) is less than *mm* in the units of image 1. |

| | |
|---|---|
| > FACTOR *xx* C_R | to set the length of a vector of 1 (in units of total polarization) to *xx* cell widths. |
| > DOCONT 1 ; DOVECT 1 ; DOGREY 4 C_R | to request vectors plus contours of image 1 and grey scale of image 4. |
| > PIXRAN $T_{min}, T_{max}$ ; FUNCTYP ' ' C_R | to scale linearly the grey-scale values from $T_{min}$ to $T_{max}$. |
| > OFMFILE 'RAINBOW' C_R | to use the standard rainbow-colored OFM table to pseudo-color the grey scales. |
| > CBPLOT 1 C_R | to plot the Clean beam in the lower left corner. See HELP CBPLOT for numerous options. |
| > INP C_R | to review your inputs and remind you of others. Most are similar to those in CNTR and sensibly defaulted. |
| > GO C_R | to generate the plot file, which can then be routed to output devices via TKPL, TVPL, LWPLA etc. |

Unless images 2 and 3 are of Q and U polarization, the lengths of the vectors are controlled by image 2 while the directions of them are controlled by image 3. Clearly this program can also be used for other combinations of images, so long as one of them represents an angle. PCNTR and following tasks have the option to draw an image of the Clean beam under control of adverb CBPLOT. In the 31DEC03 release, polarization vectors may be plotted with the color representing the angle. The value of POL3COL, if greater than zero, is that angle represented in pure red from 0 to 180 degrees. A color "spray" is plotted to calibrate the eye. The ability to plot multiple spectral planes in colored contour or polarization vectors was also added. The adverb CON3COL controls this function. In 31DEC06, the ability to select the colors of each contour level with RGBLEVS was added. These color functions are displayed at the end of this chapter in the color pages.

GREYS creates a plot file of the grey-scale intensities in the first input image plane and, optionally, a contour representation of a second input image plane. Like the other grey-scale plotting tasks, GREYS can interpret a true-color (RGB) image cube in its "true" colors. Unlike the others, it can construct the true-color image from 3 separate image planes. A sample set of inputs could be:

| | |
|---|---|
| > TASK 'GREYS' ; INP C_R | to review the inputs. |
| > DOCOLOR 1 C_R | to specify that a "true-color" image is to be plotted. |
| > INDISK *n1* ; GETN *ctn1* C_R | to select the red image. |
| > IN3DISK *n3* ; GET3N *ctn3* C_R | to select the green image. |
| > IN4DISK *n4* ; GET4N *ctn4* C_R | to select the blue image. |
| > PIXRAN $T_{minr}, T_{maxr}$ ; FUNCTYP 'SQ' C_R | to scale by a square-root function red values from $T_{minr}$ to $T_{maxr}$. |
| > APARM $T_{ming}, T_{maxg}, T_{minb}, T_{maxb}$ C_R | to scale green and blue values similarly over ranges $T_{ming}$ to $T_{maxg}$ and $T_{minb}$ to $T_{maxb}$, respectively. |
| > BLC 250 , 250 , 3 C_R | to select the lower left corner and the plane in the first image. |
| > TRC 320 , 310 , 12 C_R | to select the upper right corner in the first image and, with TRC(3), the plane in the second image. |
| > DOCONT TRUE C_R | to specify that contours are to be drawn. |
| > IN2D *n2* ; GET2N *ctn2* C_R | to select the contour image. |
| > PLEV 0 ; CLEV 0.005 C_R | to select 5 mJy/beam contour increments. |
| > LEVS -3 , -1 , 1 3 10 30 100 C_R | to plot contours at -15, -5, 5, 15, 50, 150, and 500 mJy/beam. |
| > DOWEDGE 2 C_R | to plot a 3-color step-wedge along the right-hand edge; 1 for along the top and 0 for no wedge. |
| > DOTV FALSE ; GO C_R | to make the plot file. |

When GREYS has finished, run LWPLA to view the plot file. Note that LWPLA has a variety of options which control the plotting and scaling of the grey-scale images without having to rerun GREYS. In this example case, you should remember to set FUNCTYPE = ' ' and DPARM = 0 (or at least the first 4 values to 0) in LWPLA to

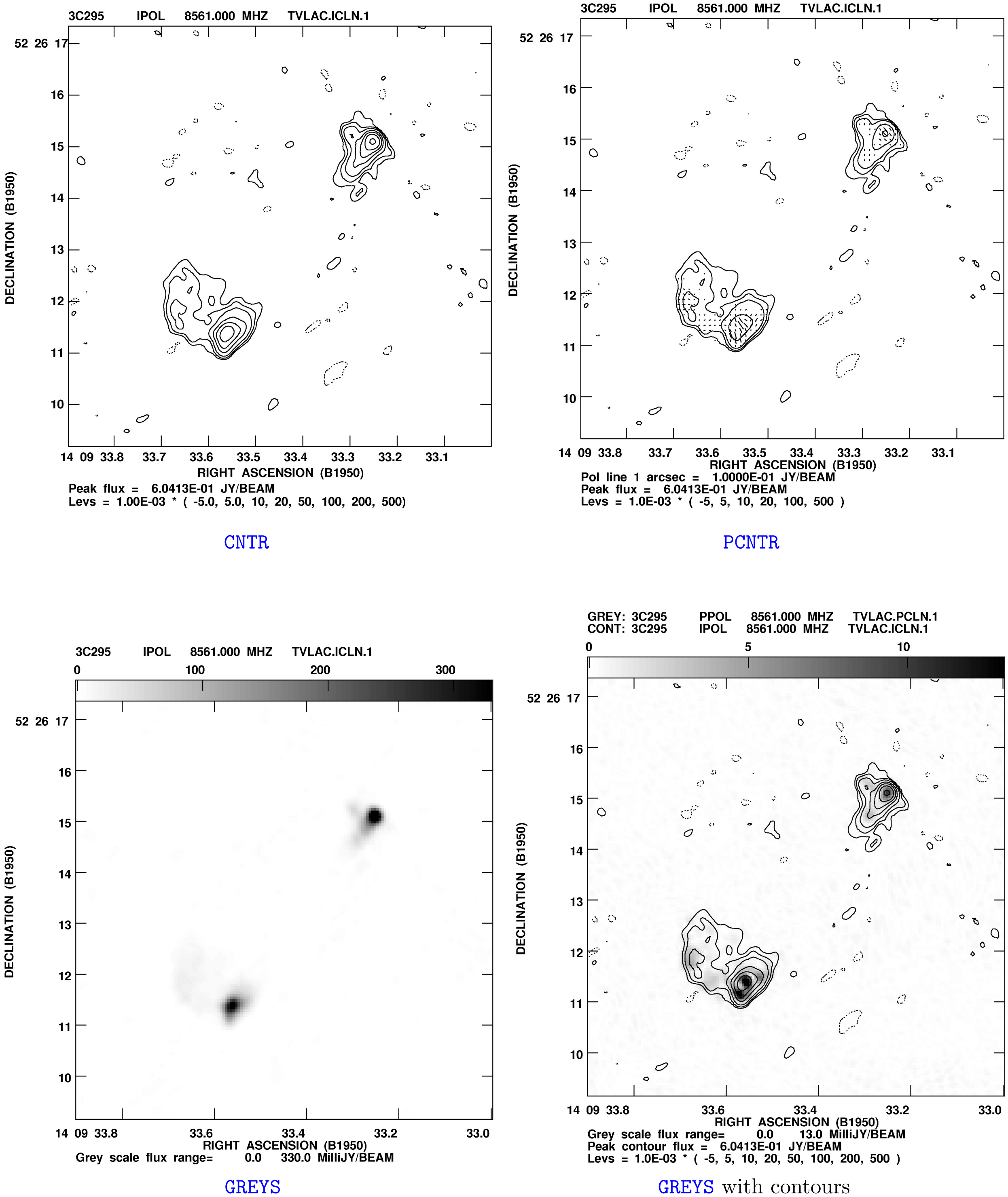



Figure 6.2: Contour, polarization, and grey-scale plots of an image

avoid additional scaling. You may wish to color the labeling, contours, and background with DOCOLOR=1 and PLCOLORS with LWPLA. The procedure TVCOLORS will set PLCOLORS to match the TV graphics-plane colors. See examples on the color pages at the end of this chapter.

There are two other contour drawing tasks which offer additional options. KNTR is able to draw multiple contour, polarization, and/or grey-scale images in a single plot file, primarily to show multiple planes of a spectral-line cube; see § 8.5.4. KNTR uses a different, and probably superior, method of drawing the contour lines. It also can use color to represent different spectral channels and/or polarization angles or simply different colors for the different contour levels. CCNTR is virtually identical to CNTR except that it can draw extra symbols on the plot representing the locations and intensities of source model components found in CC (Clean component) or MF (model fit Gaussians from SAD, see § 7.5.3 and § 10.4.4).

#### 6.3.2.2 Row tracing plots

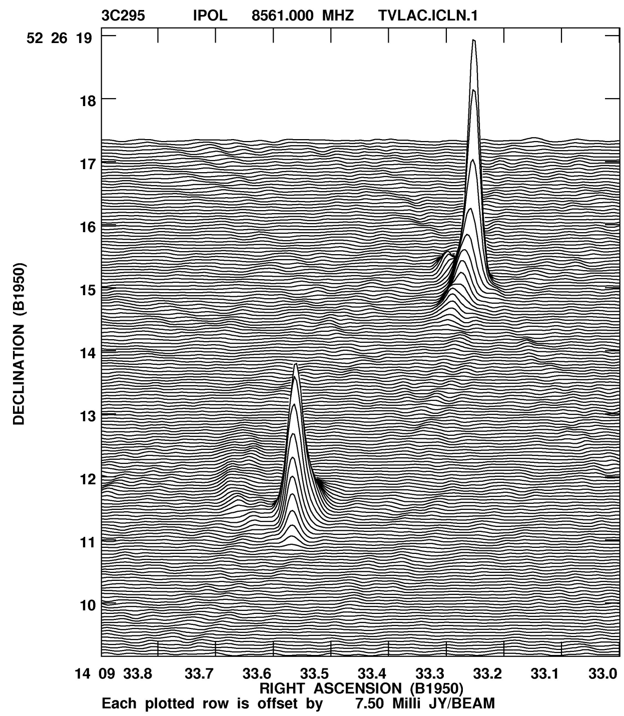
There are a number of tasks which plot rows directly. Two of these are for use with single image planes while others are more intended for use with, *e.g.*, spectral-line data cubes transposed into velocity-ra-dec order. Of the former, PLROW is the simpler. It makes a plot file of all selected rows in an image plane. Each row is plotted as a slice offset a bit from the previous row. Low intensities which are "obscured" by foreground (*i.e.*, lower row number) bright features are blanked to keep the plot readable. Example inputs would be:

| | |
|---|---|
| > TASK 'PLROW' ; INP C<sub>R</sub> | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C<sub>R</sub> | to select the image on disk *n* catalog slot *ctn*. |
| > BLC 100 ; TRC 300 C<sub>R</sub> | to select the subimage from (100, 100) to (300, 300). |
| > YINC 3 C<sub>R</sub> | to plot only every 3rd row. |
| > PIXRANGE -0.001 0.050 C<sub>R</sub> | to clip intensities outside the range −1 to 50 mJy. |
| > OFFSET 0.002 C<sub>R</sub> | to set the intensity scaling such that 2 mJy separates rows of equal intensity. |
| > INP C<sub>R</sub> | to check the inputs. |
| > GO C<sub>R</sub> | to run PLROW. |
| > GO LWPLA C<sub>R</sub> | to display the plot file on the laser printer after PLROW has finished. |

The plot files produced by PLROW are a simple, special case of those produced by PROFL. This task makes a plot file of a "wire-mesh" representation of an image plane complete with user-controlled viewing angles and correct perspective. Enter EXPLAIN PROFL C<sub>R</sub> for a full description. Both of these tasks are especially useful where the signal-to-noise ratio is high and examples of them are given in Figure 6.3.2.2.

In Chapter 8 we discuss the computation and use of "slices," one-dimensional profiles interpolated along any line in an image plane. Once a slice has been computed, it may be plotted by SL2PL on the TV or into a device-independent plot file.

Two other row-plotting tasks, PLCUB and ISPEC, are designed primarily for spectral-line and other data "cubes" (see § 8.5.4 and § 8.6). PLCUB makes one or more plot files showing the intensities in each selected row. The row subplots are positioned in a matrix in the coordinates of the 2nd and 3rd axes of the cube. ISPEC averages rectangular areas in each plane of a cube and plots the resulting spectrum. It can also save the output in a SLice file. RSPEC does the same except that it plots the robust rms in each plane rather than the data.



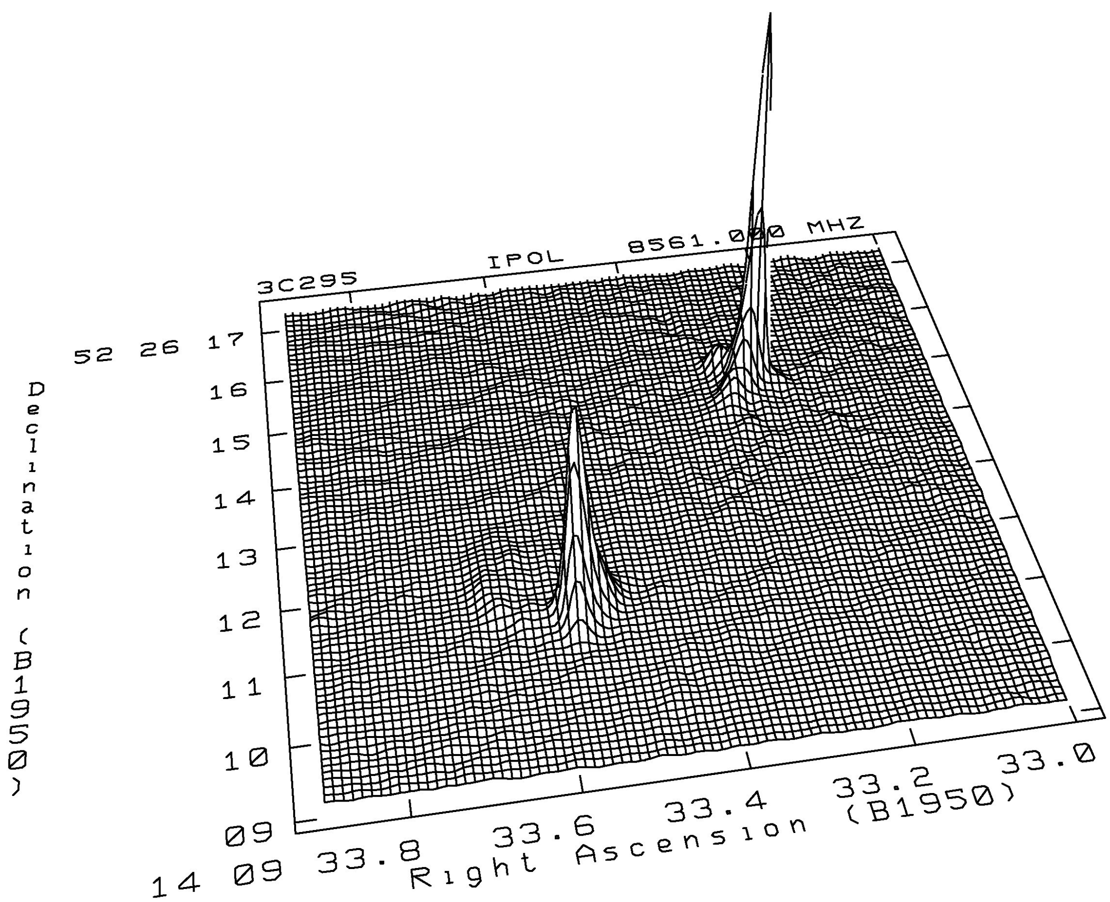
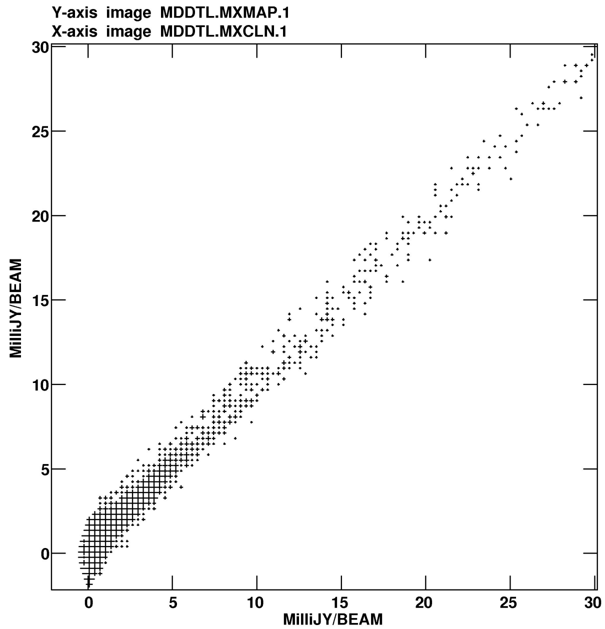
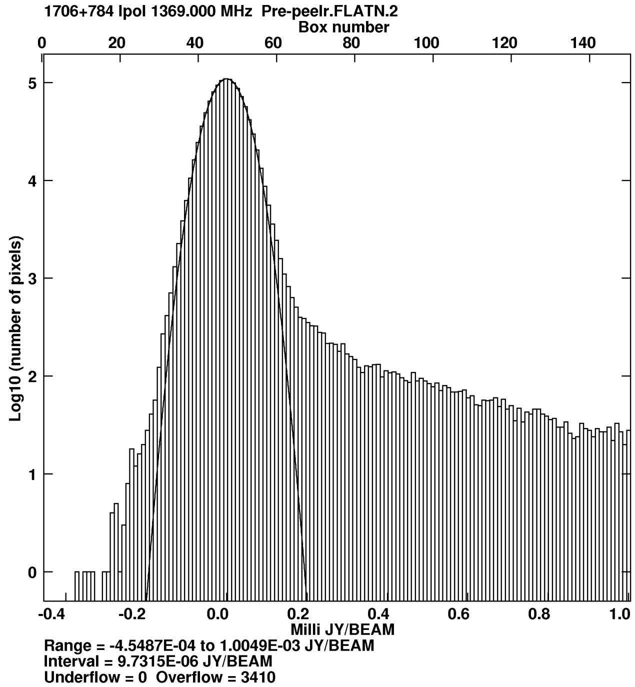




Figure 6.3: Row plots of an image with (bottom, PROFL) and without (top, PLROW) perspective



IMVIM (binned)



IMEAN

Figure 6.4: Plots of statistical parameters of an image.

#### 6.3.2.3 Miscellaneous image plots

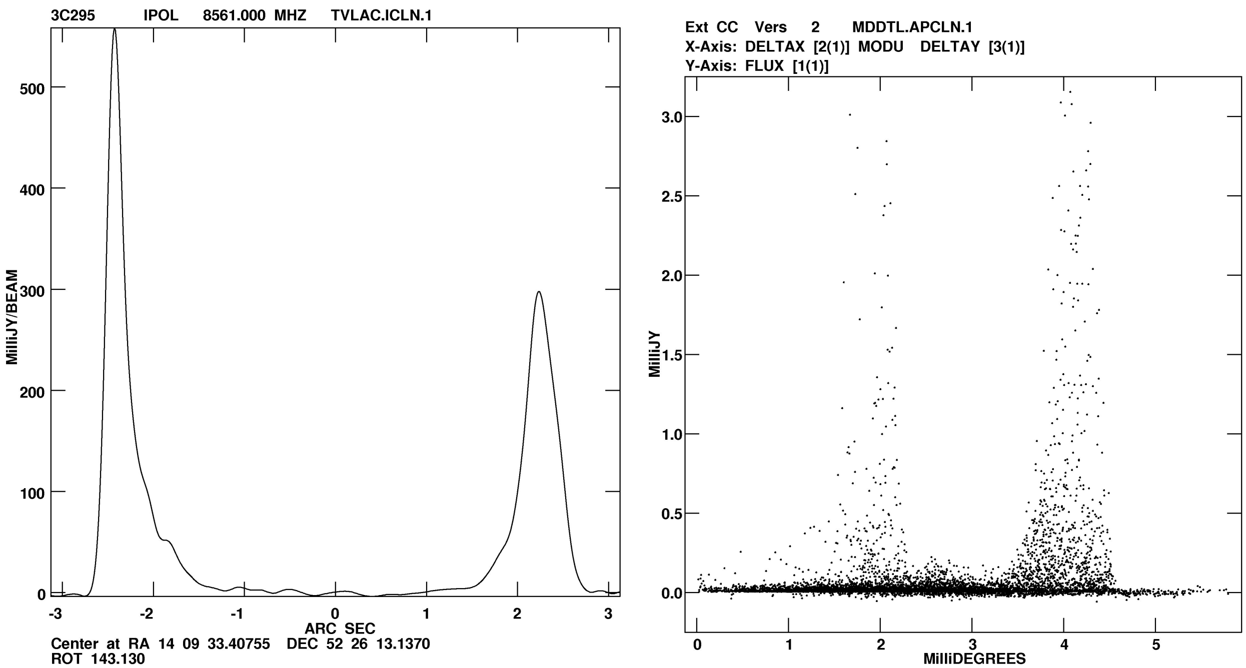
IMVIM allows a variety of image comparisons by plotting the pixel values of one image against the pixel values of another image. The special options include binning the values (and plotting symbols proportional to the number of samples in a bin) and shifting one of the images in $x$ and/or $y$ with respect to the other. The former reduces large scatter diagrams to more manageable sets of numbers while the latter allows cross-correlation functions to be developed.

IMEAN prints the mean, rms, and extrema inside or, in 31DEC08 outside, a user-specified window in an image. It also prints the intensity at, and rms of, the noise peak in the histogram and, beginning with 31DEC02 returns these values as adverbs to AIPS. Optionally, it plots histograms of image intensities over the window using a user-specified number of summing cells over a user-specified range of intensities. Beginning with 31DEC06, it also plots the fit to the noise peak on the user-specified histogram. An example of this is also shown in Figure 6.4.

### 6.3.3 Plotting your table data

TAPLT is a very general task to plot information from *AIPS* table extension files. It can plot a histogram of a function of the values in one or two columns of the table and it can plot a function of one or two columns against another function of another one or two columns. The latter can be summed or averaged in bins or have every point plotted. At first blush, the inputs seem rather complicated, but the results may well justify some effort to understand them. For example, to plot Clean component fluxes as a function of radius from the image center:

> TASK 'TAPLT' ; INP C_R          to review the inputs.




SL2PL TAPLT

Figure 6.5: Slice and table plots.

| | |
|---|---|
| > INDISK *n* ; GETN *ctn* CR | to select the image on disk *n* catalog slot *ctn*. |
| > INEXT 'CC' ; XINC 1 CR | to select every row in the Clean components file. |
| > BCOUNT 1 ; ECOUNT 0 CR | to select all rows in the table. |
| > APARM = 2 , 1, 3 , 1 , 16 , 1 , 1 CR | to plot the modulus of columns 2 and 3 on the $x$ axis (*i.e.*, $\sqrt{\Delta_x^2 + \Delta_y^2}$) and column 1 on the $y$ axis (*i.e.*, component flux). |
| > BPARM = 0 ; CPARM = 0 CR | to use self-scaling of the plot and no scaling of the column values. |
| > DOTV TRUE ; GO | to plot the fluxes on the TV screen. |

You may need to set the scaling with BPARM after seeing the preview plot in order, for example, to bring out the details in the low-level components.

There are a few tasks intended to make plotting specific kinds of tables rather easier. SNPLT plots calibration, solution, system temperature and EVLA SysPower tables for selected antennas as a function of time, antenna elevation, hour angle, or sidereal time. It will make several plots per page (one antenna per plot) and multiple pages if needed, or you can plot the most discrepant value over all antennas in a single plot. In one execution, polarizations and IFs may be plotted on separate plots or together on the same plots, optionally separated by color. POSSM will plot bandpass tables when APARM(8) is set to 2. Values 3 − 8 plot bandpass-like tables from BLCHN (BD) and PCAL (PD antenna polarization and CP source polarization). POSSM can also do multiple plots per page with all the usual data selection adverbs. BPLOT also plots BP and the other similar tables tables, with multiple times for one antenna or multiple antennae for one time on each plot. Combined with difference and coloring options, this allows close comparison of bandpasses as functions of time or antenna. WETHR plots the data in a WX weather table including parameters computed from those data such as relative humidity. FGPLT plots the times of selected flags from a flag table.

### 6.3.4 Plotting miscellaneous information

There are a few other tasks which create plot files, but which do not fit into the categories above. The most general of these is PLOTR which can plot up to ten sets of *(x,y)* points input from a text file with coloring options. CONPL is a task which plots *AIPS* convolving functions (used by various *uv*-data gridding tasks such as IMAGR) and their Fourier transform, expected signal-to-noise ratio, or convolution with a user-specified Gaussian. IRING integrates an image in concentric annuli about the user-specified object center with specified major axis position angle and inclination. The results may be placed in a plot file for later display. GAL calculates the orientation and rotation curve parameters of a galaxy from an image of the predominant velocities. The observed rotation curve is plotted together with the fitted model curve. LOCIT fits antenna location corrections to SN tables; the residual phases may be plotted as a function of sample number.

There are several tasks which create RGB cubes for later display by tasks such as GREYS and KNTR. These include RGBMP which does a weighted sum of the planes of a data cube and TVHUI which interactively uses three images as intensity, hue, and saturation to construct an RGB cube. In the 31DEC03 release, task SCLIM will scale and clip image planes to be used as inputs to LAYER, which produces an RGB cube from the colored sum of up to 10 input image planes using a complicated and general algorithm.

## 6.4 Interactive TV displays of your data

The *AIPS* TV display allows you to look at your image data in detail and to set parameters by pointing at interesting features visible on the screen. Although *AIPS* will run on a variety of hardware display devices (*e.g.*, $I^2S$ Models 70, 75 and IVAS and DeAnza), it is now used almost exclusively with the X-Windows TV-simulation program called XAS. See § 2.3.2 for information on using this basic *AIPS* tool. Information on TV verbs and tasks may be found by entering ABOUT TV C_R, ABOUT INTERACT C_R, and ABOUT TV-APPL C_R, or by consulting the corresponding sections of Chapter 13 of this *CookBook*.

### 6.4.1 Loading an image to the TV

The simplest way to load an image from your catalog to the TV and then to manipulate the display is with the procedure called TVALL:

| | |
|---|---|
| > INP TVALL C_R | to review the input parameters. |
| > INDI *n* ; GETN *ctn* C_R | to select the disk and image name parameters from the catalog. |

Use one of the following commands to specify the initial transfer function that converts your image file intensities to display pixel intensities:

| | |
|---|---|
| > FUNC 'LN' C_R | linear—this is the default. |
| > FUNC 'LG' C_R | logarithmic. |
| > FUNC 'L2' C_R | "extra" logarithmic. |
| > FUNC 'SQ' C_R | square-root, often a good compromise |
| > FUNC 'NE' C_R | negative linear. |
| > FUNC 'NG' C_R | inverse logarithmic. |
| > FUNC 'N2' C_R | inverse "extra" logarithmic. |
| > FUNC 'NQ' C_R | negative square root. |
| > PIXRA *x1*, *x2* C_R | to load only image intensities *x1* to *x2* in the units of the image. The default is to load the full range of intensities in the image. |

(The slopes and intercepts of the display transfer functions can be modified later, but the above options let you choose initially between linear, square-root, logarithmic, and negative displays and restrict the range of intensities that is loaded). Then:

> TVALL C_R to load the selected image.

The image should appear on the TV screen in black-and-white. If you see a new image but it is not what you expected, hit button D to end TVALL and then review your inputs with:

> INP TVALL C_R

If no image appears, make sure that AIPS started up with your workstation assigned as the display; see § 2.2.3 for information on starting up AIPS and assigning the TV display.

After your image has been displayed on the TV by TVALL, your trackball with its buttons (which should be labeled A, B, C, and D) — or your workstation mouse with keyboard buttons A, B, C, and D) — can be used to modify the display transfer functions, coloring and zoom. Pressing button A alone enables black-and-white and color-contour coding of the image intensities, successively. Adjust the cursor position on the TV (using the trackball or mouse) to vary the slope and intercept of the display transfer function. TVALL will superpose a calibrated horizontal wedge on the image. This should help you to choose the optimum cursor setting for the display. Black-and-white displays are generally much more suitable than color for high-dynamic-range images, while color contouring may be used to accentuate interesting features. (Note also that a much wider range of image-coloring options is available outside TVALL by invoking TVPSEUDO, TVPHLAME, and TVHELIX.) Pressing buttons B and C adjusts the zoom of the display: B to increase the magnification and C to decrease it. When these buttons are enabled, the cursor controls the position of the center of the zoomed field of view. Magnification factors of 1 through 16 are available on most workstations. Note that your terminal issues instructions when buttons are pressed, but that it is in the death-like grip of TVALL otherwise until you press button D to exit from it.

The size of the image which can be displayed depends on the size (in pixels) of your workstation screen or TV display and some other parameters which can vary from site to site. A typical Sun workstation can display up to 1024 by 900 pixels. Then, if the image is larger than about 800 pixels or so in the $y$-direction, portions of the labeling of the wedge (the units) will be omitted or superposed on top of the wedge (the tick numeric values). A useful technique for displaying large images is to load only alternate pixels. The command:

> TXINC 2 ; TYINC 2 C_R to load every other $x$ and $y$ pixel.

before TVALL would do this. Also use:

> TBLC = *n1*, *n2*, *n3*, ... C_R bottom left pixel to load.

> TTRC = *m1*, *m2*, *n3*, ... C_R top right pixel to load.

to limit the displayed field. A small image may be interpolated to fill the TV screen by setting TXINC = -1 ; TYINC = -1 C_R. Recent versions of XAS allow the verb TVROAM to function again. This verb loads adjacent portions of an image to as many as 16 memories and then "roams" with a split screen to allow you to view any contiguous portion of the loaded image. REROAM resumes roaming an already loaded roam-mode image, perhaps after adjustment of the transfer function of all channels with TVTRANSF and TVCHAN = 0. The 31DEC09 verb ROAMOFF allows you to convert the final split-screen image into a normal, more useful single-plane image.

TVALL is a procedure that insures that the desired graphics and TV channels are on and cleared and the others off, then loads the image with verb TVLOD, loads a wedge with TVWEDGE, and labels the wedge with TVWLABEL. You do not have to use TVALL, which can be rather slow, simply to load a new image on the TV. Use TVLOD instead. TVWEDGE has a variety of options concerning the width of the wedge and its position; type HELP TVWED C_R for details.

### 6.4.2 Manipulating the TV display

There are a number of verbs which allow you to manipulate the display, including:

| | |
|---|---|
| > TVINIT C_R | to initialize the entire TV and TV image catalog. The image catalog is now kept in XAS and so is always current. |
| > TVON *n* C_R | to turn on TV grey channel(s) with *n* being a bit pattern of the desired channels: $2^{(i-1)}$. Thus TVON 4 turns on channel 3. You may have to turn off other channels to see the desired channel, since the sum of two images may be rather odd. |
| > TVOFF *m* C_R | to turn off channel *m*, where *m* is a bit pattern as with TVON. |
| > GRON *n* C_R | to turn on one or more of the 8 graphics channels, where *n* is a bit pattern. |
| > GROFF *m* C_R | to turn off one or more graphics channels. |
| > TVCHAN *n* ; TVCLEAR C_R | to zero a TV channel. |
| > GRCHAN *m* ; GRCLEAR C_R | to zero a graphics channel. |
| > TVZOOM C_R | to set the zoom magnification and center interactively, follow instructions on the screen. |
| > OFFZOOM C_R | to reset the zoom and zoom center to null. |
| > GREAD C_R | to read the current color of a specified graphics overlay channel into RGBCOLOR. |
| > GWRITE C_R | to change the color of a graphics overlay channel to that specified by RGBCOLOR. This may be done for aesthetic reasons or because the default colors may not show up well when captured by TVCPS and printed on a color printer. |
| > TVPOS C_R | to read the TV cursor position, returning adverbs for use in procedures or other verbs. |
| > IM2TV C_R | to convert an image pixel in PIXXY to the corresponding TV pixel. |

### 6.4.3 Intensity and color transfer functions

The AIPS model of a TV postulates two intensity transfer functions, called the LUT and the OFM, which are basically multiplicative. In most circumstances, the LUT is used for black-and-white enhancements and the OFM for coloring, but both can be used for either. To manipulate the LUT interactively, while leaving the pseudo-coloring alone, use the TVTRAN verb. The cursor position controls the slope and intercept of the transfer function, buttons A and B switch a plot of the transfer function on and off, button C switches the sign of the slope, and button D (as always) exits. To turn the LUT back to normal, enter OFFTRAN.

A rich zoo of color coding is available with TVPSEUDO, which alters the OFM while leaving the LUT alone. Repeated hits on button A select a variety of color triangles, button B selects a circle on hue, and repeated hits on button C select a variety of color contours. First-time users should experiment with the AIPS coloring options until they develop an intuitive feel for the effects of cursor settings on the image appearance. The wedge displayed by TVALL adjusts to the alternative colorations selected with TVPSEUDO, and it is helpful to watch changes in both the wedge and the image. A flame-like coloring is available with TVPHLAME, or variations on the scheme with repeated hits on buttons A or B. TVHELIX does a helix in color space attempting to make a monotonic increase in preceived intensity. The buttons change direction, number of rotations, and saturation. In these verbs the cursor position controls aspects of the coloring such as enhancements, richness, or cycles of hue. To turn off pseudo-coloring, enter OFFPSEUD.

A set of less well-known verbs is available to allow you to create, manipulate, and save desirable versions of the OFM table. OFMSAVE allows you to save a named OFM, OFMDIR lists all saved OFMs belonging to you or generally available from the AIPS distribution, OFMGET loads a named OFM, OFMZAP deletes a named OFM, and OFMLIST prints the current OFM. OFMCONT is an elaborate interactive verb which allows you to set the hue, intensity, and saturation of the OFM divided up into a number of color contours. Each of these contours can be a constant level or a step wedge. OFMADJUS is another elaborate interactive verb to alter pieces of the OFM, while OFMTWEAK is a simpler verb to stretch the OFM.

### 6.4.4 Setting parameters with the TV

One reason to load the image to the TV is to set adverbs for use by other verbs and tasks. Verbs which use the TV cursor to set adverbs include:

> TVNAME C_R — to set INDISK, INNAME, etc. to the name parameters of the image currently visible. If there is an ambiguity, you will be asked to move the cursor to the desired image and press a button.

> TVWIN C_R — reads pixel coordinates from the next two cursor positions at which a trackball button is depressed. The TV graphics shows the current shape and position of the window. Button A allows you to switch to (re)setting the other corner while the other buttons exit after both corners have been set. TVWIN uses the pixel coordinates to set up the bottom left (BLC) and top right (TRC) corners of an image subsection, *e.g.*, for input to the contouring programs CNTR and PCNTR, to the mean/rms calculator IMEAN, and to many other tasks.

> SETXWIN ($dx$,$dy$) C_R — reads pixel coordinate of the center of a $dx$-pixel by $dy$-pixel window and sets the adverbs BLC and TRC.

> TVBOX C_R — is similar to TVWIN above except that it is used to set up pixel coordinates to define rectangular *or circular* Cleaning areas for the AIPS Clean tasks. The adverbs NBOXES and CLBOX are set. The circular option appeared in the 15JUL95 release and is not supported by APCLN and MX.

> REBOX C_R — allows revision using the TV of the Cleaning areas set previously with TVBOX. Revises NBOXES too.

> DELBOX C_R — allows deletion using the TV of the Cleaning areas set previously with TVBOX. Revises NBOXES too.

> FILEBOX C_R — is REBOX for boxes in the text file used with IMAGR; multiple fields and many more boxes are allowed.

> DFILEBOX C_R — is DELBOX for boxes in the text file used with IMAGR; multiple fields and many more boxes are allowed.

> SETSLICE C_R — works like TVWIN above to set BLC and TRC. Instead of a rectangle however, the display shows a diagonal line which is useful for setting the ends of slices.

In 31DEC09, the task FILIT performs FILEBOX and much more on a set of images, usually the multiple facets of a wide-field imaging. It offers a wide range of image display options including handling images larger than the TV, allows editing of the box information, creates boxes via the auto-boxing algorithm, and checks the multiple facets for overlapping boxes. This new task may be the quickest and easiest way to review a set of facet images.

### 6.4.5 Reading image values from the TV

There are several facilities for reading out intensity and position information from displayed images using the TV cursor:

> IMPOS C_R — displays the two coordinate values (*e.g.*, RA and Dec) from the cursor position when any button is depressed. Adverbs TVBUT and COORDINA are returned.

> IMXY ; IMVAL C_R — displays the image intensity and the two coordinate values (*e.g.*, RA and Dec) from the cursor position when any button is depressed. Adverbs PIXXY, TVBUT, PIXVAL, and COORDINA are set.

> TVFLUX C_R — displays image intensities and coordinates whenever a TV button is pressed, looping until button D is pressed. Adverbs for the first image name are set as well as PIXXY, TVBUT, PIXVAL, and COORDINA for the last pixel selected.

> TVDIST C_R — displays the angular length and position angle of the spherical vector between two pixels in one or two images shown on the TV. Name adverbs for input files 1 and 2 are set as well as adverbs PIXXY, PIX2XY and DIST.

> TVMAXFIT C_R — whenever a TV button is pressed, fits a quadratic function to the image to find the position and strength of an extremum, looping until button D is pressed. Adverbs for the first image name are set as well as PIXXY, TVBUT, PIXVAL, and COORDINA for the last object selected.

> CURVAL C_R — continuously displays (in the upper-left corner of the TV) the pixel coordinates and the image intensity in user-recognizable units at the position selected by the TV cursor.

> TVSTAT C_R — determines the mean, rms, extrema and integrated intensity (if appropriate) in user-defined "blotch" regions within the image currently displayed on the TV. The regions are irregular polygons selected with the TV cursor. Type EXPLAIN TVSTAT C_R for details. Adverbs PIXAVG, PIXSTD, PIXVAL, PIXXY, PIX2VAL, and PIX2XY are set.

> COPIXEL C_R — to convert between pixel and astronomical coordinates for an image; allows determination that a coordinate is not inside an image.

### 6.4.6 Labeling images on the TV

There are a number of facilities for labeling images on the TV including:

> TVLABEL C_R — to draw standard axis labels around the visible image. You may control the type of labeling and whether coordinates are shown as a grid or short tick marks. If more than one image is visible, you will be asked to indicate which one you want with the cursor and any button.

> TVWLABEL C_R — to draw axis labels around the visible intensity wedge.

> TVANOT C_R — to draw a text string into a grey-scale channel or a graphics plane at a location specified via an adverb or via the TV cursor.

| | |
|---|---|
| > TVLINE C_R | to draw a straight line into a grey-scale channel or a graphics plane at locations specified in part or in whole via adverbs or via the TV cursor. |
| > TVILINE C_R | to draw a straight line into a grey-scale channel or a graphics plane between two image pixel coordinates. |
| > COSTAR C_R | to plot a "star" positions at a user-specified coordinate on the TV image. |
| > TVSTAR C_R | to plot "star" positions from an ST file on top of the visible image; see § 6.3.2. |

### 6.4.7 Comparing images on the TV

It is often useful to compare two images, *e.g.*, to decide whether one contains artifacts that are not present in another at the same frequency, or to look for frequency-dependent features at constant resolution. AIPS provides several tools for such image comparisons.

The first tool is a capability for loading multiple images to the same plane (or channel) of the TV device. The parameter TVCORN specifies where the bottom left corner of the image or image subsection will be positioned in the TV frame by TVLOD or TVALL. If TVCORN is left at zero, TVLOD and TVALL adjust it to center the displayed image. You may however use TVCORN to control loading successive images to different regions of the display with successive executions of TVLOD. For example, the following commands would load two 512 by 512 pixel images from slots 1 and 2 on disk 1 *side-by-side* on channel 1 of a 1024 by 900 TV display:

| | |
|---|---|
| > INDI 1; GETN 1 C_R | to select the input disk and the first image. |
| > TVCH 1 C_R | to select TV channel 1 for the loading. |
| > TVCORN 1 193 ; TVLOD C_R | to load the first image. |
| > GETN 2 C_R | to select the second image. |
| > TVCORN 513 193; TVLOD C_R | to load the second beside the first. |

You could then adjust the color coding, transfer function, etc. for both images simultaneously with TVFIDDLE or TVTRAN. You may load as many as 256 images to a single TV plane with this technique, which is therefore a powerful method for making "montages." The number of simultaneous images is limited mostly by your image sizes, the need to avoid overlaps (which are allowed if you want) — and your ability to do the arithmetic for appropriate TVCORN settings! You are also limited by the need for all the images in one plane to share that plane's transfer function. Judicious use of the PIXRANGE and FUNC inputs to TVLOD permits making useful montages of disparate images, however.

A second tool is the classic "blink" technique from optical astronomy. TVBLINK allows you to load images to two different planes of the TV memory and then to alternate the display rapidly between the two. The two images described above could be "blinked" against each other by the following command sequence:

| | |
|---|---|
| > INDI 1; GETN 1 C_R | to select the input disk and first image. |
| > TVINIT; TVCORN 0 | to clear the TV and restore the default positioning. |
| > TVCH 1; TVLOD C_R | to load the first image on plane 1. |
| > GETN 2 C_R | to select the second image. |
| > TVCH 2 ; TVLOD C_R | to load the second image on plane 2. |
| > TVCH 12 ; TVBLINK C_R | to blink planes 1 and 2. |

The rate and duty cycle of the blinking, and the transfer functions applied to the planes, are controlled interactively with the TV cursor. Instructions for these operations appear on your terminal while TVBLINK is running.

The task PLAYR provides a menu-driven method to enhance and blink two images and to develop and save TV color tables ("OFMs").

For data cubes (*e.g.*, frequency or time sequences of images), the verbs TVMOVIE and TVCUBE combine the two previous techniques. These are described in more detail in § 8.5.4. Both verbs load one or more image planes with as many planes from the cube as possible (and as requested). Then they display each frame in sequence with interactive controls over the frame rate in movie mode, the chosen frame in single-frame mode, and the brightness, contrast, and color of the displayed images. TVMOVIE makes a somewhat more efficient movie sequence, but TVCUBE makes a better montage by using a more normal arrangement of the image planes.

Certain real TV displays used to provide powerful tools to compare images using color as well as intensity to represent real information. Unfortunately, some workstations can display only 256 simultaneous colors (or even fewer), but now most are capable of full color displays. XAS supports both kinds of workstation. The full-color displays tend to be slower which is no longer significant, but users may select to restrict themselves to pseudo-color displays; see § 2.3.2 for details. For the limited workstations, there are two tasks, also discussed in § 8.6, which attempt to recover much of this capability by trying to optimize color assignments over the limited range available. The first of these, TVHUI produces a composite display in which the intensity is set by one image, the hue is derived from another image, and the saturation is optionally derived from a third image. An interactive menu allows you to enhance each of the images individually, to select linear or logarithmic transfer functions for the intensity image, to select the subimage used during interactive enhancements, to repaint the full image, and to exit with or without writing out the final three-color image. A number of uses for this are obvious, including spectral-line moment images (velocity setting color, line width setting saturation), polarization images (polarization angle setting color in a circular scheme, polarization intensity setting saturation), and depolarization observations (color set by a two-frequency depolarization image). TVHUI is also useful on full-color displays, but for such displays, you may do much of the work of this task in a verb:

| | |
|---|---|
| > INDI *d1* ; GETN *ctn1* C_R | to select the intensity image. |
| > TVINIT; TVCORN 0 | to clear the TV and restore the default positioning. |
| > TVCH 1; TVLOD C_R | to load the first image on plane 1. |
| > INDI *d2*; GETN *ctn2* C_R | to select the hue image. |
| > TVCH 2 ; TVLOD C_R | to load the second image on plane 2. |
| > TVCH 1 ; TV2CH 2 ; TVHUEINT C_R | to display a full-color view where the intensity is controlled by image 1 and the hue by image 2 and to interactively adjust that display. |

Instructions for altering transfer functions and reversing the roles of the two images appear on your terminal while TVHUEINT is running.

TVHUI can be instructed to write out a three-color image cube containing one plane for red, one for green and one for blue. It does this using the transfer functions established interactively, but with full accuracy unlimited by the TV display. There is also an *AIPS* task called RGBMP which writes three-color cubes using weighted sums over a data cube. Three-color cubes also arise when digitizing color photographs of real scenes. The second task, TVRGB, can be used to display these three-color cubes or to generate a three-color display from any three *AIPS* image planes. Common examples of the latter are the superposition of radio continuum and/or line data on optical or X-ray images, and color-coding of effective temperatures or spectral indices from 3-channel continuum data. TVRGB can also be used to color-code different types of depolarization effects from multi-frequency polarimetry. Like TVHUI, TVRGB offers a simple menu to enhance each of the images individually or all together, to select the window specifying the subimage which is used during interactive enhancements, to repaint the full image on the TV, and to exit. TVRGB does not write an output image per se, but it can be instructed to write out a full 24-bit color PostScript plot file to be sent to a color printer. Its display (or any other TV display including that of TVHUI) can be captured and sent to a color printer; see § 6.4.10 below.

On full-color workstations, three-color images may be displayed by loading each color plane to a separate TV memory. Then each memory is turned on in the desired color only using TVON with the usually ignored COLORS adverb. If the red image is in TV channel 1, the green in 2 and the blue in 3, the verb TV3COLOR is a short-cut for all the parameter setting.

> FOR TVCH=1:3; TBLC(3)=TVCH; TVLOD; END; TV3COLOR C_R

### 6.4.8 Slice files and the TV display

In Chapter 8 we discuss the computation and use of "slices," one-dimensional profiles interpolated along any line in an image plane. Once a slice has been computed, it may be plotted by TVSLICE on the TV display in your choice of graphics channel. A second slice may be plotted on top of the first with TVASLICE. The TV graphics display is used to prepare initial guesses for SLFIT, which fits Gaussians to slices. The verbs involved are:

| | |
|---|---|
| > NGAUS *n* ; TVSET C_R | to set the number of Gaussians to be fitted to *n* and then to prepare an initial guess at the parameters by pointing at the peaks and half width points on a graphics plot of the slice. |
| > TV1SET *j* C_R | to revise the initial guess for the $j^{\text{th}}$ Gaussian. |
| > TVGUESS C_R | to plot the initial guess of the model on the graphics device, erasing any previous plot. |
| > TVAGUESS C_R | to add a plot of the initial guess of the model to the current slice plot on the graphics device. |
| > TVMODEL C_R | to plot the fit model on the graphics device, erasing any previous plot. |
| > TVAMODEL C_R | to add a plot of the fit model to the current slice plot on the graphics device. |
| > TVRESID C_R | to plot the data minus the fit model on the graphics device, erasing any previous plot. |
| > TVARESID C_R | to add a plot of the residuals (data minus model) to the current slice plot on the graphics device. |

The units for slice model parameters are those of the plot, so it is convenient to set them with these verbs. These same operations may also be done on the TEK graphics device (§ 6.5.2), but modern X-Windows emulations of such devices seem to have problems with cursor reading. They also do allow the use of multiple graphics planes while the TV verbs allow multiple colors or plot comparisons using different GRCHANs.

### 6.4.9 Other functions using the TV

There are a number of tasks which use the TV to give the user real interactive input to the operation based on the images displayed by the task on the TV. These include BLANK (§ 8.6) to blank out non-signal portions of an image, BLSUM (§ 8.6) to sum images over irregular blotch regions printing out summed spectra (and saving SLice files), TVFLG (§ 4.4.3) to edit visibility data based on grey-scale displays of some function of the visibility with baseline on the $x$ axis and time on the $y$ axis, SPFLG (§ 8.1, § 10.2.2) to edit visibility data based on grey-scale displays of some function of the visibility with spectral channel for all IFs on the $x$ axis and time on the $y$ axis, EDITR (§ 5.5.2) to edit visibility data based on plots of visibility versus time, 1–11 baselines at a time, EDITA (§ 4.4.2) to edit visibility data based on plots of system temperature (TY or SY tables) or antenna gains (SN or CL tables), WIPER to edit visibility data using UVPLT-like displays, and SNEDT to edit TY, SY, SN, and CL tables themselves.

The imaging tasks, IMAGR, SCIMG, and SCMAP display the results of the computation at its current stage on the TV and provide a menu of interactive options to the user. The menu includes the usual display enhancements, the ability to choose among the images being computed, the ability to set Clean windows in those images, and the ability to end the computation at its current stage. The computation will resume when instructed via the menu or after a period of inactivity. A number of older iterative tasks use the TV to display the results of the computation so far and then prompt the user to hit button D within some number of seconds to stop the computation. Tasks that do this include APCLN, MX, SDCLN, VTESS, and several less significant tasks. UVMAP uses the TV simply to draw a picture indicating which cells are sampled in the *uv* plane. All of these tasks are described in Chapter 5.

There is a set of related tasks for analysis of data cubes transposed so that the first axis is the one on which baselines or Gaussians are to be fit. In the case of a spectral-line cube, the image would be transposed so that velocity is the first axis. These tasks were all written to use the Tektronix graphics device, but have been rewritten to run on the TV as well. Set DOTV=1, to use the TV; it is a more reliable graphics input device. Use XPLOT first to get an idea of what the profiles really look like. It uses a flux cutoff to determine which profiles to display and prompts you for permission to continue after each plot. XBASL is used to remove $n^{\mathrm{th}}$-order polynomial baselines from each spectrum. It has a batch mode of operation and an interactive mode which uses the graphics display to plot each spectrum and to accept guidance on which channels to use in determining the baselines. XGAUS is a similar task, with the rather harder job of fitting up to four Gaussians plus a linear baseline to each profile. In its interactive mode it plots each selected spectrum on the graphics device and accepts guidance on the baseline regions and the initial guesses for the Gaussians. XGAUS writes images of the fit Gaussian parameters and XBASL can be asked to write images of the baseline parameters. Unfortunately, these tasks require you to do the full cube in a single execution, which is rather an endurance contest.

### 6.4.10 Capturing the TV

Having done all the work to prepare the absolutely perfect display on your TV screen, it would be a good idea to capture it before someone, such as the local power company, does a TVINIT. See § Z.1.2.2 for a discussion of Unix tools to do this. We recommend, however, TVCPS to capture the image on your TV, including graphics overlay channels if they are on, and to write the result to an encapsulated PostScript file. This file can be printed immediately on a black-and-white or color printer or on any other device which understands PostScript. It can also be saved for later printing or inclusion in other documents. TVCPS was used to make the picture on the title page of this *CookBook*, the picture of TVFLG's display in Chapter 4, and the picture of a right ascension - velocity - declination data cube in Chapter 9. TVCPS bases its picture on the current size of your TV display. If you are using a workstation with XAS, be sure to adjust the size of the display window to encompass all of your image plus a modest border. If you leave a large border, you will get a large border in your output. TVCPS understands both pseudo- and full-color XAS displays. Your TVCPS session could look like:

| | |
|---|---|
| > TASK 'TVCPS' ; INP C~R~ | to review the inputs. |
| > OUTFILE 'MYAREA:TV.PIX C~R~ | to save the output in a file called TV.PIX in an area defined by the logical MYAREA; see § 3.10.1. |
| > OPCODE 'COL' C~R~ | to make a color picture. |
| > APARM 8.5 , 11 C~R~ | to set the output device size to 8.5 by 11 inches, appropriate to standard quarto paper. |
| > GO C~R~ | to run the task when the inputs are set. |

TVCPS has an option to add a character string below the image with adverb REASON. If your image is too large to fit on the TV, you can instruct TVCPS to read the image from disk with DOTV = -2 C~R~, using adverbs TBLC, TTRC, TXINC, and TYINC. When doing this, you should turn off the graphics display (GROFF 32767 C~R~) since it is not aligned properly. This option works when multiple images are visible at the same time, but only when they are in separate TV planes as fully overlapped 3-color images. Some color printers and recorders have rather different transfer characteristics than the workstation screen. TVCPS offers the option to remove the "gamma correction" used for your workstation and to apply a different one appropriate to your color recorder. TVCPS now offers the option to represent colors using the CMYK (cyan-magenta-yellow-black) used in printing rather than the familiar RGB colors system. CMYK displays often require different gamma corrections from those used for RGB. To see the effects of the gamma correction, try the verb GAMMASET in AIPS. You may need to use GWRITE to select better colors for the graphics overlay planes as well.

## 6.5 Graphics displays of your data

In the dim dark past, Tektronix invented some nice graphical display devices and an inconvenient but functional way to talk to them. This communication language became so embedded in software that workstation vendors now provide X-Windows windows that understand it. AIPS also arose from this dim dark past and once upon a time talked to those lovely green screens. To retain the graphics capability, we now provide a TEKSRV server which will provide a Tektronix-like graphics screen on which certain AIPS tasks and verbs plot. When AIPS starts up on workstations, it brings up a window called TEKSRV. Leave this window in its iconic state; it is only a marker for the presence of the server. The first time you write to TEKSRV, it will create and open a window called TEKSRV (Tek) in which the plot is done. You can resize this window within some limits and the plot will automatically resize itself. When the workstation cursor is in the Tek window, it changes to a diagonal arrow pointer. When an AIPS task or verb tries to read from the Tek window, this pointer becomes a plus sign. You should position the pointer to the desired location *without* touching the keyboard or the mouse buttons. When the pointer is exactly where you want it, press any mouse button or any key (*except* RETURN) to return the pointer position to the program. Note that the functions using the graphics display are not quite as friendly as those on the TV. This is due to the inability to erase a piece of a plot without erasing all of it. You can erase the full screen with TKERASE, which will keep the window from redrawing a big plot on every expose event. In recent years, we have found unfortunately that cursor reading from Tektronix emulation screens can be unreliable. Therefore, every TK function described below also has a TV version, described in a previous subsection.

### 6.5.1 Plotting data and setting values with the graphics display

TKPL interprets AIPS plot files to the graphics window or device. Experienced AIPS users like it because it is much faster than the TV for complicated line drawings, *e.g.*, those produced by UVPLT, and because it is of higher resolution than many of the TV plots. The graphics screen can be used to read back data values and set adverbs, much like the TV:

| | |
|---|---|
| > TKXY C_R | to read the graphics cursor position, setting adverb PIXXY; requires a contour or comparable image to be shown on the screen. |
| > TKXY ; IMVAL C_R | to read the graphics cursor position and return the image value and coordinates of the selected position. |
| > TKPOS C_R | to read the graphics cursor position and return the image coordinates of the selected position. |
| > TKWIN C_R | to read the graphics cursor position twice, first setting BLC and then setting TRC. |
| > TKBOX(*i*) C_R | to read the graphics cursor position twice, first setting the lower left and then the upper right of Clean box *i*. |
| > TKNBOXS(*n*) C_R | to set NBOXES to *n* and then set all *n* Clean boxes using the graphics cursor. |

All of these verbs require a graphics display of a plot file produced by CNTR, PCNTR, GREYS, or SL2PL. The window procedures don't make much sense with a slice plot, but they will work.

### 6.5.2 Slice files and the graphics display

In Chapter 8 we discuss the computation and use of "slices," one-dimensional profiles interpolated along any line in an image plane. Once a slice has been computed, it may be plotted by TKSLICE on the graphics display. A second slice may be plotted on top of the first with TKASLICE. The graphics display is used to prepare initial guesses for SLFIT, which fits Gaussians to slices. The verbs involved are:

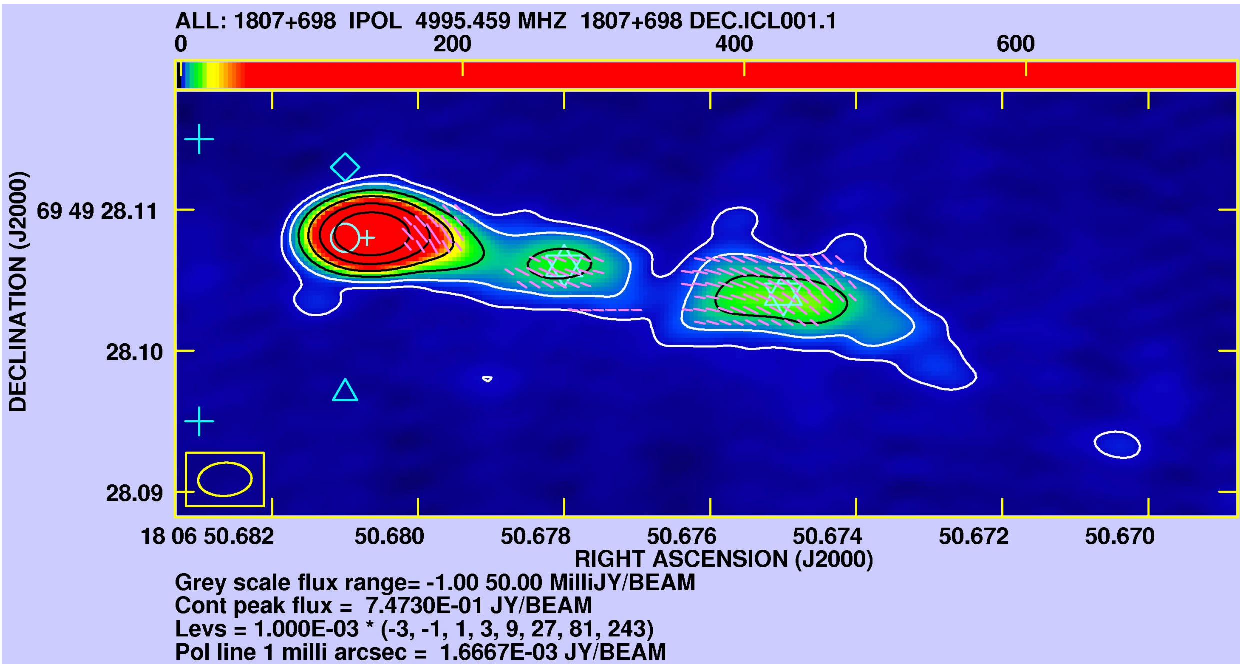
| | |
|---|---|
| > TKVAL C_R | to return the flux level pointed at by the graphics cursor. |
| > NGAUS *n* ; TKSET C_R | to set the number of Gaussians to be fitted to *n* and then to prepare an initial guess at the parameters by pointing at the peaks and half width points on a graphics plot of the slice. |
| > TK1SET *j* C_R | to revise the initial guess for the $j^{\rm th}$ Gaussian. |
| > TKGUESS C_R | to plot the initial guess of the model on the graphics device, erasing any previous plot. |
| > TKAGUESS C_R | to add a plot of the initial guess of the model to the current slice plot on the graphics device. |
| > TKMODEL C_R | to plot the fit model on the graphics device, erasing any previous plot. |
| > TKAMODEL C_R | to add a plot of the fit model to the current slice plot on the graphics device. |
| > TKRESID C_R | to plot the data minus the fit model on the graphics device, erasing any previous plot. |
| > TKARESID C_R | to add a plot of the residuals (data minus model) to the current slice plot on the graphics device. |

The units for the slice model parameters are fairly problematic, so we recommend using these graphical input and output functions. At least, they all have the same strange ideas. See § 6.4.8 for the verbs that allow this same processing using the TV display.

### 6.5.3 Data analysis with the graphics display

There is a set of related tasks for analysis of data cubes transposed so that the first axis is the one on which baselines or Gaussians are to be fit. In the case of a spectral-line cube, the image would be transposed so that velocity is the first axis. It is a good idea to use XPLOT first to get an idea of what the profiles really look like. It uses a flux cutoff to determine which profiles to display and prompts you for permission to continue after each plot. XBASL is used to remove $n^{\rm th}$-order polynomial baselines from each spectrum. It has a batch mode of operation and an interactive mode which uses the graphics display to plot each spectrum and to accept guidance on which channels to use in determining the baselines. XGAUS is a similar task, with the rather harder job of fitting up to four Gaussians plus a linear baseline to each profile. In its interactive mode it plots each selected spectrum on the graphics device and accepts guidance on the baseline regions and the initial guesses for the Gaussians. XGAUS writes images of the fit Gaussian parameters and XBASL can be asked to write images of the baseline parameters. Unfortunately, these tasks require you to do the full cube in a single execution, which is rather an endurance contest.

## 6.6 Examples of color plotting

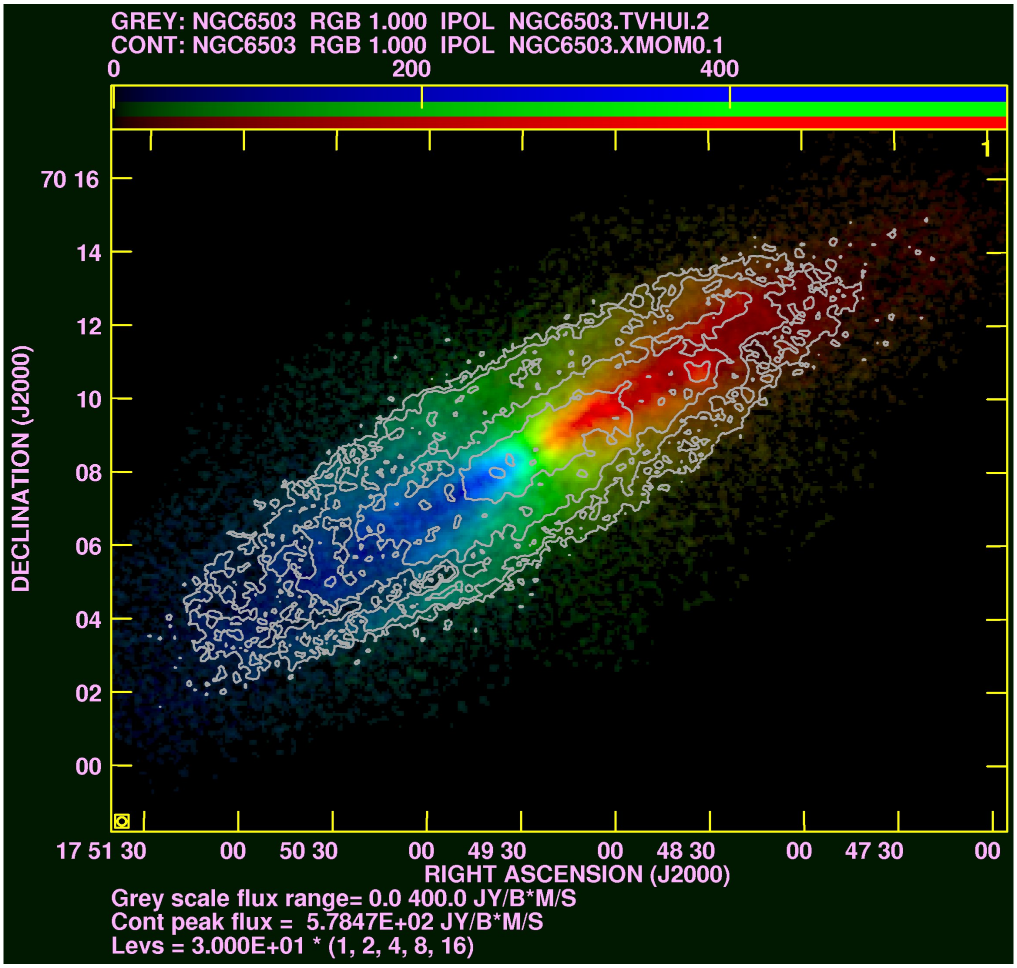



```
KNTR:  Task to generate a plot file for a contour and grey plot
DOCONT        1                     > 0 => do contours
                                    (1 or 2 => which name)
DOGREY        1                     > 0 => do grey scale
                                    (1 pr 2 => which name)
DOVECT        1                     > => do polarization vectors
                                    (1 or 2 => which is IPOL)
                                    Contour or grey or IPOL
INNAME     '1807+698 DEC'           First image name (cube?)
INCLASS    'ICL001'                 First image class
INSEQ         1                     First image seq. #
INDISK        3                     First image disk drive #
                                    Polarization intensity image:
IN3NAME    '1807+698 DEC'             (name) blank => INNAME
IN3CLASS   'QCL001'                   (class) blank => 'PPOL'
IN3SEQ        1                       (seq. #) 0 => high
IN3DISK       3                       Disk drive #,  0 => any
                                    Polarization angle image:
IN4NAME    '1807+698 DEC'             (name) blank => INNAME
IN4CLASS   'UCL001'                   (class) blank => 'PANG'
IN4SEQ        1                       (seq. #) 0 => high
IN4DISK       3                       Disk drive #,  0 => any
PIXRANGE   -1.00E-03      0.05      Min,Max of image intensity
FUNCTYPE   'SQ'                     Image intensity transfer func
OFMFILE    '                                                   '
LTYPE         3                     Type of labeling: 3 standard
DOALIGN       1                     > 0 => images must line up
CLEV        0.001                   Absolute value for levs
LEVS         -3           -1        Contour levels (up to 30).
              1            3           9          27
             81          243        *rest 0
FACTOR     1000                     Mult. factor for Pol vector
XINC          3                     X-inc. of Pol vectors. 0=>1
YINC          3                     Y-inc. of Pol vectors. 0=>1
```

```
PCUT         0.001                  Pol. vector cutoff. P units.
ICUT         0.001                  Int. vector cutoff. I units.
DOWEDGE        3                    = 3 => put on top using full
                                           range of image values
STFACTOR       1                    Scale star sizes: 0 => none.
CBPLOT         1                    Position for beam plot:&
                                      1: lower left (default)
DARKLINE       0.33                 Switch to dark lines when
                                    grey-scale > DARKLINE 0-1
```

```
LWPLA:   Sends plot file(s) to a PostScript printer or file
INNAME     '1807+698 DEC'           Image name (name)
INCLASS    'ICL001'                 Image name (class)
INSEQ          1                    Image name (seq. #)
INDISK         3                    Disk drive #
PLVER          2                    Version # of PL file. 0=>last
FUNCTYPE   '  '                     'NE','LG','NG', 'SQ', 'NQ'
                                    else linear
DPARM      *all 0                   (1,2) Clip recorded grays
DODARK         1                    Paint dark vectors as "dark"
OFMFILE    'RAINBOW'                Color grey scales....
DOCOLOR        1                    Use PLCOLORS ?
PLCOLORS       1            1       Line, character, background
               0            1       colors - see HELP.
               1            1          1           0.5
               1            0          1           1
               0            0          0           0
               0            0          0           0
               0            0          0           0
               0            0          0           0.8
               0.8          1
```

Figure 6.6: KNTR does polarization lines, contours, and grey-scale. Then LWPLA converts the grey-scale to pseudo-color and colors the lines making dark contours dark but dark polarization lines and stars bright. Data courtesy of Greg Taylor.

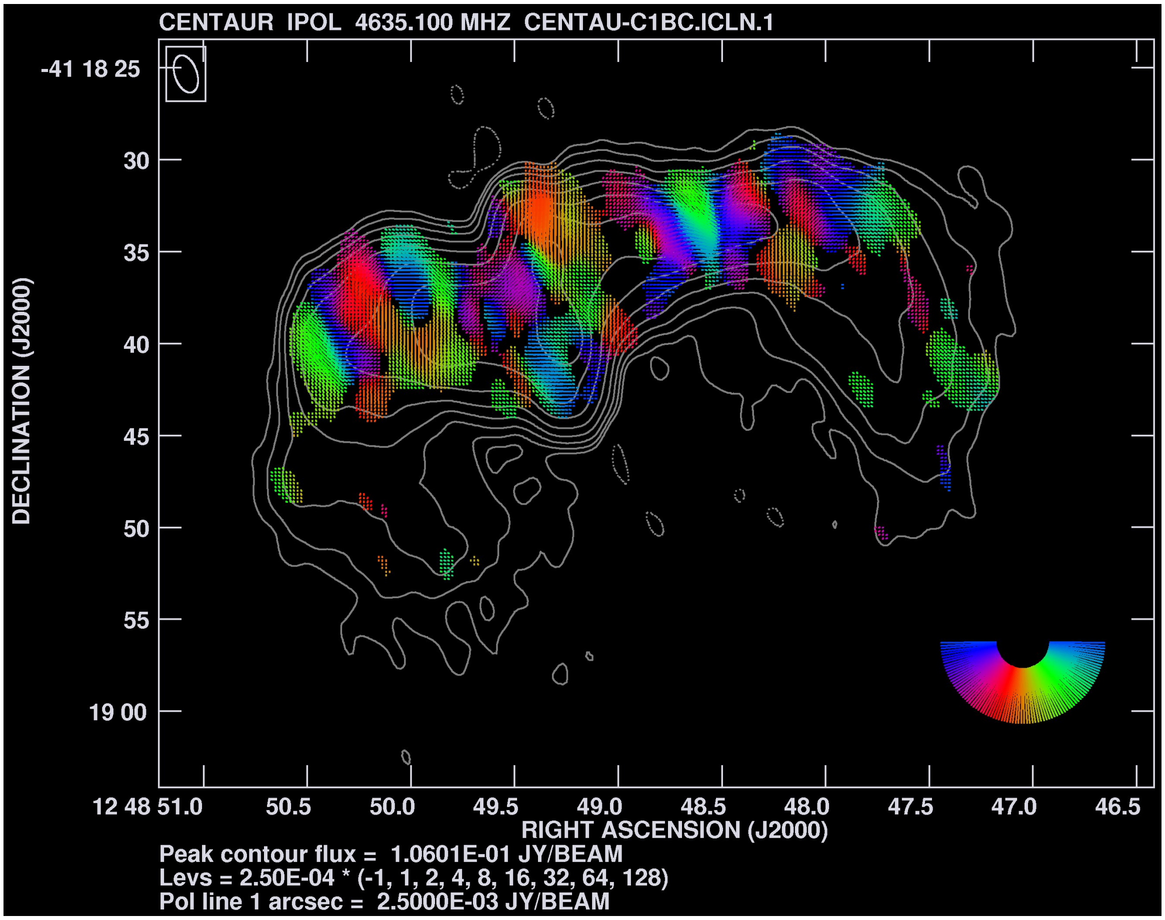



```
KNTR:  Task to generate a plot file for a contour & grey plot
DOCONT         2                      > 0 => do contours
                                      (1 or 2 => which name)
DOGREY         1                      > 0 => do grey scale
                                      (1 pr 2 => which name)
INNAME      'NGC6503     '            First image name (cube?)
INCLASS     'TVHUI '                  First image class
INSEQ          2                      First image seq. #
INDISK         3                      First image disk drive #
                                      Contour or grey or IPOL
IN2NAME     'NGC6503     '            Second image name
IN2CLASS    'XMOMO '                  Second image class
IN2SEQ         1                      Second image seq. #
IN2DISK        3                      Second disk drive #
PIXRANGE       0         400          Min,Max of image intensity
FUNCTYPE    'SQ'                      Image intensity transfer func
                                        'SQ' Square root
DOCOLOR        1                      Do RGB images as 3-color?
LTYPE         -3                      Type of labeling: 3 standard
                                      <0 -> no date/time
DOALIGN        1                      > 0 => images must line up
                                         (see HELP DOALIGN)
DOBLANK       -1                      Draw boundary between blanked
                                      areas and good areas?
DOWEDGE        3                      = 3 => put on top using full
                                             range of image values
```

```
CBPLOT         1                      Position for beam plot:
                                        1: lower left (default)
DODARK         1                      Plot dark vectors as black?
DARKLINE       0.33                   Switch to dark lines when
                                      grey-scale > DARKLINE 0-1

LWPLA:   Sends plot file(s) to a PostScript printer or file
INNAME      'NGC6503     '            Image name (name)
INCLASS     'TVHUI '                  Image name (class)
INSEQ          2                      Image name (seq. #)
INDISK         3                      Disk drive #
FUNCTYPE    '  '                      'NE','LG','NG', 'SQ', 'NQ'
                                      else linear
DPARM       *all 0                    (1,2) Clip recorded grays
DODARK         1                      Paint dark vectors as "dark"
OFMFILE     *all ' '                  Color grey scales....
DOCOLOR        1                      Use PLCOLORS ?
PLCOLORS       1         1            Line, character, background
               0         0.67         colors - see HELP.
               0.67      0.67            0            0
               0         0               0            0
               0         0               0            0.67
               0.67      0.67            0            0
               0         0               0            0
               1         0.7             1            0
               0.1       0
```

Figure 6.7: KNTR interprets the output of TVHUI as a three-color RGB image and overlays moment-0 contours. LWPLA adds coloring to the lines, using a less than pure white for both bright and dark contours so that they are not so dominant. Data courtesy of Eric Greisen, Kristine Spekkens, and Gustaaf van Moorsel.

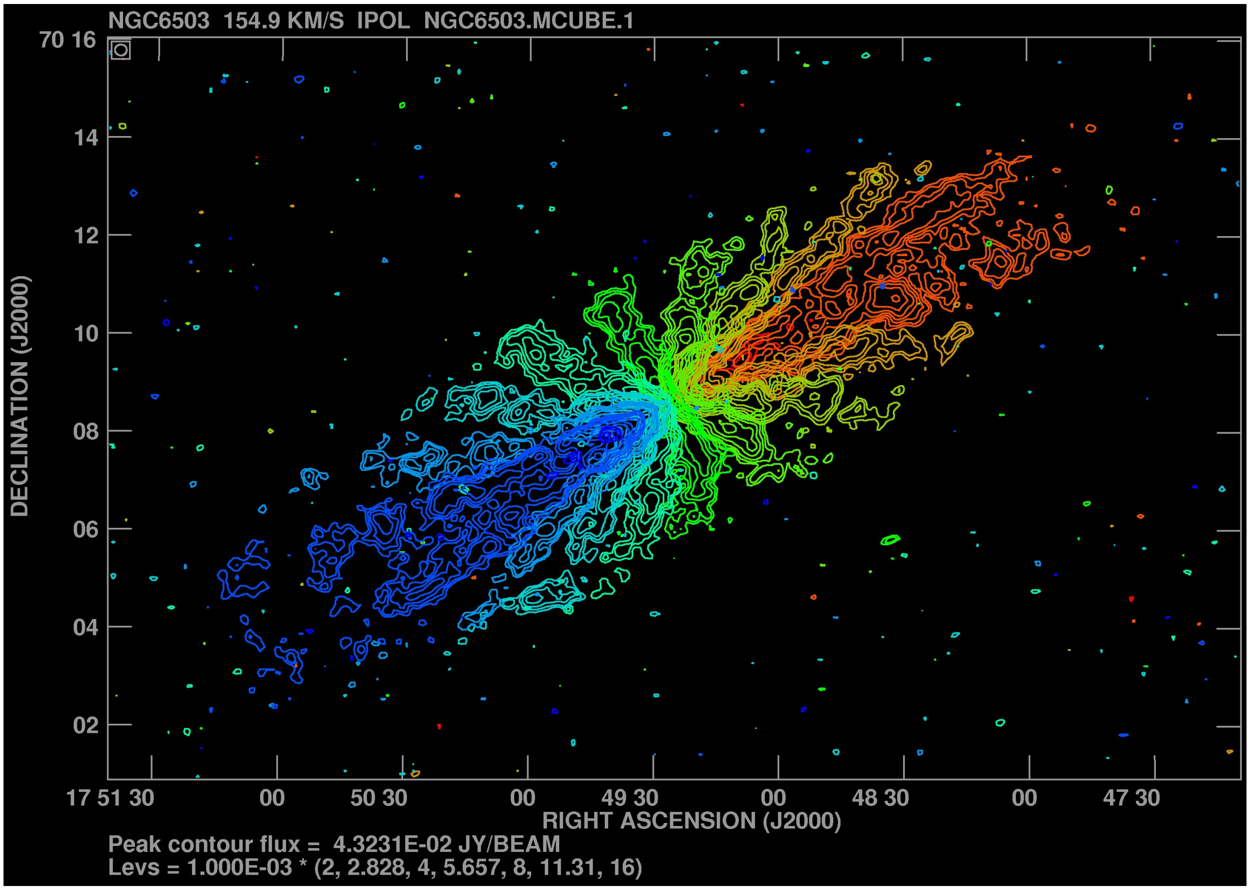



```
PCNTR:  Task to generate plot file for contour plus pol. vectors
DOCONT        1                    Draw contours? > 0 => yes
DOVECT        1                    Draw pol. vectors? > 0 => yes
DOGREY       -1                    Draw grey-scale image?
                                   Total intensity image:
INNAME     'CENTAU-C1BC '            Image name (name)
INCLASS    'ICLN  '                  Image name (class)
INSEQ         1                      Image name (seq. #)
INDISK        1                      Disk unit #
                                   Polarization intensity image:
IN2NAME    'CENTAU-C1BC '            (name) blank => INNAME
IN2CLASS   'QCLN  '                  (class) blank => 'PPOL'
IN2SEQ        1                      (seq. #) 0 => high
IN2DISK       0                      Disk drive #, 0 => any
                                   Polarization angle image:
IN3NAME    'CENTAU-C1BC '            (name) blank => INNAME
IN3CLASS   'UCLN  '                  (class) blank => 'PANG'
IN3SEQ        1                      (seq. #) 0 => high
IN3DISK       0                      Disk drive #,  0 => any
LTYPE        -3                    Type of labeling:
                                   <0 -> no date/time
CLEV       2.500E-04               Absolute value for levs
LEVS         -1           1        Contour levels (up to 30).
              2           4          8          16
             32          64         128        *rest 0
FACTOR     1000                    Mult. factor for Pol vector
                                      (see HELP)
```

```
ROTATE        0                    Angle to rotate Pol vector
                                      (in degrees)
XINC          1                    X-inc. of Pol vectors. 0=>1
YINC          1                    Y-inc. of Pol vectors. 0=>1
PCUT       1.250E-04               Pol. vector cutoff. P units.
ICUT       2.500E-04               Int. vector cutoff. I units.
POL3COL     160                    Color polarization vectors
                                   value in degrees = red
CBPLOT        4                    Position for beam plot:
                                     4: upper left

LWPLA:   Sends plot file(s) to a PostScript printer or file
RGBGAMMA      1           1        Gamma correction to apply
              2.5
DPARM      *all 0                  (1,2) Clip recorded grays
                                      before FUNCTYPE (0 to 1)
DOCOLOR       1                    Use PLCOLORS ?
PLCOLORS      0.85        0.85     Line, character, background
              0.9         0.5      colors - see HELP.
              0.5         0.5         0          0
              0           0           0          0
              0           0           0          0
              0           0           0          0
              0           0           0          0
              0.85        0.85        0.9        *rest 0
```

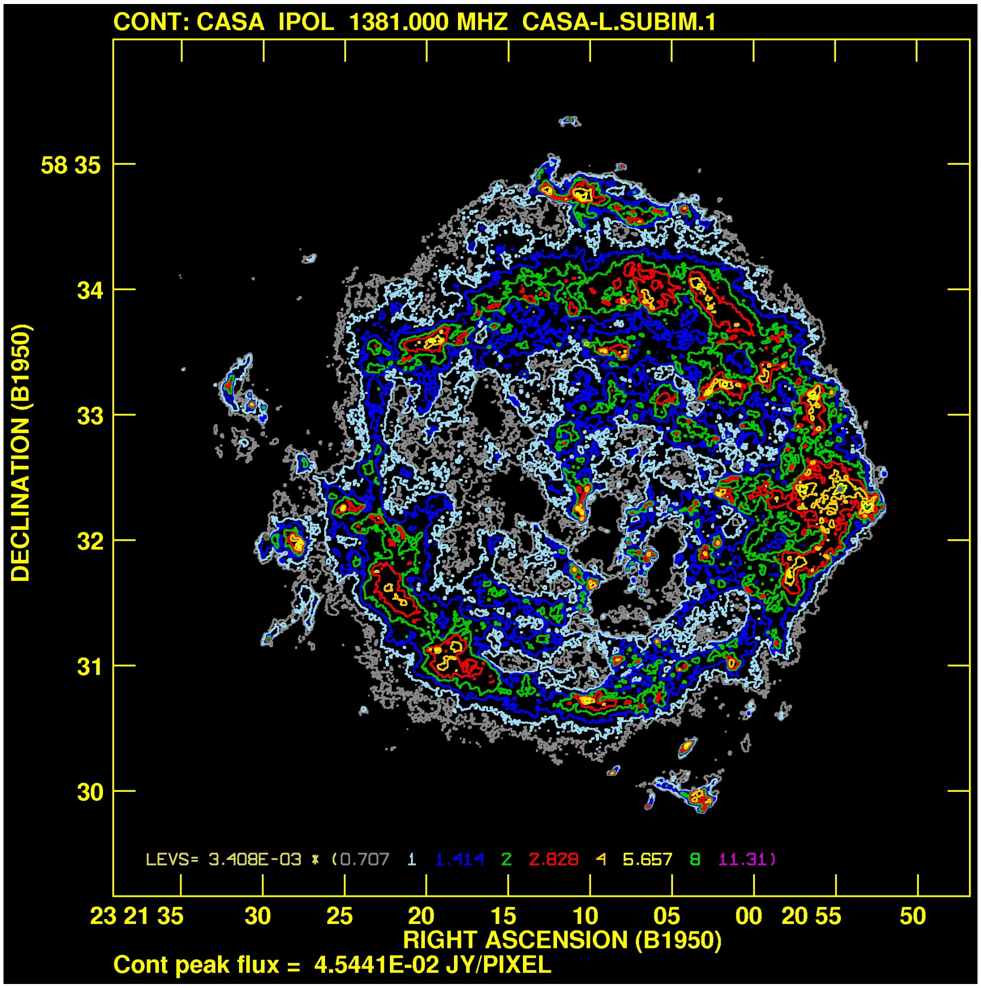
Figure 6.8: PCNTR plots contours and polarization vectors of Centaurus A. Color is used to show the complex changes in polarization position angle since the angles of short lines cannot be seen accurately. Data courtesy of Greg Taylor. For a discussion of this amazing pattern see Taylor, G.B., Fabian, A.C., & Allen, S.W. 2002, MNRAS, 334, 769, astro-ph/0109337 “Magnetic Fields in the Centaurus Cluster.”




```
PCNTR:  Task to generate plot file for contour plus pol. vectors
DOCONT        1                  Draw contours? > 0 => yes
DOVECT       -1                  Draw pol. vectors? > 0 => yes
BLC          51         167      Bottom left corner of images
             39        *rest 0
TRC         397         393      Top right corner of images
             89        *rest 0
CON3COL       5                  > 0 => overplot contours in
                                 color of multiple planes
                                 ZINC is CON3COL.
CLEV       0.001                 Absolute value for levs
LEVS          2          2.8284  Contour levels (up to 30).
              4          5.6569     8          11.3137
             16        *rest 0
CBPLOT        4                  Position for beam plot:
                                   4: upper left
```

```
LWPLA:    Sends plot file(s) to a PostScript printer or file
LPEN          3                     Pen width (dots).
RGBGAMMA      1            1        Gamma correction to apply
              2.5
DPARM      *all 0                   (1,2) Clip recorded grays
DOCOLOR       1                     Use PLCOLORS ?
PLCOLORS      0.6          0.6      Line, character, background
              0.6          0.06275  colors - see HELP.
              1            0           1           0.6706
              1            0           1           1
              0            0           0           0
              0            0           0           0
              0            0           0           0
              0.6          0.6         0.6      *rest 0
```

Figure 6.9: PCNTR plots contours every fifth plane from a data cube using colors related to the velocity. LWPLA adds coloring to the labeling and background and applies a gamma correction to blue. Data courtesy of Eric Greisen, Kristine Spekkens, and Gustaaf van Moorsel.

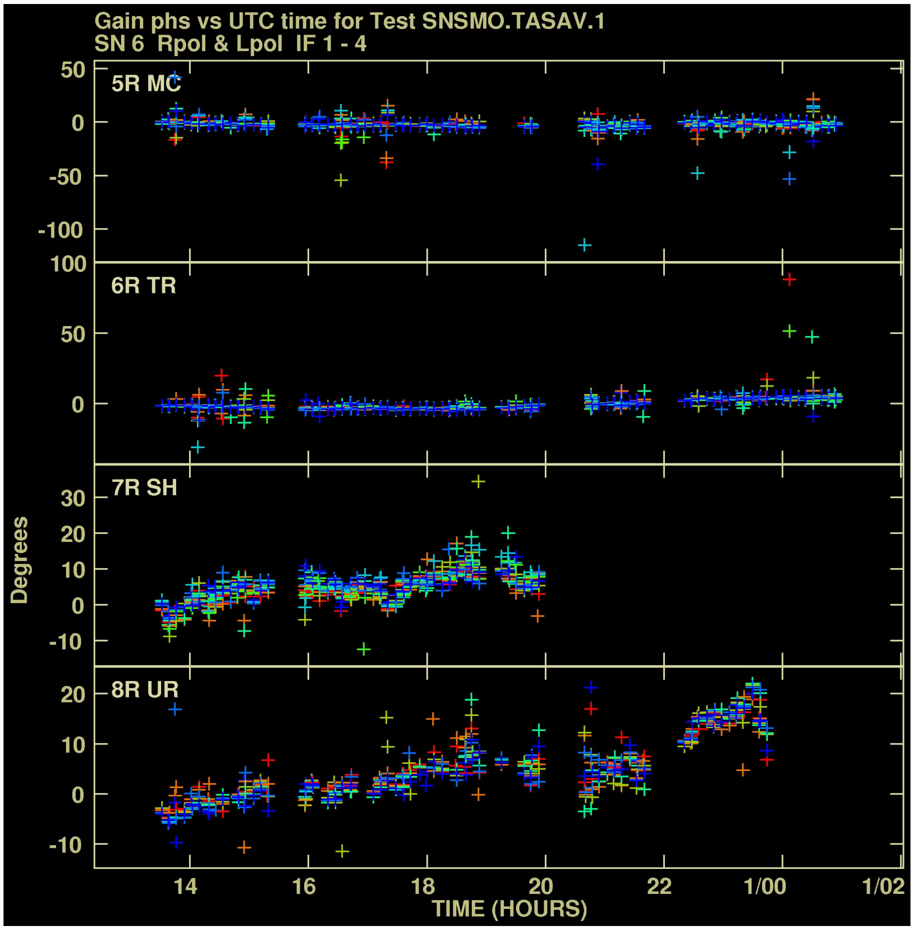



```
KNTR:  Task to generate a plot file for a contour & grey plot
DOCONT        1                   > 0 => do contours
                                  (1 or 2 => which name)
DOGREY       -1                   > 0 => do grey scale
                                  (1 pr 2 => which name)
DOVECT       -1                   > => do polarization vectors
                                  (1 or 2 => which is IPOL)
LTYPE        -3                   Type of labeling: 1 border,
                                  2 no ticks, 3 standard, 4 rel
                                  to center, 5 rel to subim cen
                                  6 pixels, 7-10 as 3-6 with
                                  only tick labels
                                  <0 -> no date/time
                                  special values for RGBLEVS
CLEV        0.003408              Absolute value for levs
                                     (used only if PLEV = 0).
LEVS          0.7071      1       Contour levels (up to 30).
              1.4142      2          2.8284      4
              5.6569      8        11.3137    *rest 0
CON3COL       0                   Color the contours by plane
```

```
RGBLEVS       0.2562      0.2562   Color each value of LEVS
              0.2562      0.3511      0.7297      0.9035
              0           0           1           0
              0.6205      0           1           0
              0           1           0.6205      0
              1           1           0           0
              0.8503      0           0.6594      0
              0.6594    *rest 0

LWPLA:   Sends plot file(s) to a PostScript printer or file
LPEN          3                       Pen width (dots).
RGBGAMMA      2.2         2.2         Gamma correction to apply
              2.2
OFMFILE    *all ' '                   Color grey scales....
DOCOLOR       1                       Use PLCOLORS ?
PLCOLORS      1           1           Line, character, background
              0         0.06275       colors - see HELP.
              1           0           1           0.6706
              1           0           1           1
              0           0           0           0
              0           0           0           0
              0           0           0           0
              1           1         *rest 0
```

Figure 6.10: KNTR plots contours of Cassiopeia A with each contour level separately colored under control of adverb RGBLEVS. The values of RGBLEVS were set by a procedure call STEPLEVS(10) made available by RUN SETRGBL. Image is from the *Images from the Radio Universe* CD, 1992, NRAO with the particular image from Anderson M., Rudnick, L., Leppik, P, Perley, R. & Braun, R. 1991, ApJ, 373, 146.




```
SNPLT:  Task to plot selected contents of SN, TY, PC or CL file.
INEXT      'SN'                      Input 'SN','TY','PC', 'CL'
INVERS        6                      Input table file version no.
STOKES     '    '                    Stokes type to plot: R, L,
                                        RR, LL, RRLL, DIFF, RATO
BIF           0                      First IF to plot, 0=>1.
EIF           0                      Last IF to plot 0 -> highest
ANTENNAS      5            6         Antennas to plot 0=>all
              7            8         *rest 0
NPLOTS        4                      Number of plots per page
XINC          1                      Plot every XINC'th point
OPTYPE     'PHAS'                    Data to be plotted:
                                     'PHAS','AMP ','DELA','MDEL',
                                     'RATE','TSYS','TANT','ATM ',
                                     'GEO ','DOPL','SNR ','SUM '
                                     'CCAL', 'DDLY', ' '=phas.
OPCODE     'ALSI'                    Type of plot:
                                     'IFDF' => diff BIF and EIF
                                     'IFRA' => ratio BIF and EIF
                                     'ALIF' => combine all IFs
                                     'ALST' => combine all Stokes
                                     'ALSI' => all IFs & Stokes
DO3COL        1                      > 0 use 3-color symbols for
                                     ALIF, ALST, ALSI OPCODEs and
                                     SUM OPTYPE.
XAXIS         0                      Variable data is to be
                                     plotted against, 0=>time.
```

```
FACTOR        1.5                    Scale plot symbols by FACTOR
                                     0 -> 1
LTYPE        -3                      Type of labeling: 1 border,
                                     2 no ticks, 3 - 6 standard,
                                     7 - 10 only tick labels
                                     <0 -> no date/time

LWPLA:   Sends plot file(s) to a PostScript printer or file
PLVER         0                      Version # of PL file. 0=>last
INVERS        0                      PL file version #, upper
                                     limit if > PLVER
ASPMM         0                      Arc sec. per mm. 0=self scale
LPEN          3                      Pen width (dots).
RGBGAMMA      1            1         Gamma correction to apply
              2.5
DPARM      *all 0                    (1,2) Clip recorded grays
                                        before FUNCTYPE (0 to 1)
DOCOLOR       1                      Use PLCOLORS ?
PLCOLORS      0.85         0.85      Line, character, background
              0.65         0.6       colors - see HELP.
              0.6          0.6          0           0
              0            0            0           0
              0.75         0.75         0.5         0
              0            0            0           0
              0            0            0           0
              0.75         0.75         0.5      *rest 0
```

Figure 6.11: SNPLT plots phases for four antennas with color indicating polarization and IF channel. Stokes 1, IF BIF is pure red changing through yellow, green, and cyan to Stokes 2, IF EIF as pure blue. When all symbols lie on top of each other, the last one (pure blue) will dominate.

# 7 ANALYZING IMAGES

In order to obtain useful astronomical information from the data, software exists for the analysis of images, combining of images, estimating of errors, etc. Only a few of the programs are described here; the others should be self-explanatory using the HELP and INPUTS files for the tasks listed in Chapter 13. A complete list of software in *AIPS* for the analysis of images may also be obtained at your terminal by typing ABOUT ANALYSIS C_R.

## 7.1 Combining two images (COMB)

The task COMB is a general purpose program for combining two images, pixel by pixel, to obtain a third image. Many options are available and, as a first example, we illustrate inputs to subtract a continuum image from a spectral line image cube.

### 7.1.1 Subtracting a continuum image from an image cube

A common method to obtain a spectral data cube containing only line signal without any continuum emission is to create a line-free continuum image $C$, and subtract it from the data cube $L$. For a more general discussion and alternative methods see § 8.3. COMB can be used to this purpose as follows:

| | |
|---|---|
| > TASK 'COMB' ; INP C_R | to review the required inputs. |
| > INDI 0 ; MCAT C_R | to help you find the catalog numbers of $C$ and $L$. |
| > INDI *n1* ; GETN *ctn1* C_R | to select the $L$ image cube from disk *n1* catalog slot *ctn1*. |
| > IN2D *n2* ; GET2N *ctn2* C_R | to select the $C$ image from disk *n2* catalog slot *ctn2*. |
| > OUTN '*xxxxx*' C_R | to specify *xxxxx* for the name of the continuum-free image cube. |
| > OUTC '*ccc*' C_R | to specify *ccc* for the class of the continuum-free image cube, *e.g.*, LCUBE. |
| > OPCODE 'SUM' C_R | to select the addition algorithm. |
| > APARM 1, -1 C_R | to specify that we want $+1 \times L - 1 \times C$. |
| > GO C_R | to compute the continuum-free, line-only output cube. |

Once COMB task has terminated with the message `COMB: APPEARS TO END SUCCESSFULLY`, you should find the requested image in your catalog:

| | |
|---|---|
| > MCAT C_R | to list the images in your catalog. |

### 7.1.2 Polarized intensity and position angle images

As a second example, we derive the polarization intensity and angle from the Q and U Stokes parameter images. To compute a polarized intensity image, enter:

| | |
|---|---|
| > TASK 'COMB' ; INP C_R | to review the required inputs. |
| > INDI 0 ; MCAT C_R | to help you find the catalog numbers of the Q and U images that you want to combine. |
| > INDI *n1* ; GETN *ctn1* C_R | to select the Q image from disk *n1* catalog slot *ctn1*. |
| > IN2D *n2* ; GET2N *ctn2* C_R | to select the U image from disk *n2* catalog slot *ctn2*. |
| > OUTN '*xxxxx*' C_R | to specify *xxxxx* for the name of the polarized intensity image. |

| | |
|---|---|
| > OUTC '*ccc*' C_R | to specify *ccc* for the class of the polarized intensity image, *e.g.*, PCLN. |
| > OPCODE 'POLC' C_R | to select the $\sqrt{\mathrm{Q}^2+\mathrm{U}^2}$ algorithm with correction for noise. |
| > BPARM *ns1* , *ns2* C_R | to specify the noise levels of the 2 images. |
| > GO C_R | to compute the corrected, polarized intensity image. |

AIPS will write the message TASK COMB BEGINS followed by a listing of the POL. INTENSITY algorithm. While it is running, you can prepare the inputs to make a polarization position angle image. Type:

| | |
|---|---|
| > OUTN '*yyyyy*' C_R | to specify *yyyyy* for the name of the polarization angle image. |
| > OUTC '*ddd*' C_R | to specify *ddd* for the class of the polarization angle image, *e.g.*, PSIMAP, CHICLN. |
| > OPCODE 'POLA' C_R | to select the $\frac{1}{2}\tan^{-1}\left(\frac{\mathrm{U}}{\mathrm{Q}}\right)$ algorithm. |

Once COMB has finished, enter:

| | |
|---|---|
| > GO C_R | to compute the polarization angle image. |

### 7.1.3 Other image combination options

COMB may also be used to rescale images, and to compute spectral indices, optical depths, etc. Type:

| | |
|---|---|
| > HELP COMB C_R | to review the available options. |

The OPCODE options are:

| | | | |
|---|---|---|---|
| 'SUM ' | Addition | $a_1M_1 + a_2M_2 + a_3$ | |
| 'SUMM' | Addition | $a_1M_1 + a_2M_2 + a_3$ | except blanked pixels replaced with 0 |
| 'MEAN' | Average | $a_1M_1 + a_2M_2$ | except $M_j$ where $M_i$ blanked |
| 'MULT' | Multiplication | $a_1M_1M_2 + a_2$ | |
| 'DIV ' | Division | $a_1M_1/M_2 + a_2$ | |
| 'SPIX' | Spectral Index | $a_1\ln(M_1/M_2)/\ln(\nu_1/\nu_2) + a_2$ | where $M_1 > a_3$ and $M_2 > a_4$ |
| 'OPTD' | Opacity | $a_1\ln(a_3M_1/M_2 + a_4) + a_2$ | where $M_1 > a_5$ and $M_2 > a_6$ |
| 'POLI' | RMS sum | $a_1\sqrt{M_1^2 + M_2^2} + a_2$ | |
| 'POLC' | RMS sum | $a_1C(M_1, M_2)\sqrt{M_1^2 + M_2^2} + a_2$ | where $C$ is a noise-based correction for Ricean bias |
| 'POLA' | Arctangent | $a_1\tan^{-1}(M_2/M_1) + a_2$ | where $\sqrt{M_1^2 + M_2^2} > a_3$ |
| 'REAL' | Real part | $a_1M_1\cos(a_2M_2) + a_3$ | |
| 'IMAG' | Imaginary part | $a_1M_1\sin(a_2M_2) + a_3$ | |
| 'RM ' | Rotation measure | $a_1 RM(M_1, M_2) + a_2$ | |
| 'CLIP' | Clipping | $M_1$ | except blanked where $a_1 > M_2 > a_2$ or $a_2 > a_1 > M_2$ or $M_2 > a_2 > a_1$ |

where the $a_i$ are user-adjustable parameters — specified by APARM — and $M_1$ and $M_2$ are the images selected by INNAME, *etc.* and by IN2NAME, *etc.*, respectively. COMB may be instructed to write an image of the estimated noise in the combination in addition to the direct result of the combination. These noise images may be used as inputs to COMB and, *e.g.*,BLANK to control later computations. When combining numerous images together, set DOHIST=-2 to prevent history files from becoming much larger than the images.

In 31DEC08, task CONVL can compute the cross-correlation of two images and report the location of the peak cross-correlation.

### 7.1.4 Considerations in image combination

COMB can use images of the uncertainties in the first two input images to control the computation of the output. The new task RMSD may be used to create an image of the rms in an image, computing the rms self-consistently in windows surrounding each pixel. Task FLATN can, in 31DEC07, compute weight and noise images corresponding to mosaiced images.

For some applications of COMB, undefined pixel values may occur. For example, if the spectral index is being calculated and the intensity level on either image is negative, the index is undefined. In this case, the pixel value is given a number which is interpreted as undefined or "blanked." Blanking also arises naturally in operations of division, opacity, polarization angle, and clipping and, of course, the input images may themselves be blanked. In addition, the output image can be blanked (set BPARM(4) = 0) whenever either $M_1$ <APARM(9) or $M_2$ <APARM(10). Alternatively, blanking may be done on the basis of the estimated noise (set BPARM(4) = 1) or signal-to-noise ratio (set BPARM(4) = 2) in the combination. See HELP COMB C_R for a description of these options and certain limitations in their use. With APARM(8) = 1 C_R, the user may specify that all undefined pixels are to be assigned an apparently valid value of zero, rather than the "magic" undefined-pixel value. Alternatively, the task REMAG can be used to replace blanked pixels in the output image with a user-specified value.

When combining two or more images, COMB, PCNTR, *et al.* must decide which pixels in the 2nd image go with which pixels in the 1st image. The user input parameter DOALIGN controls this process. A value of 1 requires the two headers to be correct and sufficiently similar that an alignment by coordinate value is possible. A value of −2 tells the programs to ignore the headers and align by pixel number. Enter HELP DOALIGN C_R for details and intermediate options. In some cases, the images may have been created on different grids which are correctly described in the headers. The observations, for example, could have differed in the phase reference position or projective geometry used or the imaging could have been done with different axis increments. Such images should *not* be combined directly. Instead, the header of one should be used as a template for re-gridding the other. tasks HGEOM and OHGEO provide this service with good interpolation methods. See § 7.6.1 and type EXPLAIN HGEOM C_R or EXPLAIN OHGEO C_R for more information.

## 7.2 Combining more than two images (SUMIM and SPIXR)

The task SUMIM is used to sum or average any number of images. Since AIPS has only a limited number of adverbs of the kind INNAME, IN2NAME, etc., SUMIM requires that all input images have identical INNAME and INCLASS. The input images are then specified by INSEQ (the sequence number of the *first* input image), IN2SEQ (the sequence number of the *last* input image), and IN3SEQ (the increment in sequence number). All input images have to reside on the *same* disk.

| | |
|---|---|
| > TASK 'SUMIM' ; INP C_R | to review the required inputs. |
| > INDI 0 ; MCAT C_R | to help you find the catalog number of the first input image. |
| > INDI *n* ; GETN *ctn* C_R | to select the first input image from disk *n* catalog slot *ctn*. |
| > IN2SEQ *s* C_R | to specify the sequence number of the last image to be included. |
| > IN3SEQ 0 | to specify the increment in sequence number (= 1). |
| > OUTN '*xxxxx*' C_R | to specify *xxxxx* for the name of the output image. |
| > OUTC '*ccc*' C_R | to specify *ccc* for the class of the output image. |
| > FACTOR *f* C_R | to specify the factor with which to multiply each image before adding. $f = 1$ leads to summation, $f = 0$ defaults to the inverse of the number of input images (average) |
| > GO C_R | to start SUMIM. |

This is a very noisy way to make a line-sum image. For more serious work, use BLANK (§ 7.4) and XMOM (§ 8.6) instead.

The task SPIXR is new in 31DEC05. It is intended to fit spectral indexes optionally including curvature to a cube of image planes. This cube is build with FQUBE to make an FQID axis out of irregularly spaced frequencies. The cube is transposed by TRANS to put the FQID or frequency axis first. Then SPIXR will do a least squares fit for spectral index. Again, the results will be noisy unless the initial images have been blanked and converted to similar spatial resolution.

The task RM reads a transposed cube of the polarization angle made with multiple COMBs, then FQUBE or MCUBE followed by TRANS. It fits the rotation measure and the intrinsic magnetic field direction using one of two possible methods to resolve lobe ambiguities. In 31DEC09, the task FARS reads two similar cubes of Q and U polarization images and performs a "rotation-measure synthesis" to image one or more rotation measure components.

## 7.3 Image statistics and flux integration

The task IMEAN is used to determine the statistics of the image inside, or outside, (starting with 31DEC08) a specified rectangular or circular area. It derives the minimum and maximum value and location, the rms, the average value and, if the image has been Cleaned, an approximate flux density within the area. A typical run might be:

| | |
|---|---|
| > TASK 'IMEAN' ; INP C_R | to list the input parameters. |
| > INDI *n* ; GETN *ctn* C_R | to select the image file from disk *n* catalog slot *ctn*. |
| > BLC *n1*, *n2* ; TRC *m1*, *m2* C_R | to set the window from (*n1*,*n2*) to (*m1*,*m2*) — or use TVWIN with the cursor on the TV. |
| > DOHIST TRUE C_R | to make a plot file of the pixel histogram. |
| > PIXRANGE *x1*, *x2* C_R | to set the range of the histogram from *x1* to *x2*. |
| > NBOXES *n* C_R | to set the number of boxes in the histogram. |
| > GO C_R | to run the task. |

A circular aperture may be specified with BLC = -1,*radius* ; TRC = $X_c, Y_c$. IMEAN attempts to determine the true noise of the image by fitting the peak of the histogram and reports both that result and the one found by including all pixels within the window. The adverbs PIXSTD gives IMEAN help in determining which values to use for the true noise fit. Before running IMEAN, try

| | |
|---|---|
| > IMSTAT C_R | to derive simple image statistics. |
| > PIXSTD = PIXSTD / 10 C_R | to change the source-affected rms to a better guess for the real non-source rms. |

Beginning with 31DEC02, IMEAN actually returns the adverbs PIXSTD and PIXAVG from the histogram fit to the AIPS program.

The statistics will appear in the AIPS window. For a hard copy type:

| | |
|---|---|
| > PRTASK 'IMEAN' ; PRTMSG C_R | with PRIO ≤ 5. |

To see the histogram of the intensities, an example of which is shown in § 6.3.2.3, type one of:

| | |
|---|---|
| > GO TKPL C_R | to display the histogram in the TEK window. |
| > GO LWPLA C_R | to display the histogram on a PostScript printer. |

The verbs TVSTAT and IMSTAT provide similar functions to IMEAN without the histogram and true rms options. Both return their results as AIPS parameters PIXAVG (mean), PIXSTD (rms), PIXVAL (maximum), PIXXY (pixel position of the maximum), PIX2VAL (minimum), PIX2XY (pixel position of the minimum). IMSTAT uses the same file name, BLC, and TRC parameters as IMEAN including the circular aperture convention. It is useful to prepare the initial rms guess for that task although the PIXSTD it returns will often be a factor of several too large. TVSTAT, however, works on the image plane currently displayed on the TV and is not limited to a single rectangular area. Instead, the TV cursor is used to mark one or more polygonal regions over which the function is to be performed. Type EXPLAIN TVSTAT C_R for a description of its operation.

The interactive task BLSUM employs a method similar to that of TVSTAT. The TV cursor is used to mark a region of interest in a "blotch" image. Then BLSUM finds the flux in that region not only in the blotch image but also in each plane (separately) of a second image. More than one region of interest may be done in any given execution of the task. In spectral-line problems, the blotch image is often the continuum or the line sum while the second image is the full "cube" in almost any transposition. In 31DEC09, the spectrum obtained may be saved as a SLice file for further analysis and display. Numerous continuum applications also exist (*e.g.*, polarization, comparison across frequency). Type EXPLAIN BLSUM C_R for a description of the operation.

The verb IMDIST is used to measure the angular distance and position angle between two pixel positions in up to two images. The separation is returned as adverb DIST. Verb TVDIST allows you to select the two pixels interactively from the TV display.

Beginning with 31DEC06, the verb IMCENTER may be used to determine the intensity-weighted centroid of a rectangular or circular portion of an image. The verb returns adverbs PIXXY, COORDINA, and ERROR giving the pixel and physical coordinates of the centroid and an indicator of success or failure.

## 7.4 Blanking of images

In order to determine accurate flux values in images, or moments of velocity profiles, it is desirable to restrict the integrations to pixels that contain emission, or, in other words, to exclude pixels that contribute only noise. If this is not done, the inclusion of noisy pixels will increase the rms in the derived integrated value to an unacceptable extent. The task BLANK gives the user the opportunity to replace pixels containing pure noise with values that AIPS and its tasks interpret as *undefined*. The decision whether a certain pixel contains pure noise, or carries some emission, can be made subjectively (using the TV) or in a more objective fashion (see below for an example). In all cases, BLANK creates an output image which is a copy of the input image with some pixels replaced by undefined values, or — if the user specifies it — by the value zero.

The most straightforward use of BLANK is to apply a cutoff to the input image, e.g. let BLANK replace with an undefined value every pixel in the input image that lies below a specified. *e.g.*, $3\sigma$ noise level. This effectively removes almost all noisy pixels. The disadvantage is that this method also removes any *signal* below the $3\sigma$ noise level. Since a substantial fraction of the total flux may be "hidden" in pixels below $3\sigma$, this method prevents an accurate total flux determination. Another straightforward use of BLANK is to remove all pixels outside a user-specified radius. This allows blanking regions for which the primary-beam corrections, and hence the noise levels, are large.

A better way to perform the blanking is one which is not based on the pixel values in the input image itself, but on those in a *second* input image. Typically this is a convolved (spatially and/or in velocity) version of the input image, which has a higher signal to noise for extended emission than the input image. In the example given here we have the input image $I_1$ of full spatial resolution, and a convolved version of this input image $I_2$ with a linear beam size roughly twice full resolution. Careful inspection of this second image has shown that there are no outlying noise peaks above $f$ mJy/beam. BLANK is then run as follows:

| | |
|---|---|
| > TASK 'BLANK' ; INP C_R | to review the required inputs. |
| > INDI 0 ; MCAT C_R | to help you find the catalog numbers of $I_1$ and $I_2$. |
| > INDI *n1* ; GETN *ctn1* C_R | to select $I_1$ from disk *n1* catalog slot *ctn1*. |
| > IN2D *n2* ; GET2N *ctn2* C_R | to select $I_2$ from disk *n2* catalog slot *ctn2*. |

| | |
|---|---|
| > OUTN '*xxxxx*' C_R | to specify *xxxxx* for the name of the blanked output image. |
| > OUTC '*ccc*' C_R | to specify *ccc* for the class of the blanked output image. |
| > OPCODE 'IN2C' C_R | to specify that the blanking is performed using pixel values in a *second* input image. |
| > DPARM(3) *sim* $-f$ , $f$ C_R | to set DPARM(3) and DPARM(4) to specify that all pixels with fluxes in the second input image in the interval *(-f,f)* should be blanked. |
| > GO C_R | to compute the blanked output image. |

The task REMAG can be used to replace blanked pixels by a value to be specified by the user.

The *AIPS* TV display may be used to do a more subjective blanking with this task. Set OPCODE 'TVCU' C_R to display the image, one plane at a time in any transposition. You will be prompted to set "blotch" regions (much like TVSTAT and BLSUM) to define the areas to be blanked. This is one method for having different regions of signal at different spectral channels. There are also four windowing methods for blanking spectral-line cubes which have been transposed to have the frequency axis be first. In these methods, a window (range of spectral channels) about the peak signal in each spectrum is retained.

The task RMSD may be used to write a version of the input image blanking pixels below $N$ times the rms in the image, computing the rms self-consistently in windows surrounding each pixel.

## 7.5 Fitting of images

There are three tasks and two verbs which estimate the position and intensity of a component on a two-dimensional image. The simplest and fastest methods are the verb IMCENTER and MAXFIT. The latter fits a two-dimensional parabola to the maximum within a few pixels of an image position, and gives the peak and its position. The tasks IMFIT and JMFIT are similar and fit an image subsection with up to four Gaussian components with error estimates. Task SAD attempts to automate the process of finding and fitting Gaussian components in an image. Additionally, in one dimension, the task SLFIT fits Gaussian components to slice data and the task XGAUS fits Gaussian components to each row of an image.

### 7.5.1 Centroid fits (IMCENTER) and parabolic fit to maximum (MAXFIT)

Beginning in 31DEC06, you may determine a centroid for a region in an image with the verb IMCENTER. Set the name parameters for the desired image and then define the region with adverbs BLC and TRC, perhaps using TVLOAD; TVWIN C_R. Set FLUX if you wish to limit the computations to pixel values greater than FLUX. Then

| | |
|---|---|
| > IMCENTER; IMVAL C_R | to find the value at the centroid. |

MAXFIT's speed makes it useful for simple regions. Type:

| | |
|---|---|
| > EXPLAIN MAXFIT C_R | to get a good explanation of the algorithm. |

The inputs should be self-explanatory. The IMSIZE parameter can be important in crowded fields. MAXFIT can be used conveniently by first displaying the image on the TV and then typing:

> IMXY ; MAXFIT C_R

First the cursor will appear on the TV. Move it close to a maximum, press the left mouse button, and hit button A, B, C, or D. The fit will appear in your *AIPS* window. Adverb values PIXXY, PIXVAL, COORDINA, and ERROR will be set appropriately.

### 7.5.2 Two-dimensional Gaussian fitting (IMFIT)

A more sophisticated least-squares fit of an image is obtained with IMFIT, which fits an image with up to four Gaussian components and attempts to derive error estimates. A linear or curved, two-dimensional "baseline" may also be fitted. A sample set-up is as follows:

| | |
|---|---|
| > TASK 'IMFIT' ; INP C_R | to list the input parameters. |
| > INDI *n* ; GETN *ctn* C_R | to select the image from disk *n* catalog slot *ctn*. |
| > BLC *n1*, *n2* ; TRC *m1*, *m2* C_R | to set the area to be fitted as (*n1*,*n2*) to (*m1*,*m2*) — or use TVWIN with the cursor on the TV. |
| > NGAUSS 2 C_R | to set the number of components to be fitted to 2. |
| > CTYPE 1, 1 C_R | to have both components be Gaussians. |
| > GMAX 0.34 0.20 C_R | to give estimates of peak intensity in Jy. |
| > GPOS 200, 100, 210, 110 C_R | to give estimates of the pixel locations of each component. |
| > GWID 6 4 20 6 4 20 C_R | to give estimates of component sizes in pixels. In this case, each component has a FWHM of 6 by 4 pixels with the major axis at position angle 20 degrees. |
| > DOWID FALSE C_R | to hold all of the widths constant (if required). |
| > INP C_R | to review inputs. |
| > GO C_R | to run the task. |

To improve accuracy, include as small an area as possible in the fit. In some cases, it is useful to hold some of the parameters constant, particularly when fitting a complex clump of emission with several components. The parameters can interact. Error estimates are given for each component. IMFIT will sometimes fail to converge in complicated regions. When this happens, you might try using the task JMFIT, which is very similar in function, but uses a different mathematical method to minimize the rms. Comparison of the results of IMFIT and JMFIT will sometimes be instructive. The tasks will correct the results for the effects of the primary beam and bandwidth smearing if you wish. It is wise to treat the results of MAXFIT, IMFIT and JMFIT with caution. The estimates of the errors, in particular, are based on theory and on trials of deconvolution over a range of widths.

Use RUN INPFIT C_R (see § 12.2.1) to obtain a procedure which will help to supply input parameters to IMFIT. This RUN file loads a procedure called INPFIT into AIPS. To invoke it, load the image which you want to fit onto the TV with TVALL and type INPFIT ( 3 ) C_R to specify three components. The procedure will prompt you to set the desired sub-image window with the TV cursor (it uses verb TVWINDOW) and then to point the TV cursor at the peaks of each of the Gaussians, click the left mouse button when the cursor is correctly placed, and push button A, B, C, or D. The inputs GMAX, GPOS, BLC, and TRC are set in this way.

### 7.5.3 Source recognition and fitting (SAD)

The task SAD (§ 10.4.4) attempts to find all sources in a sub-image whose peaks are brighter than a given level. It searches the sub-image specified by BLC and TRC for all points above this level and merges such points in contiguous "islands." For each island, initial estimates of the strength, size, and number of components are generated. Then the fitting algorithm used in JMFIT is called to determine the least square Gaussian fit. Solutions which fail to meet certain criteria can be retried as two components and, if they still fail, rejected. SAD is a task with many adverbs, a full description of which would be beyond the scope of this *CookBook*. Enter EXPLAIN SAD C_R for a full description of this task and its parameters. The effects of bandwidth smearing and the primary beam may be corrected. SAD produces a Model-Fit extension file which may be converted to a stars file (§ 6.3.2) with MF2ST. The MF file may be printed with MFPRT in formats suitable for STARS and in formats which may be used, with task BOXES, to prepare Clean boxes for input to the imaging tasks.

### 7.5.4 Gaussian fits to slices (SLFIT)

You can generate a one-dimensional slice (profile) through any plane (characterized by the first two coordinates) of an image file using the AIPS task SLICE. The output file is appended to the image file as an SL extension file. Slices are computed along lines in the two-dimensional image joining any valid pair of points selected by BLC and TRC. Beginning with 31DEC09, tasks ISPEC and BLSUM may also save slice extension files. These are somewhat different in that they usually represent a sum over an area in the sky as a function of frequency. Nonetheless, the slice file display and fitting software is of considerable use with these as well. The set of software dealing with slice file analysis and display can be obtained on your terminal by typing ABOUT ONED C_R. The list is also given in Chapter 13.

To generate a slice:

> TASK 'SLICE' ; INP C_R    to review the inputs to SLICE.

Use INDISK and GETNAME to select the input image. The beginning (BLC) and ending (TRC) points for the slice can be specified conveniently using the TV cursor if the image to be sliced is first displayed on the TV with TVLOD or TVALL. To set these points with the TV, type:

> SETSLICE C_R

then set the TV cursor to the desired beginning point for the slice, press the left mouse button, and repeat for the ending point for the slice. Note that, for slices, BLC need not be below or to the left of TRC. Finally:

> GO C_R    to generate the slice file.

Slice files may be output as ASCII text files using the OUTFILE adverb. Slice files are archived in your disk catalog as SL extensions to the image file from which they were derived. Running SLICE again with new parameters does not overwrite the slice file, but makes another with a higher "version" number. To review and/or delete slice files, follow the instructions for EXTLIST and EXTDEST of plot files in § 6.3 above, but use INEXT 'SL' C_R in place of INEXT 'PL' C_R.

When SLICE has terminated, the file may be plotted in the TV display on your workstation using:

> INP TVSLICE C_R    to review the inputs to verb TVSLICE.

> INEXT 'SL' ; EXTL C_R    to find the intensity range and number of points in the interpolated slice.

The default scales will plot all slice points on a vertical scale from the slice minimum to the slice maximum. You can alter the part of the slice that is plotted and the vertical scale by specifying, for example:

> BDROP 100 ; EDROP 225 C_R    to drop 100 points from the beginning and 225 points from the end of the plotted portion of the slice.

> PIXRANGE -0.001 0.004 C_R    to set the range of the vertical axis to be $-1$ to 4 mJy/beam.

> TVSLICE C_R    to plot the slice in the TV window.

Note: several slices may be put on one TV plot. Use TVASLICE C_R for the additional ones. Multiple colors may be achieved by using different graphics channels (GRCHAN).

Slice files may be converted into plot files by:

> GO SL2PL C_R

The resulting plot files may then be output by:

> GO LWPLA C_R    to display the plot file on a PostScript printer.

> GO TKPL C_R    to display the plot file in the TEK window.

> GO TVPL C_R    to display the plot file on a TV graphics plane.

The task SLFIT fits Gaussian components to one-dimensional data in slice files. Assuming that the usual GETNAME step has been done, a typical session would go like:

> INEXT 'SL'; EXTL C_R    to list the parameters of the slice files.

> INVERS $m$ C_R    to select the $m^{\rm th}$ file for analysis.

| | |
|---|---|
| > TVSLICE C_R | to plot the slice in the TV window. |
| > EDROP 840 ; BDROP 700 C_R | to select a subsection to fit. |
| > TVSLICE C_R | to re-plot just the subsection. |
| > NGAUSS 2 C_R | to fit 2 Gaussians. |
| > TVSET C_R | |

This verb will prompt you to POSITION CURSOR AT CENTER & HEIGHT OF GAUSSIAN COMP 1. Move the cursor to the requested position and hit any button. Then you are asked to POSITION CURSOR AT HALFWIDTH OF GAUSSIAN COMP 1. Move the cursor to the half-intensity point of the component and click any button. Continue until all components have been entered. (Note: these operations are also available on the TEK device with verbs beginning with TK. We recommend the TV versions since cursor reading in X-Windows emulations of TEK devices appears to be unreliable.) Then type:

| | |
|---|---|
| > TVAGUESS C_R | to plot the guess on top of the slice plot. |

If everything looks ok, then:

| | |
|---|---|
| > GO SLFIT C_R | to run the task. |

When the task gets an answer, the solution will be displayed as AIPS messages, recorded in the message file, and recorded in the slice file itself. To get a hard copy of the results:

| | |
|---|---|
| > PRTASK 'SLFIT' ; PRTMSG C_R | to print the message file. |

and, to display the results in the TV window, enter:

| | |
|---|---|
| > TVSLICE C_R | to re-plot the slice. |
| > TVAMODEL C_R | to add the model results to the plot. |
| > TVARESID C_R | to add the residuals (data – model) to the plot. |

To get a higher quality plot of the results, an example of which is shown in § 6.3.2.1, type:

| | |
|---|---|
| > DORES TRUE ; DOMOD TRUE C_R | to request the model and the residuals. |
| > DOSLICE FALSE C_R | to leave the slice data out of the plot. |
| > TASK 'SL2PL' ; GO ; WAIT C_R | to make a plot file and wait for it to be complete. |

### 7.5.5 Other one-dimensional Gaussian fits (XGAUS)

XGAUS is an interactive task which can fit up to four Gaussians and a linear baseline to each row of an image. It writes its results as a set of $n-1$ dimensional image files. Although XGAUS was designed for use primarily on transposed spectral-line cubes (see § 8.5.2), it has a wide variety of other applications. The interaction is optional and uses the TV or TEK window on your workstation. The data, initial guess, model fit, and the residual for each row may be plotted on the TV or TEK screen. If the number of Gaussians being fit is larger than one, you may choose for each row to enter a revised initial guess using the cursor in the TV or TEK window. This process is similar to that of TVSET described above (§ 7.5.4). This task has too many options to do them justice here. Enter EXPLAIN XGAUS C_R for details.

## 7.6 Image analysis

Image analysis is a very broad subject covering essentially all that AIPS does or would like to do plus specialized programs designed to analyze a user's particular image in the light of his favorite astrophysical theories. AIPS provides some general programs to perform geometric conversions, image filtering or enhancement, and model fitting and subtraction. These are the subjects of the following sections. Specialized programs for spectral-line, VLBI, and single-dish data reduction are described in Chapter 8, Chapter 9, and

Chapter 10, respectively. Chapter 11 of *Synthesis Imaging in Radio Astronomy*[1] covers the topic of image analysis in more detail.

### 7.6.1 Geometric conversions

The units of the geometry of an image are described in its header by the coordinate reference values, reference pixels, axis increments, axis dimensions, and axis types. The types of coordinates (celestial, galactic, etc.) and the type of tangent-plane projection (SIN from the VLA, TAN from optical telescopes, ARC from Schmidt telescopes, NCP from the WSRT) are specified in the AIPS headers by character strings. See AIPS Memo No. 27 for details of these projections. A "geometric conversion" is an alteration of one or more of these geometry parameters while maintaining the correctness of both the header and the image data. The AIPS tasks which do this interpolate the data from the pixel positions in the input image to the desired pixel positions in the output image.

The simplest geometric conversion is a re-gridding of the data with new axis increments and dimensions with no change in the type of projection or coordinates. The task LGEOM performs this basic function and also allows rotation of the image. One use of this task is to obtain smoother displays by re-gridding a sub-image onto a finer grid. To rotate and blow up the inner portion of a $512^2$ image, enter:

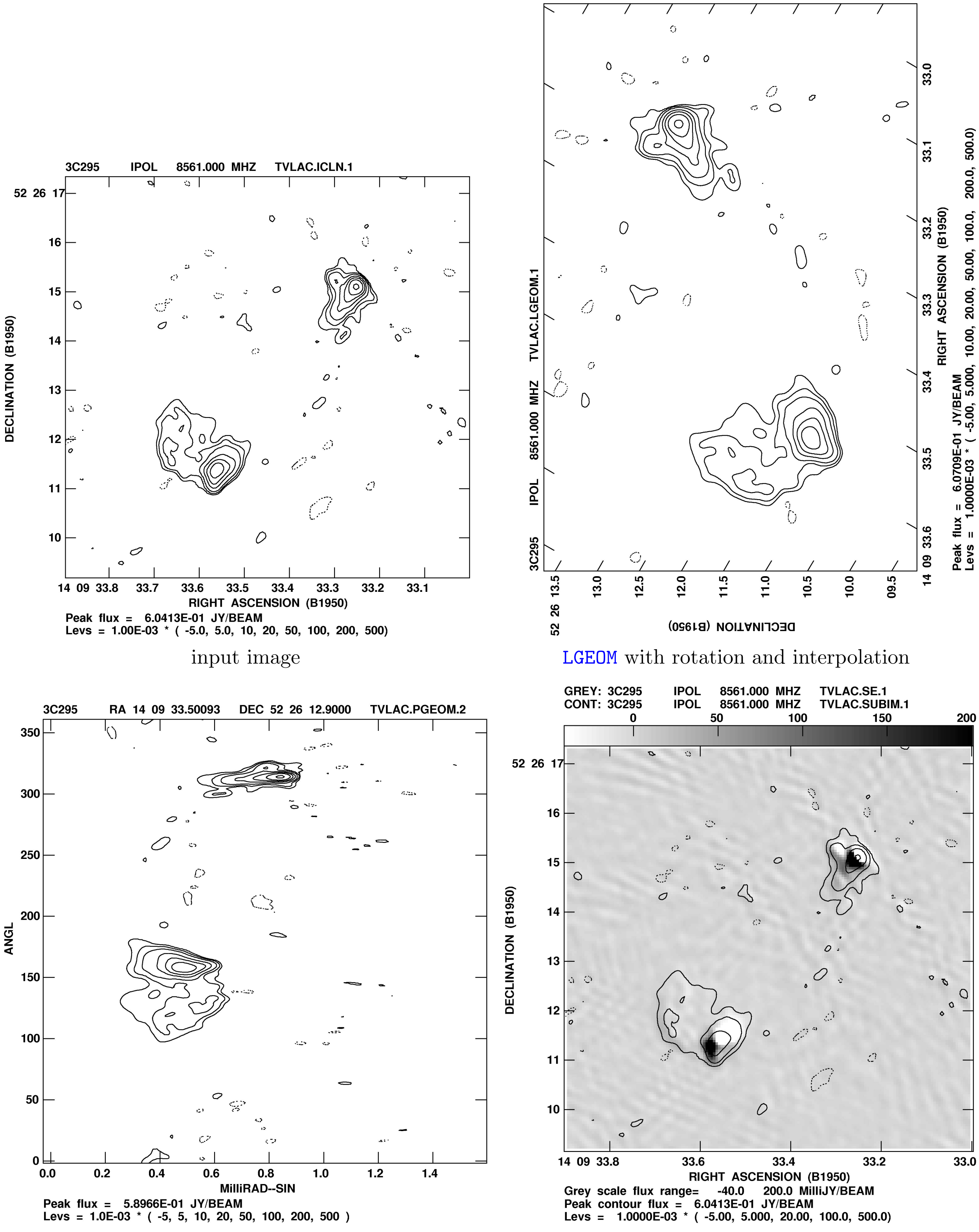
| | |
|---|---|
| > TASK 'LGEOM' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to select the image. |
| > BLC 150 ; TRC 350 C_R | to select only the inner portion of the image area. |
| > IMSIZE 800 C_R | to get an $800^2$ output image. This will allow the sub-image to be blown up by a factor of 3 and rotated without having the corners "falling" off the edges of the output image. |
| > APARM 0 C_R | to reset all parameters to defaults. |
| > APARM(3) = 30 C_R | to rotate the image 30° counterclockwise (East from North usually). |
| > APARM(4) = 3 C_R | to blow up the scale (axis increments) by a factor of 3. |
| > APARM(6) = 1 C_R | to use cubic polynomial interpolation. |
| > INP C_R | to check the inputs. |
| > GO C_R | to run the program. |

LGEOM allows shifts of the image center, an additional scaling of the $y$ axis relative to the $x$ axis, and polynomial interpolations of up to $7^{\text{th}}$ order. OGEOM is similar to LGEOM, but handles blanked pixels in a manner that does not increase the blanked area.

A much more general geometric transformation is performed by OHGEO and HGEOM, which convert one image into the geometry of a second image. The type of projection, the axis increments, the rotation, and the coordinate reference values and locations of one image are converted to those of a second image. One of these tasks should be used before comparing images (with COMB, KNTR, PCNTR, BLANK, TVBLINK, etc.) made with different geometries, *i.e.*, radio and optical images in different types of projection or VLA images taken with different phase reference positions. Use EXPLAIN OHGEO C_R to obtain the details and useful advice. SKYVE regrids images from the Digital Sky Survey (optical DSS) into coordinates recognized by AIPS.

A potentially very powerful transformation is performed by PGEOM. In its basic mode, it converts between rectangular and polar coordinates. An example of this operation is illustrated in Figure 7.1. However, PGEOM can also "de-project" elliptical objects to correct for their inclination and "unwrap" spiral objects. Type EXPLAIN PGEOM C_R for information.

[1] *Synthesis Imaging in Radio Astronomy*, A collection of Lectures from the Third NRAO Synthesis Imaging Summer School, eds. R. A. Perley, F. R. Schwab and A. H. Bridle, Astronomical Society of the Pacific Conference Series Volume 6 (1989)




input image

LGEOM with rotation and interpolation

PGEOM

NINER: 'SE ' derivative

Figure 7.1: Geometric and other functions on an image.

### 7.6.2 Mathematical operations on a single image

The task MATHS allows the user to do a mathematical operation on a single image on a pixel by pixel basis. Currently supported mathematical operators are: SIN, COS, TAN, ASIN, ACOS, ATAN, LOG, LOGN, ALOG, EXP, POLY, POWR, and MOD. An example of MATHS follows, in which the output image (OUT) is computed in terms of the natural logarithm of the input image (IN) as follows: $\texttt{OUT} = 4 + 2 \times (\log(3 \times \texttt{IN}) - 1)$

| | |
|---|---|
| > TASK 'MATHS' ; INP C<sub>R</sub> | to review the required inputs. |
| > INDI 0 ; MCAT C<sub>R</sub> | to help you find the catalog number of the input image. |
| > INDI *n* ; GETN *ctn* C<sub>R</sub> | to specify the image, on disk *n* catalog slot *ctn* as the input. |
| > OUTN '*xxxxx*' C<sub>R</sub> | to choose *xxxxx* as the name for the output image. |
| > OUTC '*ccc*' C<sub>R</sub> | to choose *ccc* as the class for the output image. |
| > OPCODE 'LOGN' C<sub>R</sub> | to specify the operation to be performed (a natural logarithm). |
| > CPARM 4 , 2 , 3 , -1 C<sub>R</sub> | to specify the coefficients. |
| > GO C<sub>R</sub> | to start MATHS. |

Undefined output pixels (in the current example, all pixels in the input image $\leq 0$) are either blanked (CPARM(6) $\leq 0$) or put to zero (CPARM(6) $> 0$). Type EXPLAIN MATHS C<sub>R</sub> for further information on the available operators and the meaning of CPARM for any particular operator.

### 7.6.3 Primary beam correction

PBCOR allows correction for the attenuation due to the shape of the primary beam. Its use is straightforward:

| | |
|---|---|
| > TASK 'PBCOR' ; INP C<sub>R</sub> | to review the required inputs. |
| > INDI 0 ; MCAT C<sub>R</sub> | to help you find the catalog number of the input image |
| > INDI *n* ; GETN *ctn* C<sub>R</sub> | to select the input image from disk *n* catalog slot *ctn*. |
| > OUTN '*xxxxx*' C<sub>R</sub> | to specify *xxxxx* for the name of the output image. |
| > OUTC '*ccc*' C<sub>R</sub> | to specify *ccc* for the class of the output image |
| > PBPARM 0 C<sub>R</sub> | to use the VLA or ATCA beam parameters fit for the particular receiver. |
| > COORDIN 0 C<sub>R</sub> | to use the pointing position from the image header. |
| > GO C<sub>R</sub> | to start PBCOR. |

The default behavior requested above uses the position in the header as the pointing position and uses the empirically determined shape of the VLA or ATCA primary beam; PBCOR will scale the primary beam shape according to the frequency provided in the image header and use the parameters associated with the particular antenna feed. These defaults can be overridden by specifying particular values of COORDIN and PBPARM.

An image of the primary beam may be generated with the task PATGN using OPCODE 'BEAM' C<sub>R</sub> with other adverbs to give the frequency, cell size, image size, and, optionally, the parameters of the beam shape. The ATCA beam may also be formed.

### 7.6.4 Changing the resolution of an image

CCRES allows you to change the resolution of a Cleaned image by removing any Clean components in the image and then restoring Clean components with your choice of resolution. The task may also be used to remove Clean components to create a residual image or to restore Clean components to an existing residual image. CCRES allows you to smooth or hyper-resolve your image. Unlike RSTOR, CCRES in 31DEC08 rescales the residual image to put it into units of Jy/beam for the new beam. This may be a superior way to image with a beam that does not replicate the central portion of the dirty beam. IMAGR leaves the residual image in units of Jy per dirty beam while restoring the Clean components in units of Jy per the Clean beam given in the header.

Note that CCRES only changes the Clean components, not the residual image resolution. Furthermore, CCRES does not take into account the varying resolutions of the many planes in an image cube. CONVL on the other hand, with OPCODE 'GAUS', will convolve both the Clean components and the residual to the requested resolution, taking into account the change in input resolution as a function of frequency.

### 7.6.5 Filtering

For our purposes here, we can define "filtering" as applying an operator to an image in order to enhance some aspects of the image. The operators can be linear or nonlinear and do, in general, destroy some of the information content of the output image. As a result, users should be cautious about summing fluxes or fitting models in filtered images. (Technically, these remarks can also be made about Clean and self-calibration.) However, filtered images may bring out important aspects of the data and often make excellent, if unfamiliar-looking, displays of particular aspects.

NINER produces an image by applying an operator to each cell of an image and its 8 nearest cells. The task offers three nonlinear operators which enhance edges (regions of high gradient in any direction). It also offers linear convolutions with a $3 \times 3$ kernel which can be provided by the user or chosen from a variety of built-in kernels. Among the latter are kernels to enhance point sources and kernels to measure gradients in any of 8 directions. The 'SOBL' edge-enhancement filter can bring out jets, wisps, and points in the data, while the gradient convolutions produce images which resemble a landscape viewed from above with illumination at some glancing angle (as when viewing the Moon). Both are very effective when displayed on the TV or by the KNTR / LWPLA combination (see Figure 7.1). Enter EXPLAIN NINER C_R for additional information.

MWFLT, at present, applies any one of six non-linear, low-pass filters to the input image. Each filter is applied in a user-specified window surrounding each input pixel. One of the operators is a "normalization" filter designed to reduce the dynamic range required for the image while bringing out weaker features. Two of the operators are a "min" and "max" within the window. When applied in succession, they produce a useful low-pass filtered image (Rudnick, L. 2002, PASP, 114, 427). Other operators produce, at each pixel, the weighted sum of the input and the median, the "alpha-trimmed" mean, or the alpha-trimmed mode of the data in the window surrounding the pixel. These filters can be turned into high-pass filters by subtracting the output of MWFLT from the input with COMB. Type EXPLAIN MWFLT C_R for further information.

Histogram equalization provides another form of non-linear filtering. HISEQ converts the intensities of the full input image to make an output image with a nearly flat histogram. This magnifies small differences in the heavily occupied parts of the histogram (usually noise) and diminishes large differences in the less occupied parts (often real signal). AHIST does an "adaptive" histogram equalization on each pixel using a rectangular window centered on that pixel. This will magnify small differences in a more local sense, bringing out structures in smooth areas of different brightness. SHADW generates a shadowed image as if a landscape having elevation proportional to image value were illuminated by the Sun at a user-controlled angle. Although these tasks magnify noise, they are likely to elucidate real structures in large areas of nearly constant brightness.

### 7.6.6 Modeling

The addition of model data to an image or *uv* data set is often useful either to simplify later processing steps or to study processing steps using a "source" of known structure. For example, the removal of the response to an appropriate uniform disk from the *uv* data for a planet will leave Clean the task of deconvolving only the remaining fine-scale structure to which it is well suited. The removal of a few bright point sources of known position and strength may allow imaging with significant tapers in a numerically smaller field. The tasks IMMOD and UVMOD will add (or subtract) up to 4 point, Gaussian, disk, rectangular, spherical, or exponential sources to the (scaled) input image or *uv* data, respectively. Both tasks can also add noise and both allow the original data to be replaced by the model. UVMOD can even handle up to 9999 sources from an external file and include a spectral index for the sources. Type EXPLAIN IMMOD ; EXPLAIN UVMOD $C_R$ for details.

The task CCMOD will create a clean-components file representing the chosen Gaussian or disk model. Clean may then be "restarted" with the model as its initial set of components. The task UVFIT may be useful for fitting Gaussian or uniform-sphere models to small ($< 2000$ visibility) *uv* data sets.

## 7.7 Additional recipes

### 7.7.1 Chicken salad with banana mayonnaise and grapes

1. Place 3 medium **bananas** cut in chunks, 2 teaspoons chopped **garlic**, 3/4 cup non-fat **plain yogurt**, 1 tablespoon **honey**, 2 teaspoons **lemon juice**, and 1/4 teaspoon **salt** in a blender or food processor. Blend until creamy.
2. Arrange 12 cups mixed **lettuces** on six plates.
3. Toss 6 **chicken breasts** cooked and cubed with banana mayo; divide onto salads.
4. Sprinkle with 2 bunchs ($\approx 48$) halved **grapes** and 1/2 cup **walnut** or **pecan** halves.

Thanks to Chiquita Bananas. See `http://www.jaetzel.de/tim/chiquit.htm`.

### 7.7.2 Banana-Rhubarb Crisp

1. Slice 2 large `bananas` into 1/4-inch rounds. Combine with $2\frac{1}{2}$ cups diced `rhubarb`, 2 tablespoon `sugar`, 1/4 teaspoon `cinnamon`, and a generous dash `nutmeg`. Spoon the mixture into a well-greased 9-inch pie plate or shallow baking dish (preferably glass or ceramic).
2. In a medium bowl, combine 1/2 cup white or whole-wheat pastry `flour`, 1/2 cup `graham cracker` crumbs, $1\frac{1}{2}$ teaspoons `baking powder`. With a pastry blender or two knives worked in a crisscross fashion, cut in 1/4 cup `butter` until the mixture is crumbly.
3. Combine 1 `egg` lightly beaten with 1/4 cup `milk` and stir into the flour mixture. Spoon the batter as evenly as possible over the fruit mixture. Sprinkle with 2 tablespoons `sugar`.
4. Bake in a pre-heated 400° F oven for 25–30 minutes.

Thanks to *Jane Brody's Good Food Book*.

# 8 SPECTRAL-LINE SOFTWARE

This chapter deals with the analysis and reduction of spectral-line data after they have had the basic calibrations, described in Chapter 4, applied. Spectral-line software generally involves three-dimensional images, often called "cubes", in which one of the three axes is frequency or velocity. Special programs are available to build, manipulate, and transpose these cubes and to display them properly. Most of the continuum software will work on data cubes or on appropriate two-dimensional subsets from a data cube. Spectral-line *uv* data can be read into *AIPS* from "*uv*" FITS tapes. Often, however, the data already exist on disk having been calibrated first within *AIPS*.

The data reduction process at this point has a number of stages, namely data preparation and assessment, self-calibration, continuum subtraction, imaging, display and manipulation of data cubes, and analysis. This chapter will address each of these areas in varying, but modest, detail on the assumption that the reader is somewhat familiar with the contents of previous chapters in this *CookBook*. Some aspects of the art of spectral-line imaging are discussed in Chapters 17 and 18 of *Synthesis Imaging in Radio Astronomy*[1]. A brief outline of the basic calibration process is given in Appendix A of this *CookBook* and an outline of spectral-line analysis and calibration is given in Appendix B.

## 8.1 Data preparation and assessment

In the following sections, it is assumed that the *uv* data are on disk and that the basic calibrations have been applied to them. If your data are not currently on disk, you will need to read them in from magnetic tape or FITS disk files. For tape, mount the tape in hardware and software (§ 3.9) and then position the tape to the desired data files:

| | |
|---|---|
| > NFILES *n* ; AVFILE C_R | to advance *n* files. |
| > TPHEAD C_R | to check that the tape is correctly positioned. |

Use FITLD to read in the data:

| | |
|---|---|
| > TASK 'FITLD' ; INP C_R | to review the inputs. |
| > OUTCL ' ' ; OUTN ' ' C_R | to use the file names recorded on tape (the default). |
| > NFILES 0 C_R | to read the current file on tape. |
| > NCOUNT 2 C_R | to load two files (if desired). |
| > GO C_R | to run FITLD. |

For FITS disk files, set DATAIN appropriately and the run FITLD. Examine the *uv* data set header with IMHEAD after FITLD finishes. It should show multiple pixels on the FREQ axis, like the *uv* header illustrated in § 3.3.4.

If your data are not yet calibrated, consult Chapter 4, especially § 4.7. When the CL, BP, and other calibration tables are complete, apply them to the line data with SPLIT:

| | |
|---|---|
| > TASK 'SPLIT' C_R | |
| > SOURCE '*sou1*' , '*sou2*' , . . . C_R | to select sources, ' ' means all. |
| > TIMERANG 0 C_R | to keep all times. |
| > BIF 1 ; EIF 0 C_R | to keep all IFs. |
| > BCHAN 1 ; ECHAN 0 C_R | to keep all spectral channels. |
| > FREQID 1 C_R | to set the one FQ value to use. |

[1] *Synthesis Imaging in Radio Astronomy*, Astronomical Society of the Pacific Conference Series, Volume 6, "A Collection of Lectures from the Third NRAO Synthesis Imaging Summer School" eds. R. A. Perley, F. R. Schwab and A. H. Bridle (1989).

| | |
|---|---|
| > DOCALIB TRUE C_R | to apply calibration. |
| > GAINUSE 0 C_R | to use the highest numbered CL table. |
| > FLAGVER 1 C_R | to apply the flag table. |
| > DOPOL TRUE C_R | to correct for feed polarization. |
| > DOBAND 1 C_R | to correct bandpass. |
| > BPVER 1 C_R | to select BP table to apply. |
| > STOKES ' ' C_R | to write the input Stokes type. |
| > DOUVCOMP TRUE C_R | to write visibilities in compressed format. |
| > APARM 0 C_R | to clear VLBA options, including the one to calibrate the data weights. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when inputs set correctly. |

The *uv* data produced by this process should have applied to them the full calibration and editing determined from the calibration sources. Whether these are adequate or will need to be enhanced from the source data themselves is now to be determined.

Your data may need to be edited further at this point. If your calibrator data were almost free of problems, save for simple matters like dead antennas, then your source data are not likely to need much editing either. If your calibrator data required detailed and erratic data flagging, then your source data will also need attention. All of the considerations of § 4.4 apply here too. In either case, the first step is to check for narrow-band interference which is a fairly common problem at some wavelengths. The best task for this is SPFLG (§ 10.2.2), a spectral-line version of TVFLG (§ 4.4.3). SPFLG displays spectral channels for all IFs along the horizontal axis and time along the vertical axis, one baseline at a time. This is tedious to use for editing all of the data from a large interferometer. Instead, select a few of the shorter baselines (with the ANTENNAS and BASELINE adverbs) and do a quick check for interference. If your data has sufficient signal-to-noise, then this quick examination should let you check which channels have signal and whether the Galaxy, for example, has contributed unwanted signal to your data. If you find significant terrestrial interference, you may flag the bad data with SPFLG (consider using the "ALL-BL" option to avoid looking at hundreds of baselines) or with UVFLG (entering "by hand" what you find with SPFLG). Tasks UVLIN and UVLSF (below and § 8.3) both offer the option to flag all channels of a particular sample if any one channel in the continuum-fitting portion of the spectrum has excessive flux after the fit. UVLSF also offers the option to flag when the rms of the continuum fit is excessive. The task CLIP (§ 5.5.1) works in a channel-dependent way on line data. It can be instructed to flag a full spectrum if more than a user-specified number of channels are flagged in that spectrum. FLGIT is designed to work on line data sets that have a great deal of interference, generating channel-dependent flagging in the output file or in a flag table. UVMLN may also be used to generate flag tables for multi- and single-source files to flag seriously deviant data. FLAGR uses multi-channel data to estimate rms and flags any times having excessive rms, amplitude, weight, etc. UVCOP will apply even a very large flag table if so instructed. These tasks will eliminate certain classes of problems without bothering you with the details, which may — or may not — be a good thing.

To do serious editing of a non-spectral nature and to do self-calibration, you will need to create a single-channel data set that represents your multi-channel data in some fashion. If your data contains little continuum signal, but does have a strong spectral-line signal, then use UVCOP to copy the data for the channel with the strongest signal to a single-channel data set. Alternatively, the task AVSPC may be used to average a few adjacent channels together to create the single-channel data. If, on the other hand, your data set contains a useful level of continuum emission — and most do — then your single channel should be some estimate of this continuum. If your line signal is weak and you have done no frequency-dependent editing, then you can use the so-called "channel-0" data set created by FILLM when you first loaded your VLA data to disk. This data set is the vector average of the center 3/4 of the selected spectral channels, but remains useful only if you have applied all of the same calibration, editing and SPLITing to it that you applied to the line data. It may be safest to create a new continuum estimate from the line data in any case. The classical method for doing this is the task AVSPC:

| | |
|---|---|
| > TASK 'AVSPC' ; INP C_R | to review the inputs needed. |
| > IND *m* ; GETN *n* C_R | to specify the input *uv* file. |
| > CLRONAME C_R | to use the default output names and disk. |
| > AVOPT ' ' C_R | to average channels only within IFs. |
| > ICHANSEL *b1* , *e1* , *i1* , *if1* , *b2* , *e2* , *i2* , *if2* ,... C_R | to average every *i1* channel from *b1* through *e1* in IF *if1*, plus every *i2* channel from *b2* through *e2* in IF *if2*, etc. |
| > ICHANSEL 10 , 50 , 1, 0, 81 , 119 , 1 C_R | *e.g.*, average channels 10 through 50 and 81 through 119 in each IF, omitting the band edges and the channels with line signal. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when you're satisfied with inputs. |

A non-classical method for estimating the continuum is provided by the task UVLSF It fits a linear "spectral baseline" in the real and imaginary parts of each visibility spectrum. By adding a slope to the channel-independent bias found in AVSPC, it allows for small changes in the continuum visibility with frequency and spatial resolution across the observed band, as well as small, time-variable changes in the spectral passband not fully removed by BPASS. In 31DEC07, the option to fit even higher order baselines was added. These are seldom useful and can run into problems since they are not constrained by data in the channel ranges containing the line signals. The principal output of UVLSF is a multi-channel data set with this baseline subtracted, *i.e.*, a continuum-free line data set. However, the user may also get a single-channel "continuum" data set evaluated at any one channel from the fit baselines. Thus:

| | |
|---|---|
| > TASK 'UVLSF' ; INP C_R | to review the inputs needed. |
| > IND *m* ; GETN *n* C_R | to specify the input *uv* file. |
| > CLRONAME C_R | to use the default output names and disk. |
| > BCHAN 0 ; ECHAN 0 C_R | to include all channels. |
| > ICHANSEL *b1* , *e1* , *i1* , *if1* , *b2* , *e2* , *i2* , *if2* , . . . C_R | to average every *i1* channel from *b1* through *e1* in IF *if1*, plus every *i2* channel from *b2* through *e2* in IF *if2*, etc. |
| > DOOUTPUT TRUE C_R | to get the continuum data set. |
| > CHANNEL 0 C_R | to select the channel at which the baseline is evaluated — in this case, the default which is the reference channel. Choose one near the center of the band. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when you're satisfied with inputs. |

The continuum data set will have AIPS class BASFIT and be on the same disk as the output line data set. You may also use UVLSF to flag data with excessive residual flux and rms in the channels used for the fitting. Beginning with 31DEC07, you may apply the usual data selection and calibration and flag tables to the input data, meaning that SPLIT need not have been run on the data previously. Note that neither AVSPC nor UVLSF should be used if the continuum visibility changes substantially across the passband, due to large bandwidth and complexity in the continuum source. If the phase of the continuum changes substantially across the passband due to the centroid of the continuum being considerably separated from the pointing center, you should instruct UVLSF to shift the phase reference position before fitting the linear function and then to shift the phases back afterwards.

Your spectral-line data may need further modification and preparation. If you did not observe with "Doppler tracking" (and even the VLA changes frequency only on a scan-by-scan basis), then your data channels are not at the same velocity through the data set. Task CVEL may be used to convert the data to full Doppler tracked form, or simply to shift the center velocity of your reference channel to, for example, the velocity used in another data set. CVEL works on multi-source as well as single-source data sets. It applies any flagging and bandpass calibration to the data before shifting the velocity (which it does by a carefully correct Fourier transform method). Note, the use of Fourier-transforms means that one *must not* use CVEL an data with channel separations comparable to the widths of some of the spectral features.

Two other tasks allow you to change the number of spectral channels in your data set. The simpler, AVSPC, allows you to average every $n$ adjacent channels together, producing a data set one $n^{\text{th}}$ as large. The other, called SPECR, uses Fourier transform methods to increase or decrease the number of channels with a corresponding change in channel spacing. This task, along with CVEL may be required to convert one data set to the same channel velocity and separation as another data set, before the two can be concatenated (task DBCON) and used together in imaging. If simple frequency smoothing is needed, the calibration routines will apply various convolutions to the spectrum under control of the adverb SMOOTH. IMAGR, allows you to "average" channels together by gridding them into the correct (channel-dependent) locations in the *uv* plane. This is seldom important to narrow-band observations, but is critical in wide "bandwidth synthesis" observations. Nonetheless, it allows you to keep full spectral resolution in the *uv* data set, but abandon it for some or all of the imaging.

## 8.2 Editing and self-calibration

Self-calibration can improve the "dynamic range" of your images significantly but **only** if there is sufficiently good signal-to-noise in the *uv* database. It works by comparing the input *uv* data with the predicted visibilities from a model of the source; from this a set of complex gain (amplitude, phase) corrections are generated for each antenna in the array as a function of time. Before engaging in a potentially long and useless exercise, it is wise to look at the continuum or single-channel data set you have created to determine whether there is sufficient signal (with respect to the noise) to enable detailed editing and/or self-calibration. Even if the continuum data would profit from these things, you must also decide whether there is sufficient signal-to-noise in the line data to benefit from the improved editing and calibration. Consult the sections on editing (§ 4.3.1 and § 4.4) and on self-calibration (§ 5.4) before deciding to continue with this section.

In fact, there is very little to be written here. The editing and self-calibration of the continuum or single-channel data set are precisely those described in Chapter 4 and Chapter 5. The goal is to create and fill an FG table (if flagging is needed) and an SN table (if self-calibration is needed) attached to the single-source, single-channel data set. Note that, for single-source data, we use an SN table containing the accumulated calibration while we use, for multi-source files, a number of SN tables with incremental calibrations and a single CL table with the net corrections. When all editing and self-calibration are done, you use TACOP (or, in 31DEC07, TAPPE if the flag table must be appended to an existing flag table) to copy the two tables to the multi-channel data set and then use SPLIT to apply both tables to the multi-channel data (and to the single-channel data set too if desired).

Unfortunately, this nice scheme does not work all the time — mostly due to various programs not being able to apply the tables to the data. Use SPLIT to get around the problem. The preferred imaging and deconvolution task is IMAGR which understands and applies such tables.

In general, you may keep the flagging information in a flag table (specified with adverb FLAGVER) and add to and apply the table whenever it is needed. Be aware that flag tables are applied only by those tasks that have the FLAGVER adverb. In the 31DEC07 release, several tasks were upgraded to understand calibration and flagging tables. In fact, data that are not in time order may have flag tables applied (if they are small enough) and time-independent calibrations (*e.g.*, DOBAND=1 and DOPOL $> 0$) may also be done.

## 8.3 Continuum subtraction

Most spectral-line observations contain a certain amount of frequency-independent, continuum radiation in addition to the frequency-dependent line signals. In most (all?) cases, it is probably best to separate the two signals at this stage of the data processing. In this way, a *single* continuum image can be constructed to apply to all frequencies. It will probably be necessary to apply Clean or other expensive deconvolution techniques to determine the best estimate of this continuum image. To do this for each channel individually would not only be considerably more time consuming, but would result in different models for the continuum in each channel. Since Clean is a data-adaptive non-linear algorithm, minor disturbances in its progress causes it to converge to surprisingly different solutions. Such "disturbances" could be caused by differing noise and line signals in different channels. (It can be caused simply by differing computational order on identical data using different computers.) Clean also increases the noise in an image in the areas at which there are sources. If the continuum is removed from the line data before Cleaning, then this increase in noise is also removed. To determine the continuum from separately Cleaned channel images is to use noisier individual determinations to get the final estimate. If the imaging and deconvolution were a linear process, then this would not matter. But the deconvolution is non-linear, making it better to start with the best possible estimate of the continuum.

In many cases, the continuum signal is stronger by far than the line signal. In such cases, it is best to use as many channels as possible to estimate the continuum and to remove that estimate as early as possible. The remaining line signal may be of fairly low signal-to-noise ratio and, therefore, not need the same processing that the continuum signal requires. In particular, it may not be necessary to Clean the channel images particularly deeply, if at all.

All of the arguments above suggest that the continuum should be estimated and subtracted in the visibility domain. This has the unfortunate attribute that we can use only those channels which are free of line signal over the entire field of view. (This is because the Fourier transform relation mixes signals from all directions in the field into every visibility sample.) In the image domain, the dirty images also have this unfortunate attribute, in this case because the dirty beam mixes signals from all parts of the field into every pixel. The above arguments suggest that the only time one should determine the continuum in the image domain is when the observations have essentially no channels which are free of line signal over the full field of view. In that case, the continuum at each position will have to be determined from deconvolved images using those channels which are free of line signal at that position.

AIPS provides three separate tasks for fitting and subtracting the continuum in the *uv* plane. All three fit a linear "baseline" to a selected group of channels and subtract that from the data. The reasons for a linear baseline are (1) a continuum source offset from the field center will produce a linear phase slope across the passband, (2) minor other changes in the visibility with baseline may be approximately linear over narrow passbands, and (3) minor passband variations with time appear also to be approximately linear. Higher-order fits can be done by UVLSF beginning with 31DEC07, but they do not seem to be justified and are often not well constrained. The first reason suggests that one should do the fit in amplitude and phase, an algorithm implemented by the task UVBAS. This should be used *only* if you have good signal-to-noise in *all* of your visibility samples. The reason for this very stringent requirement is that visibility amplitudes have Ricean rather than Gaussian noise statistics. As a result, very biased estimates are produced in moderate to low signal-to-noise cases. For these, the two tasks UVLSF and UVLIN should be used. They do the fits in the real and imaginary parts of the visibilities and, hence, do not produce biased estimates in the absence of signal. Both tasks allow you to shift the visibilities to move a strong source to the center of the field before doing the fits (and then shift the visibilities back to the original phase center). This changes sinusoidal real and imaginary parts to linear for an accurate fit, but only for those cases where a single source dominates the field. Both tasks offer the option to flag discrepant data, but they differ in the details of how they do this. UVLSF offers the option to write out a "best-fit" single-channel data set as well as subtracting it from the line data; see § 8.1 for an sample inputs to UVLSF..

There are also a number of ways to remove the continuum in the image domain, all of which assume that the channels have been imaged similarly and placed into a three- or more dimensional "cube." The "classical" method to subtract the continuum, which is the least useful, is to average those image planes which contain no line signals using SQASH on each set of line-free planes and COMB to average those averages. Finally, COMB is used to subtract the resulting plane from each plane of the initial cube. In this method, the cube is in the "natural" transposition with the frequency axis third. The other two methods require you to use the task TRANS (see § 8.5.2) to transpose the frequency axis to the first (most-rapidly varying) axis. Then IMLIN may be used to fit polynomial baselines (linear is usually all that is justified) to the line-free parts of each spectrum. This task, like all of the other tasks so far mentioned in this section, requires you to use a fixed set of channels for all positions in the field. Many objects (*e.g.*, rotating galaxies) have spatially-dependent spectra in which each pixel has a rather narrow line width compared to the object or objects as a whole. In such cases, the task XBASL may be used. This task requires some endurance on your part to complete, but it allows you to specify the baseline region for each pixel interactively using the AIPS TV or TEK graphics windows.

## 8.4 Imaging

There are several tasks which may be used to convolve spectral-line data to a rectangular grid and then Fourier transform and Clean that grid to make an image. The old tasks, which we no longer recommend, are called UVMAP, APCLN, and WFCLN and may be used if you insist. Today, IMAGR should be used for all normal imaging and Cleaning. Read § 5.2 for basic information about this task and § 5.3 for information about using it to deconvolve your images. It can read either single- or multi-source data, can apply calibration, and writes all channels into an image cube. IMAGR uses much more flexible and correct methods for data weighting (§ 5.2.3) and uses the superior multi-field method of Cleaning in which source components are subtracted from the visibility data and the images recomputed in every "major cycle." IMAGR grids each channel in exactly the proper place in the *uv* plane and can be used to do frequency smoothing ("averaging") in this most correct of ways. It also offers options to correct your data for various effects of importance over wide fields and bandwidths. It even has experimental variations on Clean (§ 5.3.4) to deal with extended sources and the Clean bias.

To produce a cube of spectral line images with IMAGR from channels *n1* through *n2* use:

| | |
|---|---|
| > TASK 'IMAGR' ; INP C_R | to review the inputs needed. |
| > IND *m* ; GETN *n* C_R | to specify the input *uv* file. |
| > CLRONAME C_R | to use the default output names and disk. |
| > BCHAN *n1* ; ECHAN *n2* C_R | to include a range of channels. |
| > STOKES 'I' C_R | to make total intensity (unpolarized) images. |
| > NCHAV 1 C_R | to avoid averaging channels. |
| > CHINC 1 C_R | to do every channel, setting the channel increment. |
| > CHANNEL 0 C_R | do not restart. |
| > CELLSIZ $\Delta x$ , $\Delta y$ C_R | to set the image cell dimensions in arc seconds. Cells do not have to be square. |
| > IMSIZE $N_x$ , $N_y$ C_R | to set the image size in pixels (must be powers of two). |
| > NITER 0 C_R | to do no Cleaning. |
| > GO C_R | to run IMAGR. |

This makes "dirty" images and beams of the specified channels. If Cleaning is needed, set the Clean adverbs NITER, NBOXES, CLBOX, GAIN, BOXFILE, etc. Note that you must image one IF at a time in order to avoid combining multiple frequencies. The task NOIFS might be useful depending on your data.

In 31DEC10, IMAGR is more careful with image units. Unless you force the Clean beam size with BMAJ, BMIN and BPA, IMAGR will image each channel at its "natural" (frequency-dependent) resolution. It now carefully scales each image plane so that it is actually in units of Jy per the Clean beam listed in the header. The Clean beam for each frequency is recorded in a CG table and used by MCUBE and CONVL among other tasks.

At this point, it is a very good idea to determine the noise in your output images and to compare it to the theoretical noise you expect. If your images are significantly noisier than expected, it is a very good idea to stop processing, to think about what may have gone wrong, and then to check and correct that. The noise may be determined using task IMEAN:

| | |
|---|---|
| > TASK 'IMEAN' ; INP C_R | to review the inputs needed. |
| > IND *m* ; GETN *n* C_R | to specify the input image file. |
| > DOHIST TRUE C_R | to plot the histogram. |
| > NBOXES 200 C_R | to use a significant number of boxes in the plot. |
| > PIXRANGE = -*x* , *x* C_R | to limit the histogram to the range *x*, where *x* should be about 5 times the expected noise. |
| > DOTV TRUE C_R | to put the plot on the TV rather than in a file. |
| > BLC *x1, y1, f1* ; TRC *x2, y2, f2* C_R | to select a sub-image of the cube that is free of signal. |
| > IMSTAT C_R | to set PIXSTD with an overestimate of the image rms. |
| > PIXSTD = PIXSTD/7 C_R | to reduce the overestimate. |
| > GO C_R | to run the task, plotting on the TV. |

This will print two rms's on your message screen one computed using all the data and one done by fitting a histogram to the noise portion of the signal. Especially if the latter fails, the plot will allow you to estimate the true rms, ignoring those pixels significantly above and below the Gaussian noise part of the histogram. Using this plot, it may be better to include all of the data (BLC 0 ; TRC 0 C_R) rather than to limit the number of pixels contributing to the histogram. The AIPS verb IMSTAT does the all-pixel rms computation without the useful plot, while the verb TVSTAT allows you to mark one or more non-rectangular regions on an image on the TV over which the rms is computed. Task RSPEC will plot robust rmses computed on a per plane basis.

## 8.5 Display and manipulation of data cubes

### 8.5.1 Building and dismantling data cubes

Many spectral-line display and analysis functions make sense only on 3-dimensional (or more) images. In particular, image creation functions may create one image per spectral channel while spectral analysis requires the images to be ordered with the spectral axis first (most rapidly varying). To combine a number of $n$-dimensional images into an $n$- or $n+1$-dimensional image, use the task MCUBE. This task requires the images to have some one physical axis whose value varies between the input images in a manner consistent with a regular axis and it is that axis which is extended to make the "cube." If the output image specified already exists, then the input maps are inserted in the output image in the appropriate places. This allows the $n$- or $n+1$-dimensional output image to be built up a bit at a time and allows replacement of portions of the image with a corrected $n$-dimensional image. Type EXPLAIN MCUBE C_R to receive a variety of hints and suggestions for using this rather general program. As an example, to put 31 frequency channel images into one cube, type:

| | |
|---|---|
| > TASK 'MCUBE' ; INP C_R | to review the inputs. |
| > INNA 'N315' C_R | to select the source. |
| > INCL 'IIM001' C_R | to select the input image class for *all* images. |
| > INSEQ 1 ; IN2SE 31 ; IN3SE 1 C_R | to set the first and last image and the step in the task's loop over input sequence number. |

| | |
|---|---|
| > AXREF 1 ; AX2REF 31 C_R | to set the pixel coordinate of the first and last image on the third axis in the cube. |
| > NPOINTS 31 C_R | to set the total number of points on the third axis. |
| > OUTN ' ' C_R | to use the default OUTNAME. |
| > OUTCL 'LMFCUB' C_R | to specify, in OUTCLASS, the order of axes. |
| > GO C_R | to run MCUBE. |

MCUBE will scale each image plane so that it is on the same brightness scale as represented by the Clean beam in the header.

Later on, you might want to replace some of these images by Cleaned images. *E.g.*, assume that you have Cleaned channels 10 through 20, one at a time. These images got the class ICL001. It is a good idea to give them sequence numbers that are the same as the channel numbers, thus 10 to 20. Putting them in the existing cube (make a backup copy with SUBIM if you are nervous) can then be done as follows:

| | |
|---|---|
| > TASK 'MCUBE' ; INP C_R | to review the inputs. |
| > INNA 'N315' ; INCLA 'ICL001' C_R | to select the clean images. |
| > INSE 10 ; IN2SE 20 ; IN3SE 1 C_R | to set the first and last image and the step in the loop. |
| > OUTN 'N315' ; OUTCL 'LMFCUB' C_R | to select the existing cube. |
| > OUTSE 1 C_R | |
| > GO C_R | to run MCUBE. |

IMAGR with its DOTV option allows you to Clean each channel with its own numbers of iterations and its own interactively set Cleaning boxes. In 31DEC09 there are new options to create boxes automatically on each image plane and an option to control whether the boxes for channel $n$ are carried over to channel $n + 1$.

MCUBE can build a cube out of a set of images that do not have a suitable axis for image building. This can be a set of images that have all the same axis parameters (*e.g.*, identical images except for date) or they can be images at, for example, an arbitrary set of frequencies. Set DOCONCAT = 2 to force MCUBE to make a SEQ.NUM. axis or, if there are different frequencies, an FQID axis with accompanying FQ table. The original coordinate values on an axis that differs from image to image are recorded in the history file and, for frequencies, also in the FQ table. Task FQUBE in 31DEC09 does this operation more naturally and can combine two cubes each of which already has an FQID axis.

Most programs work on cubes. However, you may find it convenient, on occasion, to work with single image planes. To separate the channels from the cube, use task SUBIM typing, for example:

| | |
|---|---|
| > TASK 'SUBIM' ; INP C_R | to review the inputs. |
| > INNA 'N315' ; INCL 'LMFCUB' ; INSE 1 C_R | to select the cube. |
| > OUTN 'N315' ; OUTCL 'IMAGE' C_R | to give it an output name and class. |
| > BLC 0 ; TRC 0 C_R | to select full planes. |
| > DOWAIT TRUE C_R | to run in synchronous mode. |

> FOR J=10:20 ; BLC(3)=J ; TRC(3)=J ; PRIN J ; OUTSE J ; GO ; END

This runs the program 11 times, taking planes 10 through 20 and creating separate images for them. To put the images back into the cube after they have been modified, use MCUBE.

### 8.5.2 Transposing the cube

The task TRANS will transpose the cube, ordering the axes in any way you specify. Typically, one transposes images of spectral channels into spectra at image pixels for both display and analysis purposes. Thus:

| | |
|---|---|
| > TASK 'TRANS' ; INP C_R | to review the inputs. |
| > INCLASS 'LMFCUB' C_R | to select the untransposed cube. |

| | |
|---|---|
| > TRANSC '-312' C_R | to make new axis order -3, 1, 2 in terms of the old axis order (*e.g.*, RA, Dec, Freq becomes Vel (opposite sign of Freq), RA, Dec). |
| > OUTCL 'VLMCUB' C_R | to give it an outclass reflecting the axis order. |
| > BLC 0 ; TRC 0 C_R | to transpose the whole cube. |
| > GO C_R | to run the program. |

Numerous tasks such as IMLIN, XSUM, PLCUB, and XMOM act on the first axis and, typically, make sense only when that axis is frequency/velocity. Note that such $x$-axis analysis may also be useful in other cases, including angular and time $x$ coordinates.

### 8.5.3 Modifying the image header

On occasion you may feel the need to modify or add to the information in the image header. For example, to add an alternate velocity description for the frequency axis of a cube, type:

| | |
|---|---|
| > INDISK *n* ; GETN *ctn* C_R | to select the image. |
| > AXTYPE 'OPTHEL' C_R | to specify optical-convention velocities relative to the Sun. |
| > AXREF 16 C_R | to specify the velocity reference pixel (channel 16 is the center of the band in our example). |
| > AXVAL 5.E6 C_R | the velocity at the reference pixel in m/s. |
| > RESTF 1420.4E6, 5752 C_R | to specify the line rest frequency in Hz (1420405752 Hz). |
| > ALTDEF C_R | to add the information to the header. |
| > ALTSW C_R | to switch between frequency and velocity information in axis labeling, IMHEADER, etc. |

The VLA now provides the velocity information to FILLM, making this operation unnecessary in many cases.

Observers may find the Galactic coordinates of their sources to be of interest. To switch the header between Celestial and Galactic coordinates, type:

| | |
|---|---|
| > CELGAL C_R | to go to galactic coordinates. |
| > CELGAL C_R | to go back to celestial coordinates. |

You may change many of the parameters in the image header and may fetch for use by the *POPS* language all header parameters. The verb PUTHEAD changes a header parameter and GETHEAD gets that parameter. Type EXPLAIN GETHEAD C_R for the details, including a list of recognized keywords, and EXPLAIN PUTHEAD C_R for the more restricted list of values which you may change in the header. For example, to move a header parameter from one image to another:

| | |
|---|---|
| > KEYWORD '*keyword*' C_R | to specify one of the fully allowed keywords. |
| > GETN *n* ; GETHEAD C_R | to get the header value from image *n*. |
| > GETN *m* ; PUTHEAD C_R | to put it in the header of image *m*. |

### 8.5.4 Displaying the cube

The easiest way to look at the cube is by using TVMOVIE. This verb loads portions of planes of a cube into the TV memory, and displays them in sequence at a variable frame rate. Type:

| | |
|---|---|
| > INDISK *n* ; GETN *ctn* C_R | to select the cube. |
| > INP TVMOVIE C_R | to review the inputs; use defaults for a start. |
| > TVMOVIE C_R | to load the images and start the movie. |

Now follow the instructions on your screen on how to change the transfer function, change speed, look at single frames, etc. Having terminated the movie (button D), you may restart it with

> REMOVIE C_R to resume the movie.

With the default adverbs, TVMOVIE will zoom the display so that a single frame fills the display area. If you are using a workstation, this may seriously limit the maximum possible frame rate. To use a smaller zoom factor and smaller display area, enter:

> DOCENTER TRUE C_R to enable the option.

> FACTOR *m* C_R to use a zoom factor of *m*.

> REMOVIE C_R to rerun the movie.

Note that you may set these adverbs before the initial TVMOVIE command as well.

TVMOVIE uses an image ordering on the screen designed to improve the performance of movies on "real" TV devices. To use a more pleasing ordering (left to right, top to bottom) that is nearly as efficient on workstations, use the TVCUBE verb instead. The verb REMOVIE works on these displays as well. One of the reasons to use TVCUBE is to capture a full TV plane's worth of channels and print them on a PostScript printer. The first step is to get TVCUBE to put the desired channels in one TV image plane. Set TBLC(3) and TTRC(3) to select those planes you want and set TVCHAN = 2 (or the highest TV plane allowed on your system) to force all the images into one TV image. Stop the move with button D, display the full TV memory (use the F2 button), adjust the enhancement (and color) of the display, and then run task TVCPS. If your images are too large for one channel, use TVCHAN = 1 and run TVCPS once for each channel.

Another way to see multiple image planes on a single page is with the task KNTR, which plots a page of contour and/or grey-scale drawings for each plane. This task allows you to include "star" positions and even an outline of the clean beam. A KNTR plot of neutral hydrogen emission from NGC6503 is shown in Figure 8.1.

It can be very informative to transpose the cube to look at position-velocity planes instead of position-position planes. A TVCUBE display of the NGC6503 data cube transposed to 132 (position-velocity-position) order and then captured with TVCPS is shown in Figure 8.2.

Finally, it is useful to look at the cube as a set of spectra. Use TRANS to transpose to 312 order (or -312, 321, and the like). The task XPLOT displays the spectra on the graphics display selecting only those with a sufficiently strong line signal (set by adverb FLUX) and ignoring those with really strong fluxes (controlled with PIXVAL). This can get rather tedious and it is easy to get lost in your cube. The task PLCUB, illustrated in Figure 8.3, allows you to see numerous spectra at one time plotted in correct orientation with respect to their position coordinate. It is necessary to experiment with the adverbs for PLCUB, especially YINC, ZINC, PIXRANGE, and the like, to get a good plot. Use the TV with DOTV TRUE C_R to save trees.

In general, other display programs work on one plane at a time. Therefore, you must specify which plane in the cube you want to see. For example, if you want to do TVALL on channel 16, which is on pixel 16 of the third axis, you type:

> TBLC 0 0 16 ; TVALL C_R

Note that adverbs TBLC and TTRC are used for TV displays while BLC and TRC are used for image operations.

## 8.6 Analysis

A wide variety of programs is available to do further analysis of the data. Exactly which ones you will need depends on the nature of your observations. To see the latest list of symbols related to spectroscopy, enter

> ABOUT SPECTRAL C_R to list them all on your terminal.

or consult Chapter 13 of the *CookBook* for a less current, but paper, copy of the list.

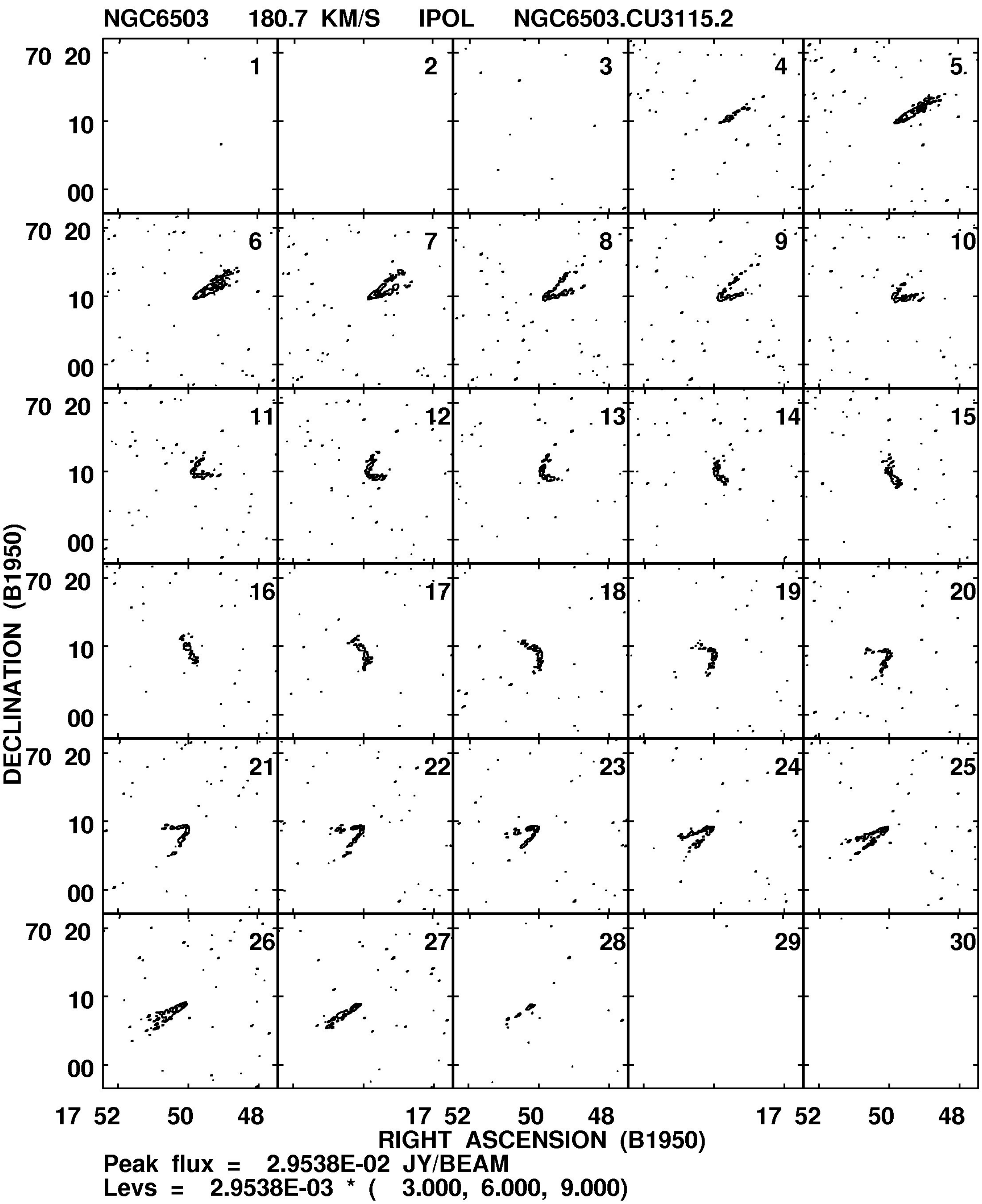



Figure 8.1: Contour images of spectral channels from a cube generated by *AIPS* task KNTR. Data on NGC6503 were provided by Don Wells from observations made with the VLA on 12 April 1983.

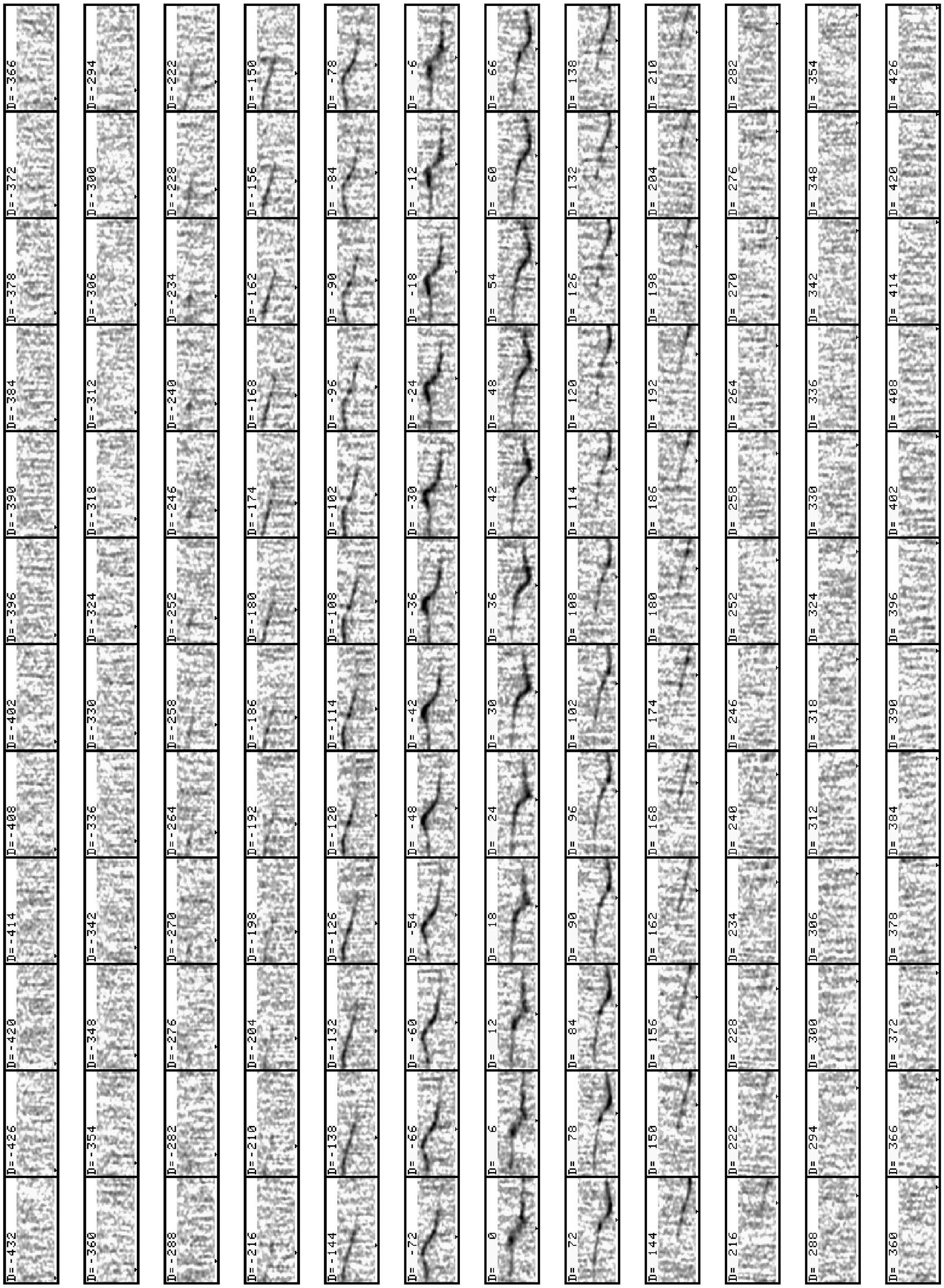


Figure 8.2: Display generated by transposing a data cube into 132 (right ascension, velocity, declination) order and then displaying the central declination position-velocity planes with AIPS verb TVCUBE. The TV display was then captured by AIPS task TVCPS for printing on PostScript printers. Data on NGC6503 were provided by Don Wells from observations made with the VLA on 12 April 1983.

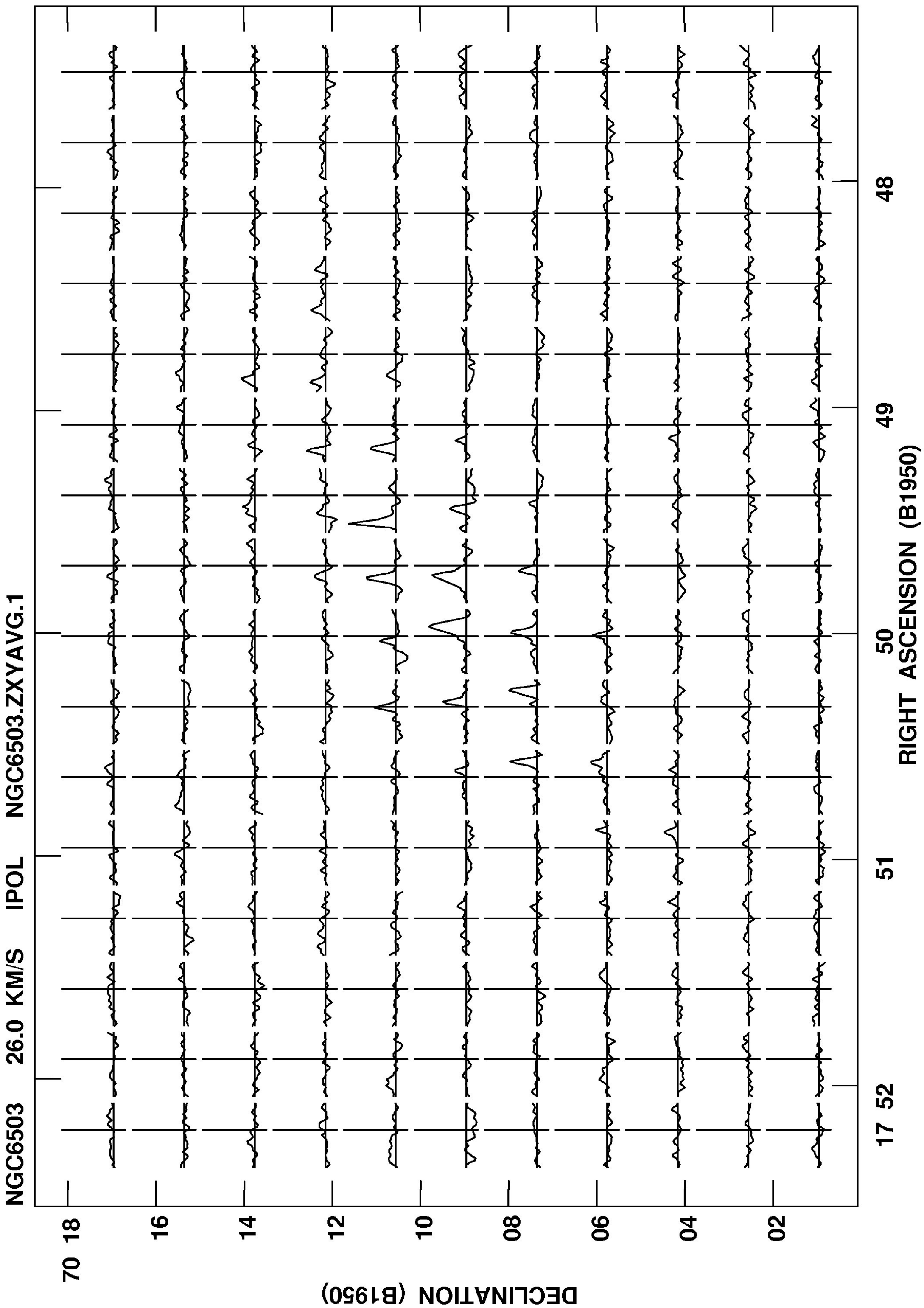



Figure 8.3: Display generated by transposing a data cube into 312 order (velocity, right ascension, declination) and then displaying selected spectra on a regular grid in the angular coordinates with AIPS task PLCUB. Data on NGC6503 were provided by Don Wells from observations made with the VLA on 12 April 1983.

The subject of finding and removing the continuum (aka spectral baseline) was discussed in § 8.3 above. In the image domain, task IMLIN may be used to remove polynomial baselines using the same spectral channels throughout the cube. The task XBASL can be used to remove baselines in an interactive (hence position-dependent) fashion. Be aware, however, that if you have made an error in the calibration, this has most likely caused slopes in amplitude *and* phase. Therefore, it is generally better to track down the error and correct it than to decide (arbitrarily) to take out slopes in (Cleaned ?) image amplitude. Task SQASH may also be used to sum or average planes in a cube, which provides, among other things, a simple but crude way to determine a continuum image which can then be subtracted from the cube by COMB.

Smoothing and blanking are important for almost all analysis programs. CONVL works on cubes and does a spatial smoothing (on position-position-velocity cubes). In 31DEC10, CONVL will use the CG table to smooth all image planes to the same spatial resolution. This is preferable to forcing a resolution with BMAJ since it smooths the resisuals as well as the components. Using all the defaults in XSMTH performs a Hanning smoothing in velocity (on transposed velocity-position-position cubes) and can be used to do other kinds of smoothing as well. This is not just useful for bringing out weak extended signals. Smoothed images can also assist in determining the boundaries of sources to set windows for subsequent spectral analysis. For example, the smoothed cube could be used to set the CLIP limits in task COMB to be applied to the unsmoothed cube.

In fact, finding all regions of significant line signal may be difficult in large image cubes. The task SERCH offers an algorithm by Juan Uson to find line signals which match specified line widths and exceed a specified signal-to-noise ratio. Histograms may be plotted or printed and a S/N hyper-cube may be written.

The task BLANK offers a variety of algorithms for "blanking" out regions of bad data or source-free regions in spectral-line cubes. It has an interactive mode, which allows you to indicate with the cursor on the TV what are "good" regions. Set everything but the image name to default values, use OPCODE 'TVCU' C~R~ and type GO BLANK C~R~. Then just follow the instructions, pushing button A to lay out the polygon and button D followed by C~R~ to go to the next image. If marking "bad" regions is easier, set DOINV TRUE C~R~ before running BLANK. A less subjective way is to use BLANK with OPCODE = IN2C. Blanking is done based on the pixel values in a second cube, usually a smoothed version of the original cube. The new task RMSD can be used to blank an image based on its rms in a window surrounding each pixel.

The blanked cubes can be used to calculate integral profiles with BLSUM and to calculate moments 0 to 3 of the profiles with XMOM. Thus, the 0-moment image will be the integral under the profile (*e.g.*, total HI), the first moment is the velocity field, etc. Task MOMNT does the smoothing, blanking and calculating of moments all in one run. This is very easy to use, but can be dangerous since you don't see what is going on. A display of the $0^{\text{th}}$ and $1^{\text{st}}$ moment images computed by XMOM is shown in Figure 8.4.

Moment images (or any other 2 or 3 images) may be combined in a display in which one image controls intensity, a second image controls hue (color), and a third optional image controls saturation (color richness or purity, done by varying the ratio of white to pure color). In the days of powerful television display devices, this display could be done at truly interactive speeds in the display hardware. Today, some workstations are capable of displaying full color images and the *AIPS* display program supports them. The verb TVHUEINT will display the two specified TV channels using one as the intensity and the other as hue. This is slower than it used to be but fully functional. *AIPS* task TVHUI may also be used with either full or pseudo color TV displays. This task offers a small menu of interactive options to enhance the images and otherwise control the display. It also offers the option to write out an image cube having RGB as its third axis and using much greater mathematical accuracy than is allowed in the TV display.

RGBMP computes "integral" images another way — as three weighted sums representing the low, center, and high velocity parts of the cube. Like TVHUI, RGBMP writes its results as a cube with RGB as the third axis. Task TVRGB can display these outputs (or any other RGB cube or any three image planes), using one image plane to control the red image, one to control green, and one to control blue. It works on real TV displays and full-color workstations and, using an algorithm to minimize the loss of color information, on pseudo-color workstations. Like TVHUI, it offers a small menu of interactive enhancement options. TVRGB can write 24-bit

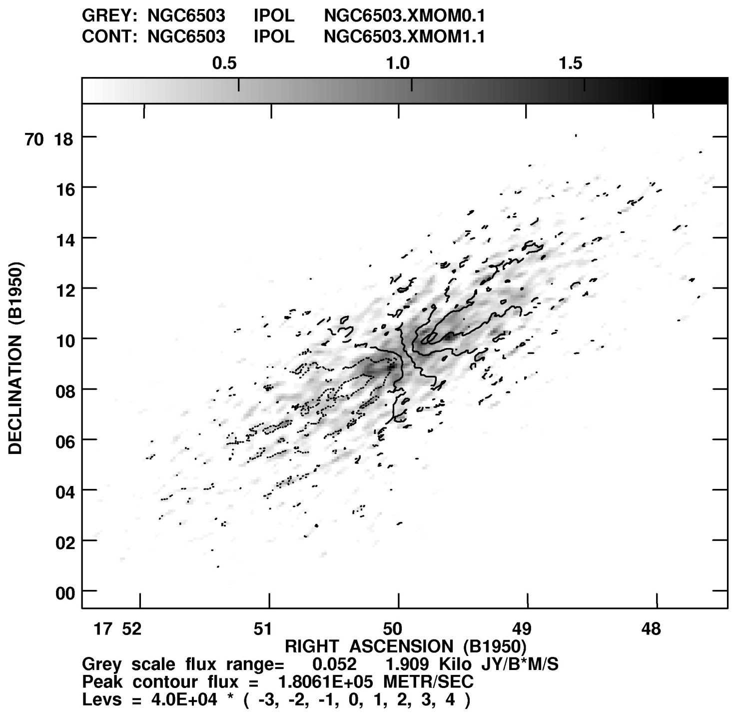



Figure 8.4: Display generated by GREYS and LWPLA using the moment 0 image for grey levels and the first moment image for contours. Data on NGC6503 were provided by Don Wells from observations made with the VLA on 12 April 1983.

color PostScript files beginning with the 15JAN96 release. TVCPS is another way to capture the displays generated by TVHUI and TVRGB to send to color PostScript printers.

If you prefer to fit Gaussians instead of calculating moments, the program XGAUS can be used. It is a good idea to use XPLOT first to look at (a sample of) the profiles, before you do any Gaussian fitting. XGAUSS offers a non-interactive mode, but it is frequently unstable and depends on the fit channels and the initial guesses being virtually independent of position. Therefore, in most cases, it is preferable to use the interactive mode, so that you can see what is happening, but be aware that it might be rather time-consuming.

The cube can be rotated with OGEOM (if the $\alpha - \delta$ pixels are square), *e.g.*, to align one of the axes with the major axis of a galaxy. If the pixels are not square, use OHGEO to regrid the image instead. A single profile can be produced from these images with SLICE, then plotted using TKSLICE,TVSLICE, or SL2PL (see § 6.5.2, § 6.4.8, § 6.3.2.2, and Figure 6.5). PLCUB, PLROW and XPLOT are convenient programs for displaying multiple individual spectral profiles after the cubes have been transposed.

To compute and display spectral profiles summed over regions in the two angular coordinates, use ISPEC for rectangular regions and BLSUM for irregular regions set interactively using the TV display and cursor. Both tasks print their results; BLSUM makes a printer plot, while ISPEC makes a standard AIPS plot file. Note that both tasks sum over areas in the first two axes and plot that as a function of position on the third axis, no matter what the three axes actually represent. This suggests a variety of interesting possibilities, such as time functions or line integrals versus position in the source. In 31DEC09, both tasks can write the results as slice extension files which may then be plotted and Gaussian fit in a variety of ways. Task RSPEC is similar to ISPEC except that it plots the rms rather than the data.

Note that if all you require is a single spectral profile, it may be possible to use POSSM which works on the *uv* data directly. If the spectral profile is a function of position within a well-resolved source, then you will have to go to the image plane.

GAL fits models of galaxy rotation to images of the predominant velocity (*e.g.*, the first moment images written by XMOM, XGAUS, or MOMNT). It accepts a second input image to be used as weights for the first input image; it is common practice to use a the zero'th moment image for this. Plots may be produced. The task MODVF creates a model velocity field based on a user provided model for the rotation curve, orientation, and warping of the plane.

A much more powerful, but tricky to use, task named CUBIT was developed by Judith Irwin and contributed to AIPS for the 31DEC07 release[2]. This task fits a galaxy rotation and emitter (usually HI) distribution to the full data cube. It uses dynamic memory and so can work on any reasonable size cube. It is much more likely to work if the cube has been very carefully BLANKed and if you approach it with patience. Make the best initial guesses for all the parameters that you can. Then fit for one parameter at a time until you begin to get a reasonable result. Then allow the task to fit all of the parameters at once. And finally, check the fits going through the galaxy in halves or quadrants. But first, study EXPLAIN CUBIT C_R in detail. The results from this task are worth the trouble to get it to work on your data.

## 8.7 Additional recipes

### 8.7.1 Golden mousse

1. Combine 1 cup mashed ripe **bananas**, 2 tablespoons **orange juice**, 1/4 cup shredded **coconut**, 3 tablespoons **brown sugar**, a few grains **salt**, and 1/8 teaspoon grated **orange rind**.
2. Whip until stiff 1 cup **heavy cream**.
3. Fold whipped cream into fruit mixture and turn into freezing tray. Freeze rapidly without stirring until firm.

### 8.7.2 Sopa de Plátano

1. Cook 10 whole red-skinned under-ripe **bananas** in one quart of water over low heat.
2. Peel and mash bananas with 1/4 teaspoon **cloves**, 1/4 teaspoon **orégano**, and 1 teaspoon **powdered cinnamon**.
3. Knead the mixture, add a pinch of **salt**, and fry in 4 tablespoon **shortening** until slightly browned.
4. Chop 4 medium-sized **tomatoes**, 2 **green peppers**, and 1 medium-sized **onion**.
5. Fry vegetables in 1/4 cup **olive oil** about 5 minutes and then add 1 teaspoon **salt**.
6. Place banana mixture on serving dish and garnish with the hot vegetables.

Thanks to Ruth Mulvey and Luisa Alvarez *Good Food from Mexico*.

[2] Irwin, Judith A. 1994, "Arcs and bridges in the interacting Galaxies NGC 5775/NGC 5774," ApJ, 429, 618-633.

# 9 REDUCING VLBI DATA IN $\mathcal{AIPS}$

This chapter describes the reduction of VLBI data in $\mathcal{AIPS}$ . A Step-by-step recipe, covering both simple and more difficult situations, is presented. See Appendix C for simpler and shorter recipes suitable for straightforward observations using only the VLBA and HSA (Arecibo, Effelsberg, GBT, and phased VLA) and the VLBA correlator. Procedures to simplify some of the VLBI reduction steps are mentioned and become available to you after you enter the command RUN VLBAUTIL C_R. We also include here some background information concerning the structure of VLBI data sets, the data reduction philosophy and a description of some of the effects for which corrections must be determined and applied. It is important to understand these aspects if you wish to reduce your data reliably. For more background information on VLBI data reduction consult *VLBI and the VLBA*, Astronomical Society of the Pacific (ASP) Conference Series No. 82, 1995.

Programs of particular interest for VLBI may be found in Chapter 13 or displayed from inside $\mathcal{AIPS}$ by typing ABOUT VLBI C_R or APROPOS VLBI C_R. Remember, the best and most complete information available on all $\mathcal{AIPS}$ verbs and tasks may be found in their EXPLAIN files. A 15APR97 or later version of $\mathcal{AIPS}$ is required to support full Space VLBI data reduction.

Most types of VLBI data, once read into $\mathcal{AIPS}$, appear very similar in structure as far as the user is concerned. We shall concentrate on describing the reduction path for data produced by the VLBA correlator, but most operations also apply to MkIII and MkII data. This chapter contains no specific discussion of data from a MkIV correlator since we have little experience as yet with such data. Where appropriate, we shall draw the reader's attention to any differences. In particular, § 9.2.2 deals with reading data from a MkIII correlator into $\mathcal{AIPS}$ and the steps necessary to prepare such data for calibration. The few extra steps necessary for calibrating phase-referencing observations are described in § 9.4.8.4. Note that successful phase-referencing observations require careful planning **before** the observations. See VLBA Scientific Memo No. 24 by J. Wrobel, C. Walker, J. Benson, and A. Beasley.

Some of the VLBI-related tasks require the ability to read files resident outside $\mathcal{AIPS}$ . To communicate to $\mathcal{AIPS}$ the directory in which these files exist it is necessary to define a logical pointer or environment variable. Please refer to § 3.10 to see how this is done.

While the majority of VLBI observations are continuum observations, more sophisticated data reduction techniques are increasingly common. Continuum VLBI observers sometimes also apply spectral-line VLBI techniques to improve the dynamic range of their data sets. For these reasons, this chapter is organized to make the discussion of data reduction techniques more uniform. The overview in this section of the steps involved for several type of VLBI data reduction is meant to guide the user through the rest of the chapter. It is strongly recommended that you read the overview carefully before proceeding.

The expected size of the output *uv* data file can be an important consideration in VLBI data reduction. The disk space required by $\mathcal{AIPS}$ for a compressed dataset is given by the relation:

$$\text{Disk Space} = 4 \text{ x } 10^{-6}\ N_{Stokes}\ N_{chan}\ N_{IF}\ \frac{N_{ant}}{2}(N_{ant}+1)\ \frac{T_{expt}}{\triangle T}\ \text{MBytes}$$

where $T_{expt}$ is the total observing time, $\triangle T$ the correlator integration time, $N_{Stokes}$ the number of polarization correlation pairs $(RR, LL, RL, LR)$, $N_{chan}$ the number of spectral channels per IF, $N_{IF}$ the number of IF's, and $N_{ant}$ the number of antennas in the network. Space VLBI (SVLBI) data can have different integration times for the ground and space baselines of $\triangle T_g$ and $\triangle T_s$, respectively, and therefore the total disk space requirement is larger. If $N_{ant}$ is the number of ground telescopes,

$$\text{Disk Space} = 4 \text{ x } 10^{-6}\ N_{Stokes}\ N_{chan}\ N_{if}\ \left[\frac{1}{2}N_{ant}(N_{ant}-1)\frac{T_{expt}}{\triangle T_g} + N_{ant}\frac{T_{expt}}{\triangle T_s}\right]\ \text{MBytes}$$

In uncompressed format the same data set will require two-three times the disk space. Be forewarned that some tasks (including FRING) attempt to create uncompressed scratch files which may not fit into the available disk space. The amount of available free disk space can be determined using the AIPS command FREE. The blocks referred to in the FREE output are equal to 1024 bytes.

Note that certain operating systems are still subject to a 2-Gigabyte limit for any individual file, as a result of their 32-bit file systems. Larger *AIPS* files are supported on DEC Alpha, SGI (running XFS), HP, Solaris (revision ≥ 2.6), and Linux (kernel ≥ 2.4.2). The last three require all *AIPS*' C code to be compiled with an additional option. The size of the output file can be reduced by IF selection or limited concatenation in FITLD or by time- or spectral-averaging later using UVAVG, SPLAT or AVSPC.

It is possible to construct data sets on disk that cannot be written to a single tape using FITTP because FITTP uncompresses the data when writing to tape. The task FITAB is designed to address this problem. FITAB writes data in compressed form to tape and can write data in pieces to multiple tapes. Note that FITAB is only available in 15APR99 and later releases and that versions of FITLD from earlier releases cannot read such data. Packages other than *AIPS* may also be unable to understand these files.

One large point of divergence in the reduction of continuum polarization VLBI data is the question of whether or not to determine separate LL and RR phase solutions. The polarization-specific portions of the recipe given below are based upon the premise that L and R phase solutions should always be determined separately on the grounds that it is safer and should work with data from a wide variety of antennas. If the L-R phase offsets for antennas in your data set are small and constant in time, you may consider modifying the recipe in § 9.1 by determining averaged LL,RR phase solutions everywhere except in step 7.

## 9.1 VLBI data calibration recipe

See Appendix C for simpler and shorter recipes suitable for straightforward observations using only the VLBA and its correlator.

1. LOAD THE DATA For data from the VLBA correlator, run FITLD (§ 9.2.1.1); if needed, follow up with MSORT, USUBA, INDXR, VBGLU, VBMRG, and MERGECAL (§ 9.2.1.4–§ 9.2.1.7). For data from a MkIII correlator, run MK3TX, MK3IN, MSORT, DBCON, UVAVG, TAMRG, SBCOR, and INDXR as needed (§ 9.2.2.1–§ 9.2.2.6). Data from the Penticton correlator should be loaded using FITLD, sorted (MSORT, § 9.2.1.4), and indexed (INDXR, § 9.2.1.6).

   POLARIZATION: The combination of the VLBA correlator and FITLD incorrectly labels polarizations for dual parallel-hand correlation (RR and LL only), even if RR and LL are in different frequency bands (*e.g.*, LL at 5 GHz and RR at 8.4 GHz). For these types of data, you must run FXPOL (§ 9.2.1.8).

2. EXAMINE THE DATA It is important to familiarize yourself with the data set before proceeding further, especially if you have little experience with VLBI data. There are many *AIPS* tasks for the examination of your data (see § 9.3 for a fuller discussion). Minimally, you should at first run LISTR, IMHEAD, EDITR, POSSM, VPLOT, and PRTAN. At later stages you will probably find SNPLT, PRTAB, DTSUM, and SHOUV useful for examining data and calibration tables.

   SVLBI: Task OBPLT allows you to examine different aspects of the spacecraft orbit.

3. PROCESS THE CALIBRATION FILES You will have either received calibration files, or instructions on where to obtain them. Some calibration files can be automatically processed into a form suitable for use within *AIPS* using VLOG (§ 9.4.2). ANTAB is now the primary *AIPS* task for loading calibration information from log files.

   VLBA CORRELATOR: Beginning on 1 April 1999, the VLBA correlator will have attached calibration information directly to your data for all VLBA and some other antennas. This obviates the need to run VLOG, ANTAB, PCLOD, and UVFLG to process your *a priori* calibration information for VLBA antennas. Some information for non-VLBA antennas must still be processed as usual.

POLARIZATION: Be careful to make sure that the polarization labeling of the IFs in the calibration text files is the same as the labeling in the data.

4. CORRECT FOR THE IONOSPHERE For low frequency experiments TECOR should be run to remove at least part of the ionospheric contribution to the phase offsets. This should also be considered for higher frequencies (*e.g.*, 8 GHz) depending on the amount of phase wrapping caused by the ionosphere.

5. CORRECT FOR THE EARTH ORIENTATION PARAMETERS For phase referencing experiments correlated at the VLBA correlator, particularly between 5-May-2003 and 2-August-2005, CLCOR (OPCODE='EOPS') should be run. This will correct the possibly inaccurate Earth Orientation Parameters used by the VLBA correlator. This is particularly important for astrometry experiments but can effect any phase referencing experiment including those correlated outside the above range of dates.

6. EDIT THE DATA Identifying and editing bad data now can save you time later. Data should first be edited using UVFLG to apply editing information supplied with your calibration files (§ 9.4.3). Some useful tasks for examining and editing data are EDITR, UVFLG, TVFLG, SPFLG, EDITA, FLAGR, FINDR, VPLOT, and QUACK.

   POLARIZATION: You may want to edit the data consistently in all polarizations (select STOKES = 'IQUV' within EDITR, TVFLG or SPFLG) — this can greatly simplify the imaging stage (see step 15).

7. APPLY *A PRIORI* CALIBRATION Corrections for sampler biases should be applied using ACCOR (§ 9.4.4.1) for data from the VLBA and some other correlators. Some correlators apply this correction to the data before writing them out — notably the EVN JIVE correlator and correlators used for the Australian LBA. The VLBA hardware and software (DiFX) correlators do *not* apply this correction to the data. Therefore, ACCOR is required for the VLBA correlators and any others that do not apply the correction. ACCOR should be benign (do nothing) for those correlators that do apply the correction prior to reading the data into AIPS. Note that you can always run ACCOR and look at the SN table produced with PRTAB or SNPLT to see if it was benign or not. It is recommended that this step be taken for both 1-bit and 2-bit data. Use APCAL to complete the *a priori* amplitude calibration (§ 9.4.4.2) — this is called the $T_{sys}$ method of amplitude calibration. APCAL can also be used to perform opacity corrections.

   POLARIZATION: For alt-az mounted antennas, a parallactic angle correction for the rotating orientation of the antenna feeds with respect to the observed source must be performed as the first step in the phase calibration using CLCOR (§ 9.4.4.3). This step should be performed no later than immediately after the $T_{sys}$ calibration.

   PHASE REFERENCING: You *will* want to perform the parallactic angle correction described above for phase referencing observations even if you only correlated the parallel hands (RR, LL).

   SPECTRAL-LINE: Unless the line emission is very weak, you may wish to defer amplitude calibration of your *line sources only* until step 12 below. The template method described there is much more accurate than the $T_{sys}$ method.

8. CALIBRATE THE SCALAR BANDPASS RESPONSE FUNCTION Run BPASS or CPASS to determine the bandpass response function using the *total-power* spectra (§ 9.4.5). Note that cross-power spectra may not be used until the phase slopes due to delay are corrected. This step is not necessary for most continuum observations unless very high dynamic range is sought and even then may not significantly improve the calibration. You should probably skip this step initially and return to it later if you suspect that your images are limited by bandpass effects.

   SPECTRAL-LINE: The bandpass response function should be determined using only the continuum calibrator sources. This step may be skipped in general so long as a good cross-correlation bandpass function is determined later.

9. CALIBRATE THE INSTRUMENTAL DELAYS *Phase-cals*, or measured single band and multi-band instrumental phase errors, should be applied using PCCOR (§ 9.4.8.5). You can manually perform a phase-cal by running FRING on a limited subset of your data to account for missing phase-cal information or to refine the reported phase-cal measurements (§ 9.4.8.6).

   VLBA CORRELATOR: Phase-cal information is now provided by the VLBA correlator (for VLBA antennas) and loaded by FITLD into a PC table; PCLOD (§ 9.4.8.5) may be needed for data from other telescopes.

   SPECTRAL-LINE: Delay calibration should be carried out only on the continuum sources at this stage.

   POLARIZATION: When running FRING, be certain to solve for independent left- and right-polarization delay solutions APARM(3) = 0. Run RLDLY after calibrating the instrumental delays, to determine a single delay offset between left and right polarization (§ 9.4.8.13).

   PHASE REFERENCING: Note that in general, you do not want to manually perform a phase-cal upon your *target*, or phase-referenced, source. However, see § 9.4.8.4 for further discussion on this topic.

10. FRINGE FIT THE DATA Estimate and remove residual delays, rates and phases using FRING or BLING and CLCAL (§ 9.4.8.9–§ 9.4.8.10).

   SPECTRAL-LINE: Only fringe-fit the calibrator source at this stage. Check the coherence of the target source using the resulting solutions to decide whether or not to zero the rate solutions using the 'ZRAT' option in SNCOR (§ 9.4.8.12).

   PHASE REFERENCING: You should **not** fringe-fit on the *target*, or phase-referenced source. Rather, you should fringe-fit on the *cal*, or phase-reference calibrator. When you apply the solution, be sure to set the CALSOUR and SOURCES adverbs in CLCAL appropriately to interpolate the solutions for the cal source onto the target source (see § 9.4.1.2). If you are not interested in astrometric calibration and your target source is strong enough, you may wish to consider fringe-fitting on it to further refine the phase calibration (§ 9.4.8.4).

11. ESTIMATE THE INSTRUMENTAL POLARIZATION (polarization data only). Correct for the instrumental polarization terms, commonly known as 'D-terms' using PCAL, LPCAL, or SPCAL on the polarization calibrator (§ 9.4.8.15). This polarization calibrator should first be fully calibrated and imaged before this step can be performed.

12. CALIBRATE THE POLARIZATION POSITION ANGLE (polarization data only). If a calibration source with known polarization orientation is available, use CLCOR to make a final correction to adjust the polarization angles of the target source data (§ 9.4.8.13).

13. CALIBRATE THE COMPLEX BANDPASS RESPONSE FUNCTION Run BPASS or CPASS to determine a complex-valued bandpass response function. This step may not be necessary and and is often skipped. However, even for continuum observation, your final images are likely to be limited by uncorrected bandpass functions (§ 9.4.5).

   SPECTRAL-LINE or POLARIZATION: The bandpass response function should be determined using only the calibrator source. Unlike step 7, this step cannot be skipped.

14. APPLY THE DOPPLER CORRECTION (spectral-line data only). Run CVEL to compensate for the changing Doppler shifts of the antennas with respect to the source during the observation and between the different observations (§ 9.4.6).

15. REFINE THE AMPLITUDE CALIBRATION (spectral-line data only). Run ACFIT to amplitude calibrate the program source using the template spectra method (§ 9.4.7). Note that the traditional $T_{sys}$ method (§ 9.4.4.2) can also be used if the line emission is too weak for the template method to work successfully.

16. DETERMINE RESIDUAL RATES (spectral-line data only). Now estimate the residual rates ONLY by running `FRING` or `BLING` on one or a few spectral points on the target source (§ 9.4.8.12).

17. APPLY CALIBRATION, AVERAGE, AND INSPECT THE FINAL DATA Run `SPLIT` or `SPLAT` to apply the calibration solutions and to average the data in frequency if appropriate (§ 9.5.1), and `UVAVG` to average the data in time (§ 9.5.2). You can also run `SPLAT` to combine these three operations into a single step. It is recommended that you take the time to inspect the calibrated data to see if more editing is needed, and to check that no gross calibration errors remain in the data (§ 9.5.3).

18. SELF-CALIBRATE/IMAGE OR SELF-CALIBRATE/MODEL-FIT THE DATA The final complex gain corrections are determined by iterating self-calibration with imaging of the resultant data set. This is called hybrid-mapping. Alternatively, self-calibration can be iterated while fitting models directly to the data — the goal is to self-calibrate using the best model possible. The options are outlined in § 9.6.

    SPECTRAL-LINE: One final distinction remains between continuum and spectral-line data. Only one or a few spectral points are used to determine final complex gain corrections which are then applied to all spectral points in the line data. After applying these gains, the line source data can be imaged to form an image cube.

    POLARIZATION: While the Stokes I and Stokes V images formed using the `RR` and `LL` visibilities will be real-valued, the Stokes Q and Stokes U images formed using `LR` and `RL` visibilities can, in principle, be complex-valued. You must use a fully complex imaging and deconvolution technique (see the `HELP` files for `CXPOL` and `CXCLN`) or you can simply edit the `LR` and `RL` visibilities to enforce the condition that the whenever you have a `RL` visibility on a baseline, you also have the `LR` visibility on the same baseline; this ensures that the Stokes Q and U images are real-valued and allows you to use the standard imaging tasks.

## 9.2 Loading and inspecting data

In theory, *AIPS* can process data from multiple frequency bands (`FQ` numbers in *AIPS* parlance) coexisting within the same data set. In practice, many observers prefer to separate the data for different frequency bands as soon as possible after loading the data and process each `FQ` number separately. If you wish to do this, you should do it immediately after performing the relevant steps in § 9.2, using the task `UVCOP` or procedure `VLBAFQS`.

### 9.2.1 Loading data from the VLBA correlator

#### 9.2.1.1 Running `FITLD`

The information below applies to data from the VLBA Correlator in what the VLBA archive calls "raw" format, more formally known as FITS-IDI format. The archive now also contains data called "calibrated" which have been run through a few of the simplest VLBA procedures but which are nowhere near calibrated. These files are recommended under normal circumstances. They may also be loaded with `FITLD`, but the `DOCONCAT` option does not work with the FITS table format used in the archive.

Data generated by the VLBA correlator are loaded from DAT (or Exabyte) tape (or from disk files) into *AIPS* using `FITLD`. First, physically load your tape and `MOUNT` it (§ 3.9), then run `FITLD`. Often the data on your tape will be divided into a number of separate files (corresponding to separate "correlator jobs"). In this case, run `FITLD` with `NCOUNT` set equal to the number of files on the tape (or a suitably large number), as listed on the paper index which comes with the tape. The adverb ANTNAME added in 31DEC10 allows the user to control the antenna numbering if desired. Also set DOCONCAT = 1 C_R to ensure that all tape files with the same structure are concatenated into a single AIPS file. Note that standard tape handling tasks (*e.g.*, PRTTP and TPHEAD) can be used to inspect the tape contents.

Note that antennas, sources, frequency IDs, and other things may be numbered differently in different correlator jobs. FITLD fixes all this for you, but only if you set DOCONCAT = 1 and, better still, load as many files as possible in each execution of FITLD. To help with this, beginning with the 31DEC03 release, FITLD can load VLBA correlator data from multiple disk files so long as they have the same name plus a consecutive post-pended number beginning with 1. If you forget to put all the related data together with FITLD you can use MATCH to align the antenna numbers followed by DBCON later.

Typical inputs to FITLD would be;

| | |
|---|---|
| > TASK 'FITLD' ; INP C_R | to review the inputs. |
| > INTAPE $n$ C_R | to specify the input tape number. |
| > NFILES 0 C_R | to skip no files on tape. |
| > DATAIN ' ' C_R | to load from tape, not from disk. |
| > OUTNAME 'TEST' ; OUTCL 'FITLD ' C_R | to specify the name of the output file. |
| > OUTSEQ 0; OUTDI 1 C_R | to specify the sequence number and disk of the output. |
| > OPTY ' ' C_R | to load any type of file found. |
| > NCOUNT 20 C_R | to load 20 tape files. |
| > DOUVCOMP 1 C_R | to save disk space by writing compressed data. |
| > DOCONCAT 1 C_R | to concatenate files with same data structure into one disk file. |
| > CLINT $\triangle t$ C_R | set CL table interval to $\triangle t$ minutes (see discussion below). |
| > DIGICOR 1 C_R | to request digital corrections (VLBA correlator only). |
| > DELCORR 1 C_R | to request delay decorrelation corrections (VLBA correlator only). |
| > WTTHRESH 0.65 C_R | flag incoming visibilities with correlator weights less than 0.65. |
| > SOURCES ' '; QUAL 0 C_R | to accept all sources found. |
| > TIMERANG 0 C_R | to accept data from all times. |
| > BCHAN 0; ECHAN 0; BIF 1; EIF 0 C_R | to accept all channels in all IFs. |
| > SELBAND 0 C_R | bandwidth to select (kHz). |
| > SELFREQ 0; FQTOL 0 C_R | frequency to select with tolerance of 10 kHz. |
| > OPCODE ' ' C_R | to not copy the tape statistics table ('VT' table). |
| > GO C_R | to run the program. |

This may seem a bit formidable. For straightforward VLBA observations, there is a collection of procedures to simplify matters including the loading of data. Enter

| | |
|---|---|
| > RUN VLBAUTIL C_R | to acquire the procedures; this need be done only once since they will be remembered. |
| > INTAPE $n$ C_R | to specify the input tape number. |
| > NCOUNT 20 C_R | to load 20 tape files. |
| > OUTNAME 'TEST' ; OUTDI 1 C_R | to specify the name and disk of the output file. |
| > DOUVCOMP 1 C_R | to save disk space by writing compressed data. |
| > CLINT $\triangle t$ C_R | to set the CL table interval to $\triangle t$ minutes (see discussion below). |
| > INP VLBALOAD C_R | to review the inputs. |
| > VLBALOAD C_R | to run the procedure. |

Because the data files tend to be very large, you will usually write compressed data (DOUVCOMP=1). These files take about 1/3 of the space of 'uncompressed' data sets, but cause information about the weights of individual polarizations, spectral channels, and IFs to be lost. There is some loss in dynamic range and sensitivity when the weight information is (partially) compromised. (See Appendix F for an expanded discussion of when to and when not to write 'compressed' data sets.) If your observation has more than one DAT or Exabyte tape, simply run FITLD for each tape. Setting DOCONCAT 1 and setting the output file name completely will ensure that the data from separate tapes with compatible observing band/data structure will be appended to existing AIPS files. Generally, after loading all of your data, you will have one file for each such observing band and/or observing mode. However, observations which require multiple passes through the correlator (including MkIII Modes A, B, and C observations) will have one file per observing mode *per correlation pass*. Data from separate correlator passes can be concatenated using task VBGLU and/or merged with task VBMRG.

Adverb CLINT, which specifies the CL table time sampling interval, must be short compared to the anticipated coherence time. CLINT should be set such that the shortest anticipated fringe-fit interval is spanned by a few CL entries. Time sampling in the CL table that is too coarse can lead to calibration interpolation errors when applying the fringe-fit solutions at later stages of the data reduction. If the interval is made unnecessarily short the CL table may become unmanageably large.

It is recommended that corrections for digital representation of the correlated signals be performed in FITLD under control of adverb DIGICOR, but only for data from the VLBA correlator. DIGICOR should be set to one for all continuum and nearly all spectral line experiments. However, in the special case of spectra with very strong narrow features, the absence of correlator zero-padding may limit the accuracy of the quantization corrections. See the FITLD help file for further information. The details of digital correction for FX correlators can be found in *Radio Science* **33**, 5, 1289–1296, "Correction functions for digital correlators with two and four quantization levels", by L. Kogan.

Adverb DELCORR enables amplitude corrections for known delay decorrelation losses in the VLBA correlator, as described in AIPS Memo 90 (1995, "Delay decorrelation corrections for VLBA data within AIPS" by A. J. Kemball). Setting DELCORR=1 will create a correlator parameter frequency (CQ) table for each file written by FITLD. Do this for the VLBA correlator only. The presence of this table enables the delay decorrelation correction once the residual delays have been determined in fringe-fitting. These corrections will not be applied if the data were not correlated at the VLBA correlator or if the CQ table is missing. For older FITLD files the CQ table can be generated using task FXVLB and this must be done before any changes in the frequency structure of the file are made. The CQ table is used for rate and delay amplitude decorrelation corrections after residual delay and rate errors have been determined by fringe-fitting, and are being applied to the data. The CQ table has no immediate effect on the data written by FITLD but is essential for later processing.

The WTTHRESH adverb can be applied to drop incoming data with playback weights less than the specified limit. Note that data flagged in this way are *unrecoverable* except by re-running FITLD. The data weights are normalized to unity so good data usually have weights close to 1.0. You should examine your data carefully if you use WTTHRESH to make sure that you have not discarded too much data at this stage. Typically 0.8 or higher is good for the VLBA, but for non-VLBA stations a lower value such as 0.6 or 0.7 may be appropriate.

Calibration data have been transferred from the correlator with your data if your data include VLBA antennas and were correlated after 1 April 1999 and your IMHEADER listing shows the presence of GC, TY, WX, PC and FG tables, as in the example below. If you loaded more than one tape file, you must merge the calibration tables. Beginning with the 31DEC02 version, VLBALOAD does the merging for you. See § 9.2.1.2 for additional details. Note that, as this example shows, it is possible your data have calibration transfer tables even though they were correlated before 1 April 1999. If your IMHEADER does not show GC and TY tables, you do not have calibration transfer and must manually load calibration information in from text files. Also, even if you have calibration transfer, you may still have to manually load calibration information for some non-VLBA antennas (see http://www.vlba.nrao.edu/astro/obscor/cal-transfer/ for some information in this regard).

The output files produced by FITLD are in standard multi-source format (as described in § 4.1) and contain data from all the target and calibrator observations in your observation. FITLD also writes a large number of extension tables including an index (NX) table, and many tables containing calibration information. A description of the VLBA correlator table types is given in § 9.7. If you are missing the CORR-ID random axis, your AIPS release is stale (pre-15APR97) and you are strongly encouraged to upgrade to the latest release; much of the information presented in this chapter will not be usable with pre15APR97 releases of AIPS. Your catalog header should be similar to the one, obtained using verb IMHEADER, given below. If you have GC, TY, FG, WX, and PC tables as in this example data header, your data were processed with calibration transfer - see § 9.2.1.2 for more details.

```
Image=MULTI     (UV)         Filename=329         .OVLB  .   1
Telescope=VLBA               Receiver=VLBA
Observer=TM008               User #=   44
Observ. date=23-SEP-1998     Map date=06-JAN-1999
# visibilities      6567     Sort order  **
Rand axes: UU-L  VV-L  WW-L  TIME1  BASELINE  SOURCE  FREQSEL
           INTTIM  CORR-ID  WEIGHT  SCALE
----------------------------------------------------------------
Type    Pixels   Coord value     at Pixel     Coord incr   Rotat
COMPLEX      1   1.0000000E+00       1.00  1.0000000E+00     .00
STOKES       1  -2.0000000E+00       1.00 -1.0000000E+00     .00
FREQ        16   4.9714900E+09        .53  5.0000000E+05     .00
IF           8   1.0000000E+00       1.00  1.0000000E+00     .00
RA           1    00 00 0 .000       1.00        .000000     .00
DEC          1    00 00 0 .000       1.00        .000000     .00
----------------------------------------------------------------
Coordinate equinox 2000.00
Maximum version number of extension files of type HI is   1
Maximum version number of extension files of type CQ is   1
Maximum version number of extension files of type AT is   1
Maximum version number of extension files of type IM is   1
Maximum version number of extension files of type CT is   1
Maximum version number of extension files of type GC is   1
Maximum version number of extension files of type TY is   1
Maximum version number of extension files of type FG is   1
Maximum version number of extension files of type PC is   1
Maximum version number of extension files of type MC is   1
Maximum version number of extension files of type OB is   1
Maximum version number of extension files of type AN is   1
Maximum version number of extension files of type WX is   1
Maximum version number of extension files of type FQ is   1
Maximum version number of extension files of type SU is   1
Keyword = 'OLDRFQ  '  value =  4.97149000D+09
```

Note that the sort order of the output data set is listed as ** rather than TB and that there are no attached CL and NX tables. This happens when FITLD detects what might be a sub-array condition (two frequency IDs or two sources observed at the same time) on reading the data. In clear cases, the actual simultaneous frequency IDs and sources will be reported. In this case, FITLD detected the use of multiple integration times on different baselines in the data set; this is common for SVLBI data. The message reported by FITLD in this case takes the form:

```
**********************************************
FITLD5:  Subarray or multiple dump-rate condition found.
```

```
FITLD5:  NX/CL tables deleted.
FITLD5:  Use USUBA to set up subarrays.
FITLD5:  Rerun INDXR using CPARM(3) and (4)
FITLD5: *******************************************
```

Unless any of the following criteria are met, the data written by FITLD are immediately ready for further processing.

- If the sort code has been blanked as in this example, you must sort the data (use UVSRT or MSORT).
- If the source subarray condition is encountered, you may need to run USUBA.
- If the frequency ID subarray condition is encountered, you must separate the frequency IDs into separate data sets; procedure VLBAFQS will do this for you.
- If FITLD does not leave behind CL and NX tables, you must run INDXR to create them. Procedure VLBAFIX will do all of the above for you.
- If you wish to join together data processed in multiple correlator passes, you must run VBGLU and/or VBMRG.

FITLD can also be used to load archived AIPS data previously written to tape using either FITTP or FITAB, as described in § 5.1.2. In this case the VLBA correlator-specific adverbs, such as those enabling digital and delay corrections, are not active.

#### 9.2.1.2 Calibration transfer

Beginning on 1 April 1999, the VLBA correlator attaches calibration information for VLBA and some non-VLBA antennas directly to the output FITS files. If your IMHEADER listing shows GC, TY, WX, FG, and PC tables, then the correlator has provided calibration information; this service is called *calibration transfer*. Note that projects correlated at slightly earlier dates may also have calibration transfer information. You must have 15APR99 or later version of AIPS to take advantage of calibration transfer. Not all antennas provide all the information needed for calibration transfer to the VLBA correlator, see

http : //www.vlba.nrao.edu/astro/obscor/cal − transfer/

for the latest information on this subject. For those antennas for which calibration information was not transferred by the VLBA correlator, you must process the log files in the traditional way as outlined in § 9.4.2. Calibration for the VLA and the GBT began to be transferred with the FITS files in November 2003.

The information processed by the correlator is somewhat redundant so that the calibration tables, the GC table in particular, must be merged using TAMRG, a very general and hence complicated task. Beginning with 31DEC00, there is a procedure to do this for you in the VLBAUTIL package:

| | |
|---|---|
| > RUN VLBAUTIL C_R | to acquire the procedures; this should be done only once since they will be remembered. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > INP VLBAMCAL C_R | to review the inputs. |
| > VLBAMCAL C_R | to run the procedure. |

You should use VLBAMCAL after you have finished loading the data from tape, but before you either change the polarization structure of the data with FXPOL (or VLBAFIX), load any calibration data for non-VLBA telescopes, or apply the calibration data. Note that VLBALOAD runs VLBAMCAL automatically when needed beginning in the 31DEC02 release.

A procedure named MERGECAL also has been provided for the same purpose with 15APR99 and later versions of AIPS. You must first compile MERGECAL, before you can examine its inputs and run it:

| | |
|---|---|
| > RUN MERGECAL C_R | to load the procedure and define some adverbs |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > GCVER 0 C_R | to specify the input GC table version. |
| > TYVER 0 C_R | to specify the input TY table version. |
| > PCVER 0 C_R | to specify the input PC table version. |
| > OUTVERS 0 C_R | to specify the output versions for all three tables. |
| > TIMETOL 0.1 C_R | to specify the range in time (in seconds) to be regarded as equal and merged. |
| > BADDISK 0 C_R | to specify which disks not to use for scratch |
| > INP MERGECAL C_R | to review the inputs. |
| > MERGECAL C_R | to run the procedure. |

Note that the first step, RUN MERGECAL, does not run MERGECAL; it only loads the procedure and defines necessary adverbs. The inputs above will process GC, TY, and PC tables version 1 into GC, TY, and PC tables version 2. We strongly recommend that you preserve the original versions loaded by FITLD since if they are corrupted, they can only be recovered by re-running FITLD. You may also find it productive to examine/edit the entries in the MERGECAL'd tables using PRTAB, SNPLT, and TABED.

It is also recommended that FG version 1 be copied over to FG version 2 using TACOP and that all further flagging operations modify FLAGVER 2 (or higher). Don't forget to set FLAGVER (in later tasks) to take advantage of the pre-loaded and user-set flagging information.

#### 9.2.1.3 Repairing VLBA data after FITLD

As listed above, there are a variety of reasons why VLBA data may need some repair after FITLD has been run. They may need to be sorted into strict time order, to have the subarray nomenclature corrected, to be split into different frequencies, to have the polarization structure fixed, and/or to have the original index (NX) table and calibration ((CL) recreated. These repairs can all be done by the procedure VLBAFIX, which will examine the data and perform any of the necessary fixes. If the data contain subarrays then the procedure must be told to split the data into multiple subarrays (SUBARRAY=2), otherwise it will assume no subarrays and force all the data into one subarray.VLBAFIX is intended to replace VLBASUBS, VLBAFQS and VLBAFPOL, all of which can be run individually instead.

| | |
|---|---|
| > RUN VLBAUTIL C_R | to acquire the procedures; this should be done only once since they will be remembered. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > CLINT $\triangle t$ C_R | to set the CL table interval to $\triangle t$ minutes (see discussion above in § 9.2.1.1). |
| > OUTDISK *m* C_R | to specify the output disk when needed. |
| > INP VLBAFIX C_R | to review the inputs. |
| > VLBAFIX C_R | to run the procedure. |

Remember that all of the VLBAUTIL procedures have HELP files with good discussions about when to use the simple procedures and when to use the tasks directly.

#### 9.2.1.4 Sorting and indexing VLBA correlator data

If multiple integration times are used on different baselines, the VLBA correlator will write data that are not in strict time-baseline (TB) sort order. In general, task UVSRT can be used to sort randomly ordered *uv* data files in AIPS, but has significant disk space requirements through the use of intermediate scratch files. A special task, MSORT, has been written which uses a direct memory sort with sufficiently large buffers to accommodate the scale over which the data deviate from true time-baseline sort order. No intermediate scratch files are used and it can be significantly faster than UVSRT for this special case. MSORT competes with UVSRT in performance even in other cases, particularly when the individual visibility records are large due to many spectral channels and/or IFs. The inputs to MSORT are similar to those required by UVSRT and take the form:

| | |
|---|---|
| > TASK 'MSORT' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > OUTDISK *n* ; OUTNAM ' ', OUTCLA ' ' | to specify the output file. |
| > SORT ' ' C_R | to select default sort order ('TB' or time-baseline). |
| > GO C_R | to run the program. |

Note that if the input and output file names are identical, the input file is sorted in place. In-place sorting is dangerous, but may be necessary if there is insufficient disk space for a second copy of the data set or for the intermediate scratch files required by UVSRT. *Never abort an in-place sort in progress because you will destroy the integrity of your data set.* VLBAFIX will perform this operation if needed (§ 9.2.1.3).

#### 9.2.1.5 Subarraying VLBA correlator data

If the project was observed without using subarrays (defined as times at which separate antennas are simultaneously observing different sources or at different frequencies), *this step involving* USUBA *is not necessary and should be skipped*.

If the observations have been scheduled in separate subarrays, defined either by source or frequency selection, the subarrays should be labeled in AIPS before proceeding any further. The VLBA correlator does not conserve subarray information, which in any event often has no unique characterization. This is specified in AIPS using task USUBA which allows subarrays to be defined through either the input adverbs, an external KEYIN text file, or through the use of an automatic algorithm to identify and label subarrays found in the data. The automatic algorithm is recommended, *but its results should be checked closely.*

If you have subarrays, they need to be sorted, have the subarray nomenclature corrected, and/or have the index (NX) table and calibration (CL) version 1 table rebuilt. In this case, there is a simplified procedure to combine the three repair operation, VLBASUBS. Only use this procedure if you know you have subarrays.

| | |
|---|---|
| > RUN VLBAUTIL C_R | to acquire the procedures; this should be done only once since they will be remembered. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > CLINT $\triangle t$ C_R | to set the CL table interval to $\triangle t$ minutes. |
| > INP VLBASUBS C_R | to review the inputs. |
| > VLBASUBS C_R | to run the procedure. |

The only user-controllable input is the CL table interval; see discussion above. VLBAFIX will perform this operation if requested (§ 9.2.1.3).

For automatic subarray labeling by USUBA, representative input parameters would be:

| | |
|---|---|
| > TASK 'USUBA' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > OPCODE 'AUTO' C_R | to identify subarrays automatically. |
| > TIMERANG 0 C_R | to include all times. |
| > ANTENNAS 0 ; SOURCES ' ' C_R | to include all antennas and sources. |
| > FREQID -1 ; SUBA 0 C_R | to include all frequency IDs and subarrays. |

> INFILE ' ' C_R to use no external file for subarray identifications.
> GO C_R to run the program.

Sometimes FITLD erroneously identifies a subarray condition, usually because of spurious total-power data points. In such cases, you can set OPCODE = ' ' ; SUBARRAY = 1 to force all data into the first subarray.

#### 9.2.1.6 Indexing VLBA correlator data

If FITLD had not written NX or CL tables or it was necessary to sort the data as described in § 9.2.1.4, you must run task INDXR. INDXR will generate an NX table and, if need be, a CL table. Typical parameters for INDXR are:

> TASK 'INDXR' ; INP C_R to review the inputs.
> INDISK *n* ; GETN *ctn* C_R to specify the input file.
> PRTLEV 0 C_R to print minimal details of progress.
> CPARM 0, 0 , $\triangle t$ , 1 C_R to set the CL interval to $\triangle t$ and recalculate the model.
> GO C_R to run the program.

Note that CPARM(4) can be set to zero unless the correlator model is required in later reduction (*e.g.*, in astrometry or geodesy observations) The CL table sampling interval $\triangle t$ should be chosen subject to the same considerations given regarding adverb CLINT in the discussion of FITLD in § 9.2.1.1. VLBAFIX will perform this operation if needed (§ 9.2.1.3).

#### 9.2.1.7 Concatenating VLBA correlator data

Sometimes an observation is correlated using multiple passes through the VLBA correlator. In this context, multiple pass means different IFs/pass; this is due to data rate limitations in the correlator. Be careful to have FITLD load each pass into a separate disk file; otherwise a very confused data set will be produced. If it is desired to join together the IFs correlated on each pass, the task VBGLU should be used. VBGLU can only join data sets which are identical except in the frequencies covered. Task MATCH may be used to make the antenna, source, and frequency ID numbers in one data set the same as those in another data set so that they may be used as inputs to VBGLU.

The inputs to VBGLU are rather simple. Each of the input files to be glued together is specified via INNAME–IN4NAME, and an output file is specified via OUTNAME. The choice of input file 1 is no longer (in 31DEC06) important. No data are lost in the revised version of this task.

> TASK 'VBGLU' ; INP C_R to review the inputs.
> INDISK *n* ; GETN *ctn* C_R to specify the input file.
> IN2DISK *n* ; GET2N *ctn* C_R to specify the 2nd input file.
> IN3DISK *n* ; GET3N *ctn* C_R to specify the 3rd input file.
> IN4DISK *n* ; GET4N *ctn* C_R to specify the 4th input file.
> OUTDISK *n* C_R to specify the output disk.
> GO C_R to run the program.

With the changes in recording technology, it is also possible that a correlator will not have enough playback units for all antennas in an experiment. In this case, multiple correlations will also have to be done in order to correlate every possible baseline. But, inevitably, certain baselines will appear more than once in these correlations. FITLD will load all passes into a single data set (if DOCONCAT=1) or separate disk files which may be concatenated, after MATCH, with DBCON. Sort the data set into 'BT' order with UVSRT. Then task VBMRG may be used to discard any duplicate data.

#### 9.2.1.8 Labeling VLBA correlator polarization data

The VLBA correlator does not preserve polarization information unless it is operating in full polarization mode. This results in polarizations not being labeled correctly when both RR and LL polarizations are observed without RL and LR. Each VLBA correlator band is loaded into *AIPS* as a separate IF and is assigned the same polarization. FXPOL takes a data set from the VLBA correlator and produces a new data set that has the correct IF and polarization assignments. Unfortunately, there is no reliable way to determine the polarization of each IF from the input data set and you must specify the polarization assignments using the BANDPOL adverb.

Most VLBA setups assign odd-numbered bands to RCP and even-numbered bands to LCP. In this case BANDPOL should be set to `'*(RL) '` (the default) and FXPOL will generate a new data set that is of equal size to the input data set, but has two polarizations and half the number of IFs. This case normally applies if LISTR shows pairs of IFs with the same frequency and QHEADER shows one pixel on the STOKES axis with coordinate value RR, but there may be exceptions to this rule when non-VLBA antennas are used.

Most MkIII and MkIV VLBI setups reverse the polarizations and assign odd-numbered bands to LCP and even-numbered bands to RCP. In this case BANDPOL should be set to `'*(LR) '` and the output data set will again be of equal size to the input data with two polarizations and half the number of IFs. This case normally applies if LISTR shows pairs of IFs with the same frequency and QHEADER shows one pixel on the STOKES axis with coordinate value LL, but there may be exceptions to this rule when non-VLBA antennas are used.

Beginning with 31DEC00, there is a procedure for use with VLBA-only data that attempts to determine which of the above cases applies and then runs FXPOL for you:

| | |
|---|---|
| > RUN VLBAUTIL C_R | to acquire the procedures; this should be done only once since they will be remembered. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > INP VLBAFPOL C_R | to review the inputs. |
| > VLBAFPOL C_R | to run the procedure. |

Use VLBAFPOL to check whether you need to relabel the polarizations in your data after loading the data, looking for subarrays, and merging redundant calibration data, but before reading any calibration data from non-VLBA stations. VLBAFPOL assumes that all of your FREQIDs have similar polarization setups. For this reason, you should normally run VLBAFPOL after copying each frequency ID to a separate file using VLBAFQS (§ 9.4). This strategy also reduces the amount of disk space needed for VLBAFPOL. VLBAFIX will perform this operation if needed (§ 9.2.1.3).

To use FXPOL directly, typical inputs are:

| | |
|---|---|
| > TASK 'FXPOL' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > BANDPOL '*(RL)' C_R | to specify the normal VLBA polarization structure. |
| > GO C_R | to run the program. |

Consult HELP FXPOL for further information about more complicated cases. Note that FXPOL has to write a new output file since the structure of the data is being changed. All standard extension files are also converted, but it is still a good idea to run FXPOL before running the calibration tasks.

In single-polarization observations, LL data may simply be mis-labeled as RR or vice-versa. This does not need to be corrected within *AIPS* but the user needs to take this into account when selecting or calibrating the data, particularly in specifying the polarization in the amplitude calibration text file (§ 9.4.2). The Stokes axis can however be modified. Before running PUTHEAD, you should run IMHEAD to check which axis is the Stokes axis in the catalog header.

| | |
|---|---|
| > INP PUTHEAD C_R | to review the inputs. |

| | |
|---|---|
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > KEYWORD 'CRVAL*m*' C_R | to select the Stokes or $m^{\mathrm{th}}$ axis in the header. |
| > KEYVALUE = -2 C_R | to set the Stokes value to 'LL' (or -1 for 'RR'). |
| > PUTHEAD C_R | to set the coordinate value. |

#### 9.2.1.9 Ionospheric corrections

At low frequencies (2 GHz and lower) the ionosphere can cause large unmodeled dispersive delays, seen as rapid phase wrapping. This can be of particular importance in phase referencing observations, where phases must be interpolated over weak sources. Even at high frequencies (*e.g.*, 8 GHz) the ionosphere can be important, depending on the experiment and the condition of the atmosphere during the observation. One way to remove at least some of the ionospheric phase offsets is by applying a global ionospheric model derived from GPS measurements. The AIPS task TECOR processes such ionospheric models that are in standard format known as the IONEX format. These models are available from the Crustal Dynamics Data Information System (CDDIS) archive. There is a procedure (available from November 3, 2005) which is part of VLBAUTIL, called VLBATECR. This procedure automatically downloads the needed IONEX files from CDDIS and runs TECOR. It will examine the header and the NX table and figure out which dates need to be downloaded, so the observation date in the header must be correct and an NX table must exist. See EXPLAIN VLBATECR for other requirements.

| | |
|---|---|
| > RUN VLBAUTIL C_R | to acquire the procedures; this should be done only once since they will be remembered. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > INP VLBATECR C_R | to review the inputs. |
| > VLBATECR C_R | to run the procedure. |

You can also download the files manually from the CDDIS archive through anonymous ftp and run TECOR, see EXPLAIN TECOR for detailed instructions on how to retrieve the models. TECOR interpolates between the maps of electron content in the ionosphere; therefore IONEX files must be retrieved to cover the entire experiment. Presently, each IONEX file contains maps every 2 hours from hours 00:00 to 24:00. Before November 2002, they contained maps every 2 hours from hours 1:00 through 23:00. Therefore, for example, if an experiment prior to November 2002 started at 0:00 then files must be retrieved for the day of the experiment and the previous day so the times between 0:00 and 0:59 can be interpolated. More recent experiments require two or more files only if they occurred in two or more days.

Typical inputs to TECOR are:

| | |
|---|---|
| > TASK 'TECOR' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > INFILE 'FITS:JPLG1230.01I' C_R | to set the name of the IONEX file. If there is more than one file, this name *must* be a standard format and be the first file. See EXPLAIN TECOR for more details. |
| > NFILES *n* C_R | to set number of IONEX files to be read. |
| > SUBARRAY 0 C_R | to process all subarrays. This option allows you to process subarrays used on different dates. |
| > ANTENNAS 1 2 3 4 6 7 8 9 10 C_R | to find corrections for all antennas except antenna 5 in a ten antenna experiment. This is important because if the IONEX models do not cover an antenna and it is not excluded here then all the solutions for that antenna will be undefined and the data flagged when the CL table is applied. |
| > GAINVER 1 C_R | to apply corrections to the first CL table. |

| | |
|---|---|
| > GAINUSE 2 CR | to create CL table 2 with the corrections. |
| > APARM 1 0 CR | to correct for dispersive delay; otherwise only the ionospheric Faraday rotation will be corrected. |
| > GO CR | to run TECOR, correcting for the ionosphere in a new CL table. |

The dispersive delays should be checked using SNPLT (options INEXT 'CL'; INVERS 2; OPTY 'DDLY') and VPLOT (options BPARM 0; APARM 0; DOCAL 1; GAINUSE 2). TECOR is only as good as the models, which at this time are quite rough. Therefore, it is a very good idea to compare the corrected and uncorrected phases using VPLOT.

In 31DEC09, CLCOR has a new OPCODE = 'IONO' to make delay corrections for the ionosphere, similar to the 'ATMO' operation which is for the atmosphere (§ 9.4.8.7).

#### 9.2.1.10 Corrections to the Earth Orientation Parameters

This correction is only useful for experiments correlated at the VLBA correlator. VLBI correlators must use measurements of the Earth Orientation Parameters (EOPs) to take them out of the observations. These change slowly with time and therefore the EOPs used by the correlator must be continually updated. From 5-May-2003 to 9-Aug-2005 the VLBA correlator used old predicted EOPs which could be significantly wrong and will effect all phase referencing experiments. Incorrect EOPs can both move the position and possibly smear the target of a phase referencing experiment. Self-calibration can improve the smearing. Even outside the above quoted period of particularly bad EOPs the EOPs can be off so it is recommended that all phase-referencing experiments, particularly astrometry experiments should have their EOPs corrected. CLCOR (OPCODE='EOPS') can do this correction. It uses the CT table which is only produced by the VLBA correlator, so at the moment CLCOR can only correct experiments processed at the VLBA correlator. CLCOR also uses a file of measured EOPs, which can be downloaded from NASA (see EXPLAIN CLCOR for details). There is a new procedure (available from October 20, 2005), called VLBAEOPS, which downloads the file automatically and runs CLCOR. To run the procedure:

| | |
|---|---|
| > RUN VLBAUTIL CR | to acquire the procedures; this should be done only once since they will be remembered. |
| > INDISK *n* ; GETN *ctn* CR | to specify the input file. |
| > INFILE '' CR | to automatically download file. |
| > INP VLBAEOPS CR | to review the inputs. |
| > VLBAEOPS CR | to run the procedure. |

The procedure will correct the highest CL version while copying it to a version one higher.

To run CLCOR manually, download the file using the instructions in CLCOR's explain file. Sample inputs are as follows:

| | |
|---|---|
| > TASK 'CLCOR' ; INP CR | to review the inputs. |
| > INDISK *n1* ; GETN *ctn* CR | to specify the input file. |
| > OPCODE 'EOPS' CR | to select correction of the EOPs. |
| > GAINVER *clin* CR | CL table to read, new default is the current highest version. |
| > GAINUSE 0 CR | CL table to write; version highest+1 is written unless GAINUSE = GAINVER. |
| > INFILE 'FITS:usno_finals.erp CR | to specify file with correct EOPs — note missing close quote to retain lower case letters. |
| > GO CR | to run the program. |

#### 9.2.1.11 Preparing the OB table for SVLBI data

The spacecraft orbit table (OB) as produced by FITLD contains the spacecraft position $(x, y, z)$ and velocity $(v_x, v_y, v_z)$ as calculated to high accuracy from the JPL reconstructed orbit using the SPICE package (developed at JPL). These quantities are calculated by the correlator on-line software and are passed directly through to AIPS via FITLD by the VLBA correlator. The orbit table is indexed on time and can include information such as the angle between the spacecraft pointing direction and the Sun, the time since the start and end of the last eclipse, and the spacecraft parallactic angle. The latter quantities are not available to the correlator on-line software and, if desired, need to be computed separately for later use in AIPS by task OBTAB. Additionally OBTAB stores orbital elements in the AN table; these are essential for later use in plotting or inspecting spacecraft orbit information. Sample inputs for OBTAB, are as follows:

| | |
|---|---|
| > TASK 'OBTAB' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > INVERS 1 C_R | to process OB table 1. |
| > SUBARRAY 1 C_R | to select subarray number. |
| > APARM 1, 0 C_R | to update orbital elements in AN table |
| > GO C_R | to run the program. |

Note that APARM(8) can be used to directly specify which antenna is the orbiting antenna (this task assumes there is only one orbiting antenna).

Task OBTAB determines mean orbital elements from the OB table using the spacecraft positions and velocities and updates the AN table under control of APARM(1). The orbital elements can be examined by using PRTAB to review the updated AN table. The mean elements are used to compute *uv* coordinates for the spacecraft so that model amplitudes AND closure phases and amplitudes can be plotted (by tasks VPLOT, CLPLT, and CAPLT). The orbit table can be plotted using task OBPLT. Alternatively, the task TAPLT can be used to display individual columns. Use PRTAB to determine the names of the columns you wish plotted.

#### 9.2.1.12 Loading the time corrections file for SVLBI data

The round-trip residual delay measurements determined by the tracking stations are supplied to the correlator in FITS format. These so-called delta-T tables are not passed to AIPS by the correlator but can be loaded indirectly. This table might be used, for example, to plot the time correction as a function of time. Such information could be useful if a user suspects a loss of coherence due to a poor predicted orbit or a clock jump at the tracking station. The table contains no internal time stamps, so the row number must be used to determine the approximate time of a given entry (there are typically 10 rows per second).

The delta-T tables can be loaded at present using FITLD and attached to a null *uv* data file, using input parameters as follows:

| | |
|---|---|
| > TASK 'FITLD' ; INP C_R | to review the inputs. |
| > OUTDISK *n* C_R | to specify a separate output file. |
| > OUTNAM 'DUMMY', OUTCLA 'DT' | |
| > DATAIN 'FITS:3551708.kct.a C_R | to specify the external FITS file. |
| > GO C_R | to run the program. |

The other FITLD adverbs are not relevant in this instance. Note that lower case letters can be used in the DATAIN adverb if the trailing quotation mark is omitted. FITLD will load the external FITS file successfully but will print an error message complaining that no array geometry table was found. This message can be ignored in this case. The delta-T table will appear as an unknown table of type UK, and can be plotted using task TAPLT

### 9.2.2 Loading data from a MkIII/MkIV correlator

#### 9.2.2.1 Running MK3IN

Data from a MkIII correlator, such as that in Bonn, Germany or Haystack, Massachusetts, can also be read into AIPS. To do this you need to be supplied with the so called "A" tape output, also known as "type 52's." These data tapes can be read and translated by the task MK3IN. The process of reading MkIII correlator data into AIPS and preparing it for further processing is more cumbersome than the equivalent process for VLBA correlator data. This simply reflects the manner in which data are generated on a baseline-based correlator with a limited number of playback drives. MkIII data may also appear in the form of a Unix `tar` file. For such data, use M3TAR and TFILE rather than MK3IN and AFILE, respectively.

Before running MK3IN, run the task MK3TX to extract the text files from the MkIII archive tape. These text files contain information about the correlated scans in the data set. MK3TX will first provide an index of all the text files and then ask you to select files for loading onto disk. It then asks you interactively for the desired destination of the text files. It is important to load and concatenate all the "A" files, *i.e.*, those files having names like A*tttt*. The meaning of the other text files is described in the MK3TX Explain file. Sometimes the text files are not on the tapes, which means that you cannot select sub-sets of the data using the A-files, but is not otherwise catastrophic.

If the A-files are present and have been loaded onto the disk, use AFILE to sort and edit these files to produce a list of scans to be loaded by MK3IN. Use APARM settings in AFILE to establish criteria for selecting between any duplicate scans which may appear on the archive. If the data set contains data at multiple frequencies, you should edit the resulting output text file so that there is a version for each frequency, containing only those scans at that frequency.

The final step before running MK3IN is to create another text file which provides the commands for the task. This step is necessary since some information that is needed by AIPS is not present on the tape. Ideally, in this text file (as shown below), the parameter `STATIONS` should be a list of all the stations correlated, with the exact name used at correlation. If you do not have such a list, you can instead specify a list containing `STATIONS 'ANY', 'ANY'` ... Note that there must be at least as many `'ANY'` entries as there are stations in the data set or some of the stations will not be loaded. The parameters in this text file are:

STOKES='RR','LL' — the Stokes range of the output file. The standard abbreviations are used to select the polarization range. The largest consistent range is used. For example: `STOKES='RR','LL'` will cause only RR and LL to be written. `STOKES='LL'` will cause just LL to be written. `STOKES='RR','LR'` will cause all four circular polarization combinations to be in the output file, since RR and LR span the range of allowed AIPS Stokes values.

FREQCODE='R','L','r','l' — the polarization codes used by MkIII correlators are anything but standard and they need to be supplied to MK3IN using the parameter `FREQCODE`. The one character polarization identifiers are expected in the order RR, LL, RL, and LR. The usual correlator convention is 'R'=RR, 'L'=LL, 'r'=RL, 'l'=LR and this is the default assumed by MK3IN. However, other codes are possible. For example `FREQCODE = 'A', 'B', 'C', 'D'` will interpret 'A' as RR, 'B' as LL and so forth, while `FREQCODE = 'R', 'C', 'r', 'l'` will use the default abbreviations except that 'C'=LL. If MK3IN encounters an unidentified polarization code the task will report: `AT20XX: Unidentified Stokes parameter: '`*X*`'`. In this case, modify the `FREQCODE` parameter to include this polarization identifier. This will ensure that polarizations are not misidentified inadvertently.

NO_POL=2 the number of polarization correlations (*e.g.*, RR, LL, RL and LR), the default is 1.

STATIONS='NRAO','VLA','OVRO','FDVS','MPI' station names.

/ `keyin` style delimiter.

Then, from inside `AIPS`, mount the tape (§ 3.9) and run `MK3IN`:

| | |
|---|---|
| > TASK 'MK3IN' ; INP C_R | to review the inputs. |
| > INFILE 'MYVLB:PARAM.LIS' C_R | to define the text control file. |
| > IN2FILE 'MYVLB:AFILE.LIS C_R | to point to a file containing a list of scans to be loaded as produced by `AFILE` |
| > INTAPE 4 C_R | to specify the tape drive number. |
| > NFILES 0 C_R | to skip no files on tape. |
| > OUTNA 'EXP 86-34' C_R | to select the output file name. |
| > OUTCL 'MK3IN' C_R | to select the default output class name. |
| > REFDATE '12/11/89' C_R | to tell `MK3IN` the start date of the observations — get this right or you may get negative times. |
| > SOURCES '' C_R | to accept all sources found. |
| > TIMERANG 0 C_R | to accept data from all times found. |
| > DOUVCOMP 1 C_R | to write data on disk in compressed format. |
| > APARM 1, 0 C_R | to set the time increment in the `CL` table entries in minutes. |
| > APARM(7) 1 C_R | to separate sidebands into separate AIPS IFs; the default is to store both USB and LSB in the same IF. |
| > GO C_R | to run the program. |

If the data are contained on more than one Exabyte or DAT tape, load the second tape and re-run `MK3IN`, setting DOCONCAT = 1 C_R so that the data are appended to the previous output file. Before running `MK3IN` a second time, it is important to set the list of `STATIONS` in the control file to exactly those found when loading the first tape; use `PRTAN` on the output file to obtain this list. Also leave additional `'ANY'` entries after the list for any stations that are on the second tape but which were not on the first tape. The use of `DOUVCOMP = 1` is recommended for most data sets, see Appendix F.

#### 9.2.2.2 Sorting MkIII/IV data

The AIPS data files created by `MK3IN` will be in an arbitrary sort order. Use `UVSRT` or `MSORT` to sort them into time-baseline order:

| | |
|---|---|
| > TASK 'UVSRT' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to select the input file. |
| > OUTNA INNA ; OUTCL 'TBSRT' C_R | to specify the output file. |
| > SORT 'TB' C_R | to sort to time-baseline order. |
| > GO C_R | to make the sorted *uv* file. |

#### 9.2.2.3 Concatenating MkIII/IV data

If you did not set `DOCONCAT=1` when running `MK3IN` and as a result several files were loaded from tape for one observation, use `DBCON` to concatenate them together. In order to have the concatenated data all appear in a single subarray, both input files for `DBCON` must have the same reference day number and identical antenna numbers. That is, the antennas extension (`AN`) files with each input *uv* data file must be the same. `MATCH` may be used to repair discrepancies.

You may list the contents of AN files using PRTAN. To run DBCON:

| | |
|---|---|
| > TASK 'DBCON' ; INP C_R | to review the inputs. |
| > INDISK *n1* ; GETN *ctn1* C_R | to select the 1st input file. |
| > IN2DISK *n2* ; GET2N *ctn2* C_R | to select the 2nd input file. |
| > OUTNA INNA ; OUTCL 'DBCON' C_R | to specify the output file. |
| > DOARRAY 1 C_R | to force DBCON to mark the output data records as being in the same sub-array. For this to work properly, both of the input files must have the same reference day and have identical antennas files. |
| > GO C_R | to concatenate the two files. |

#### 9.2.2.4 Merging MkIII/IV data

MkIII VLBI correlators usually produce redundantly correlated data. You must merge the data using UVAVG:

| | |
|---|---|
| > TASK 'UVAVG' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > OUTNA INNA ; OUTCL 'UVMRG' C_R | to specify the output file. |
| > YINC 4.0 C_R | to set the averaging interval of the input data records (in seconds). |
| > OPCODE 'MERG' C_R | to direct the task to perform the merge operation. |
| > GO C_R | to run the program. |

The CL table should only contain one entry for each antenna at each time stamp. But, due to the merging process described above and the fact that redundant correlations may have been performed, there is one step to follow before you have consolidated your database fully. You must run TAMRG to remove the redundant CL entries:

| | |
|---|---|
| > TASK 'TAMRG' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > INEXT 'CL' C_R | to specify the table type to merge. |
| > INVER 1; OUTVER INVER C_R | to process the input table in place. |
| > APARM 4, 1, 4, 0, 1, 1, 1, 0 C_R | to control the merging: don't ask why, just do it! |
| > BPARM 1, 4 C_R | to set compared columns — again, don't ask. |
| > CPARM 1.157e-5, 0.2 C_R | to set degree of equality — ditto. |
| > GO C_R | to run the program. |

#### 9.2.2.5 Correcting MkIII/IV sideband phase offsets

If your observation contains a mixture of VLBA and non-VLBA antennas and you have not stored the sidebands as separate IFs, there will be a phase offset of about 130° between the upper and lower sidebands on baselines from VLBA to non-VLBA antennas. A correction for this offset is achieved using the task SBCOR:

| | |
|---|---|
| > TASK 'SBCOR' ; INP C_R | to review the inputs. |
| > INDISK *n1* ; GETN *ctn* C_R | to specify the input file. |
| > OUTNA INNA ; OUTCL 'SBCOR' C_R | to specify the output file. |
| > BCHAN 1 C_R | to specify the lowest channel of lower sideband. |
| > ECHAN 4 C_R | to specify the highest channel of lower sideband. |

| | |
|---|---|
| > APARM(1) 0 C_R | to apply the default phase offset (*i.e.*, $-130^{\rm deg}$.) |
| > ANTENNAS = VLBA ; INP C_R | to specify the VLBA antenna numbers; the = sign is required here. The verb VLBA reads the antenna file to find VLBA antennas. |
| > GO C_R | to run the program. |

If you have loaded the VLBAUTIL procedures, then you may use a procedure called ANTNUM to translate a station name into a station number. Thus ANTENNAS = ANTNUM('BR'), ANTNUM('FD'), .... The verb VLBA in 31DEC07 is easier.

#### 9.2.2.6 Indexing MkIII/IV data

Next, you must index your data. The NX table is useful as a summary of the file for you, and is also used by the calibration programs to provide quick access for reading data. Create this file with INDXR:

| | |
|---|---|
| > TASK 'INDXR' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > CPARM 0, 30, -1 C_R | to allow ≤ 10-minute time gaps within scans, to limit scans to ≤ 30 minutes, and to not create a new CL table. |
| > GO C_R | to run the program. |

Other than these initial loading and merging steps, the reduction of MkIII and MkIV correlator data is identical to that of VLBA correlator data.

## 9.3 Tools for data examination

Before proceeding further it is important to examine the data, to make sure they are all loaded, and (especially if this is the first time you have reduced VLBI data) to familiarize yourself with the data structure. As processing continues it is also important to inspect the data periodically to check on the progress of the calibration. Use the verb IMHEAD regularly to check the *uv*-data header, particularly the list of tables (as seen in § 9.2.1.1).

Some tasks that can be used to examine the data and the associated tables are LISTR, DTSUM, POSSM, VPLOT, CLPLT, CAPLT, EDITR, TVFLG, SPFLG, SNEDT, SNPLT, PRTAB, FRPLT, PRTAN, COHER, OBPLT, and SHOUV. Some of these tasks are described in the next few pages.

### 9.3.1 Textual displays

As a first step, use the procedure VLBASUMM to print out the essential contents of your data set:

| | |
|---|---|
| > RUN VLBAUTIL C_R | to acquire the procedures; this should be done only once since they will be remembered. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > DOCRT -1 C_R | to direct the output to the line printer. |
| > INP VLBASUMM C_R | to review the inputs. |
| > VLBASUMM C_R | to run the procedure. |

This will make a listing of the scans, sources, frequency structure, and antennas found in your data set. You should run this procedure after "fixing" the data with VLBAMCAL, VLBAFQS, VLBASUBS, and VLBAFPOL, but you may also find it useful on the initial dataset.

VLBASUMM runs the task LISTR to give a listing of the scans, with source names, time ranges, frequency ID's and total number of visibilities per scan for each of your output files. It is often useful to print out a paper copy of this to facilitate later data plotting/editing. If you did not do VLBASUMM, use:

| | |
|---|---|
| > TASK 'LISTR' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > OPTYP 'SCAN' C_R | to request printing of scan summaries. |
| > DOCRT -1 C_R | to direct the output to a printer. |
| > OUTPRINT ' ' ; C_R | to have the output printed immediately. |
| > GO C_R | to run the program. |

Note that at the end of the above LISTR output is useful information about the frequency structure of your data set. LISTR with OPTYP = 'LIST' and DPARM(1) = 1 is also a good way to look for phase coherence. If LISTR fails at this point, you may have forgotten to run INDXR and/or MSORT (see § 9.2.1.6 and § 9.2.1.4).

Other verbs/tasks for inspecting your data include;

1. IMHEAD lists the file header including information on the number of frequency channels and Stokes parameters in the data and gives a list of all the extension tables.
2. PRTAB can be used to print the contents of any of these extension tables, for instance the SU or Source table contains information about each of the sources observed. Some tables have very many columns. You can use input parameter BOX to select the list of the columns you want to print.
3. PRTAN, run by VLBASUMM, provides a listing of the antenna names and their associated antenna numbers. This is useful because antennas are generally specified by their antenna numbers. (Procedure ANTNUM in the VLBAUTIL set allows you to translate station names into numbers.)
4. DTSUM produces a matrix showing the number of visibilities on each baseline for each scan allowing a check to be made that all baselines have been loaded. It also tells you the data integration time. DTSUM also has a mode (triggered by setting APARM(1) = 1) that will produce a useful matrix summary of your whole data set. DTSUM does not properly report the integration times when there are multiple integration times in the data set.

### 9.3.2 Spectral displays: POSSM

Your data file will probably contain a number of IFs, observed at different frequencies, corresponding to the separate "IF channels" used during the observations. While the VLA has a maximum of two such IF channels (four polarizations are counted separately), VLBA antennas have up to eight IFs (and effectively 16 if double sideband recording was used). MkIII Mode A observations can produce up to 28 IF channels. Within each IF channel are a number of equally spaced and contiguous "spectral channels" generated from each IF data stream by the correlator. For continuum applications, the correlator will generally produce 8 or 16 such spectral channels; in the spectral-line case there may be as many as 1024 such spectral channels. Use IMHEAD to find the number of IF channels and the number of spectral channels per IF channel, or examine the LISTR output. The reason that the data must be stored in narrow spectral channels, even for continuum applications, is that, in VLBI, the geometrical and propagation errors affecting the data can be large enough to cause significant phase changes across an IF channel bandwidth, preventing a coherent integration over the full bandwidth.

The frequency structure of the data can be inspected using POSSM, which provides a plot of visibility data as a function of frequency as integrated over a specified time interval. Optionally, data from up to nine baselines can be plotted on a single plot page. Initially it may be interesting to view the frequency structure of data on a bright calibrator source, as in the example below. Because, prior to calibration, the phases in each IF channel are likely to vary rapidly with time, it is important to average data coherently only over a short time interval. In general, you will see phase slopes and offsets affecting the data; these phase errors must be determined and removed before the data can be averaged in frequency and/or time. See § 9.4.8 for more information and a sample plot Beginning with 31DEC01, there is a procedure simplifying the use of POSSM:

| | |
|---|---|
| > RUN VLBAUTIL C_R | to acquire the procedures; this should be done only once since they will be remembered. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > SOURCES ' ' C_R | to plot all sources. |
| > TIMERANGE 0 C_R | to plot all times. |
| > SUBARRAY 0 C_R | to plot all subarrays. |
| > REFANT *n* C_R | to plot the cross-power spectrum for baselines with antenna *n*. |
| > STOKES 'I' C_R | to plot Stokes I. |
| > GAINUSE *CLin* C_R | to apply CL table *CLin* to the data before plotting. |
| > DOTV 1 C_R | to plot the data on the TV; -1 to make a plot file. |
| > VLBACRPL C_R | to plot the data. |

To use POSSM directly to display the visibility spectrum of a source on the TV, use:

| | |
|---|---|
| > TASK 'POSSM' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > SOURCE 'OQ208', ' ' C_R | to specify a single source name. |
| > TIMER 1 2 15 0 1 2 15 30 C_R | to define a time range. |
| > ANTENNAS 8 ; BASELINE 0 C_R | to plot all baselines to antenna 8. |
| > DOCAL -1 C_R | to plot the data without calibration. |
| > APARM 1 , 1 , 0 , 0 , -180 , 180 , 0 , 0 , 3 , 0 C_R | to control the plot: APARM(1)=1 to use vector averaging, APARM(2)=1 to use fixed scale plots, APARM(5) and APARM(6) to set phase range, APARM(9)=3 to plot all IFs and polarizations together in one diagram. |
| > BIF 0 ; EIF 0 ; BCHAN 0 ; ECHAN 0 C_R | to include all IFs and spectral channels. |
| > STOKES 'HALF' C_R | To plot RR and LL separately. |
| > CODETYPE ' ' ; POLPLOT ' ' C_R | to plot amplitude and phase. |
| > SOLINT 0 C_R | to average over the full time range. |
| > NPLOTS 9 ; BPARM 0 ; OUTTEXT ' ' C_R | to have 9 plots per page without division by “channel 0” and without writing the spectrum to a file. |
| > DOTV 1 C_R | to plot on the TV, else create plot extension. |
| > BADDISK 0 C_R | to use all disks for scratch. |
| > GO C_R | to run the program. |

Note that the amplitudes are totally uncalibrated at this stage and are in units of “correlation coefficients”; these will generally appear on plots mislabeled as mJy (representing multiples of $10^{-3}$ in correlation coefficient). POSSM can produce text output into the file given by OUTTEXT.

Sample POSSM displays are given in Figure 9.1, Figure 9.2, and Figure 10.2.

Task SHOUV with OPTYPE 'SPEC' will display the data from a number of channels on the printer with optional time averaging.

### 9.3.3 Time displays: VPLOT, CLPLT, and CAPLT

The task VPLOT can be used to view the visibility data as a function of time (or other variables). Again, data from several baselines can appear on one plot page. Plots of amplitudes and phases and several other quantities can be made, although, to view closure phase and amplitude, you must use tasks CLPLT and CAPLT. Note that VPLOT can average spectral channels or plot them individually under control of AVGCHAN and can plot spectral channels and IFs in separate panels or all together under control of CROWDED. Data points are plotted with a user-selected SYMBOL and may be connected by lines under control of FACTOR. Calibration can be applied to the data before they are plotted. The data can be averaged in time and the max/min within the interval plotted along with the average. Also, if desired, a model can be plotted against the data. The model can either be displayed at the times of the data samples or, with somewhat less accuracy, continuously, even at times for which there are no associated data or recorded *uv* coordinate values.

The following parameters will display uncalibrated amplitudes and phases from a single spectral channel of a single IF channel for a short scan on a bright calibrator:

| | |
|---|---|
| > TASK 'VPLOT' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > CLR2NAME C_R | to ensure no model is plotted. |
| > SOURCE 'OQ208' C_R | to specify the source name. |
| > BIF 4 C_R | to give first included IF channel. |
| > EIF 4 C_R | to give last included IF channel;, if EIF > BIF then IFs are averaged. |
| > BCHAN 8 C_R | to set the lowest spectral channel to include in average prior to plotting. |
| > ECHAN 8 C_R | to set the highest spectral channel to include in average prior to plotting; no averaging in this case. |
| > TIMER 1 2 15 0 1 2 25 00 C_R | to define a 10-minute time range. |
| > DOCAL -1 ; DOBAND -1 C_R | to apply no calibration tables or bandpass tables to data. |
| > OPTYP ' ' | to display cross-correlations; 'AUTO' to get auto-correlations. |
| > SOLINT 0 | to do no time averaging of the data before plotting. |
| > XINC 1 C_R | to plot every record. |
| > BPARM 0 , -1 C_R | to set *x*-axis type (BPARM(1) = 0 plots time (Hrs, min, sec)), *y*-axis type (BPARM(2)= -1 plots both amplitude and phase), and to use self-scaling. See EXPLAIN VPLOT C_R for other options. |
| > NPLOT 4 C_R | to plot 4 baselines/page. |
| > GO C_R | to run the program. |

An example VPLOT output appears as Figure 9.1. It may be useful to make a plot of data "weight" versus time on the autocorrelation data from each antenna (set BPARM(2)=16 and OPTYP = 'AUTO'). The weight depends on the number of valid bits correlated and is a good indication of tape playback quality.

### 9.3.4 EDITR

Another task which can display data as a function of time is EDITR. This program is used primarily to edit data interactively (see § 5.5.2), but its interactive aspects (*i.e.*, allowing the user to "zoom" in on certain time periods) make it useful for pure data inspection. EDITR has been much improved in recent releases to offer options reminiscent of difmap, the VLBI data reduction package from CalTech. In particular, the CROWDED adverb allows displays of all IFs and/or all polarizations at the same time and the FLAG QUICKLY run-time option allows fast sample deletion with only quick mouse clicks. It is well worth exploring the abilities of this powerful program. Tasks TVFLG (§ 4.4.3), SPFLG (§ 10.2.2), and WIPER are also useful in this way.

### 9.3.5 SNPLT

Supplied with your VLBI data will be a number of important tables used for calibration, and many more are generated as calibration proceeds. § 9.7 summarizes the contents of each of these tables. Two of the most important tables are the calibration or CL tables and the solution or SN tables.

The task SNPLT should be used periodically to inspect the contents of the latest CL and SN tables. Beginning with 31DEC01 AIPS, there is a simplified procedure for making these plots:

| | |
|---|---|
| > RUN VLBAUTIL C_R | to acquire the procedures; this should be done only once since they will be remembered. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > INEXT 'CL' C_R | to plot a CL table. |
| > INVERS 0 C_R | to plot the highest version. |
| > SOURCES ' ' C_R | to plot all sources. |
| > TIMERANGE 0 C_R | to plot all times. |
| > STOKES ' ' C_R | to plot both R and L solutions. |
| > SUBARRAY 0 C_R | to plot all subarrays. |
| > OPTYPE 'AMP' C_R | to look at amplitudes; 'PHAS', 'DELA', and 'RATE' are other useful choices. |
| > DOTV 1 C_R | to plot the data on the TV; -1 to make a plot file. |
| > VLBASNPL C_R | to plot the data. |

Using SNPLT directly, the example below plots the antenna-based amplitude corrections stored in CL table *m*.

| | |
|---|---|
| > TASK 'SNPLT' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > OPTYPE 'AMP' C_R | to plot amplitudes. |
| > OPCODE 'ALST' C_R | to plot both polarizations in each plot; selected IFs are plotted separately. |
| > INEXT 'CL' ; INVER *m* C_R | to choose CL table version. |
| > DOBLANK 1 ; DOTV 1 C_R | to plot on the TV screen including failed solutions; otherwise, create plot extension files. |
| > NPLOTS 5 C_R | to plot 5 antennas/IFs per page. |
| > GO C_R | to run the program. |

SNPLT can also be used to plot quantities from other tables generated by the calibration process including the contents of TY ("system temperature"), and PC ("phase-cal") tables.

### 9.3.6 COHER

The task COHER can be used to determine the coherence time in a *uv* data set broken down both in time and by antenna and baseline. The coherence time is estimated by comparing vector and scalar averaged amplitudes over increasing time averaging intervals. Averaging is not performed over source scan boundaries. The coherence time is defined as the averaging interval over which the ratio of vector and scalar amplitudes falls below a pre-assigned level. This can be set under user control. In addition, data that fall below a specified signal-to-noise ratio can be excluded from the coherence time estimates. Provision is made for selection by source name, time range, IF channel, antenna and frequency ID, and the ability to average over a subset of individual frequency channels. The input parameters to task COHER take the form:

| | |
|---|---|
| > TASK 'COHER' ; INP C_R | to review the inputs. |

| | |
|---|---|
| > INDISK *n* ; GETN *ctn* CR | to specify the *uv* input file. |
| > APARM 0 CR | SNR cutoff 5; vector to scalar cutoff 0.8. |
| > TIMERANG 0, 10, 5, 0, 0, 10, 15, 0 CR | time range selection. |
| > BIF 5 ; BCHAN 1 ; ECHAN 8 CR | IF and channel selection. |
| > SOURCES 'DA193' , ' ' CR | source selection. |
| > FREQID 1 CR | Frequency ID selection. |
| > GO CR | to run the program. |

Be warned that COHER can take quite a long time to run. A simpler, though less rigorously correct method for determining coherence intervals is to examine the data on different baselines using EDITR.

### 9.3.7 FRPLT

A preliminary examination of the coherence of individual scans or time segments in the data can also be performed using task FRPLT, which allows time series or fringe-rate spectra to be plotted for one or more baselines and time intervals. This task allows data to be selected by the usual criteria, including time range, source name, and frequency parameters, amongst others, and will then plot the individual time series in amplitude and phase or the associated fringe-rate spectrum. Provision is made for averaging over frequency channels within each IF, for varying degrees of padding in the FFT, and for division by the pseudo-continuum average "channel zero" before plotting. Typical input parameters to FRPLT are:

| | |
|---|---|
| > TASK 'FRPLT' ; INP CR | to review the inputs. |
| > INDISK *n* ; GETN *ctn* CR | to specify the input file. |
| > SOURCES 'DA193' , ' ' CR | to select a source. |
| > TIMERANG 0, 10, 5, 0, 0, 10, 15, 0 CR | to select a time range, strongly recommended. |
| > SOLINT 2 CR | to plot fringe-rate spectra for every 2-minute interval in TIMERANGE. |
| > NPLOTS 6 CR | to do 6 plots per page. |
| > STOKES 'LL' CR | to select a single Stokes. |
| > BIF 1 ; EIF 0 CR | to select the IFs included. |
| > BCHAN 3 ; ECHAN 12 CR | to select the range of frequency channels averaged within each IF. |
| > ANTENNAS 3, 4 CR | to select baseline 3-4, 3-5, and 4-5. |
| > BASELINE 4, 5 CR | to select baseline(s) plotted in the familiar way. |
| > DOCAL -1 ; DOPOL -1 CR | to apply no continuum calibration. |
| > DOBAND -1 CR | to do no bandpass calibration. |
| > APARM(1) 1 ; APARM(2) 0 CR | integration time 1 sec; self-scale the plots. |
| > APARM(7) 0 CR | plot fringe-rate spectra with no padding. |
| > BPARM 0 CR | to do no division by "channel zero." |
| > DOTV 1 CR | to plot directly on the TV device. |
| > GO CR | to run the program. |

The underlying time series in amplitude and phase can be plotted by setting APARM(7)=1; otherwise the fringe-rate spectrum is plotted. Note that the baseline(s) shown are selected with ANTENNAS and BASELINE in the usual way and a time range must be selected with TIMERANG. APARM(1) sets the integration time to be used before doing the FFT over the selected time range. SOLINT may be used to break the time range into intervals. Separate plots are produced for each IF, baseline, and time interval.

## 9.4 Calibration strategy

If you have multiple frequency IDs in your data, you may want to separate the data for different FREQID before performing any calibration. Use UVCOP to do this and take advantage of the opportunity to delete data flagged by the correlator with FLAGVER=1. Beginning with 31DEC07, you no longer need to re-run INDXR on the output files. Again there is a procedure to do this for you:

| | |
|---|---|
| > RUN VLBAUTIL C_R | to acquire the procedures; this should be done only once since they will be remembered. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > CLINT $\triangle t$ C_R | to set the CL table interval to $\triangle t$ minutes (see discussion above in § 9.2.1.1). |
| > INP VLBAFQS C_R | to review the inputs. |
| > VLBAFQS C_R | to run the procedure. |

VLBAFQS will normally be run after searching for subarrays (VLBASUBS § 9.2.1.5) and before fixing polarization labels (VLBAFPOL § 9.2.1.8).

We can now begin the process of calibrating VLBI data. As the calibration process proceeds, both amplitude and phase corrections are incorporated into the CL tables. VLBI correlator output is in terms of dimensionless "correlation coefficients." To convert to Janskys, large amplitude correction factors have to be entered into the CL tables. In addition, phase correction factors must be entered into the CL table to correct for phase offsets and ramps as functions of frequency and time. These corrections must be made so that the data can be averaged over frequency and time without loss of coherence. The process of determining the phase corrections is known as "*fringe-fitting*" in VLBI; see § 9.4.8.

Unlike VLA users, VLBI users normally do not attempt to calibrate the absolute phase of the data using external calibrator sources. VLBI users just calibrate out the phase derivatives with respect to time and frequency. The absolute phases are normally left uncalibrated and "self-calibration" methods are then used to generate images (see § 9.6). The alternative of absolute-phase calibration using an external calibrator, known as "phase-referencing" in VLBI circles, is a little more difficult in VLBI than for the VLA. In general terms, "phase-referencing" VLBI data in AIPS is accomplished by similar methods as used for VLA data in AIPS; be sure to read § 9.4.1.2 and § 9.4.8.4 for details on how to calibrate phase-referenced observations.

For astrometric data reduction methods in AIPS the reader is referred to the guide to AIPS astometric data reduction available from within AIPS by typing HELP ASTROMET.

Optimum fringe-fitting results are obtained if amplitudes are calibrated first, since, in this case, the data will be weighted appropriately (the AIPS task FIXWT may be used to adjust the weights in the data to reflect the scatter of the actual data). We therefore describe the process of amplitude calibration first in § 9.4.4.2. Then, in § 9.4.8, we describe the calibration of residual phase using "fringe-fitting" techniques. Note however, that for observations of strong sources or observations using only VLBA antennas (where, particularly at centimeter wavelengths, the sensitivities on all baselines are roughly the same), the order of the two calibration steps may be reversed.

### 9.4.1 Incremental calibration philosophy

The general strategy adopted by AIPS for calibration is, starting with the lowest version of the CL table, to incorporate step-by-step amplitude and phase corrections for a number of different effects. At each stage either an existing CL table is modified or a new version is created from a lower version by a task which applies a certain type of calibration. Note that the actual visibilities are not changed until you are satisfied that you have the best possible calibration file; at this point the task SPLIT can be used to apply the calibration information of the best CL table to the data. However at each point along the way the effect of a particular CL table on the data can be viewed using POSSM or VPLOT by setting DOCAL=1 and GAINUSE equal to the chosen CL table. Since many CL tables may be produced in the course of calibrating a VLBI data set it is important to keep a note of which effects are included in each one. Ideally one should delete CL tables which are judged incorrect and ensure that the accumulated corrections lie in the highest numbered CL table. It is suggested that version 1 of the CL table, as produced by FITLD, be copied to CL version 2 using TACOP before any calibration is begun, and that CL version 2 be used as the starting point in the calibration sequence. An effort is made within AIPS to insure that CL version 1 is not deleted inadvertently. If this does occur however it can be re-generated using task INDXR (described in § 9.2.1.6). (Note that INDXR cannot re-generate some types of information, *e.g.*, the phase-cals inserted by the MKIII correlator so that it is important to try to preserve the first CL table.) The task TASAV can be used to back up your tables by copying all of them to a dummy file containing no data. This can be used to save a "snapshot" of the tables at various points in your data processing for insurance purposes. The tables can be copied back into your data file if necessary using TACOP.

You can also use the verb HINOTE to add comments into the history file. This can be very useful for check-pointing progress during calibration.

When you are ready to apply the calibrations, you run either SPLIT or SPLAT. Both tasks can average data in the spectral domain if appropriate. SPLAT can also time-average the data and produces multi-source data sets on output if requested.

#### 9.4.1.1 Smoothing and applying corrections in SN and CL tables

The various stages of calibration described below produce SN tables which are then used to create CL tables using CLCAL. The ancillary tasks SNCOR, SNSMO, SNEDT, and CLCOR can be used to modify the SN and CL tables directly. It is important to choose the proper methods of interpolation in these tasks.

SN tables can be smoothed using tasks SNEDT and SNSMO before being used to update CL tables using CLCAL. SNSMO uses superior smoothing methods to those available in CLCAL and should always be used to do any smoothing of VLBI data, *i.e.*, data with non-zero delays and rates. The adverb DOBLANK now controls which data are actually altered by the smoothing; use it carefully.

Typical inputs for SNSMO would be:

| | |
|---|---|
| > TASK 'SNSMO ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > SOURCES ' ' C_R | to modify the solutions for all sources. |
| > SELBAND -1; SELFREQ -1; FREQID 0 C_R | to do all frequency IDs. |
| > BIF 0; EIF 0 C_R | to include all IFs. |
| > TIMERANG 0; ANTENNAS 0 C_R | to include all times and antennas. |
| > SUBARRAY 0 C_R | to select the first subarray; NB, SNSMO works only on one subarray at a time. |
| > SAMPTYPE 'MWF' C_R | to use the median window filter method. |
| > SMOTYPE 'AMPL' C_R | to smooth amplitudes only. |
| > BPARM 0.5,0 C_R | to use a 30-minute filter time for amplitude. |
| > DOBLANK 1 C_R | to replace blanked values with interpolated values *only*. |
| > CPARM 0.5, 0, 0, 0, 0, 0.02, 0 C_R | to set ranges of allowed values. |
| > INVER *snin* ; OUTVER *snout* C_R | to read in the SN table version *snin* and to write SN table version *snout* (which should be a new table). |
| > REFANT 0 ; BADDISK 0 C_R | to keep the current reference antenna and to allow all disks to be used for scratch files. |

| | |
|---|---|
| > INP C_R | to check the inputs. |
| > GO C_R | to run the task. |

Typical inputs for CLCAL would be:

| | |
|---|---|
| > TASK 'CLCAL' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > CALSOUR ' ' C_R | to use all corrections in the SN table. |
| > SOURCE ' ' C_R | to apply corrections to all sources. |
| > OPCODE 'CALI' C_R | to apply SN tables to a CL table. |
| > INTERPOL ' ' C_R | to use linear vector interpolation ('2PT'). |
| > SAMPTYPE ' ' C_R | to do no further smoothing of the merged SN tables.. |
| > SNVER *snin* ; INVERS 0 C_R | to select the one SN table containing solutions to be interpolated. |
| > GAINVER *clin* C_R | to select the CL version to which solutions are to be applied. |
| > GAINUSE *clout* C_R | to select the output CL version, containing updated calibration information. |
| > REFANT 0 ; BADDISK 0 C_R | to try to use use a single reference antenna if possible during all steps of calibration. |
| > INP C_R | to check the inputs. |
| > GO C_R | to run the task. |

Note well that SNVER=0 means here to combine the solutions from all SN tables, GAINVER=0 means to apply the solutions to the highest numbered CL table and GAINUSE=0 means to write a new CL table. If two SN tables contain two similar attempts at finding corrections and SNVER=0 then, effectively, CLCAL will be inconsistent in applying the solutions from these two tables. Basically, CLCAL simply concatenates all SN tables and then, in 31DEC05, merges apparently identical records (same time and antenna) to eliminate blanked solutions and to complain about otherwise non-identical solutions.

The parameters INTERPOL and SAMPTYPE allow the user to choose between several different methods of smoothing the SN files followed by interpolation to the times in the CL table. Use EXPLAIN CLCAL C_R to view all the options. The default interpolation option is INTERPOL = '2PT', in which the SN table is linearly interpolated between the measurements in the SN table. Using SAMPTYPE = 'BOX' causes the SN table to be smoothed with a boxcar function before being interpolated onto the CL table. The smoothing times for delay, rate etc. are specified in parameter BPARM. DOBLANK controls how both failed and good solutions are handled when smoothing. DOBLANK $\geq 0$ replaces failed solutions with smoothed ones, while DOBLANK $\leq 0$ replaces good solutions with smoothed ones. However it is recommended that SN smoothing be done prior to CLCAL using task SNSMO.

With good quality data, the INTERPOL = 'AMBG' option should work well. Note, however, that this option uses the SN solutions immediately before and after a CL entry to make the interpolation and it uses any SN solution found for any source specified in CALSOUR. Therefore, if CALSOUR is left blank (allowing all sources) and delay and rate solutions were significantly different for different sources, then inappropriate solutions may be applied for a few minutes before or after a source change.

One way of avoiding this problem is to run CLCAL with INTERPOL = 'AMBG' several times, once for each source, setting both SOURCE and CALSOUR to the name of the desired source with all other inputs remaining unchanged. Another way of avoiding the problem is to use INTERPOL = 'SELF'. In this option, only solutions found on a given source are used to calibrate that source and the SN table entries closest in time for that source are used with interpolation. This is not as good as doing multiple runs with the INTERPOL = 'AMBG' option because there can be jumps in phase at points equidistant from two SN table entries.

If there are bad SN solutions, INTERPOL = 'POLY' is used to fit a polynomial to the rate solutions and then integrate this polynomial to determine the phase corrections to be entered into the CL table.

A final note on CLCAL. It is sometimes the case that *a priori* information is not available for all antennas in a single format. For example, you may have system temperature information for VLBA antennas in your SN version 2 table and for non-VLBA antennas in SN version 3. You can merge this information by running CLCAL twice with the same GAINVER and GAINUSE; each time you should explicitly set the SN version number and list the antennas to be processed using the ANTENNAS adverb. If you leave the ANTENNAS adverb blank, the final CL table will contain information only for antennas present in the last SN table processed.

#### 9.4.1.2 Running CLCAL for phase referencing observations

In particular, this example illustrates how to set the inputs for CLCAL for the specific case when phase corrections determined for the cal source 'J1636-16' are to be transferred to the target source 'P1643-12' in a phase referencing experiment:

| | |
|---|---|
| > TASK 'CLCAL' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > CALSOUR 'J1636-16', ' ' C_R | to use the corrections determined for the cal source. |
| > SOURCE 'J1636-16', 'P1643-12', ' ' C_R | to apply corrections to both the cal source and the target source. |
| > OPCODE 'CALI' C_R | to apply SN tables to a CL table. |
| > INTERPOL 'AMBG' C_R | to use linear vector interpolation with no SN table smoothing and simple phase ambiguity removal. See above for more discussion of INTERPOL. |
| > SAMPTYPE ' '; BPARM 0 C_R | to clear smoothing parameters. |
| > SNVER *snin* C_R | to select the SN table containing solutions to be interpolated. |
| > GAINVER *clin* C_R | to select the CL version to which solutions are to be applied. |
| > GAINUSE *clout* C_R | to select the output CL version, containing updated calibration information. |
| > REFANT 5 ; BADDISK 0 C_R | Use a single reference antenna if at all possible during all steps of calibration. |
| > INP C_R | to check the inputs. |
| > GO C_R | to run the task. |

It's a good idea to always apply the calibration information to both the cal and target sources when running CLCAL for phase-referencing observations. This allows you to monitor the cal source data to check the progress of the phase calibration procedure.

### 9.4.2 Processing observing log and calibration information

As of 1 April 1999, the VLBA correlator provides calibration transfer information, as described in § 9.2.1.2 for VLBA antennas. Experiments correlated after November 2003 also have full calibration transfer for the VLA, the GBT, Arecibo and the Bonn 100m. Consequently, **you can skip § 9.4.2 entirely** unless you have data from non-VLBA telescopes (*e.g.*, the VLA before November 2003, Space, other European telescope) or other correlators or you wish to process the log files manually for other reasons.

This section describes the processing of external calibration information, as supplied in ASCII log files. The information that may be used by AIPS includes $T_{sys}$ or related total power measurements, edit flags as written by the tracking stations or on-line monitor control system, weather information, and pulse-calibration data. These external data can be read into AIPS by tasks ANTAB, UVFLG, APCAL, and PCLOD respectively, as described in § 9.4.2.5, § 9.4.3, § 9.4.4.2 and § 9.4.8.5.

You should have received information about where to obtain your calibration data. VLBA calibration log files may be obtained by ftp as described below. Similar calibration files for other participating antennas and VSOP should be obtained from the appropriate sites.

#### 9.4.2.1 Automatic formatting of VLBA and VLBA-like log files

For VLBA antennas, the external calibration file for a given experiment can be downloaded from
`http://www.vlba.nrao.edu/astro/VOBS/astronomy/`*mmmyy*`/`*xxxxx*`cal.vlba.gz`
where *mmmyy* is the month and year (*e.g.*, `aug03`) and *xxxxx* is the project code (*e.g.*, `bz199`). The calibration file is named as above and is in GNU-zipped format. Gain curve information can be obtained from the same web site in the `astronomy` directory (*i.e.*, two directories up from the project directory). The gain curve should be concatenated to the external calibration file.

The external calibration file, if suitably close to the standard VLBA format, concatenated with the gain curve file, can be automatically subdivided and re-formatted to comply with AIPS requirements using task VLOG. Typical inputs would be:

| | |
|---|---|
| > TASK 'VLOG' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the FITLD output file. |
| > SUBARRAY 1 C_R | to select the required subarray. |
| > CALIN 'FITS:bz199cal.vlba C_R | to specify the input external calibration file. |
| > OUTFILE 'FITS:BZ199' C_R | to define the directory and prefix for the output files. |
| > FQTOL 1000 C_R | to set the tolerance for frequency match in kHz; one channel width is recommended. |
| > PRTLEV 0 C_R | to limit output; in particular to avoid echoing the calibration file to the screen. |
| > GO C_R | to run the program. |

A sequence of output text files will be created in the specified (`$FITS` here) directory named `BZ199.*` with suffixes:

1. `.TSYS`: $T_{SYS}$ calibration data, including gain curves, suitable for direct use by `ANTAB`. An `INDEX` record is constructed for each frequency ID if possible. If no match can be made to the FQ data, a warning message is printed and the `INDEX` keyword is omitted; the `INDEX` keyword must then be inserted by hand (see the HELP file for `ANTAB`). Gain curve entries for the frequency and time range in the *uv* data are copied to this output file. It is recommended to insert $T_{SYS}$ values at the end of scans immediately before source changes to avoid interpolation problems for sources of greatly differing flux density or use `INTERPOL = 'SELF'` in `CLCAL`. Occasionally spurious data from previous observing runs or system startup files will end up in the `.TSYS` file and must be edited out by hand.

2. `.FLAG`: Flag data, suitable for direct use by `UVFLG`. In the older format "antennas=vlba_xx" the appropriate antenna and day numbers are inserted.

3. `.WX`: Weather data, as used by `APCAL` if performing an opacity solution. This file is altered to conform with `APCAL` requirements (*e.g.*, `WEATHER` keyword) and lines with bad entries (*) are commented out.

4. `.PCAL`: Pulse-calibration data, for input to `PCLOD`. No editing is performed.

Files with suffixes `.SCAN` and `.MKIII` contain scan summaries and MkIII information and are for information purposes only.

#### 9.4.2.2 VLA and EVN log files

VLA calibration files, named *xxxxx*`cal.y.gz` (stored in gzipped format) can be obtained from the same server and disk directory as for VLBA files. The VLA file starts with an explanatory preamble, including minor editing instructions. See § C.8 for more detailed instructions.

The EVN (European VLBI Network) prepares calibration tables in `ANTAB` format. Follow the links to "EVN Data Calibration in ANTAB Format" from the `http://www.nfra.nl:80/jive/evn/evn.html` page. There are files called *xxxxx*`.newantab` in directories named by the month and year. These files are supposed to include parameters of the gain curves as well.

#### 9.4.2.3 SVLBI log files

HALCA calibration files may be obtained by pointing a web browser to `http://www.vsop.isas.ac.jp` and following the link to "HALCA Calibration". You will need to get the `.TSM` files which are in a VLBA-like log format and the `halca_gains.key` file. Note that the `.TSM` files are not always kept up to date.

#### 9.4.2.4 Manual formatting of log files

Partitioning of the calibration file can and must be done by hand if the calibration file format is sufficiently distinct from the standard VLBA format or, possibly, if it contains multiple frequency bands. If your observation used non-VLBA antennas, you will need to edit the calibration text file manually to add any log information supplied for these antennas. The necessary steps are as follows:

Extract the flagging and $T_{SYS}$ information from the calibration text file. You will also need to prepend gain curves to the $T_{SYS}$ file. Try `EXPLAIN ANTAB` to see an example file in the proper format. The parameter `TIMEOFF` should be set to zero for each station since both flag information and data are stored with UTC times. The keyword `DTIMRANG` is also supported which pads each flagged time interval to insure that even very short flag intervals are applied.

While older VLBA format calibration files were supplied with the `ANTENNA` keyword, newer VLBA format calibration files are supplied with the `ANT_NAME` keyword. In the former case, the file should be edited to insert the antenna numbers as listed in the `AN` table (use `PRTAN` on your *AIPS* file to find these) and the absolute day numbers must be replaced by relative day numbers with respect to the *AIPS* reference date. In the latter case, no adjustments to either day numbers or antenna numbers are necessary.

#### 9.4.2.5 Loading calibration log information

The calibration information in the external text files such as $T_{SYS}$ and gain curve measurements are read into `TY` and `GC` tables using `ANTAB`. These tables are then used by `APCAL` to generate an amplitude solution (`SN`) table, allowing an optional solution for atmospheric opacity. The user is advised to read the `ANTAB` help file closely and check the syntax of the text file carefully.

The `INDEX` keyword is used to assign the tabulated $T_{SYS}$ data to individual *AIPS* IF channels and polarizations. Up-to-date information on the usage of the `INDEX` keyword may be found by typing `EXPLAIN ANTAB`. Be careful to match up the proper polarization labels for the tabulated $T_{SYS}$ information. The frequency and polarization association for each IF channel in the *AIPS* file can be compared (use `LISTR` with `OPTYPE = 'SCAN'`) with that at the head of the calibration text file.

The CONTROL group at the head of the calibration file is used only to specify a default index mapping. If the IF channel orders in the calibration file and the *uv* file are identical it is not required.

Source flux densities are not specified in the ANTAB input file. If source flux densities are required by APCAL, the source (SU) table will be searched. Use SETJY to insert flux densities if necessary.

The parameter TIMEOFF in the input file adds a time offset to the all entries. Non-VLBA stations sometimes measure the system temperature between, rather than during, scans causing ANTAB to be unable to match the measurements with the source and frequency ID. The ANTAB input parameter OFFSET serves the same purpose, but is more successful since the scan times are expanded at both ends.

ANTAB permits specification of IF-dependent and tabulated gains; the format description may be found by typing EXPLAIN ANTAB.

ANTAB can be run multiple times to append to the same TY and GC tables. Also, calibration files from separate antennas (*e.g.*, VLA) which have $T_{sys}$ data tabulated in a different format can be concatenated and processed in one run. In this case the INDEX keyword must be specified for each antenna to fix the data format.

Note that ANTAB will (usually) ignore calibration data for which there are no corresponding *uv* data (see the help file for ANTAB). There is one exception however: calibration data for an antenna that does not appear in the AN table will cause ANTAB to fail. If ANTAB quits under such circumstances, you have two choices. You can edit the calibration text file, removing all reference to the missing antennas; or you can use the input adverb SPARM to specify explicitly the names of antennas for which there are calibration data, but which do not appear in the AN table.

**** The use of* SPARM *is no substitute for careful inspection of the calibration text files. ****

Having created the input text file, typical inputs for ANTAB would be:

| | |
|---|---|
| > TASK 'ANTAB' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > CALIN 'MYVLB:BC25CAL.VLBA' C_R | to specify the text file. |
| > SUBARRAY 1 C_R | to select subarray one. |
| > TYVER 0 ; GCVER 0 C_R | to create new TY and GC tables. |
| > BLVER 0 C_R | to create new BL table for any specified baseline factors. |
| > PRTLEV 1 C_R | to select print level. |
| > GO C_R | to run the program. |

PRTLEV = 2 will echo the calibration file as it is processed, which can be useful in locating format errors.

### 9.4.3 Data editing

Before proceeding to calibrate, you should first flag any obviously bad data. In summary, initial editing is based on the flagging information supplied by the on-line antenna monitor systems, which is applied using UVFLG. This information may be extracted to a .FLAG file as outlined in the previous section or subsequent editing based on the station report logs, or elevation limits can also be performed using UVFLG. Finally, graphical editing tasks such as EDITR and IBLED may be used for interactive baseline-based editing. Until the data are converted into single-source data format, flagging information is stored in the FG table instead of being used to discard data directly. Flag tables may also be used with single-source files (at least with all tasks offering the FLAGVER adverb). One may also undo a flag operation using OPCODEs 'UFLG', 'REAS', and 'WILD' in UVFLG. Note that this operation works *only* when the operation being undone is in the current flag table. (Note that many tasks delete fully flagged data when copying a data set.)

To edit *uv* data by reading a text file listing periods of known errors (*e.g.*, the .FLAG text file created by VLOG) run UVFLG with the following inputs:

| | |
|---|---|
| > TASK 'UVFLG' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > SOURCES '' C_R | to flag all sources, which is usually desired. |
| > SUBARRAY 0 C_R | to select the required subarray, all in this case. |
| > FREQID -1 C_R | to flag all frequency IDs. |
| > OUTFGVER 2 C_R | to specify the output flag table; use 2 *only* if you copied FLAGVER 1 to 2 as suggested in § 9.2.1.2. |
| > INTEXT 'MYVLB:BC25CAL.FLAG' C_R | to specify the input text file. |
| > GO C_R | to run the program. |

This will generate a FG table with entries read from $MYVLB:BC25CAL.FLAG.

To edit *uv* data based on elevation limits, UVFLG can be used with input parameters:

| | |
|---|---|
| > TASK 'UVFLG' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > SOURCES 'DA913' , ' ' C_R | to select one source. |
| > SUBARRAY 1 C_R | to select subarray one. |
| > ANTENNAS 3, 4, 5, 8 C_R | to flag only certain antennas. |
| > APARM 0, 0, 0, 0, 10 C_R | to flag data between elevations 0 and 10 degrees (APARM(4) to APARM(5)), with no flagging on amplitude or weight. |
| > OUTFGVER 2 C_R | to specify the output flag table. |
| > GO C_R | to run the program. |

This will generate FG table flagging time ranges that fall between the specified elevation limits.

Note that in both of these examples, the flagging information is incorporated into a FG table instead of "irrevocably" deleting your data. In order to apply these flags, you must set FLAGVER to the appropriate FG table version.

Another editing task which may be useful is QUACK, which can edit the selected portion of the scan at its beginning and/or end. This might be needed because (at non-VLBA antennas) the telescopes were still slewing or system temperature measurements were being made. The first 20 seconds or so of a scan, for baselines to the VLA, are often unusable while the VLA correlator phases up at the new source position. The first second or so after a scan may also need to be flagged (OPCODE 'TAIL') since some antennas may not leave the previous source promptly, leaving bad data marked good. QUACK can be used to flag specific antennas for these and other reasons.

Tasks EDITA and EDITR can be used to inspect and edit the data interactively. IBLED is no longer of much use except for its ability to display the degree of coherence in the data. These tasks are similar in many respects to TVFLG, but are more suited to interferometers with small numbers of baselines. It is also possible to use TVFLG to perform your editing although the TV display is somewhat confusing on sparse arrays of data, especially if there is significant source structure. Read § 4.4 through § 4.4.2 and § 5.5 for more details on the editing of data. Also VPLOT may be used to edit data which deviates excessively from the mean amplitude over a specified averaging interval; see HELP VPLOT C_R for details. Task WIPER is a dangerous but powerful editing tool as well.

The task DEFLG appeared first in the 31DEC01 release. It generates a flag table to delete data having coherence less than a user-specified limit. It must be run only on sources that should be strongly coherent although it may be used to flag data from other sources in between the strong-source scans. The task SNFLG is also used to flag data whenever the phase jumps in an SN or CL table are excessive on a baseline-by-baseline basis.

The VLBA correlator may produce a lot of samples which it knows to be bad and which are flagged by the transferred flag table. For this reason alone, or if you also flag a noticeable fraction of the data set, you may wish to run UVCOP to discard the flagged data to conserve disk space and processing time.

### 9.4.4 *a priori* calibration

The calibration steps described in this section use *a priori* information about the performance of the antennas. These should be performed before any other *a posteriori* calibration. The order of these different calibrations is not particularly important, but probably they should be done in the order listed here.

The voltage threshold levels in the digital samplers at the antennas may differ from their optimum theoretical values and this may vary from antenna to antenna and from polarization to polarization. This sampler bias, which is usually significant only in two-bit quantization, introduces an antenna/polarization-based amplitude offset. In full polarization observations this appears as an amplitude offset between RR and LL. The cross-correlation amplitudes may be corrected if the auto-correlation spectra have been measured. See VLBA Scientific Memo No. 9 (1995, "Effect of digitizers errors on the cross and auto correlation response of an FX correlator", by L. Kogan). Task ACCOR can be used to remove these digital sampler biases from VLBA correlator data, if FITLD was run with DIGICOR = 0, 1, or 2; see § 9.4.4.1.

The recommended method of amplitude calibration using *a priori* $T_{sys}$ and antenna gain information is now to use the task APCAL. For high frequencies ($\geq$ 15 GHz) it may be desirable to do an opacity correction while running APCAL, particularly if an accurate source flux is needed. Set DOFIT to 1 in VLBACALA in order to solve for the atmospheric opacity. See § 9.4.4.2 for a more detailed description of APCAL.

There is a procedure which runs ACCOR, smooths the results with SNSMO, runs APCAL, and applies the solutions using CLCAL. To use this procedure *for VLBA data only*:

| | |
|---|---|
| > RUN VLBAUTIL C_R | to acquire the procedures; this should be done only once since they will be remembered. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > FREQID *ff* ; SUBAR *ss* C_R | to select the frequency ID and subarray numbers — only one of each per execution. |
| > INP VLBACALA C_R | to review the inputs. |
| > DOFIT 1 C_R | to enable the opacity correction; $\leq 0$ disables it. |
| > VLBACALA C_R | to run the procedure. |

VLBACALA will normally be run after correcting the polarization labels with VLBAFPOL (if needed) and loading any gain curves or system temperature data for non-VLBA antennas using ANTAB. Use this procedure only on data from the VLBA correlator.

The RCP and LCP feeds on each antenna will rotate in position angle with respect to the source during the course of the observation for alt-az antennas (which probably constitute a majority of the antennas in your observation). Since this rotation is a simple geometric effect, it can be corrected by adjusting the phases without looking at the data. This correction must be performed before any phase calibration which actually examines the data is executed. This correction is important for polarization and phase-referencing observations, so it should probably be applied to all cases.. Task CLCOR is used for this purpose; see § 9.4.4.3.

There is a procedure which assists you in running CLCOR to correct phases for parallactic angle:

| | |
|---|---|
| > RUN VLBAUTIL C_R | to acquire the procedures; this should be done only once since they will be remembered. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > SUBAR *ss* C_R | to select the subarray number — only one per execution. |

| | |
|---|---|
| > INP VLBAPANG C_R | to review the inputs. |
| > VLBAPANG C_R | to run the procedure. |

VLBAPANG will normally be run after applying *a-priori* amplitude corrections with VLBACALA, but before applying any other phase corrections.

#### 9.4.4.1 Digital sampler bias corrections for VLBA correlator data

***** ACCOR is only intended to run on data from the VLBA correlator. *****

For one-bit quantization, no significant sampler bias correction is expected. Nonetheless, it is recommended that ACCOR be run on one-bit data as a consistency check. If the ACCOR gain factors deviate from unity, there may be overall scaling or *b*-factor errors. For 2-bit quantization, however, the amplitude offsets for the VLBA correlator are typically of order $5 - 10\%$, but values as high as 20% have been observed. These can be corrected by examination of the autocorrelation spectra using task ACCOR. Since ACCOR computes the necessary correction by examining the total-power spectra, it must be run immediately after FITLD in the sense that nothing else should be run that actually modifies the total-power spectra directly. Although ACCOR ignores any SN or CL tables that are present, it is essential to correct for the sampler biases before performing any *a posteriori* calibration, *e.g.*, fringe-fitting or self-calibration.

See § 9.4.4 for a simplified procedure (VLBACALA) to run ACCOR and APCAL along with all required subsidiary tasks. If you have not used VLBACALA, typical inputs to ACCOR for this correction would be:

| | |
|---|---|
| > TASK 'ACCOR' ; INP C_R | to review the inputs. |
| > INDISK *n*; GETN *ctn* C_R | to specify the input file. |
| > TIMERANG 0 C_R | to select data from all times. |
| > SOLINT 2 C_R | to set the solution interval for sampler corrections (min). |
| > GO C_R | to run the program. |

The correction factors were expected to be fairly stable over time, but they have been found to vary over times less than an hour. With a solution interval of a few minutes, such as the two minutes indicated here, it is well to examine the solution (SN) table generated by ACCOR using SNPLT for any bad points or inconsistent values. One approach is to inspect the SN table and then run SNSMO with clipping to get rid of discrepant points. Alternatively, the interactive table editing task SNEDT can be used.

#### 9.4.4.2 Continuum amplitude calibration

The TY table can be examined using SNPLT with OPTYPE='TSYS' or 'TANT' or LISTR with OPTYPE='GAIN'; the GC table is examined with PRTAB. SNEDT may also be used to inspect the TY table and even used to delete or smooth some of the measurements. In 31DEC07, TYSMO can be used to delete discrepant system temperatures and replace the bad and/or good values with time-smoothed values. Note, however, that anomalously high system temperatures may indicate possible bad data (*e.g.*, due to weather) rather than bad measurements of the system temperature. Note that flagging bad *uv* data will not change the appearance of the TY table since no flags are applied in plotting this table. EDITA may also be used to examine the TY data interactively and, if bad system temperatures are found, to flag the associated *uv* data. (This task does flag displayed $T_{\rm sys}$ when the data are flagged.) APCAL can then be used to derive an amplitude calibration (SN) table.

Atmospheric opacity becomes significant at high frequencies ($\geq$ 15 GHz). APCAL can fit for an opacity correction, if needed, using weather information and system temperature. The weather information can be taken from the WX table by setting INVERS (after October 7, 2003) or loaded from disk by setting CALIN. In order to have APCAL fit for opacity set OPCODE to 'GRID', 'OPAC' or 'LESQ' and DOFIT to 1 (both of these are necessary for an opacity fit). OPCODE 'GRID' and 'OPAC' need an initial guess for the receiver temperature (TREC or TRECVR, before and after November 5, 2003 respectively) and zenith opacity (TAU0). However, APCAL versions after November 5, 2003 will estimate these initial guesses from the data if TRECVR and/or TAU0 are 0. If OPCODE is set to 'GRID', 'OPAC' or 'LESQ' and DOFIT $\leq 0$ then the opacity correction is applied using the provided TRECVR. This is a good option if you have a reliable measurement of the receiver temperature. The fits are fairly robust, but the plots that APCAL makes should be examined. Note: a large number of bad Tsys values can make the fits unreliable. APCAL will warn you if fits appear to be incorrect (beginning in 31DEC06).

See § 9.4.4 for a simplified procedure (VLBACALA) to run ACCOR and APCAL along with all required subsidiary tasks. If you have not used VLBACALA and do not want to correct for atmospheric opacity, typical inputs to APCAL are:

| | |
|---|---|
| > TASK 'APCAL' ; INP CR | to review the inputs. |
| > INDISK *n* ; GETN *ctn* CR | to specify the input file. |
| > ANTENNAS 0 ; SUBARRAY 0 CR | to select all antennas and subarrays. |
| > SOURCES ' ' ; STOKES ' ' CR | to select all sources and Stokes. |
| > BIF 1 ; EIF 0 ; FREQID 1 CR | to select all IFs of frequency ID 1. |
| > TIMERANG 0 ; OPCODE ' ' CR | to select all times and use no opacity solutions. |
| > TYVER 0 ; GCVER 0 CR | to use the latest TY and GC tables. |
| > SNVER 0 CR | to create a new SN table. |
| > GO CR | to run the program. |

If atmospheric opacity correction is desired, set the following inputs as well as the above:

| | |
|---|---|
| > OPCODE 'GRID' CR | do a grid search. |
| > DOFIT 1 CR | to fit the opacities. |
| > INVERS 1 CR | to use WX table 1. |
| > TAU0 0 ; TRECVR 0 CR | to let APCAL estimate initial values. |

The resulting solution (SN) table can be smoothed and clipped using SNSMO and applied using CLCAL as described in § 9.4.1.1). Substantial smoothing of the TY table (task TYSMO in 31DEC07), especially for VLBA-only observations, is not generally recommended since variations of the system temperature often reflect a real response to the weather. Smoothing can be useful for data from the phased-VLA, when the amplitude calibration information reflects low signal-to-noise. For non-VLBA antennas, it is important to check with SNEDT that the TY information is associated with the correct source and SNEDT can be used to delete occasional bad system temperature measurements before they are applied to the data. When opacities are fit, APCAL generates plots of the receiver temperature versus zenith angle and the opacity versus time. APCAL will warn you about bad fits, but the plots should be checked for problems with the data or the fits.

#### 9.4.4.3 Polarization calibration: parallactic angle corrections

For full polarization experiments, the parallactic angle contribution to the phase should be removed at the very start of the phase calibration. This correction is also important in phase referencing experiments, because the parallactic angle difference between calibrator and target is different at different stations which leads to an extra phase error which can be corrected. See § 9.4.4 for a simplified procedure (VLBAPANG) to do this correction. If you have not used VLBAPANG, the parallactic angle correction is made with task CLCOR. Note that CLCOR may directly modify the specified version of the CL table, but this is no longer required.

| | |
|---|---|
| > TASK 'CLCOR' ; INP CR | to review the inputs. |
| > INDISK *n1* ; GETN *ctn* CR | to specify the input file. |
| > OPCODE 'PANG' CR | to select the parallactic angle correction. |
| > CLCORPRM 1,0 CR | to specify the sense of parallactic angle removal. |
| > GAINVER *clin* CR | CL table to read, new default is the current highest version. |

| | |
|---|---|
| > GAINUSE 0 C_R | CL table to write; version highest+1 is written unless GAINUSE = GAINVER. |
| > GO C_R | to run the program. |

This will copy CL version GAINVER to version GAINUSE and then modify the latter.

### 9.4.5 Bandpass calibration

Full bandpass response calibration is usually only performed for spectral-line observations although it can be important for certain types of continuum observations.

A quick and dirty bandpass calibration can be carried out for most types of continuum observations by throwing away the outer channels in the data set since these are the most affected by the bandpass response function. The number of channels to throw away should be determined by examining the bandpass effects on the total-power spectra and carefully weighing the competing considerations of signal-to-noise loss by tossing channels versus non-closing errors by keeping channels. This procedure of tossing channels may not be as good as performing an actual bandpass, but it is simpler and easier to carry out.

It is suggested that integrating over a variable bandpass function is one of the most significant sources of non-closing errors in continuum VLBI data. By calibrating the bandpass before averaging over frequency, these effects can be avoided. In VLBA test observations, a dynamic range of 28,000:1 was achieved on the source DA193 (Briggs *et al.* 1994, VLBA Memo No 697A, "High Dynamic Range Imaging with the VLBA") after applying bandpass calibration.

Bandpass calibration is carried out using the task BPASS using either the auto- or cross-correlation data. The output is a BP or bandpass table. The derived bandpass solutions can be plotted using POSSM by setting APARM(8)=2. The effect of applying these bandpass solutions to your data can also be viewed using POSSM by setting DOBAND=1 and BPVER. An example of the inputs to produce bandpass spectra from the auto-correlation data would be:

| | |
|---|---|
| > TASK 'BPASS' ; INP C_R | to review the inputs. |
| > INDISK *n1* ; GETN *ctn1* C_R | to select the multi-source visibility data as the input file. |
| > CALSOUR 'BLLAC' , 'DA193' C_R | to specify the continuum source(s) which were observed for the purpose of bandpass calibration. |
| > DOCALIB -1 C_R | to apply no calibration. |
| > SOLINT 0 C_R | to average data over whole scans before determining the bandpass. |
| > BPASSPRM 1, 0 C_R | to use the self-spectra. |
| > BPASSPRM(5) 1 C_R | to not divide by "channel 0." |
| > BPASSPRM(9) 1 C_R | to interpolate over flagged channels. |
| > BPASSPRM(10) 1 C_R | to normalize the amplitude solutions. |
| > GO C_R | to run the program. |

Be careful with the adverb SMOOTH. If you smooth, or do not smooth, the data while finding a bandpass solution, then you must apply the same SMOOTH adverb values whenever you apply that bandpass solution to the data. The only exception is that you may smooth the data after applying the bandpass solution with SMOOTH(1) values 5 through 8 when you did no smoothing in BPASS.

This will produce a BP table containing the antenna-based bandpass functions to be applied to the data. Since only the self-spectra were used, the phase response of the bandpasses is not determined. If you wish to correct for phase errors across the band, then you must first fringe-fit the calibrator data (see § 9.4.8.9 below), then set DOCALIB to 1 and BPASSPRM(1) to 0, and run the task. See § 9.4.9 for details. However, you should check your results very carefully. The BP tables can be plotted with POSSM or printed with PRTAB.

Note that this task merely creates a BP table. To use this BP table, set BPVER and DOBAND as described in § 4.7.3 when running any later *AIPS* tasks.

### 9.4.6 Spectral-line Doppler correction

Normally, when observing, you will have kept the frequency constant throughout the run for ease of observing. Therefore, although your data will have the same frequency, the center velocity of your spectrum will change with time and the spectral-line signals will wander backwards and forwards through the spectrum. To ensure that the velocity is constant throughout the data you should run SETJY and then CVEL. The VLBA correlator compensates for the revolution of the antennas relative to the center of the Earth. In this case, the only movement which CVEL should compensate is the rotation of the antennas together with the Earth around the Sun. This movement should be the same for all antennas and gives a smaller effect than the rotation relative to the center of the Earth. Nonetheless, CVEL is required for the VLBA correlator at least to be able to compare observations made at different times. Without CVEL such comparisons will show the velocity shift of the Earth's orbit about the Sun.

SETJY will insert the velocity information required in the `SU table`:

| | |
|---|---|
| > TASK 'SETJY' ; INP CR | to review the inputs. |
| > INDISK *n1* ; GETN *ctn1* CR | to select the data. |
| > SOURCE 'OH127.8' , ' ' CR | to specify the line source whose velocity is to be specified. |
| > OPTYPE ' ' CR | to switch off flux modification. |
| > SYSVEL -66.0 CR | to specify the velocity of the "center" of the band in km/s. |
| > APARM 65, 0 CR | to specify which spectral pixel is the "center" of the band, actually the pixel to which SYSVEL refers. |
| > RESTFREQ 1612e6, 231.09e3 CR | to give the rest-frequency in Hz, *e.g.*, that of the OH transition. Note that the two single-precision adverb numbers are summed in double precision inside SETJY. |
| > VELTYP 'LSR' CR | to select the rest frame of the velocity. |
| > VELDEF 'OPTICAL' CR | to define velocities by the optical convention. |
| > GO CR | to run the program. |

Then run CVEL:

| | |
|---|---|
| > TASK 'CVEL' ; INP CR | to review the inputs. |
| > INDISK *n* ; GETN *ctn* CR | to select the data. |
| > OUTDISK 3 ; OUTCLASS 'CVEL' CR | to specify the output file. |
| > SOURCE 'OH127.8' , ' ' CR | to select the source(s) to be shifted, all others will be passed un-shifted. |
| > DOBAND 1 CR | to apply the bandpass correction — important. |
| > BPVER 1 CR | to specify the version of BP table to use. |
| > GO CR | to run the program. |

After applying the BP table, CVEL will not copy it to the output file to protect you from applying it twice. Although CVEL allows you to select which sources are to be shifted, the BP table, if DOBAND is set appropriately, will be applied to all sources found.

### 9.4.7 Spectral-line amplitude calibration

The calibration scheme suggested in *AIPS* for spectral-line VLBI data utilizes the total-power spectra method described in Lecture 12 of *VLBI, Techniques and Applications*, eds. Felli and Spencer, published by Kluwer Academic Publisher, 1988. The continuum method using $T_{sys}$ values (see § 9.4.4.2) can also be used. The first step is to generate a so-called template spectrum. This is a high quality spectrum from the most sensitive antenna in the array that has been corrected for the effects of the bandpass filter. For example:

| | |
|---|---|
| > TASK 'SPLIT' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > SOURCE 'OH127.8', ' ' C_R | to write the program source. |
| > BCHAN 0 ; ECHAN 0 C_R | to write all spectral channels. |
| > DOCALIB -1 C_R | to avoid applying any calibration. |
| > DOBAND -1 C_R | to skip the bandpass correction since the data will have been corrected already in CVEL. |
| > TIMERANG 0 22 0 0 0 22 30 0 C_R | to select the data from a range of times when the antenna elevation was high and the source spectrum of high quality. |
| > APARM 0, 0, 0, 0, 1 C_R | to pass only self-spectra. |
| > GO C_R | to run the program. |

You should then run ACFIT to do a least-squares fit of the template total-power spectrum to the total-power spectra of all other antennas and to write the resulting time-dependent amplitude gain correction factors into an SN table.

| | |
|---|---|
| > TASK 'ACFIT' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > IN2DISK *n* ; GET2N *ctn* C_R | to specify the template file. |
| > CALSOUR 'OH127.8 ' C_R | to select the source to use for calibration. |
| > DOCALIB -1 C_R | to avoid applying any previous calibration. |
| > DOBAND -1 C_R | to skip the bandpass correction since it was done when CVEL was run. |
| > SOLINT *n* C_R | to average the self-spectra over *n* minutes (*e.g.*, 10) before doing the least-squares fit. |
| > REFANT 1 C_R | to select the desired reference antenna from the template file. |
| > BCHAN 50 ; ECHAN 70 C_R | to set the range of spectral channels over which the fit is performed. |
| > APARM 0, 0, 50, 0, 0.72 C_R | program control: APARM(1) and APARM(2) specify the orders of the polynomial spectral baseline to remove from the source and template spectra; APARM(3) and APARM(4) specify the sensitivity of the template antenna (in Jy/deg) in the first and second (if needed) polarizations; APARM(5) and APARM(6) specify the minimum and maximum relative antenna gains allowed, with defaults to allow all positive values; APARM(7) specifies the maximum allowed gain error, with 0 meaning all; APARM(8) specifies the print level, with 0 providing minimal information, 1 providing useful information on the gains determined for each antenna and solution interval and 2 giving the gory details for each fit; APARM(9) specifies that the fits are done after subtracting a spectral baseline (0) or without a baseline (1); and APARM(10) controls whether baseline-subtracted spectra are written to an output file. |

| | |
|---|---|
| > BPARM 80, 120 C_R | to set up to 5 pairs of start and stop channels to use in determining the baseline polynomial to be removed from the source spectra. The order of the polynomial is specified in APARM(1). |
| > CPARM 80, 120 C_R | to set up to 5 pairs of start and stop channels to use in determining the baseline polynomial to be removed from the template spectra. The order of the polynomial is specified in APARM(2). |
| > XPARM 45.1, 48.0, 50.1, 49.5 C_R | to specify $T_{sys}$ values in the first polarization for each IF for the template scan of the reference antenna. YPARM provides an equivalent list for the data, if any, from a second polarization. |
| > SNVER 0 C_R | to create a new SN table into which the solutions are to be written. |
| > GO C_R | to run the program. |

ACFIT will generate an SN table, which has to be applied to the CL table. If needed, run SNSMO to smooth the amplitude correction factors determined by ACFIT before running CLCAL. A 30-minute smoothing interval for SNSMO (set using CPARM 0.5,0) should be sufficient.

### 9.4.8 Phase calibration

After carrying out amplitude calibration, the remaining calibration steps involve correcting the phase of the data within and between the separate IF channels and between the different integration periods. This will allow averaging of the data over both frequency and time without loss of coherence. The phase offsets may be corrected using *a priori* 'phase-cal' measurements if available and/or by directly fitting to the data.

For those antennas for which phase-cal measurements are available, task PCCOR can be used to incorporate the phase-cals into an SN table. (see § 9.4.8.5). If you have other antennas for which phase-cal measurements are not available, you can run CLCAL using the OPCODE='CALP' option to incorporate the incomplete SN table information loaded by PCCOR without throwing away data for the antennas with missing phase-cal information.

For MkIII data from the Bonn correlator, phase-cal measurements are incorporated directly into the first CL table produced by MK3IN — this is another strong reason to protect the first CL table.

If external phase-calibration data (pulse cals) are not available then directly fringe-fitting a short scan of data to measure the phase and single-band delay offsets may be applicable under limited circumstances (see § 9.4.8.6). Even when phase-calibration information is available, performing a manual phase-cal can be a good idea to confirm that the IF-dependent delays and phases have been successfully estimated and removed. One good check is to inspect the data using POSSM at times different from the time used to determine the manual phase calibration. Note that time-dependent delays may still be seen because of low elevation and ionospheric effects.

Even after removing instrumental phase offsets from each IF, the data will in general still contain frequency and time dependent phase variations. The purpose of "fringe-fitting" is to determine these phase errors and then remove them from the data.

The primary *AIPS* task for fringe-fitting is FRING. This task estimates time variable station-based delays (phase derivatives wrt frequency) and rates (phase derivatives wrt time) using a self-calibration-like algorithm. Once these delays and rates are determined, the task CLCAL is used to produce the phase correction that should be applied to each integration period and spectral channel to correct for delay and rate effects. This use of FRING and CLCAL is discussed in detail in § 9.4.8.9. Two alternatives to FRING are the tasks BLING and BLAPP and the experimental version of FRING named KRING. BLING and BLAPP are discussed briefly in § 9.4.8.10. KRING provides a superset of the functionality in FRING with numerous enhancements such as: the use of extremely small scratch files, a parsimonious use of memory, possible solution extrapolation both backwards and forwards in time and a rationalized definition of SNR. For more information about KRING, type HELP KRING from within AIPS. When fringe-fitting to many small scans, KRING can be substantially slower than FRING. When fringe-fitting data sets with large numbers of spectral channels and long solution intervals, KRING can be substantially faster than FRING.

The process of fringe-fitting, and then interpolating the solutions using CLCAL, can be a very time consuming process. Although it depends a lot on the size and structure of the data set, *the fringe-fitting time can equal or exceed the observing time for a large data set.* For this reason it is probably wise to run through the fringe-fitting procedure described in § 9.4.8.9 on a small amount of data first (say 30 minutes' worth) before attempting to process the whole data set. This is especially true if this is your first time processing multi-IF, multi-channel VLBI data. It is probably simplest to use UVCOP to copy out a short time range of data from your main file and to work only on this initially. Doing so also avoids the possible confusion of having many versions of extension tables.

#### 9.4.8.1 Special considerations: SVLBI

The existing fringe-fitting tasks within *AIPS* have been enhanced to improve their performance when dealing with SVLBI data. In addition, several new tasks have been written to address problems specific to SVLBI fringe-fitting. The primary SVLBI fringe-fitting tasks in *AIPS* are BLING and FRING and are discussed in § 9.4.8.9–§ 9.4.8.11. The tasks COHER and FRPLT, described in § 9.3.6 and § 9.3.7, may be of particular interest when reducing SVLBI data.

There may be delay discontinuities in the recorded data for a variety of reasons such as tracking station handoffs, clock glitches, etc. The recommended method for dealing with such discontinuities is to force scan boundaries at such events. The task INDXR can be used to generate a new NX table with scan boundaries at desired locations using an input text file. In practice, either INDXR will do the right thing by design, or your P.I. information letter should have contained instructions on how to construct a text file in the proper format for INDXR.

A new task, OBEDT, is available which allows selection of specific orbital parameter ranges, through the creation of an output flag (FG) table. This can be used to constrain initial fringe searching.

SVLBI data often contain tracking passes three or four hours in length, for which fringes are mostly (or wholly) not apparent. Typically, the space-ground baselines will have the highest correlation coefficients near perigee, when those baselines are shortest. However, the imperfectly known orbit will cause high fringe rates and short coherence times. Near apogee, the coherence time is longer, and may be limited by the atmosphere above the ground telescopes, but the correlated flux also is much lower. Sometimes, it may be possible to find fringes for only 15 or 20 minutes, but that's better than nothing.

If no fringes are seen anywhere during a tracking pass, a useful trick is to set APARM(7) = 0.01 to let through the highest SNR for each solution interval, and set DPARM(5) = 1 to turn off the least squares solution. Then run FRING for an entire tracking pass, and use SNPLT with OPTYP = 'DELA' and OPTYP = 'RATE' to look for repeating values (usually easier to see in delay than in rate). Also, make plots with OPTYP = 'SNR' to see if slightly higher SNRs are found at a time when there seems to be some consistency in delay values. It may be necessary to try this process with several values of SOLINT in order to arrive at a guess for the fringe location. Use VPLOT to plot *uv* distance versus time for the space-ground baselines, then search using the TIMERANG and REFANT that provide the shortest projected baselines. Another possibility is to set REFANT = ANTNUM('MK'), since the atmospheric coherence time should be longest at Mauna Kea, and increase SOLINT to a fairly large value in hopes something will show up. (Note, however, that a large SOLINT with a wide-open search window in delay and rate may require a large-memory computer or great inefficiency due to page faulting.)

If fringes are found somewhere, use CLCOR to center the fringes (see § 9.4.8.6), then run FRING again with small delay and rate windows (*e.g.*, `DPARM(2) = 200` to 400 and `DPARM(3) = 40` to 80 at 1.6 GHz, or ∼ 200 at 5 GHz). Set low SNR thresholds with `APARM(7) = 3.5`, and turn the least-squares solutions back on with DPARM(5)=0. Usually, it's best to turn on the exhaustive antenna search with `APARM(9) = 1`, since only a few space-ground baselines may show fringes. It can be helpful to use SEARCH to order the search from shortest to longest space-ground baselines.

It generally doesn't work well to use one tracking station to predict the results of another, because clock initialization offsets are typically relatively large and have unrelated errors, and fringe-rate errors also may be unrelated.

#### 9.4.8.2 Special considerations: spectral-line

Delay and fringe-rate calibration of spectral-line VLBI data must be handled differently. The residual delay cannot be estimated from the source itself because, due to the very nature of the source, the delay is a rapidly varying function of frequency. The continuum calibrator, observed for this purpose, is first used to determine residual delays and fringe-rates which are then applied to the spectral-line source. A suitable channel or range of spectral-line channels "on-source" is then used to determine the residual fringe-rates. It is very important to note that in some situations, the residual fringe-rates determined from the calibrator may not be applicable to the line source because the fringe-rate residuals towards the two sources may be quite distinct. In such situations, the residual fringe-rates determined from the continuum source should not be applied to the line source. See § 9.4.8.12 for more details.

#### 9.4.8.3 Special considerations: polarization

In addition to phase calibrating the LL and RR data separately, for polarization data the R-L phase and delay offsets must also be determined. This is outlined in § 9.4.8.13. After fringe-fitting, all parallel-hand fringe solutions need to be re-referenced to the same antenna.

#### 9.4.8.4 Special considerations: phase-referencing

The process of phase referencing for VLBI data is conceptually very simple. Unfortunately, the technical difficulties in conducting a successful phase-referencing observation are primarily in setting up the schedule. So by the time you get around to reading this section, your project is either guaranteed to succeed or guaranteed to fail, depending upon how well your observations were designed. See the lecture by A. Beasley and J. Conway in "VLBI and the VLBA", 1995, (ASP), and VLBA Scientific Memo No. 24 (2000, by J. Wrobel, C. Walker, J. Benson, and A. Beasley) for more details on how to design phase-referencing observations.

In "phase referencing," the phase calibration for your target source is derived from a calibrator, or phase referencing, source observed for that purpose. First, you apply any available *a priori* phase-cals to both the target and cal source. Next, you fringe-fit, self-calibrate, and/or hybrid-map the cal source — whatever is needed to complete the phase calibration for that source. Finally, you apply the phase corrections so determined to the target source. In practice this is done by specifying the target as well as the cal source in the SOURCES adverb list whenever an SN table containing phase corrections for the cal source is applied using

CLCAL. See § 9.4.1.2 for a specific example of how to run CLCAL to transfer phase corrections determined using a cal source to a target source.

Certain "instrumental" corrections such as those for unmodeled zenith delay may have subtle but significant effects on phase referencing. See § 9.4.8.7 for a discussion.

You can perform a "hybrid" form of phase referencing in some instances. It may be that your target source is too weak for initial fringe-fitting. In this case, you can fringe-fit the cal source data to determine the phase corrections to be applied to the target source data. Then, after averaging in frequency, the target source data may have adequate signal-to-noise to allow rate corrections to be determined for it by fringe-fitting. In this mode, you may or may not wish to zero the rate corrections determined on the cal source. If the cal source is "far" from the target source, the rate corrections may do more harm than good for the target source and should be zero'ed. On the other hand, your target source may be entirely too weak to fringe-fit on at all. In this case, you must rely on determining the phase corrections solely using your cal source.

If you are attempting phase-referenced astrometry, you may have a target source that is brighter than your cal source(s). In this case, you simply fringe-fit on the target source and transfer the solutions to the cal source(s). Be careful, if your goal is to extract absolute positional information, not to independently self-calibrate the cal and target sources.

#### 9.4.8.5 Instrumental phase corrections

If you run POSSM on a short ($\approx 1$ minute) section of data on a strong calibrator using the inputs described in § 9.3.2 and set DOCAL = -1 C_R, you will see that each individual IF channel has its own independent phase offset and its own phase gradient against frequency. These phase offsets and instrumental "single-band delays" are caused by passage of the signal through the electronics of the VLBA baseband converters (or MkIII/MkIV video converter units). The VLBA and MkIII systems can inject narrow band signals ("phase-cals") into the data recorded at each antenna from which the IF channel phase offsets, and the instrumental single-band delays, can be determined.

Data produced by a MkIII correlator are provided with the phase offsets in version 1 of the CL table (see § 9.2.2). To check whether your data from a MkIII correlator contains phase-cal data, use SNPLT on CL table version 1 to plot the phases. If the values are non-zero, phase-cal data are present.

As of 1 April 1999, the VLBA correlator is capable of transferring phase-cal information directly to a PC table for some antennas. For other antennas, the phase-cal information may be read into the PC table using the task PCLOD. Type EXPLAIN PCLOD for further information. If you are unsure whether your VLBI data has phase-cal information, use IMHEAD to list the extension tables and look for a PC extension.

Phase-calibration data in a PC table can be used by task PCCOR to generate an SN table which corrects for the single-band instrumental phase and delay offsets (note that PCCOR uses two phase-cals in each IF). A short calibrator scan must be specified to be used by PCCOR to resolve any $2\pi$ phase ambiguities in the phase-calibration data. The specified time range must include at least one PC table entry for each antenna appearing in the PC table. Having resolved the $2\pi$ phase ambiguities, PCCOR uses the whole PC table to calculate entries in an SN table for all times (not just the TIMERANG used to resolve the ambiguities). 31DEC01 AIPS offers the procedure VLBAPCOR to run PCCOR, FRING (if needed), and CLCAL for you. Inputs are:

| | |
|---|---|
| > RUN VLBAUTIL C_R | to acquire the procedures; this should be done only once since they will be remembered. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > TIMERANGE *d1 h1 m1 s1 d2 h2 m2 s2* C_R | to specify a short scan on a calibrator. There is no default. |
| > REFANT *m* C_R | to select a particular reference antenna. |
| > SUBARRAY 0 | to do all subarrays. |

| | |
|---|---|
| > CALSOUR '*cal1*', ' ' | to specify the calibrator source name. |
| > GAINUSE *CLin* C_R | to indicate the CL table with all calibration up to this point. |
| > OPCODE 'CALP' C_R | to indicate that there are antennas with no usable pulse cals; use OPCODE ' ' if all antennas have pulse cals. |
| > ANTENNAS *a1 a2 a3* C_R | to solve for antennas *a1, a2, a3* "manually" (using FRING). |
| > VLBAPCOR C_R | to run the procedure. |

This should be done after the *a-priori* amplitude calibration (VLBACALA) and, for polarization and phase-referencing experiments, the parallactic angle correction (VLBAPANG), but before any global fringe fitting. The CALP option requires the data in the specified TIMERANG to include strong fringes for those antennas lacking phase-cal data.

Running the tasks individually, typical inputs to PCCOR are:

| | |
|---|---|
| > TASK 'PCCOR' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > TIMERANG 1 2 15 0 1 2 20 0 C_R | to isolate a short scan on a calibrator; *no default*. |
| > SNVER 0 C_R | to create a new SN table. |
| > INVER 1 C_R | to specify the input PC table version. |
| > REFANT 5 C_R | to specify reference antenna. |
| > SUBARRAY 1 ; FREQID 1 C_R | to set subarray and freqid. |
| > CALSOUR '3C345',' ' C_R | to set calibrator source name. |
| > GO C_R | to run the program. |

The resulting solution table is applied using CLCAL. If you are missing phase-cal information for some antennas, you must use the 'CALP' mode of CLCAL; this mode allows calibration information for some antennas to be incorporated into the CL table while passing other antennas through without modification. Examine the corrected data using POSSM to determine if the instrumental phase and delay offsets between the IF channels have been removed correctly.

To check that the applied phase-cals are valid, run POSSM on a short section of data containing a strong source setting DOCAL = 1, GAINUSE to the version number of the CL table containing the phase-cal calibration, and APARM(9) = 1 to place all IFs on the same plot. The phase as a function of frequency on each baseline should be smoothly varying, with no sharp jumps between different IF channels. There may be an overall linear gradient with frequency due to residual delay errors. Unless these conditions hold for all baselines, you should proceed to § 9.4.8.6.

#### 9.4.8.6 "Manual" instrumental phase corrections

If your file does not have phase-cal information, or if these phase-cals do not successfully remove frequency phase offsets, you can use observations of a bright calibrator source and the task FRING to correct for these effects. If you attempted phase-cal calibration, it is best to avoid possible confusion by first deleting any partial or erroneous phase-cal information that already exists. Using CLCOR:

| | |
|---|---|
| > TASK 'CLCOR' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > GAINVER *clin* ; GAINUSE 0 C_R | to specify which CL table to modify after copying it to a new table. |
| > OPCODE 'PCAL' ; CLCORPRM 0 C_R | to set phase-cals to zero. |
| > INP C_R | to check the inputs. |
| > GO C_R | to run the task. |

If you have large known delay offsets you may also wish to run CLCOR using OPCODE='SBDL' to shift the center of the fringe search window.

If you have a known clock offset, as may be common for an SVLBI data set, you may wish to run CLCOR with OPCODE = 'CLOC' and CLCORPRM = 0, *offset*, 0, 0, 0, 0, 1, 0.

Now you can determine the manual phase correction for one or two strong calibrator scans for which all the antennas are present using VLBAMPCL. This procedure runs FRING and CLCAL once or twice, depending on whether one or two scans are used. Choose a scan with strong fringes to all antennas; if none exists, find a second scan that has strong fringes to the antennas missing from the first. Note that if you use 2 scans the REFANT must have good fringes in both scans. Typical inputs are:

| | |
|---|---|
| > RUN VLBAUTIL C<sub>R</sub> | to acquire the procedures; this should be done only once since they will be remembered. |
| > INDISK *n* ; GETN *ctn* C<sub>R</sub> | to specify the input file. |
| > TIMERANGE *d1 h1 m1 s1 d2 h2 m2 s2* C<sub>R</sub> | to specify a short scan on a calibrator. There is no default. |
| > REFANT *m* C<sub>R</sub> | to select a particular reference antenna. |
| > SUBARRAY 0 | to do all subarrays. |
| > CALSOUR '*cal1*', ' ' | to specify the calibrator source name. |
| > GAINUSE *CLin* C<sub>R</sub> | to indicate the CL table with all calibration up to this point. |
| > OPCODE 'CALP' C<sub>R</sub> | to indicate that there are antennas with no fringes for the scan in TIMERANGE; use OPCODE ' ' if all antennas will be corrected by the first scan. |
| > TIME2 *d1 h1 m1 s1 d2 h2 m2 s2* C<sub>R</sub> | to specify a short second scan on a calibrator. |
| > CALSOUR '*cal2*', ' ' | to specify the calibrator source name for the second scan. |
| > ANTENNAS *a1 a2 a3* C<sub>R</sub> | to solve for antennas *a1, a2, a3*. |
| > VLBAMPCL C<sub>R</sub> | to run the procedure. |

If you wish to run FRING separately, you can determine the phase offsets/single band delays by running FRING on a short section of calibrator data where all or most of the antennas are present. Suitable inputs for FRING for this purpose are shown below; for more details of some of the FRING input parameters see § 9.4.8.9. Note that it is simplest to choose a single short section of data within a single scan using TIMERANG and to set SOLINT equal to the scan length so that a single solution is achieved. The interval chosen must be less than than an atmospheric coherence time, but long enough that high signal-to-noise is achieved. At centimeter wavelengths with Jansky-level calibrators, solution intervals of a few minutes will work well. For example:

| | |
|---|---|
| > TASK 'FRING' ; INP C<sub>R</sub> | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C<sub>R</sub> | to specify the input file. |
| > CALSOUR '0954+658 ' , ' ' C<sub>R</sub> | to select a strong calibrator source. |
| > TIMERANG 0, 16, 0, 0, 0, 16, 2, 0 C<sub>R</sub> | to select a single short scan. |
| > DOCALIB 1 ; GAINUSE 2 C<sub>R</sub> | to apply the amplitude calibration from CL table 2 to the weights as well as the visibilities. |
| > FLAGVER 0 C<sub>R</sub> | to apply the most recent flag table. |
| > SMODEL 0 C<sub>R</sub> | to use the null (point-source at the origin) source model. |
| > REFANT 5 C<sub>R</sub> | to specify a reference antenna that will give fringes to most other antennas. |
| > SOLINT 0 C<sub>R</sub> | to set the solution interval in minutes; do not exceed the atmospheric coherence time. |
| > APARM 0; DPARM 0 C<sub>R</sub> | to initialize FRING options to defaults. |
| > APARM(1)=2 C<sub>R</sub> | to require at least 2 antennas. |
| > APARM(6)=1 C<sub>R</sub> | to solve for the rate, single-band delay and phase of each IF separately. |
| > DPARM(1)=1 C<sub>R</sub> | to use only 1 baseline in the initial (coarse) fringe search. |

| | |
|---|---|
| > DPARM(9)=1 C_R | to suppress fitting of rates; rates will be 0 in the SN table. |
| > SNVER 0 C_R | to create a new SN table. |
| > ANTWT 0 C_R | to apply no additional weights to the antennas before doing the solutions. |
| > INP C_R | to check the inputs. |
| > GO C_R | to do the fit. |

If there was no single scan where all the antennas were present, you can run FRING again for another scan setting REFANT to be one of the antennas found in the first run (the same REFANT would be best) and ANTENNAS to this antenna plus all of the antennas *not* found in the first run. FRING will generate a new SN table each time; be careful to keep track of which SN tables you wish to use.

The phase solutions in the SN table(s) are interpolated onto a calibration or CL table using task CLCAL as described in § 9.4.1.1. To apply the calibrator solutions to the other sources in the data file, set CALSOUR to the calibrator source used when running FRING (in the example above, CALSOUR '0954+658') and set SOURCE = ' ' for all sources. Also, set REFANT to whatever was used when running FRING. If multiple runs of FRING were required, you can set SNVER=0 so that all SN tables are combined before being applied ; if you do this, you must first be careful to delete all SN tables except those generated by FRING. Or you can run CLCAL multiple times specifying each SN table in turn, with the specific antenna numbers, while keeping the same CL table versions.

To check the output CL table, run POSSM for the scan used for the FRING solution with DOCAL = 1 and GAINUSE = 3 (*i.e.*, the output CL table from the CLCAL above). The phase should be flat as a function of frequency on all baselines, although it may not be centered on zero. Run POSSM on another scan containing a strong calibrator to check that the assumption of constant IF phase offset holds.

#### 9.4.8.7 Correcting for atmospheric delays

VLBI correlators remove some estimate of the non-dispersive atmospheric delay at the elevation and frequency of the observation from the data. These a priori models are usually fairly good, but careful observations can improve upon them. Beginning with the 31DEC03 release, AIPS offers a number of options to deal with this problem. DELZN uses multi-band delay (see § 9.4.8.8) in an SN table to fit for the zenith tropospheric delay and the clocks as a function of time. It works best if the observations include data on a variety of calibrators well distributed around the sky. DELZN applies a correction to a CL table or writes a file to disk with zenith atmospheric delays and possibly clock offsets that can be used by CLCOR, OPCODE='ATMO' to correct a CL table. The second option is for the situation where the data used by DELZN is in a different file from the data that needs to be corrected.

To correct an attached CL table, the typical inputs for DELZN would be:

| | |
|---|---|
| > TASK 'DELZN' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > SNVER *snin* C_R | to select the SN table containing multi-band delays. |
| > GAINVER *clin* C_R | to select the CL version to which solutions are to be applied. |
| > APARM(4) 1 C_R | to create a new CL table. |
| > APARM(5) 1 C_R | to solve for atmosphere and clocks |
| > SOURCES 'DA913' , ' ' C_R | to specify the sources to be corrected. |
| > CALSOUR '0103+337', '0140+412', '0150-334', '0159+418', '0202+319', '0244-297', '0358+210', '0425+174', '0641+392' C_R | to specify the calibrator sources observed at a large variety of elevations |
| > OPTYPE 'MDEL' C_R | to use multi-band delay |

| | |
|---|---|
| > DOTV -1 C_R | to make PL files |
| > GO C_R | to run the program. |

This will generate a CL table and several PL files that show the data and the fitted model. You are **strongly encouraged** to examine these.

To create an output file rather than correct a CL table use the same inputs as above except:

| | |
|---|---|
| > APARM(4) 0 C_R | to create no CL table. |
| > SOURCES ' ' C_R | to correct no sources |
| > CALSOUR '*' C_R | to use all calibrator sources. |
| > OUTFILE 'MYVLB:BZ199.DELZN' C_R | output file name |

Again, you are advised to examine the resulting plot files which show both the data and the fitted model. The output file can be read in with CLCOR (OPCODE='ATMO'; INFILE='MYVLB:BZ199.DELZN') to correct a CL table.

There is also a new task in 31DEC03 to deal with the effects of zenith delay in phase-referencing observations. Phases for the target source in phase referencing are corrected by the phases at the calibrator which usually is at a different elevation. Task DFCOR is a special version of CLCOR which applies the 'ATMO' operation to correct the CL table for the difference in elevation between the target source and adjacent calibration sources without applying the full atmospheric delay correction.

#### 9.4.8.8 Finding multi-band delays

For astrometric and geodetic experiments and to use DELZN (see § 9.4.8.7), the multi-band delay must be determined. The multi-band delay is the delay caused by errors in the station positions and the difference between the correlator model and reality for clocks and the troposphere. The multi-band delay is best determined over IFs which are widely spaced in the frequency band. After the instrumental phases have been corrected (§ 9.4.8.5–§ 9.4.8.6), the multi-band delay can be determined in one of two ways. For strong sources do a global fringe fit as described in § 9.4.8.9 setting APARM(5)=0, and then run MBDLY on the resulting SN table.

Typical inputs for MBDLY would be:

| | |
|---|---|
| > TASK 'MBDLY' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > INVERS SN *table from FRING* | to select input SN table |
| > OUTVERS 0 C_R | make new SN table |
| > BIF 0; EIF 0 C_R | to select all IFs. |
| > SUBARRAY 0 C_R | to select all subarrays. |
| > APARM 0 C_R | the defaults are generally O.K. |
| > GO C_R | to run the program. |

This will produce a new SN table with the MBDELAY columns filled in.

For weak sources, use APARM= 2 0 0 1 1 in FRING. This averages each IF and fits a multi-band delay across them. Note that this *does not* solve for single-band delays, unlike the previous method. This will also produce a new SN table with the MBDELAY columns filled in.

#### 9.4.8.9 Antenna-based fringe-fitting

To see an example of the residual phase errors in your data, use POSSM to view the phase on a short calibrator scan (at some time other than that used to solve for the phase-offsets in § 9.4.8.6). In general, there will be a gradient in phase between the IFs (due to the "multi-band" delay) and also small gradients within each IF (caused by small residual "single-band" delays). These time-variable phase gradients are mainly due to inaccuracies in the geometrical time delays that the correlator assumed for the time of arrival of the wavefront at each antenna. These inaccuracies arise from propagation effects through the troposphere and ionosphere, inaccurate Earth geometry, etc. and give *phase* errors which are proportional to frequency. Such phase errors prevent integration of the data over frequency (or cause a loss of coherence if you do). Similarly, VPLOT will show, on any single IF and spectral channel, phases which change rapidly with *time*. Again, these are due to unavoidable inaccuracies in the correlator model; such large "phase rates" prevent integration over time. Both of these points are illustrated in Figure 9.1.

You will want to run FRING to correct for these residual rates. FRING and KRING use a global fringe-fitting algorithm described by Schwab and Cotton, 1983, *Astron. J.*, **88**, 688. Unfortunately, these are large and complicated tasks. Beginning with the 31DEC01 release, procedure VLBAFRNG is available to simplify access to FRING and VLBAKRNG access to KRING. Versions of these procedures for phase-referencing experiments are called VLBAFRGP and VLBAKRGP. For all these procedures, if the SOURCES adverb is set, then CLCAL is run once to apply the results of FRING (or KRING) for each source in SOURCES. For the phase-referencing procedures (VLBAFRGP and VLBAKRGP), any source that is in the SOURCES list that is *not* in the CALSOUR list will be phase referenced to the *first* source in the CALSOUR list. Note that, if every source in the SOURCES list occurs in the CALSOUR list, VLBAFRNG and VLBAKRNG will run identically to VLBAFRGP and VLBAKRGP, respectively. If the SOURCES list is empty, VLBAFRNG and VLBAKRNG will run CLCAL once over all sources, while VLBAFRGP and VLBAKRGP will run CLCAL once referencing all the sources to the first source in CALSOUR. These procedures will produce new (highest numbered) SN and CL tables.

Sample inputs for procedure VLBAKRNG are:

| | |
|---|---|
| > RUN VLBAUTIL C_R | to acquire the procedures; this should be done only once since they will be remembered. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > TIMERANGE 0 | to include all times. |
| > BCHAN 0 ; ECHAN 0 C_R | to use all frequency channels. |
| > GAINUSE *CLin* C_R | to use the CL table with all the calibration up to this point. |
| > REFANT *n* C_R | to specify an antenna that is present most of the time as the reference antenna. |
| > SUBARRAY 0 C_R | to use all subarrays. |
| > SEARCH 0 C_R | to try all antennas as a reference antenna if fringes cannot be found using REFANT. *This is different from* FRING*; in* FRING *this must be set to try other reference antennas.* |
| > OPCODE ' ' C_R | to leave all solutions in the output SN table. |
| > CPARM 0 C_R | to use defaults for KRING steering parameters; this is okay for strong sources. |
| > CPARM(1) *x* C_R | to specify the minimum integration time in seconds. |
| > CPARM(8) 1 C_R | to avoid re-referencing solutions; do this *only* for polarization experiments. |
| > CALSOUR '*src1*', '*src2*' C_R | to specify the sources to fringe fit using KRING. |
| > SOURCES '*src1*', '*src2*' C_R | to have CLCAL run for each source using the interpolation method given below. |
| > INTERPOL 'AMBG' C_R | to use the "AMBG" interpolation method (linear phase connection using rates to resolve phase ambiguities). |
| > BADDISK 0 C_R | to use all disks for scratch files. |
| > VLBAKRNG C_R | to run the procedure. |

Procedure VLBAKRGP sets the same adverbs as VLBAKRNG *except*

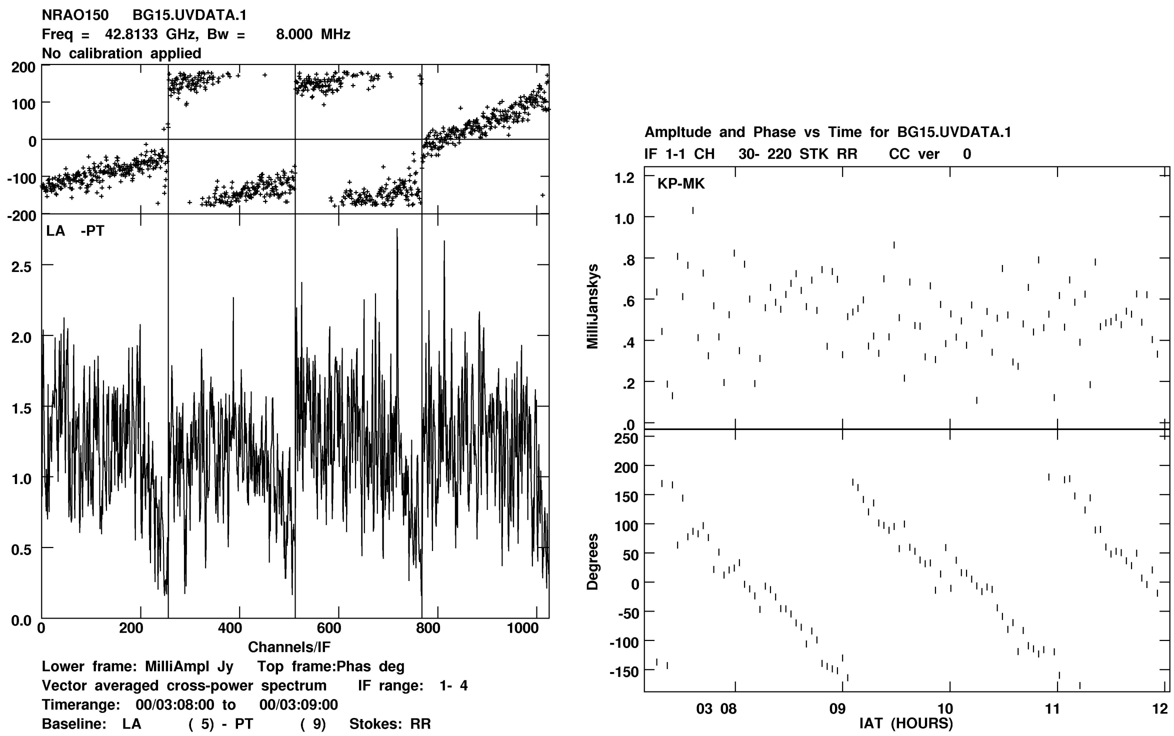



Figure 9.1: *left:* A POSSM plot of the 43-GHz spectrum of the quasar NRAO150 on the Los Alamos to Kitt Peak baseline. The plot shows that the observation was performed with 4 IFs, with 256 spectral channels within each IF. The upper frame shows the phase variation with frequency; within each IF, the small phase slope is caused by a residual delay error. The phase offsets between the IFs can be clearly seen as well. Both the residual delay error and the phase offsets must be determined and removed before the data can be spectrally averaged (see § 9.4.8). *right:* A VPLOT plot of the uncalibrated amplitude (upper frame) and phase (lower frame) as a function of time for the source NRAO150 at 43 GHz on the baseline Kitt Peak to Mauna Kea. Note how the phase varies as a function of time; this variation is equivalent to a residual fringe rate of 8.3 mHz. Unless the fringe rate is determined and removed (see § 9.4.8), the data cannot be averaged in time.

| | |
|---|---|
| > SOURCES '*src1*', '*src2*', '*src3*' CR | to have CLCAL run for each source using the interpolation method given by INTERPOL. Any source here that is not in the CALSOUR list will be phase referenced to the first source in the CALSOUR list. In this example, *src3* is phase referenced to *src1*. |
| > VLBAKRGP CR | to run the procedure. |

VLBAFRNG and VLBAFRGP are identical except there is no OPCODE (it is equivalent to DPARM(8)) and DPARM(4) and DPARM(7) in FRING are the same as CPARM(1) and CPARM(8) in KRING, respectively. Also note the different use of SEARCH in FRING and KRING.

Suitable inputs for the fringe-fitting task FRING are, in detail:

| | |
|---|---|
| > TASK 'FRING' ; INP CR | to review the inputs. |
| > INDISK *n* ; GETN *ctn* CR | to specify the input file. |
| > CALSOUR ' ' CR | to find solutions for all sources. |
| > TIMER 0 CR | to find solutions for all times. |

> DOCALIB 1 C_R — to apply the most complete calibration file including amplitude calibration and IF and channel phase offsets to both the visibilities and the weights.

> GAINUSE 3 C_R — to use CL table 3.

> SNVER 2 C_R — to write solutions into SN table 2.

> BCHAN 0; ECHAN 0 ; CHINC 1 C_R — to use all spectral channels within each IF channel.

> FLAGVER 0 C_R — to apply the most recent flag table.

> SMODEL 0 ; CLR2NAME C_R — to use a point-source at the origin model for the sources, rather than a Clean-component model.

> SOLINT 3 C_R — to set the solution interval in minutes; do not exceed the atmospheric coherence time (see below). Setting SOLINT to 0 sets solution intervals equal to scan lengths.

> SEARCH *ref2*, *ref3*, ... C_R — to specify the order over which antennas are searched for fringes when the exhaustive search is requested. If APARM(9) is set, all antennas will be searched for fringes with SEARCH controlling the order of the search. Note, REFANT should be SEARCH(1). The use of APARM(9) and SEARCH makes FRING much more likely to find fringes to weak antennas and is highly recommended.

> ANTWT 0 C_R — to apply no additional weights to the antennas before doing the solutions. If the amplitude calibration was incorrect, you can use this option to force antenna weights up or down to control the weight FRING gives to data to each station when making the global solutions. Unless the SEARCH option described above is chosen, ANTWT also controls the order in which antennas are tried as secondary reference antennas after failing to find fringes on the REFANT. Give higher weight to antennas you want to see used as secondary references.

> ANTENNAS 0; DOFIT 0 C_R — to allow all antennas to be fit. Only baselines between antennas listed in the ANTENNAS adverb are used in the fringe search. If any antennas are specified in DOFIT however, a solution is made only for those antennas; all other selected antennas are assumed to be already calibrated and are passed through with no additional corrections. See the HELP file for FRING under DOFIT. **DOFIT is only active if APARM(9) is set.**

> REFANT 5 C_R — to choose an antenna that will give fringes for most of the scans. This is important: FRING will search for fringes to this antenna first. If it fails for some reason, it will select another reference antenna, based on the ANTWT data, and, if it still fails, give up (see however the discussion of the new SEARCH adverb above). In this case, you should look for scans with no fringes or a bad reference antenna may be causing the problem. A big, sensitive antenna is often used as REFANT (*e.g.*, Effelsberg). Occasionally, it may be helpful to split your data set up into 2 or 3 sections, which are fringe-fitted with different REFANT (*e.g.*, a "European" and a "US" part of the observations). Changes in reference antenna should, in general, not cause problems.

> APARM(1) 2 C_R — to accept solutions when only 2 antennas are present; default is 6.

> APARM(2) 0 C_R — to have the data divided by the model before fitting fringes; `APARM(2) > 0` tells FRING that the data have already been divided by a model.

> APARM(3) 0 C_R — to treat polarizations separately; `APARM(3) > 0` averages RR and LL.

> APARM(4) 0 C_R — to use the frequencies individually within each IF; `APARM(4) > 0` causes the frequencies within each IF to be averaged before the solution.

> APARM(5) 0 C_R — to do least-squares fits in each IF. APARM(5) $\leq 0$ means to solve separately for the rate, single band delay and phase of each IF. $1.5 >$ APARM(5) $> 0$ means to solve for one single rate and multi-band delay affecting all IFs. If $2.5 >$ APARM(5) $> 1.5$, the task additionally solves for the difference between the multi-band delay and single-band delay, *i.e.*, it allows for a different gradient of phase versus frequency within an IF than between IFs. Note, however, that unlike `APARM(5)=0`, this option assumes that the single-band delay is the same in each IF; it therefore solves for a single value for the difference between multi-band and single-band delay affecting all IFs. Normally users should use `APARM(5)=0` for multi-IF data. Primarily for the EVLA, a fourth option, `APARM(5) = 3` has been added. It solves for one delay in IFs 1 through $N_{\rm IF}/2$ and a second delay in IFs $N_{\rm IF}/2+1$ through $N_{\rm IF}$.

> APARM(6) 1 C_R — to get some useful, but limited, messages, including the SNR.

> APARM(7) 9 C_R — to avoid false detections by setting a moderately high minimum for the SNR accepted. You may wish to use a lower threshold (especially for SVLBI) although `APARM(7)` less than about 3 is probably not useful.

> APARM(8) 0 C_R — to set the maximum number of antennas (if no `AN` table).

> APARM(9) 1 C_R — to enable the exhaustive search mode.

> DPARM(1) 1 C_R — to use one baseline combination in the initial coarse (FFT) fringe search. This provides a starting guess for the least-squares solution. If you are searching for weak fringes you should consider using two and three baseline combinations in the search; this can improve sensitivity in the initial fringe search. See Lecture 19 in *Synthesis Imaging in Radio Astronomy*, edited by R. Perley, F. Schwab, and A. Bridle, for an explanation of how this global multi-baseline searching works. Note that if your source structure is complex and you have not divided the data by an accurate source model, then setting this parameter to one is safest. `DPARM(1)>1` works even when the integration times are not equal.

> DPARM(2) 0 C_R — to set the full width of the delay window in nsec, centered around 0, to search; the default, chosen here, is to use the full Nyquist range defined by the frequency spacing. A smaller search window can permit a lower SNR threshold to be set, but can also result in lost data due to failed fringe searches. For the VLBA, a `DPARM(2) = 1000` window is usually adequate.

> DPARM(3) 0 C_R — to set the full width of the fringe-rate window in mHz, centered around 0; the default, chosen here, is to use the full Nyquist range defined by the integration time. A smaller search window can permit a lower SNR threshold to be set, but can also result in lost data due to failed fringe searches. For the VLBA, a DPARM(3) = 200 window is usually adequate.

> DPARM(4) 2 C_R — to specify the correlator integration time in seconds; use DTSUM to find the correct value. For data from the VLBA correlator, DPARM(4)=0 will cause FRING to determine the correct integration time by examining the data file directly.

> DPARM(5) 0 C_R — to do both the coarse and the least squares solutions; set to 1 if you require only FFT solutions.

> DPARM(6) 1 C_R — to keep, for single-source files, frequencies separated in the output file; the default is to average frequencies within IFs. This parameter does not affect multi-source files.

> DPARM(7) 0 C_R — to re-reference solutions to a common reference antenna; when processing polarization data, set this to 1 to avoid the re-referencing.

> DPARM(8) 0 C_R — to disable the zero'ing options — see the HELP file. *WARNING,* DPARM(8) > 0 *will discard parts of the final solution. Be sure to use this option with extreme care.*

> DPARM(9) 0 C_R — to allow fitting for rate. DPARM(9)> 0, causes the task to suppress rate fitting entirely rather than zeroing it after the fact as in DPARM(8).

> INP C_R — to check the inputs.

> GO C_R — to do the fit — finally.

Note that FRING finds solutions in two steps. First approximate solutions are found in the FFT step using combinations of one, two, or three baselines (see DPARM(1) above). Then, as long as DPARM(5) < 1, a least-squares algorithm uses these approximate values as a starting point for refining the solutions. Especially for weak sources, the least-square solution may wander outside narrow constraints set by DPARM(2) and DPARM(3).

Note that the SOLINT interval should be selected with consideration of the atmospheric coherence time, but must be long enough that high signal-to-noise-ratio solutions are achieved. For observations between 1.6 and 15 GHz, solution intervals of 3–6 minutes (and often longer) should be fine. At other frequencies shorter solution intervals may be required. In these cases, experiment with different length solution intervals on short sections of data. Note that solution intervals greater than the scan length will never be used; the scan lengths are listed in the NX table and may be examined using PRTAB or LISTR with OPTYPE='SCAN'.

If the source is complex, and especially if the visibility phase of the source changes during SOLINT, it is useful to divide the data by a Clean model derived from previous observations or from an earlier attempt at processing the data. This Clean model can be specified by filling in IN2NAME *et al.* Situations where this is useful include observations of equal doubles (where there are zeros in the amplitude and, hence, rapidly changing phases) or very large sources (of order arcseconds). If you are using multi-baseline searching (*i.e.*, DPARM(1) > 1), then solutions may be more sensitive to source structure and an input model may be useful if the structure phases are larger than one radian on many baselines. When using a model, convergence may be improved by weighting the data by $1/\sigma$ rather than $1/\sigma^2$; set WEIGHTIT = 1.

You should check the SNRs found by FRING carefully; they are printed if APARM(6) > 0. The SNRs estimated during the FFT search are used to determine if the SNR of a solution is $\geq$ the threshold set in APARM(7). If they are not, then that solution is flagged before being passed to the more accurate least-squares routine. Users should check that the SNRs found in the LSQ routine match those expected. If the detected SNRs are too low, SOLINT may be too long or too short or other parameters may be set wrongly.

Be warned that proper scaling of the SNRs by FRING depends upon whether or not the data weights have been properly calibrated. Task FIXWT may be used to calibrate the weights, but changing the SNR threshold for FRING directly (APARM(7)) usually produces satisfactory results.

The final delay and rate solutions and their SNRs should be inspected using LISTR:

| | |
|---|---|
| > TASK 'LISTR' ; INP C<sub>R</sub> | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C<sub>R</sub> | to specify the input file. |
| > OPTYPE 'GAIN' C<sub>R</sub> | to list gain solutions. |
| > INEXT 'SN' ; INVER 2 C<sub>R</sub> | to list SN table 2 (as above). |
| > DPARM 6, 0 C<sub>R</sub> | to list delay; use 7 for rate, 1 for phase, and 8 for SNR. |
| > GO C<sub>R</sub> | to run the program. |

Alternatively, the solutions can be plotted against time to make sure they are sensible. Use SNPLT:

| | |
|---|---|
| > TASK 'SNPLT' ; INP C<sub>R</sub> | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C<sub>R</sub> | to specify the input file. |
| > OPTYPE 'RATE' ; DOBLANK 1 C<sub>R</sub> | to plot rate solutions including failed ones, OPTYPE 'DELA' for delay solutions. |
| > OPCODE ' ' C<sub>R</sub> | to plot each polarization and IF in separate plots. |
| > NPLOTS 5 C<sub>R</sub> | to plot five antennas/IFs/polarizations per page. |
| > INEXT 'SN' ; INVER 2 C<sub>R</sub> | to plot SN table 2 (as above). |
| > GO C<sub>R</sub> | to run the program. |

It is a good idea to plot the solutions for OPTYP 'RATE' and 'DELA' (single-band delay) as well as the associated 'SNR's. They should be smoothly varying functions. Delays and rates should be found only within your specified windows. Check for suspicious detections at the limits of the search windows — for instance, they could be detections of side lobes of the main fringe. If you used windows smaller than Nyquist, you may want to check your detections using bigger windows. Gaps in detections with time can occur if, *e.g.*, tapes were bad, antennas were off source, the source visibility is in a minimum, or the reference antenna choice was bad. It pays to investigate such problems at this point before proceeding.

Discrepant SN solutions can be removed using the interactive task SNEDT or the non-interactive task SNSMO. If, in the latter, the CPARM values are set, then the SN solutions will be clipped if they differ from the running mean by amounts which you can specify. If the BPARM values are set, the solutions are then smoothed and clipped entries can be replaced with mean values based on a boxcar- or median-window-filter average. See the explain file for details. Although SNSMO allows the option of modifying the input SN table, it is safest to have it create a new one. If you have a lot of discrepant SN values, you should also consider using option INTERPOL = 'POLY' in task CLCAL (see below).

If there isn't enough disk space to run FRING on all the data at once (because of the large scratch file that FRING insists on creating), you can run FRING multiple times specifying time ranges and explicitly setting SNVER to the same SN table.

If, for some reason, you set the parameters of FRING or SNSMO wrongly and the resulting SN table is unusable, it is wise to avoid confusion by deleting it using EXTDEST and starting over again.

Once a valid SN table has been produced, the next step is to interpolate the solutions found onto the finer grid of entries in a CL table using the task CLCAL with INTERPOL = 'AMBG' as described in § 9.4.1.1.

Once a final CL table is generated, its effect on the data can be viewed using tasks VPLOT and POSSM by setting DOCAL=1 and GAINUSE to the version number of the final CL table; see § 9.3. Optionally, in VPLOT, one can average over spectral channels and/or IF channels before plotting. Use VPLOT to plot a time range

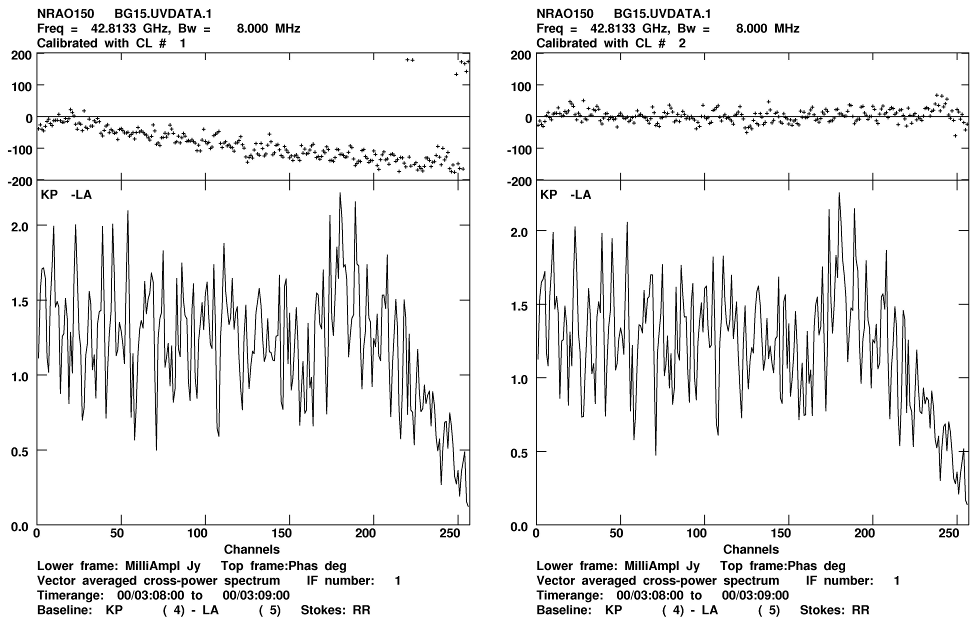



Figure 9.2: *left:* A POSSM plot of the uncalibrated spectrum of NRAO150 at 43 GHz on the baseline Kitt Peak to Los Alamos. The plot shows the spectrum for a single IF to show the effects of the residual delay error more clearly. The phase slope as a function of frequency is clear evidence for a small delay error in the correlator model. *right:* The same data as shown on the left, but corrected for a delay error of -55 nanosec and a residual fringe-rate of -2.0 milliHz. Note how the phase as a function of frequency is now flat and centered around zero degrees. These data can now be averaged in frequency, if desired.

covering a few FRING solution intervals on a strong source. Phase variations should be small with no jumps. If this is not the case, check the inputs to FRING (especially SOLINT) and CLCAL. A comparison of before and after phases is shown in Figure 9.2.

#### 9.4.8.10 Baseline-based fringe-fitting

Baseline-based fringe-fitting, implemented in BLING and BLAPP, is an alternative to using FRING and CLCAL described above. Whereas FRING searches and solves for station rates and delays globally, BLING makes independent fits to each baseline for delays and rates, creating a BS table of baseline-based solutions.

In most cases, the global fringe-fitting described in § 9.4.8.9 should be used since FRING should be able to fringe-fit weaker sources more reliably. However, there are some instances in which baseline-based fringe-fitting is to be preferred. Note that FRING may be used to do baseline-based fringe-fitting by running it many times, each time specifying only 2 antennas. BLING has not been actively maintained or used, and so may be less reliable. Amongst the advantages of the baseline-based fringe-fitting are:

1. BLING may be more robust than FRING even in the absence of an accurate source structure model.
2. Fringe solutions can be found for cross-polarized fringes without editing the *uv* header.
3. As presently implemented, for a given number of IF and spectral channels, BLING can solve for longer scans than can FRING.
4. BLING has the option of adjustable, non-zero centered fringe-search windows, which can be controlled from an external file. This option may be important in fringe-fitting Space VLBI data.

BLING is distinguished from FRING by the ability to directly control the fringe search on each separate baseline, and by the ability to solve for fringe acceleration if required. Separate fringe windows in delay, rate and acceleration, and different solution intervals can be set for each individual baseline. The fringe windows may have non-zero offsets and can be specified using the input adverbs or, more flexibly, by drawing up an external ASCII control file of fringe-prediction windows and BLING control parameters. The latter option allows the specification of time-variable fringe-search parameters across the observing file. The general algorithm follows that described by Alef and Porcas, 1986, (*Astron. Astrophys.*, **168**, 365); BLING also allows the stacking of data from different baselines, as discussed by Schwab and Cotton, 1983, *Astron. J.*, **88**, 688. In addition, model division is possible before the fringe-fitting is performed and cross-polarized fringe searches can also be conducted without editing the *uv* header. BLING writes the results to a BS table. These baseline-based solutions can be converted into antenna-based corrections using the separate task BLAPP and then applied to the data.

Acceleration may be solved for by conducting a coarse search in the specified acceleration window. The results of this search are then interpolated to estimate the final solution. Fringe acceleration searches can considerably increase the amount of CPU time it takes to run BLING. Therefore, you may wish to turn off the acceleration search (DPARM(7) to DPARM(9)) unless you need it for space VLBI.

Full details concerning BLING input parameters can be found by typing EXPLAIN BLING. This includes information concerning the format required for the external control file. Earlier versions of BLING are discussed in *AIPS* Memo 89 (1994, "Baseline-Oriented Fringe Searches in *AIPS*" by Chris Flatters). Typical input parameters to BLING are given below:

| | |
|---|---|
| > TASK 'BLING' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > CALSOUR 'DA193', ' ' C_R | to specify the calibrator source. |
| > STOKES 'LL' C_R | to select the Stokes. |
| > TIMERANG 0, 10, 5, 0, 0, 11, 0, 0 C_R | to limit the time range. |
| > ANTENNAS 3 ; BASELINE 0 C_R | to select all baselines to antenna 3. |
| > SUBARRAY 1 C_R | to use subarray 1. |
| > FREQID 1 ; BIF 1 ; EIF 0 | to use frequency ID 1 with all IFs. |
| > BCHAN 1 ; ECHAN 0 C_R | to use all spectral channels. |
| > DOCAL 1 ; GAINUSE *clin* C_R | to apply amplitude calibration before fringe fitting. |
| > CLR2N ; NMAPS 0 C_R | to do no model division. |
| > SOLINT 0.5 C_R | to use a 30-second fringe solution interval. |
| > INFILE ' ' C_R | to use the adverbs rather than an external control file. |
| > APARM(1) 2 ; APARM(2) 0 C_R | to set the integration time; no model division. |
| > APARM(3) 0 C_R | to do no stacking of baselines. |
| > APARM(4) 0 ; APARM(5) 0 C_R | to set minimum acceptable SNR to 5 and accept coherence of 20% |
| > DPARM 0 C_R | to use the default fringe windows and no acceleration search. |
| > DOUVCOMP 1 C_R | to use compressed scratch files. |
| > BADDISK 0 | to use all disks for scratch files. |
| > GO C_R | to run the program. |

Note that baseline-stacking (APARM(3)) is not implemented for data sets with unequal integration times. Also, note that the fringe-rejection criteria specified using APARM(4) and APARM(5) are important parameters. The use of compressed scratch files is recommended and is not believed to have a significant impact on precision. Note, if model division is required, APARM(2) should be set and the source should be entered explicitly.

BLING will execute with a summary line marking the start of each baseline processed. The resulting BS table can be examined using task BSPRT, with input parameters:

| | |
|---|---|
| > TASK 'BSPRT' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > INVERS *bsin* C_R | to specify the BS table version number. |
| > DOCRT -1 C_R | to send output to an external file. |
| > OUTPRINT 'FITS:BSPRT.LIS' C_R | to define the output file name. |
| > GO C_R | to run the program. |

For printing to the screen, select DOCRT=1.

The BS table output includes the estimated fringe parameters and their associated errors. Note that due to changes in FFT interpolation the errors may be an overestimate. The BLING solutions are interpolated and factorized into antenna-based gain solutions using BLAPP. This task either writes a solution (SN) table which can be applied using CLCAL, or allows a CL table to be updated with the calibration information directly. These options are selected using OPCODE='SOLV' or OPCODE='CAL' respectively. BLAPP can interpolate solutions with unequal time sampling and includes the acceleration term in interpolation if it is available. Typical inputs to BLAPP are:

| | |
|---|---|
| > TASK 'BLAPP' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > INVERS *bsin* C_R | to specify the input BS table version number. |
| > SOURCES ' ' ; STOKES 'LL' C_R | to do all sources and a specific Stokes. |
| > FREQID 1 C_R | to select frequency ID 1. |
| > TIMERANG 0 ; ANTENNAS 0 C_R | to do all times and antennas. |
| > SUBARRAY 1 ; REFANT 3 C_R | to do subarray 1 with reference antenna 3. |
| > ANTWT 0 C_R | to use equal antenna weights. |
| > OPCODE 'SOLV' C_R | to solve for a SN table. |
| > GAINVER clin C_R | to specify the input CL table which defines the times for which solutions are desired. |
| > BADDISK 0 C_R | to use all disks for scratch files. |
| > GO C_R | to run the program. |

The resulting solution (SN) table can be plotted using SNPLT in the standard fashion. For OPCODE='CAL' the output CL table also needs to be specified using GAINUSE. If an SN table is generated, it can be smoothed or clipped using task SNSMO and applied using CLCAL as described in § 9.4.1.1.

#### 9.4.8.11 SVLBI-specific techniques

An alternative approach to direct fringe detection of each individual baseline to the orbiting antenna is to first calibrate the ground array using conventional fringe-fitting techniques, then coherently combine all ground antennas to improve the fringe detection sensitivity to the spacecraft. Several incarnations of this approach exist within AIPS. The AIPS tasks FRING, BLING, and KRING all allow baseline stacking which can be used to fringe fit the space baseline using composite baselines. It was shown in VLBA Scientific Memo No. 13 (1996, "Global ground VLBI network as a tied array for space VLBI", by L. Kogan) that the method of phasing a group of ground-based antennas and the method using global fringe fitting with baseline stacking give the same minimum detectable flux density. Therefore, baseline stacking with DPARM(1)=3 in FRING should yield the best possible sensitivity. There are other options which also may be explored. The adverb DOFIT in FRING and KRING can be used to solve for subsets of the available antennas in order to find good solutions for the ground antennas in a dual round of fringe-fitting. The exhaustive baseline search mode, used by default in BLING and KRING and activated in FRING by setting APARM(9)=1, allows more baselines to the spacecraft to be searched.

#### 9.4.8.12 Spectral-line fringe-fitting

The determination of the delay and fringe-rate calibration is a two- or three-step process for spectral-line VLBI data. First, the residual delay and fringe-rates are estimated for each antenna from the continuum calibrators. Then, residual fringe-rates must be determined again for the line source using a "strong" channel or range of channels. As an intermediate step, the phases of the line source should be examined to check that the calibrator's residual fringe-rates haven't destroyed phase coherence; if so, then the calibrator's residual fringe-rates should not be applied to the line source.

If computer memory is limited, FRING must trade off the number of spectral channels against the length of the solution interval. For continuum calibrators in a spectral-line dataset, the large number of spectral channels may force FRING to require too short a solution interval. (FRING now allocates memory dynamically and may be able to handle large cases so long as the computer is adequately equipped with real and swap memory.) This limit can be overcome by running UVCOP to extract the continuum calibrators into a separate data file and then running AVSPC with AVOPTION 'SUBS' to average spectral channels coherently within each IF. INDXR should be run to regenerate an NX table. FRING will then allow more reasonable solution intervals.

Run FRING as follows only on the continuum calibrators to determine residual delays and fringe-rates:

| | |
|---|---|
| > TASK 'FRING' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > CALSOUR 'BLLAC','DA193' C_R | to select continuum calibrator sources. |
| > DOCALIB 1 C_R | to apply the current calibration. |
| > GAINUSE *clin* | to specify which CL table to use. |
| > SMODEL 0 C_R | to use the null source model (points at the origin). |
| > FLAGVER 0 C_R | to apply the most recent flag table. |
| > BCHAN 10 ; ECHAN 115 C_R | to exclude the edges of the band; normally the data in these channels are corrupted by the bandpass filters. |
| > REFANT 5 C_R | to select a reference antenna (see continuum discussion). |
| > SOLINT 6 C_R | to set the solution interval in minutes. It should not exceed the coherence time. |
| > APARM(6) 1 C_R | to get some useful, but limited, printout; gives SNR. |
| > APARM(7) 7 C_R | to avoid false detections by setting the minimum acceptable SNR. *Warning:* solutions with lower SNR will be flagged as bad which will ultimately flag the affected data. |
| > DPARM(1) 1 C_R | to use one-baseline combination in initial, coarse fringe search (FFT). This provides starting points for the least-squares solutions. |
| > DPARM(2) 10000 C_R | to select a delay window in nsec, centered around 0(!). The default is to use the Nyquist range. For a 250kHz-bandwidth observation, setting this value to 10000 nsec is equivalent to setting the search window to 5 delay channels, which is usually sufficient. |
| > DPARM(3) 200 C_R | to select a fringe-rate window in mHz. |
| > DPARM(4)= 1 C_R | to tell FRING the correlator integration time. |
| > DPARM(5) 0 C_R | to do the least-squares solution. |
| > SNVER 0 C_R | to write solutions in a new SN table. |
| > GO C_R | to do the fit. |

If the calibrators had been extracted to a separate data set, use TACOP to copy the resultant SN table back to the line data set. In 31DEC09. SNCOP may be used when the number of IFs in the two data sets is different.

This is more likely to arise when you use a strong line signal in one IF to solve for the delays of a larger data set.

Run CLCAL to apply the delay and fringe-rate solutions to all sources, as is described in § 9.4.1.1, and then carefully examine the phase coherence of the line source in a suitable line channel (or group of channels) using POSSM or COHER before and after applying the new CL table. It may be that the fringe-rate solutions have made the phase coherence worse. In this case, you must run SNCOR using the 'ZRAT' option to zero the fringe-rates and then re-run CLCAL.

After this point, the calibrator data is usually of little or no interest. But, if you do plan to use the calibrator data further, remember to be careful to juggle the SN and CL tables correctly. Even if you decide not to apply the calibrator fringe-rates to the line-source, they are still applicable for the calibrator itself. The CL table created using the un'ZRAT'-ed SN table contains the proper corrections for the calibrator data while the CL table created using the 'ZRAT'-ed SN table contains the proper corrections for the line source.

Now re-run FRING to determine the residual fringe-rates for the line source, this time selecting a suitable line channel or group of channels:

| | |
|---|---|
| > TASK 'FRING' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > CALSOUR 'OH127.8' , ' ' C_R | to select the spectral-line source. |
| > DOCALIB 1 C_R | to apply the previous amplitude and delay/rate calibration. |
| > GAINUSE *clin* | to specify which CL table to use. |
| > FLAGVER 0 C_R | to apply the most recent flag table. |
| > SNVER 0 C_R | to write a new solution table. |
| > BCHAN 72 ; ECHAN 72 C_R | to select the strongest and/or simplest spectral channel as a reference. |
| > REFANT 5 C_R | to try to use the same reference antenna as in the previous run of FRING. |
| > SOLINT 6 C_R | to set the solution interval in minutes. It should not exceed the coherence time. |
| > APARM(6) 1 C_R | to get useful, but limited printout. |
| > APARM(7) 9 C_R | to avoid false detections by setting the minimum acceptable SNR. *Warning:* solutions with lower SNR will be flagged as bad which will ultimately flag the affected data. |
| > DPARM(1) 1 C_R | to use one-baseline combination in initial, coarse fringe search (FFT). |
| > DPARM(2) = -1 C_R | to prohibit a search in the delay domain by setting the delay window to a negative number. Remember setting this to 0 means to use the Nyquist value, which is not what we want. |
| > DPARM(3) 0 C_R | to search for fringes over the full Nyquist fringe-rate window since we don't know where the fringes are. |
| > DPARM(4)= 0 C_R | to let FRING automatically determine the correlator integration time (if this fails, you will have to set the proper value here — see DTSUM). |
| > DPARM(5) 0 C_R | to do the least-squares solution. |
| > GO C_R | to do the fit. |

Then run CLCAL again to apply these solutions to the previous calibration tables. You have then generated a full set of calibration tables and data. Remember that the calibration information for the continuum and line sources are stored in different CL tables.

#### 9.4.8.13 Polarization-specific fringe-fitting

The phase and delay corrections obtained using RR and LL data can only remove R-R and L-L offsets between different antennas. There still may be R-L phase and multi- and single-band delay offsets. The R-L delay corrections can be determined using the RL and LR data and a task named RLDLY is available for determining these effects. This still leaves an overall R-L phase offset.

Once the cross-hand calibration has been completed, the instrumental polarization (otherwise known as the feed D-terms), can be determined. Several different methods are available for this purpose, implemented in the tasks PCAL, LPCAL and SPCAL. The last task is designed for polarization calibration of spectral-line data sets, but PCAL is now fully capable of doing a channel-dependent polarization solution. PCAL is discussed briefly below and further details for each of these tasks can be found in the appropriate EXPLAIN files.

The determination of the absolute polarization position angle is equivalent to the determination of the absolute R-L phase difference. For an unresolved source this can be measured in much the same way as for VLA data (see § 4.6) using task RLDIF to determine the cross-polarized phase on the polarization calibrator. Alternatively, a source with known polarization properties can be used, *e.g.*, 3C286 or 3C279. For a resolved polarization calibrator a sum of Clean components is required to compare to the integrated polarization position angle as measured by the VLA or single-dish observations nearby in time. Once the R-L phase correction is known it is applied using task CLCOR with OPCODE='POLR' or task RLCOR (see § 4.6). See also VLBA Scientific Memo No. 26, "Polarization Angle Calibration Using the VLA Monitoring Program," by G. Taylor and S. Myers, October, 2000.

After feed calibration and the determination of the absolute polarization position angle, the final Stokes Q and U images can be formed directly. Note that task PCNTR, which is used for displaying polarization images, allows an arbitrary rotation of all polarization vectors under control of input adverb ROTATE. This is only necessary if CLCOR wasn't used to correct the R-L phase; also the polarization angle specified for PCNTR is half the R-L phase difference.

#### 9.4.8.14 R-L delay calibration

RLDLY is a task which replaces RUN file procedures VLBACPOL and CROSSPOL. It determines R-L delay differences and produces a CL table which corrects for these effects. It is best run on a set of calibrator data for which the source is at least moderately polarized (source polarization dominates instrumental polarization). Several baselines should be averaged but RL or LR fringes (or both) must be detectable on each baseline to the reference antenna. This task should leave a single R-L phase difference that must be determined from a calibrator of known polarization angle.

| | |
|---|---|
| > DEFAULT RLDLY ; INP CR | to set the task name and examine the inputs. |
| > INDISK *n* ; GETN *ctn* CR | to specify the input file. |
| > OUTDI 1 CR | to use disk 1 for temporary files. |
| > FLAGVER 0 CR | to use the highest numbered flag table. |
| > GAINUSE *CLin* CR | to use the CL table with all calibration up to this point; *no default*. |
| > SUBARRAY 0 CR | to do all subarrays. |
| > BASELINE 0 CR | to use all antennas. |
| > REFANT $A_{\rm ref}$ CR | to select the reference antenna; any antenna may be used but all baselines to it should have RL and LR fringes. |
| > CALSOUR '*cal1*' , ' ' CR | to specify the calibrator source to use. |
| > TIMERANGE *d1 h1 m1 s1 d2 h2 m2 s2* CR | to specify a time range with high SNR for RL and LR. |

| | |
|---|---|
| > SOLINT 0 C_R | to specify the minimum integration time in seconds; 0 causes it to be found from the data. |
| > GO C_R | to run the task. |

RLDLY should be done after parallel-hand instrumental delays are removed (VLBAPCOR). It may be done before or, with a slight preference, after fringe fitting (VLBAFRNG, VLBAKRNG, VLBAFRGP, or VLBAKRGP). The corrections should be checked with VLBACRPL, by setting STOKES to 'RL' and/or 'LR'. The RL and LR phases should be continuous across the bandpass on each baseline and be flat if the RR and LL phases are flat (no residual delays).

#### 9.4.8.15 Feed D-term calibration

The feed D-terms, or instrumental polarization terms, can be determined using PCAL. SOLTYPEs 'ORI-' and 'RAPR' are appropriate for VLBI data. 'ORI-' uses a non-linear orientation-ellipticity feed model and is appropriate if instrumental polarization exceeds a few percent (*e.g.*, EVN, or VLBA at 18 or 13 cm). 'RAPR' uses a linearized "D-term" model — this is faster but less accurate.

Typical inputs for PCAL would be:

| | |
|---|---|
| > TASK 'PCAL' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > CALSOUR 'DA193' , ' ' C_R | to select the source. |
| > TIMERANG 0 C_R | to use all times. |
| > SELBAND 0; SELFREQ 0; FREQID -1 C_R | to select all frequencies. |
| > BIF 0; EIF 0 C_R | to select all IFs. |
| > ANTENNAS 0; UVRANGE 0 C_R | to select all antennas and baselines. |
| > SUBARRAY 0 C_R | to select all subarrays. |
| > FLAGVER 0 C_R | to apply the most recent flag table. |
| > DOCALIB 1 C_R | to apply the previous amplitude and delay/rate calibration. |
| > GAINUSE *clin* | to specify which CL table to use. |
| > IN2DISK *n*; GET2N *ctn* C_R | to specify Clean images as models for the I, Q, and U polarizations. |
| > INVERS 1 C_R | to select a CC table version. |
| > REFANT 1 C_R | to use the same reference antenna as in the previous run of CALIB. |
| > NCOMP 77; NMAPS 1 C_R | to specify the number of Clean components to use and to explicitly set the number of Clean images supplied. |
| > SOLINT 6 C_R | to set the solution interval in minutes. It should not exceed the coherence time. |
| > SOLTYPE 'RAPR' C_R | to specify the type of feed model. |
| > PRTLEV 0 C_R | to print minimal information |
| > BPARM(1) 0 C_R | to use the initial feed model if found in the AN table. |
| > BPARM(3) 0 C_R | to not fit for R-L phase difference. |
| > BPARM(4) 0 C_R | to not specify the initial R-L phase. |
| > BPARM(5) 0 C_R | to not solve for Vpol. |
| > BPARM(6) 0; BPARM(7) 0 C_R | to solve for the orientations of both polarizations of the reference antenna. |
| > BPARM(8) 0 C_R | to solve for all orientations. |
| > BPARM(9) 0 C_R | to solve for all ellipticities. |

| | |
|---|---|
| > BPARM(10) 0 C_R | to fit for the source polarization model parameters. |
| > CPARM(1) 0 C_R | to find separate solutions for each IF. |
| > CPARM(8) 0 C_R | to not limit the number of iterations. |
| > CPARM(9) 0 C_R | to use the default convergence tolerance. |
| > CPARM(10) 0 C_R | to use default convergence criterion. |
| > BADDISK 0 C_R | to specify which disks to avoid for scratch. |
| > GO C_R | to run the program. |

The instrumental polarization may vary rapidly with frequency and independent solutions may be necessary in each IF. Both 'ORI-' and 'RAPR' model the source Q and U as scaled versions of I which is generally only true in the limit of unresolved or unpolarized sources. The D-terms can be determined iteratively by subtracting estimates of source polarization (Q, U Clean components) in UVSUB. Note: this should be done on data for which instrumental polarization corrections have *not* been applied.

Tasks LPCAL and SPCAL also can be used to compute D-term corrections for continuum and spectral-line polarization data respectively. Be forewarned that both of these tasks use linearized D-term models.

### 9.4.9 Complex Bandpass

For spectral line experiments and continuum observations where a high dynamic range is required, it is be a good idea to do a complex bandpass at this point. In § 9.4.5 a scalar bandpass was done; *i.e.*, only the amplitude was calibrated but not the phase. Now that the phases have been calibrated in time (by fringe-fitting), a complex bandpass may be solved for. This will take out any dependence of the phase on frequency. To do this, run BPASS, again applying the CL table that includes all the calibration. With the inputs we recommend here, the phases *must be stable in time over the entire bandpass calibrator scan(s).* Check this with VPLOT before proceeding. Then

| | |
|---|---|
| > TASK 'BPASS' ; INP C_R | to review the inputs. |
| > INDISK *n1* ; GETN *ctn1* C_R | to select the multi-source visibility data as the input file. |
| > CALSOUR 'BLLAC' , 'DA193' C_R | to specify the continuum source(s) which were observed for the purpose of bandpass calibration. |
| > DOCALIB 1 C_R | to apply calibration. |
| > GAINUSE *CLin* C_R | to indicate the CL table with all calibration up to this point. |
| > BPVER -1 C_R | do not apply previous bandpass table |
| > SOLINT 0 C_R | to average data over whole scans before determining the bandpass. |
| > BPASSPRM 0 C_R | to do a complex bandpass and set rest to 0. |
| > BPASSPRM(5) 1 C_R | to not divide by "channel 0." |
| > BPASSPRM(9) 1 C_R | to interpolate over flagged channels. |
| > BPASSPRM(10) 4 C_R | to normalize the amplitude and phase of the bandpass solutions. |
| > GO C_R | to run the program. |

As recommended in § 9.4.5, you should look at the bandpass with POSSM. This is the bandpass that should be applied when the data is calibrated and averaged (*e.g.*, with SPLIT).

Note, if your bandpass calibrator is not stable or strong enough during the observation (your bandpass calibrator data should have a better S/N than the data you're trying to correct with the bandpass), you could consider using the phase reference source (if there is one) and use SOLINT = -1 (include all scans to make one bandpass solution). If the bandpass calibrator is strong enough, but the average phase varies through the scan, then divide each record by "channel 0" by setting BPASSPRM(5) = 0. You should select a range of channels that have similar phases to be averaged as channel 0 using adverb ICHANSEL.

### 9.4.10 Baseline-based errors

Baseline-based non-closing phase and amplitude errors can limit the dynamic range of the final images. One way to proceed is to try to solve directly for the non-closing effects using bright, point-like calibrator observations and the task BLCAL. This task writes a BL table containing the estimated non-closing baseline-based errors which can later be applied in SPLIT, or any of the other calibration tasks. To use BLCAL the noise in the calibrator-source images should approach the theoretical limit. Furthermore, the signal-to-noise ratio in the visibility data must be at least 100:1 on baseline-averaged data. BLCAL will divide your data by your best model and then write a BL table containing the baseline-based corrections. Use this task carefully only after reading the EXPLAIN file thoroughly. As an example:

| | |
|---|---|
| > TASK 'BLCAL' ; INP C_R | to review the inputs. |
| > INDISK *n1* ; GETN *ctn1* C_R | to select the multi-source visibility data as the input file. |
| > IN2DISK *n2* ; GET2N *ctn2* C_R | to select your best image as the input model file. |
| > SOURCE 'DA193' C_R | to select your calibration source. |
| > DOCALIB 1 ; GAINUSE *clin* C_R | to select the CL table to use. |
| > BLVER 1 C_R | to create BL table version 1. |
| > SOLINT 1440 C_R | to determine one complex gain correction per baseline for the whole observation. |
| > GO C_R | to run the program. |

Set ICHANSEL to select only the most desirable spectral channels to average. In 31DEC09, an experimental task BLCHN is available to compute baseline-based errors on a channel-by-channel basis. It writes a BD table which can be plotted by POSSM and BPLOT, but the calibration itself is applied only in the output file produced by BLCHN.

## 9.5 After initial calibration

### 9.5.1 Applying calibration

Having obtained your best possible calibration CL table (and BP and BL tables if bandpass or baseline-dependent errors were found), you finally get to make a calibrated data set. This is done with SPLIT, which applies the calibration and splits the database into separate files, one for each source observed.

| | |
|---|---|
| > TASK 'SPLIT' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input file. |
| > SOURCE ' ' C_R | to write all sources. |
| > DOCALIB 1 ; GAINUSE clin C_R | to specify which CL table to use. |
| > DOBAND 1; BPVER 1 C_R | to apply BP table 1 if present. |
| > BLVER *blin* C_R | to apply BL table *blin* if present. |
| > APARM(1) 1 ; NCHAV 0 C_R | to have all spectral channels within each IF averaged: read the help file closely, other useful averaging options are available. |
| > APARM(2) 2 C_R | to have an amplitude correction made for the correlator integration time (in seconds) |
| > GO C_R | to run the program. |

The options for SPLIT given above will apply calibration and then average the spectral channels within each IF, but not average IF channels together . To average over IF channels as well, set APARM(1) = 3 in SPLIT. (The task AVSPC no longer averages IFs although it is useful in averaging spectral channels in calibrated data sets.)

The task SPLAT can be used instead of SPLIT to do time averaging and different options in spectral averaging. SPLAT can be used also to assemble the selected sources into a multi-source file after applying the specified calibration and averaging. This option allows the user to continue calibration on a smaller data set.

At this point, it is well worth spending time to examine your output visibility data carefully. You may plot the data against time with VPLOT, IBLED, EDITR, or UVPLT, and list them with LISTR, PRTUV, or UVPRT. POSSM is now no longer useful since you have averaged your data in frequency.

### 9.5.2 Time averaging

It is now convenient to average the data in time using UVAVG both to reduce the bulk of the data and to increase the signal-to-noise for subsequent iterations of the self-calibration/imaging cycle. However, it is important to realize that the fringe-fitting process to this point has only removed gradients of phase over the fringe-fitting solution interval. There will still be stochastic atmospheric (and clock) phase errors affecting the data on short time scales. These phase errors can be significant over minutes at frequencies of 22 GHz and above (and possibly even at 15 GHz) and a reduction in amplitude can occur if data are directly averaged. The ionosphere can cause similar problems at lower frequencies. Self-calibration should remove such phase errors.

For data at frequencies below 15 GHz (and ≈ minute integrations), it should be safe to proceed with UVAVG (see below). For higher frequency data, it may be worth your while to examine the phase coherence of the data first. VPLOT can be used to examine your target or calibrator data to see directly the level of residual phase error over your chosen averaging time. Alternatively, the task IBLED allows you to view the degree of coherence of data averaged over different averaging times. If there are coherence problems (and the target data has enough SNR), CALIB can be run to align the phases prior to coherent averaging. Try:

| | |
|---|---|
| > TASK 'CALIB' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the single-source input file. |
| > OUTNA INNA ; OUTCL 'ALIGN' C_R | to specify the output file. |
| > CALSOUR ' ' ; SMODEL 1, 0 C_R | to use the source with a point-source model. |
| > DOCALIB -1 ; GAINUSE 0 C_R | to not apply any tables to the input data. |
| > SOLTYPE ' ' C_R | to use normal least squares. |
| > SOLMODE 'P' C_R | to solve for phase. |
| > SOLINT (10.0/60.0) C_R | to solve for phase in 10-second intervals. This should probably be set as low as the strength of the source will allow. The limit is the integration time that gives a SNR > 2 on most baselines. |
| > ANTWT 1 C_R | to use weights from calibration with no additional weights applied to the antennas. For the purposes of phase alignment, it is appropriate to use the data weights; this allows the noise in the solution to be distributed over the noisiest baselines. This may not be the case when using CALIB for self-calibration in the hybrid mapping sense (see § 9.6). |
| > APARM(1) 3 C_R | to require 3 antennas present for solution. |
| > APARM(6) 0 C_R | to skip diagnostic printout. |

| | |
|---|---|
| > APARM(7) 1 C_R | to set the minimum allowed SNR. This limit should be low since the SNR is calculated as a phase difference from model and this can be large. Start with a value $\leq 1$. |
| > GO C_R | to run the program. |

Note that CALIB will only give valid solutions if the signal-to-noise over the solution interval on most baselines is greater than 2 (and preferably much higher). At high frequencies on weak sources, it may not be possible to select a solution interval long enough that the signal-to-noise satisfies this criterion, yet short enough to follow the atmospheric phase variations. In such cases, it is probably best not to attempt to self-calibrate the data, but instead to use a short averaging time and to live with any coherence losses in the data.

When the data are sufficiently phase coherent, they should be averaged over time down to a reasonable size using UVAVG:

| | |
|---|---|
| > TASK 'UVAVG' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the CALIB output file as the UVAVG input file. |
| > OUTNA INNA ; OUTCL 'UVAVG' C_R | to specify the output file. |
| > YINC 30.0 C_R | to set the time-averaging interval to 30 seconds. |
| > OPCODE ' ' C_R | to enable the averaging operation. There are several options controlling the averaging interval selection and reported times. |
| > GO C_R | to run UVAVG. |

If SPLAT was used to assemble the selected sources into a multi-source file (while applying the preliminary calibration), CALIB will write an SN table which must be converted to a CL table by CLCAL. This new CL table can be applied by SPLAT with time averaging.

### 9.5.3 Verifying calibration

Before proceeding to image your data, it's worth checking that the calibration performed in § 9.4 is sensible. For each of your sources, produce a plot of the correlated flux density against *uv* distance using UVPLT. As well as identifying bad data which can then be deleted with IBLED, EDITR, WIPER, or UVFLG, these amplitude versus distances plots (especially those of your calibrator sources) can be used to identify stations where the amplitudes are too high or too low. Furthermore, by fitting simple models to the calibrator data, constant correction factors can be determined for each station which can be used to correct the amplitude calibration. It is often the case that the amplitude calibration to a certain station (particularly non-VLBA stations) is out by a constant factor, either due to uncertainties in the antenna gain or in the noise calibration signal.

Most VLBI calibrator sources can be adequately described by one or two Gaussian components. The task UVFIT can be used to fit such a model while finding constant correction factors for the antenna gains. Note that UVFIT can handle no more than 250,000 visibilities, so further averaging with UVAVG may be required. The following example shows how to fit antenna gains and a single elliptical Gaussian model of known position and flux to one of the single-source data sets produced by SPLIT or SPLAT (with spectral averaging)

| | |
|---|---|
| > TASK 'UVFIT' ; INP C_R | to review the inputs. |
| > INDISK *n* ; GETN *ctn* C_R | to specify the input *uv* data set. |
| > OPCODE 'GAUS' ; NGAUS 1 C_R | to specify 1 Gaussian component. |
| > GMAX 1.2 ; DOMAX FALSE C_R | to fix the flux at 1.2 Jy. |
| > GPOS 0 ; DOPOS FALSE C_R | to hold the position fixed at the origin. |
| > GWIDTH 0.002 , 0.001 , 45. C_R | to provide an initial guess of the Gaussian widths as $2 \times 1$ mas at a position angle of 45 deg. |
| > DOWIDTH TRUE C_R | to fit for size. |
| > GAINERR 1 C_R | to fit for all antenna gains with initial guess = 1. |

| | |
|---|---|
| > NITER 50 C_R | to limit the fitting to 50 iterations. |
| > IMSIZE 0.0005 , 0.01 C_R | to limit sizes to be in the range 0.5 to 10 mas. |
| > DOCAT TRUE ; INVER 1 C_R | to save the solution in a CC file of version number 1. |
| > INP C_R | to check the inputs. |
| > GO C_R | to run UVFIT. |

UVFIT can also be applied to the multi-source file, but SOURCE, DOCAL, GAINUSE etc. must then be set.

Another way to test your amplitude calibration is to use the task UVCRS for bright sources with long tracks. This task calculates correction factors for the amplitudes of the stations using regions of the *uv* plane where *uv* tracks cross. UVCRS can write the correction factors into an SN table.

Once the scale factors are determined, there are a number of options for correcting the data. The simplest option is to apply the correction factors to the single-source data sets using task VBCAL. Alternatively, the correction factors can be incorporated into the highest version CL table of the multi-source data file and task SPLIT run again to make new calibrated data files. The corrections to the CL table are done with CLCOR. Unlike VBCAL, CLCOR must be run separately for each antenna whose calibration you wish to alter; ANTENNA must be set to the antenna number you wish to change, OPCODE = 'GAIN', and CLCORPRM(1) set to the square of the amplitude scale factor found in UVFIT; all higher values in the array CLCORPRM should be zero. The effect of the altered calibration can be viewed using UVPLT with DOCAL = 1. If it is satisfactory, SPLIT can be re-applied to the data. We recommend using CLCOR to perform such amplitude corrections. It now produces a new CL table each time it is used unless you specify both GAINVER and GAINUSE as having the same, non-zero version number.

Another way of incorporating amplitude corrections is to edit the calibration text files used by ANTAB. This can be accomplished by setting the FT parameters for affected stations. For instance, if the Bonn scale factor is 1.043, set the FT parameter on the BONN TSYS card to FT=(1.043*1.043). If amplitude calibration was carried out *after* fringe-fitting (*not recommended!*, then it is only necessary to rerun ANTAB, delete the latest CL table containing amplitude calibration and rerun APCAL using the highest CL table produced in the fringe-fitting step. If however, as we have described in this chapter, the amplitude calibration was done prior to fringe-fitting, then correcting the amplitudes is more involved. It is probably best to delete all CL tables except the first one and start again at § 9.4. However, it may not be necessary to carry out the time consuming FRING solutions again. If the amplitude changes are small, the phase, rate and delay solutions will be essentially unchanged. Therefore, with care, the existing SN tables can be used in lieu of re-running FRING.

## 9.6 Self-calibration, imaging, and model-fitting

We are now in a position to make images. As with VLA data, we do this by iteratively self-calibrating the data and deconvolving using Clean, MEM *et al.* We describe below a typical self-calibration and imaging sequence for VLBI data. The tasks used are described in more detail in Chapter 5.

1. CALIB self-calibrates the *uv* data.
2. IMAGR images and Cleans. IMAGR is now the preferred task for imaging VLBI data in AIPS.
3. SCMAP images, Cleans, and self-calibrates. SCMAP is meant to provide the functionality of the popular VLBI data analysis package difmap. SCIMG is a multi-field version of SCMAP.

The main difference between the processing of VLBI and VLA data is that, initially, absolute phases of VLBI data are un-calibrated (unless phase-referencing is used). Therefore, many more iterations around the imaging loop are required for the VLBI case; dozens of self-calibration iterations are not uncommon. Given this, it may be convenient to use the procedure HYB which executes a whole cycle of hybrid mapping (*i.e.*, an IMAGR plus CALIB). It also plots images and allows editing of Clean component files prior to self-calibration. Type HELP HYB C_R for more information. Note that it does not use the superior imaging algorithms available in IMAGR, SCMAP, and SCIMG.

Note that VLBI imaging is not an exact science and there are a number of different views on the "correct" imaging method and the "correct" software to accomplish this method. Some users take their AIPS data into a package written at CalTech to use the `difmap` program (see `ftp://phobos.caltech.edu/pub/difmap/`). Others use the AIPS tasks SCMAP and SCIMG (see § 5.4), while still others follow the older HYB path. It is beyond the scope of this document to explain in detail all aspects of VLBI imaging. For more details, see Craig Walker's chapter on "Practical VLBI Imaging" in the publication *VLBI and the VLBA*, **1995**, edited by A. Zensus, P.J. Diamond, and P.J. Napier which is available on the World-Wide Web (www.cv.nrao.edu/vlbabook). Here we make a few suggestions on how to control CALIB and IMAGR. Again, please note that the latter is preferable to all previous imaging tasks; SCIMG and to a lesser extent SCMAP offer the same improved imaging techniques. They do not offer several experimental algorithms found in IMAGR including Clean component filtering, the SDI Clean algorithm, and multi-resolution Cleaning.

### 9.6.1 CALIB

1. Start by correcting antenna phases only, *i.e.*, use SOLMODE = 'P' C_R. Switch on the amplitude correction only after you have converged to a fairly good image. On the first iteration, you will need to invent an input model. For most extragalactic continuum sources, a point-source model is a good choice. Set SMODEL(1) to the zero-spacing flux density as extrapolated by eye using UVPLT and consider using a circular Gaussian model at the origin to reduce the impact of the longest spacings. Start with the so-called SNR parameter APARM(7) small ($\leq 1$) and gradually increase it as the image improves. If this parameter is large during early iterations, when the model used is far from correct, then large portions of your data in the output file may be flagged. This is not too important if you use the original input *uv* file as the input to CALIB in all iterations. You can also set APARM(9) = 1 to leave data affected by failed solutions uncalibrated.

2. On subsequent iterations, use the Clean image as produced by IMAGR as your input model. VLBI applications usually require Clean components well beyond the first negative component to be used in calculating the source model. One possibility is to use PRTCC to find the point where a significant fraction (*e.g.*, one third) of all new Clean components are negative. An alternative is to use all of the Clean components, but to use tight windowing in IMAGR — which can now be done interactively on the TV as IMAGR progresses. Alternatively, use tight windowing and clipping of the Clean components in IMAGR (IMAGRPRM(8) and IMAGRPRM(9)) or afterward with CCEDT or CCSEL before running CALIB. Tight windowing is especially important when *uv* coverage is poor. Editing Clean components after IMAGR, but before CALIB, can be effective in removing possibly spurious features; if they are real they will usually reappear in later iterations. IMAGR offers a filtering option to remove weak, isolated components when requested from the TV and at the end before the components are restored to the image. This removes much of the need for CCSEL.

3. When carrying out the next CALIB iteration with the new Clean model, you can either self-calibrate the original data set or, alternatively, self-calibrate the data set (output by CALIB) which was used to produce that Clean model. It is advantageous to use the original data set at least until you turn on amplitude calibration. At that point, you should stick with the file produced from the original data with the best phase-only solution. Amongst other things, this can prevent the telescope amplitudes from "wandering" (see below).

4. When the model contains extended structure, there may be problems with convergence when weighting the data "correctly" (*i.e.*, by $1/\sigma^2$.) The WEIGHTIT adverb allows you to use less extreme weights, such as $1/\sigma$ or $1/\sqrt{\sigma}$. If your array contains antennas that have a wide range of sensitivities, *e.g.*, the VLBA plus the phased VLA and/or the Effelsberg 100-m, it is helpful to alter the weights of

the antennas in your CALIB solutions. If this is not done, then your solution will be dominated by only a few baselines and the uniqueness of the solution is not guaranteed. Use PRTUV to inspect the weights of your data. Then set the CALIB input array ANTWT, which provides multiplicative factors adjusting the weights for each antenna prior to the CALIB solution. Set these parameters so that the effective range of baseline weights is only 10 to 100. Alternatively, use WTMOD to raise the original weights to a power between 0.25 and 0.5.

5. As you iterate, keep an eye on how the model image is converging to fit the data. Use VPLOT, CLPLT, CAPLT, and UVPLT.

6. When your source has a lot of extended structure and/or your VLBI array has relatively few short spacings, you should consider setting UVRANGE to only include the range of spacings in which the model provides a good fit to the data. However, given the relatively small number of antennas in most VLBI observations, you may need to compromise to allow in enough baselines to get good self-cal solutions. Set `WTUV > 0`.

7. When you are finally ready to solve for amplitude corrections, you should first apply all previous phase calibration including the final phase-only self-calibration solution. Then run CALIB setting `SOLMOD 'A+P'`, initially setting the solution interval (SOLINT) to a longer time than used for phase-only solutions (*e.g.*, 3 times). Try to prevent the antenna amplitudes from "wandering," which can sometimes happen if there is still a significant amount of short spacing flux density missing from the source model. Setting UVRANGE is useful, as is setting `CPARM(2) = 1` to constrain the mean amplitude solutions over all antennas to be one. You can also set `SOLMODE='GCON'` and the array GAINERR to the expected standard deviation of the gains for each antenna. This constrains amplitude solutions to conform to the expected statistics. Setting the gain constraint factor SOLCON to values larger than 1 will increase the importance of these gain error constraints. Finally, going back and self-calibrating starting with the original data set and the best available Clean model is useful way to prevent amplitude wander.

CALIB has been enhanced to improve its usefulness for SVLBI data sets. This has involved the implementation of improved antenna selection and partial array calibration, through the new adverb DOFIT. The possibility of solving only for a subset of selected antennas has been implemented in this manner and may prove useful for SVLBI data. The implementation of adverb DOFIT in CALIB is analogous to its implementation in FRING (see § 9.4.8.9).

### 9.6.2 IMAGR, SCIMAG, and SCMAP

1. Before using IMAGR or SCMAP or SCIMG, print out and read the EXPLAIN file. They are powerful and complicated tasks with many adverbs — some of which are new — and shouldn't be used blindly.

2. The quality of images produced may depend on the type of weighting used. With VLBA-only experiments, the best quality images are often produced using natural (UVWTFN 'NA' C~R~) weighting in IMAGR. These images will represent the extended structure of the source better. If the highest resolution is required, try uniform (UVWTFN 'UN' C~R~) weighting. The ROBUST parameter allows weightings intermediate between these two extremes often with both good signal-to-noise characteristics and a narrow synthesized beam. It may also be worth experimenting with the UVBOX parameter to allow smoothing of weights over larger areas of the *uv* plane (*i.e.*, to use "super-uniform weighting"). If the array contains antennas with very different sensitivities, (for instance, if it includes Effelsberg, the phased VLA, and/or HALCA), then it may be advantageous to alter the weights of baselines to these antennas. Although this increases the thermal noise in the image, it will improve the *uv* coverage, which, otherwise, will contain effectively only the baselines to the most sensitive antennas. One way of doing this is to use UVWTFN = 'UV' C~R~ in IMAGR. This option takes the fourth root of the input weights before applying uniform weighting. SCMAP and SCIMG also support these weighting options.

Another flexible (but deprecated) approach is to use task WTMOD to change the weights in the data set prior to running IMAGR.

3. After an initial self-calibration against a point-source starting model, the deconvolved image will often show spurious symmetric structure. Convergence can be speeded up by placing Clean boxes CLBOX) around the side showing the brighter structure. Note that CLBOX may be used to produced circular as well as rectangular windows for use with IMAGR. Alternatively, CCEDT can be used to edit the Clean components after IMAGR, but before the next CALIB. IMAGR, SCIMG, and SCMAP allow this to be done interactively at the start of each major Clean cycle including the first.

4. Use DOTV = 1 C_R to view the residuals and possibly modify the Clean boxes as you Clean. You can stop Cleaning if you feel that you are including spurious structure into your model or if you feel you need to reset a Clean box to include a new feature. Note the BOXFILE and OBOXFILE options which allow you to retain interactively set Clean boxes for use in the next self-cal iteration.

5. SCMAP and SCIMG, at each self-calibration cycle, offer a powerful interactive data editing tool which displays input and residual data from up to 11 baselines simultaneously. This is the same editor as found in task EDITR.

The hints outlined above are by no means the whole story when it comes to self-calibrating and imaging VLBI data. Unfortunately, it can still be somewhat of an art form. Very experienced users can produce noise-limited images, but there is no simple recipe that will enable inexperienced users to do the same.

### 9.6.3 Non-conventional methods of imaging

Since fringe rate is a function of source position, we can use measurements of the fringe rate to estimate the positions of sources. Fringe rate imaging is widely used with maser sources which are usually widely separated point objects. The angular resolution of fringe rate images is not as good as conventional aperture synthesis imaging, but it can be used for an initial determination of the location of emitting clusters. This will help in setting field shifts and Clean windows for use by IMAGR. Having measured the fringe rate $FR(i)$ for each sample in (baseline-time) and computed the derivative of fringe rate ($UDOT(i)$) wrt to right ascension ($X$) and the derivative ($VDOT(i)$) wrt declination ($Y$), we obtain a set of equations of straight lines

$$FR(i) = UDOT(i) * X + VDOT(i) * Y$$

describing the loci of constant fringe rate for each observation. The positions of the source component(s) can be determined by finding the places of highest density of crossing lines. (Details can be read in Giuffrida,T.S, 1977 Ph.D.thesis MIT and in Walker R.C., 1981, *Astr. J.*, **86**, 9, 1323.)

This algorithm is implemented in AIPS as the task FRMAP. The task plots the straight lines on the TV or prepares a plot file. Then it determines the positions of higher density of crossing lines. The coordinates in RA and DEC of the components found are written in an output file. The fringe rate method is especially attractive in SVLBI because of the better angular resolution due to faster movement of the orbiting antenna. Figure 9.3 shows an example of a fringe rate image.

FRMAP can be used for more accurate definition of the source coordinates that is required by the correlator. In this case the correlator carries out two passes. After the first one (short) FRMAP is used to find a more accurate position of the source. The new coordinates are then used in the second pass covering the whole experiment.

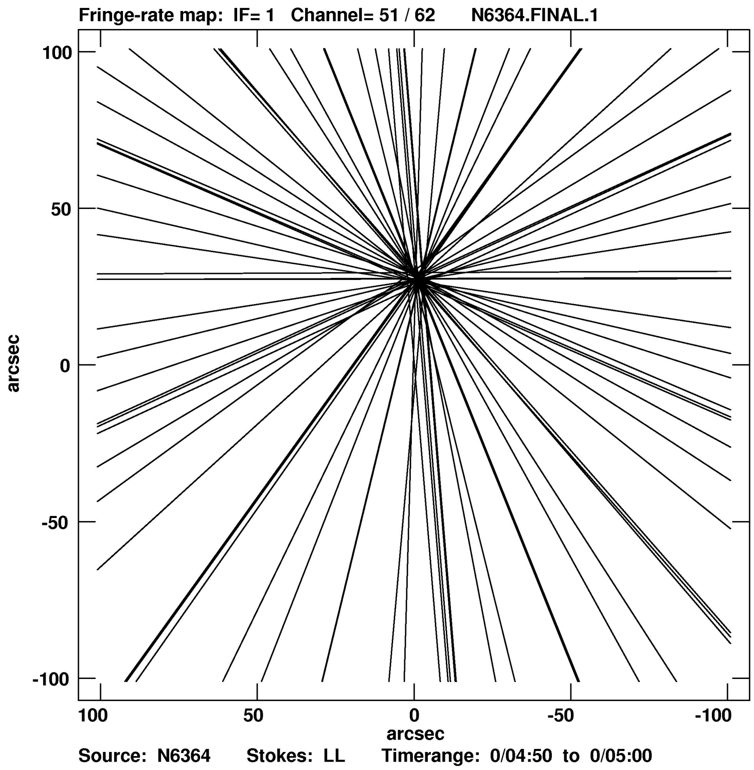



Figure 9.3: An example of a preliminary determination of the source location using fringe-rate analysis. The position of the source in channel 51 is shifted relative to the reference channel (62) by ≈ 25 asec to the north. Conventional imaging can be carried out near this position.

## 9.7 Summary of VLBI calibration tables

Several different tables are supplied with a VLBI data set created by the Socorro and other correlator; various other tables (*e.g.*, SN tables) are created by the calibration process. A list of these tables is given below for your edification. Not all tables will be present with all files.

**AN** Antenna table. Contains a list of the antenna names and station coordinates. Also contains instrumental polarization terms.

**AT** Antenna characteristics table. Contains additional information about antenna properties, including some time variable quantities.

**BL** Baseline offset table. Contains non-closing baseline-dependent phase and amplitude errors as determined by BLCAL.

**BS** Baseline solution table. Contains baseline delay, rate and phase solutions as determined by BLING.

**CL** Calibration table. Version 1 contains, amongst other things, the default calibration parameters for the amplitude (usually unity), phase, and single-band delay (usually zero) for each source for each IF as a function of time. It also contains polynomial coefficients allowing the correlator delay and phase models to be recomputed. As calibration proceeds, higher versions of this table are created which incorporate more and more calibration effects into the phase, delay, and amplitude entries.

**CQ** Correlator parameter frequency table. Contains VLBA correlation parameters for each AIPS IF, and activates VLBA delay decorrelation corrections. Type EXPLAIN FXVLB for further information.

**CT** CALC table. Contains the input parameters passed to CALC to generate the polynomials recorded in the IM table.

**FG** Flag table. Contains information used to delete selected portions of the data.

**FQ** Frequency table. Contains information about the IF frequencies, channel spacings, bandwidths, etc.

**GC** Gain Calibration table. Contains the expected zenith gain and gain-elevation curve for each antenna. It is used for amplitude calibration.

**HF** Haystack FRNGE table. Contains information generated from the *AIPS* tables that can be exported to the CALC and SOLVE package.

**IM** Interferometer model table. Contains the actual polynomial coefficients which the VLBA correlator used to calculate the geometrical model. Unlike the coefficients in the CL table, these have not been re-interpolated onto the CL time grid, but have time stamps corresponding to the times at which the correlator computed the geometrical model.

**MC** Model Components table. Contains the various components of the geometric model used in the VLBA correlator to generate the IM table.

**NX** Index File. Contains information about the time, source, sub-array and location within the data file of each observation or "scan." It is used by some *AIPS* tasks in accessing the main data file and subsidiary tables.

**OB** Spacecraft Orbit table. Contains information about the positions and velocities used by the correlator for an orbiting antenna.

**PC** Phase-calibration table. Contains phases within each IF computed from the injected phase calibration signals. It is used to determine the phase offsets and single-band delays for each IF channel.

**SN** Solution table. Contains antenna delay, rate, phase, and amplitude corrections solved for by CALIB and FRING and other tasks.

**SU** Source table. Contains a list of the sources found within the multi-source file, including information on source positions and flux density.

**TY** System temperature table. Contains the system temperature as a function of time for each antenna and IF channel. It is used for amplitude calibration.

**VT** VLBA Tape table. Contains tape playback statistics for use mainly by the VLBA correlator group.

**WX** Weather table. Contains weather-related information for each station.

# 10 SINGLE-DISH DATA IN *AIPS*

*AIPS* was not originally intended as a reduction package for single-dish data and cannot be considered as such today. However, because of the similarity of single-dish data taken at "random" pointings on the sky to interferometric data taken at "random" locations in the *uv* plane, *AIPS* was seen as a system to be used to solve large imaging problems arising from single-dish observations. Many of the *AIPS* *uv*-data tasks are able to do something sensible — or even desirable — with single-dish data and a few special tasks to process single-dish data have been written. The present chapter contains a discussion of the representation of single-dish data in *AIPS* followed by a description of how such data may be calibrated, corrected, converted into images, and analyzed by *AIPS*. A final section on using single-dish observations to improve the imaging of interferometric data represents what little we now know about this potentially important process.

## 10.1 *AIPS* format for single-dish data

Single-dish data in *AIPS* is treated as *uv* data with different, but related random parameters and with the imaginary part of the visibility replaced by an additive calibration or offset. The $u$ and $v$ random parameters are replaced by parameters labeled RA and DEC, although other labels such as ELON, ELAT, GLON, and GLAT are also recognized. (Conversion between these coordinate systems is not provided in the "*uv*" plane although some conversion can be done on images.) The random parameter data are the sample coordinates in degrees. The TIME1 random parameter is the time (IAT) since midnight on the reference date in days as with real *uv* data. The BEAM random parameter corresponds to BASELINE and is used to separate data which should be edited and calibrated separately (*e.g.*, separate beams of a multi-feed system, different polarizations or observing runs of a multi-polarization system). The actual beam number is recorded as 257 times the desired number so that visibility-data tasks will recognize the "baseline" as auto-correlation data. Two other random parameters, SCAN and SAMPLE, have no relation to any visibility parameters and are simply used to retain the "scan" number and sample number within the scan which are traditional in single-dish observations. Very little is made of these, but INDXR will make a new index entry when the scan number changes and PRTSD will display the scan and sample numbers. SDVEL uses the scan numbers to determine when to update the reference velocity in some observing modes. Single-dish data may be stored in compressed form, in which the weight and compression scale are stored as random parameters exactly as in true visibility data. This should *not* be done if the applied offset is large as in beam-switched continuum observations.

The measured single-dish flux, usually in units of degrees Kelvin, appears in the real part of the "complex visibility." The imaginary part of the visibility is sometimes used to hold an offset which can be applied to the data to remove, for example, a time-variable bias. The data weight is used to weight the data and should be proportional to $\sigma^{-2}$, where $\sigma$ is the uncertainty in the flux. The visibility sample can contain multiple polarizations, described with the STOKES axis (values 1 through 4 for I, Q, U, and V, respectively). The sample can also contain multiple spectral-line frequencies, described with a FREQ axis giving the observed reference frequency and increment in Hz.

The *uv*-data header in an *AIPS* data set is expected to contain the reference (usually central) longitude and latitude given either as 1-pixel coordinate axes and/or in the "observed" coordinate location. The convolution size is usually used to hold the single-dish beam width (fwhm) and rest frequency and velocity information should also appear with spectral-line data. Many of the parameters can be added to the header by the user if they are missing and needed. Verbs ADDBEAM, ALTDEF, and PUTHEAD are useful for this purpose. A complete data set will also have an antenna extension file giving the location of the antenna. This allows tasks to compute things like zenith angles and Doppler corrections when needed. (OTFUV began making antenna tables in the 15JAN96 release.)

### 10.1.1 On-the-fly data from the 12m

At the present time, the only reliable routes for single-dish data into *AIPS* are provided by the tasks OTFBS and OTFUV. These tasks work only on beam-switched continuum and on spectral-line observations, respectively, from the NRAO 12m telescope. They use files in the UniPops native format and do not read the FITS table format written by UniPops. Both programs are designed for "on-the-fly" or "OTF" observing modes in which the telescope takes data rapidly while continuously changing its pointing position.

#### 10.1.1.1 Listing OTF input files

To read OTF files, you must first define an environment variable to point to the disk area in which your data resides. This environment variable and your file names should be in upper case letters, but there is an AIPS "feature" which allows you to use lower case. On Unix systems, you may set the environment variable and rename the files to upper case with

| | |
|---|---|
| % cd /my/disk/directory C_R | to switch to the disk directory containing your data. |
| % setenv MYAREA 'pwd' C_R | to define $MYAREA under c shell, or |
| % export MYAREA='pwd' C_R | to define $MYAREA under Bourne, bash, korn shells. |
| % mv mysdd.file MYSDD.FILE C_R | to rename the data file to upper case letters. |
| % mv mygsdd.file MYGSDD.FILE C_R | to rename the gain file to upper case letters. |

Then start your AIPS session.

To review the contents of your data set, use the task OTFIN which will list SDD modes, IF and scan numbers, times, coordinates, velocities, and number of samples. This output should help in setting the range of scan numbers to be loaded by OTFUV or OTFBS. Type:

| | |
|---|---|
| > TASK 'OTFIN' ; INP C_R | to list the required inputs on your screen. |
| > DATAIN 'MYAREA:MYSDD.FILE' C_R | to specify the name of the 12m raw data file, where MYAREA is an environment variable which points at a disk data area and MYSDD.FILE is the name of your file in that area. See § 3.10. If your environment variable and/or your file name contain lower case letters, type the name carefully with the correct case for all letters and leave off the second (close) quote mark. When you use this "feature" of the AIPS compiler, you cannot type anything following the DATAIN name (or other string adverb) on that line. |
| > BCOUNT 0 ; ECOUNT 0 C_R | to include all 12m scans in the file. |
| > BIF 0 C_R | to include all SDD "IFs." |
| > DOCRT -1 C_R | to print the listing on the line printer, or |
| > DOCRT 1 C_R | to view the listing, one page at a time, on your terminal window. The width given (if > 72) should match the width desired; a width of < 72, as given here, uses the actual width ot the window and so maximizes the information per line. |
| > INP C_R | to review the parameters. |
| > GO C_R | to run the task. |

#### 10.1.1.2 Reading spectral-line OTF files into *AIPS*

To run OTFUV after running OTFIN, type

| | |
|---|---|
| > TASK 'OTFUV' ; INP C_R | to list the required inputs on your screen. |
| > DATAIN 'MYAREA:MYSDD.FILE' C_R | to specify the name of the 12m raw data file, where MYAREA is an environment variable which points at a disk data area and MYSDD.FILE is the name of your file in that area. See § 3.10. |
| > DATA2IN 'MYAREA:MYGSDD.FILE' C_R | to specify the name of the 12m gain file corresponding to the file specified with DATAIN. |
| > BCOUNT $n_1$ ; ECOUNT $n_2$ C_R | to include 12m scans $n_1$ through $n_2$ in the output file. |
| > BIF 0 ; EIF 0 C_R | to include all SDD "IFs" matching the lowest numbered one found. IFs which do not match in central frequency or channel width are skipped. |
| > DOUVCOMP TRUE C_R | to write the data in a compressed format. This reduces the size of the file by nearly a factor of 3 with no significant loss of information in this case. |
| > XINC 1 ; YINC 1 C_R | to write out all data samples with no time averaging. One can smooth by YINC samples and write out the data every XINC sample times in order to reduce the size of the output data set and improve the signal-to-noise of the individual samples with only a minor loss of information.. |
| > DOWEIGHT 1 C_R | to use offs and gains interpolated to the time of each observation. This seems to produce better results. |
| > DETIME 0 C_R | to add no offset to the actual observation times. |
| > BCHAN 0; ECHAN 0 C_R | to include all spectral channels. |
| > CHANSEL 0 C_R | to flag no channels. CHANSEL 31,34,3 C_R, for example, would mark channels 31 and 34 as bad. Data may be edited later more selectively. |
| > INP C_R | to review the parameters. |
| > GO C_R | to run the task. |

While OTFUV runs, it will show you (on the message monitor or your window) the name and location of the output *AIPS* file created and then provide a list of the scans and IFs read and the gain scans used upon them.

In many cases, the 12m in OTF mode observes two separate polarizations using the same center frequency and spectral resolution. In the UniPops/12m nomenclature, these are separate "IFs." A similar nomenclature is used to distinguish the feeds in the multi-feed system. OTFUV can now read up to eight IFs at the same time, avoiding the necessity of multiple runs of OTFUV, followed by a data sort to restore time order. OTFUV will distinguish the IFs not by an *AIPS* "IF axis," but by assigning them beam numbers equal to the SDD IF number (or autocorrelator baseline number equal to the SDD IF number with itself).

You may append data from another IF in the first input data set or data from another OTF pass on the source to the *AIPS* data set created above, by entering new DATAIN and DATA2IN names and new BCOUNT and ECOUNT ranges, if needed and

| | |
|---|---|
| > BIF $m_1$ ; EIF $m_2$ C_R | to load IFs $m_1$ through $m_2$. |
| > DOCONCAT TRUE C_R | to enable the concatenation mode. |
| > OUTDISK $n$ ; GETONAME $m$ C_R | to select the output file, where $n$ and $m$ are the output disk and catalog slot number used by the first run of OTFUV. |

| | |
|---|---|
| > FQTOL *ff* C_R | to allow data sets within *ff* MHz of each other to be concatenated. Doppler tracking will cause two OTF passes to appear to be at separate frequencies. Narrow-band, wide-field observations should not be concatenated in this way; see the discussion of SDVEL below (§ 10.2.4). |
| > GO C_R | to run the task appending the additional data. |

Another way to concatenate two 12m IFs — or multiple observing runs — is to create two output files with OTFUV and then concatenate them with DBCON. If the two OTFUV files are in time order, then DBCON will actually merge the two data sets, retaining the time order. Avoid the use of multiple sub-arrays, which are a useless complication in this case, by setting DOARRAY = 0. To have the most "complete" antenna file, put the data set with the higher 12m IF in the first input name set (INNAME, INCLASS etc.)

#### 10.1.1.3 Reading continuum OTF files into AIPS

The NRAO 12m telescope can observe in a beam-switched continuum on-the-fly mapping mode. Such data may be read into AIPS and reduced, in a somewhat experimental fashion, into images. To read in the data (after using OTFIN), enter

| | |
|---|---|
| > TASK 'OTFBS' ; INP C_R | to list the required inputs on your screen. |
| > DATAIN 'MYAREA:MYSDD.FILE' C_R | to specify the name of the 12m raw data file, where MYAREA is an environment variable which points at a disk data area and MYSDD.FILE is the name of your file in that area. See § 3.10. |
| > BCOUNT $n_1$ ; ECOUNT $n_2$ C_R | to include 12m scans $n_1$ through $n_2$ in the output file. |
| > BIF 0 ; EIF 0 C_R | to include all SDD "IFs" matching the lowest numbered one found. IFs which do not match in central frequency or channel width are skipped. |
| > INP C_R | to review the parameters. |
| > GO C_R | to run the task. |

While OTFBS runs, it will show you (on the message monitor or your window) the name and location of the two output AIPS files created (one for "plus" and one for "minus" beam throws) and then provide a list of the scans and IFs read with the number of samples. The two output files will have the same names except for a "+" and a "–" as the sixth character of the output class.

### 10.1.2 Other input data formats

Another method for getting single-dish data into AIPS is through the use of FITS-format binary tables. If the data are able to be put in a usable table, then the AIPS FITS reading tasks such as FITLD (see § 5.1.2) can be used to read them into a disk table attached to a cataloged file. Then SDTUV can be used to convert the table into the *uv* format described above applying a variety of calibrations along the way. Unfortunately, the non-AIPS program that did the UniPops to FITS conversion has been lost and the AIPS FITS readers cannot handle the FITS tables written by UniPops. There are two problems with the latter: AIPS is unable to handle tables with more than 128 columns while UniPops writes tables with around 200 columns. Even if AIPS could be extended in some special task, it would be unable to handle the current UniPops tables since the parameters given do not correctly describe the contents. Specialized unpublished knowledge about each receiver is required to disentangle the coordinate information and data structure.

The task SDTUV expects a sequence of related tables each with a number of keywords giving useful information such as scan, observer, telescope, object, scan start UT date and time, sample rate, velocity, and the like. The data are then a regular time sequence with each row of the table containing the right ascension, declination, and data for $N$ receivers. Breaks in the time sequence are assumed to be new scans found in the next table. SDTUV has the ability to apply receiver position offsets and pointing corrections and to fit and remove receiver baselines using a sliding median window and spline fit. Interference rejection, lateral defocusing corrections, and a priori baseline removal are also offered. At present SDTUV is an example of what can be done rather than a directly usable task. It is limited to continuum problems currently and is moderately restricted in the number of data samples that can be read in any one scan.

Therefore, it will be necessary to write some sort of program in addition to those in the standard AIPS release to get single-dish data into AIPS. We encourage anyone who develops such a program to provide it to the AIPS group so that we may offer it to other single-dish users.

## 10.2 Single-dish data in the "uv" domain

Once you have gotten your data into AIPS, a wide range of tasks become available to you. In addition to the single-dish specific tasks discussed below, these include data movement tasks (UVCOP, UVSRT, DBCON), data averaging (AVER, UVAVG, AVSPC), non-interactive editing (CLIP, UVFLG), interactive editing (SPFLG, EDITR, TVFLG), data backup and restore (FITTP, FITLD), and data display (PRTAN, PRTUV, UVPRT, UVPLT).

### 10.2.1 Using PRTSD, UVPLT, and POSSM to look at your data

In the process of calibrating, modeling, editing, and imaging of single-dish data, there are occasionally problems that seem to arise because users are not aware of the data that they actually have. PRTSD is the task for such users. It displays the data with or without calibration for selected portions of your data set. This will help you identify what pointing positions actually occur in your data, which channels are highly variable or bad, and the like. SPFLG, UVPLT, and others are good for looking at the data set as a whole, but PRTSD really shows you what you have.

To run it, type:

| | |
|---|---|
| > TASK 'PRTSD' ; INP C_R | to list the required inputs on your screen. |
| > INDISK *n* ; GETN *ctn* C_R | to select the single-dish "*uv*" file to be displayed. |
| > DOCRT 1 C_R | to select the on-screen display at its current width; make sure your window is at least 132 characters across for the best results. |
| > DOCELL -1 C_R | to look at the data values; DOCELL $> 0$ causes the offsets that have been removed (usually 0) to be displayed. |
| > CHANNEL *m* C_R | to display channels $m$ through $m + 5$. |
| > DOCAL FALSE C_R | to apply no calibration. Note that the 12m off scans and instrumental gains are applied by OTFUV; this parameter applies only to any additional calibration contained in CS files. See § 10.2.3. |
| > TIMERANG 0 C_R | to look at all times. |
| > ANTENNAS $a1, a2, \ldots$ C_R | to look at beams/IFs $a1, a2, \ldots$ only. |
| > BPRINT *bb* C_R | to begin the display with the $bb^{\rm th}$ sample in the data set *before* application of the other selection criteria (TIMERANG, ANTENNAS, etc.) |
| > NPRINT 2000 C_R | to shut off the display interactively or after a lot of lines. |
| > XINC *x* C_R | to display only every $x^{\rm th}$ sample of those selected by the other criteria. |

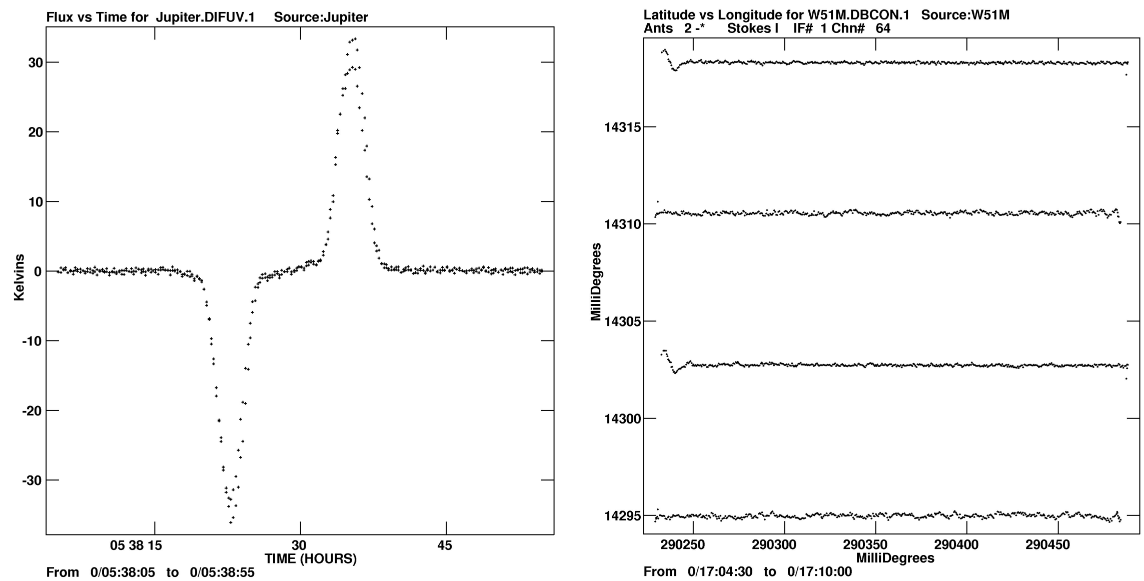



Figure 10.1: *left:* UVPLT display of 12m beam-switched continuum data on Jupiter. The time range is set to display one row of the OTF observation and the "minus" beam throw data have been subtracted from the "plus" throw. *right:* UVPLT display of the right ascension and declination of each sample in spectral-line OTF data set over a limited time range.

| | |
|---|---|
| > INP $C_R$ | to review the inputs. |
| > GO $C_R$ | to start the task. |

PRTSD will start and, after a pause to get through any data not included at the start of the file, will begin to display lines on your terminal showing the scan number, time, coordinates, and data for six spectral channels. After 20 or so lines, it will pause and ask if you want to continue. Hit $C_R$ to continue or type Q $C_R$ or q $C_R$ to quit. If you decide to get hard copy, set DOCRT = -1 and the output will be printed. To save the display in a text file, without printing, set DOCRT = -1 and give the name of the file in the OUTPRINT adverb. See § 3.2 and § 3.10.1 for more information on printing.

There are a number of tasks which plot *uv* visibility data; see § 6.3.1. The most basic of these is UVPLT, which can be useful for single-dish data sets. For example, to generate the plot of flux versus time in 12m OTF beam-switched continuum differenced data seen in the accompanying figure (Figure 10.1), the parameters given below were used:

| | |
|---|---|
| > TASK 'UVPLT' ; INP $C_R$ | to review the inputs. |
| > INDI *n* ; GETN *ctn* $C_R$ | to select the disk and catalog entry of the data set. |
| > DOCALIB FALSE $C_R$ | to apply no calibration; UVPLT does not understand single-dish calibration. |
| > BPARM = 11,9,0 $C_R$ | to plot time in hours on the $x$ axis and flux in Kelvins on the $y$ axis. The other parameters can be used to specify fixed scales on one or both axes, but are just self-scaled in this example. |
| > XINC 1 $C_R$ | to plot every selected sample. |
| > BCHAN 1 ; ECHAN 1 $C_R$ | to plot only "spectral channel" 1, the actual data values. |
| > ANTENNA 1,0 ; BASELINE 0 $C_R$ | to do all baselines with antenna 1, namely 1–1 or, in 12m nomenclature, IF 1.. |
| > TIMER = 0, 5, 38, 5, 0, 5, 38, 55 $C_R$ | to restrict the times to a single scan. |
| > DOCRT = -1 ; GO $C_R$ | to make a plot file of these data. |

After UVPLT is running, or better, after it has finished:

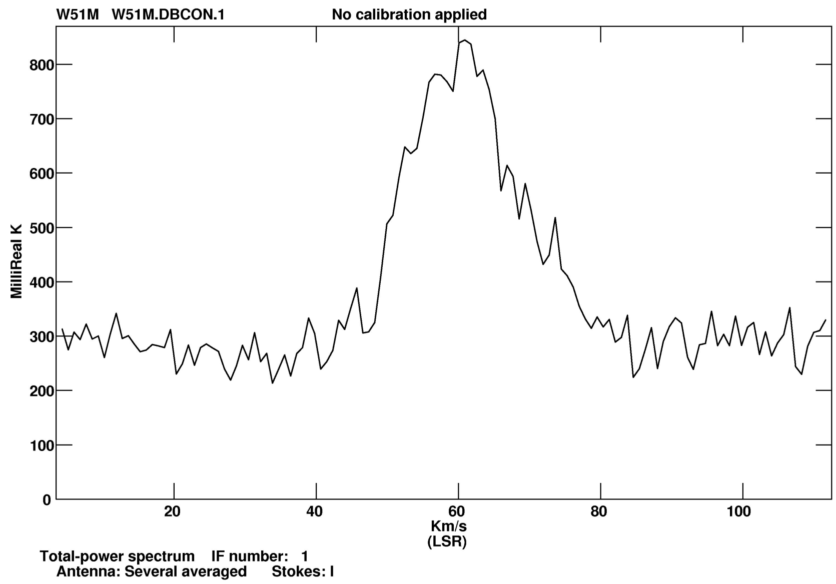



Figure 10.2: POSSM display of all of a 12m observation taken on W51. All samples (on and off the actual source) and both "antennas" are averaged together.

> PLVER 0 ; GO LWPLA C_R — to plot the latest version on a PostScript printer/plotter.

The second plot in Figure 10.1 was generated with BPARM = 6, 7 and shows where samples occur on the sky in a different data set.

With spectral-line data, POSSM will plot observed spectra averaged over selected "antennas," time ranges, and the like. Thus,

> TASK 'POSSM' ; INP C_R — to review the inputs.
> INDI *n* ; GETN *ctn* C_R — to select the disk and catalog entry of the data set.
> BCHAN 0 ; ECHAN 0 C_R — to plot all channels.
> ANTENNAS 0 ; BASELINE 0 C_R — to average all 12m IFs.
> TIMERA 0 ; SOLINT 0 C_R — to average all times into one plot.
> APARM(7) = 2 C_R — to have velocity labels on the $x$ axis.
> GO C_R — to run the task.

LWPLA was then used to make a PostScript version of the plot seen in Figure 10.2.

### 10.2.2 Using UVFLG, SPFLG, and EDITR to edit your data

Editing is the process by which you mark data samples as "unreliable" or "bad." In AIPS, there are two methods for doing this. The simplest is to have the editing software alter the weight of the sample to indicate that it is flagged. If the data are not compressed, this is a reversible operation. If the data are compressed, however, then the data themselves are marked as "indefinite" and the operation is not reversible. The second method is the use of a flag (FG) extension table attached to your *uv* data set. This method requires that the data be sorted into time order for large FG tables and is supported by most, but not all, tasks. Small ($<$ 6000 row) FG tables may be used with data in any sort order. If the task does not have the FLAGVER adverb, then it does not support flag tables. However, since flag tables can be applied to the data by SPLIT, we use them in the recipes below.

To sort the data into "time-baseline" (TB) order,

| | |
|---|---|
| > TASK 'UVSRT' ; INP C_R | to review the inputs. |
| > INDI *n* ; GETN *ctn* C_R | to select the disk and catalog entry of the data set. |
| > SORT 'TB' C_R | to sort into time-baseline order. |
| > ROTATE 0 C_R | to avoid damage to the coordinates. |
| > INP C_R | to check the parameters, *e.g.*, the output name. |
| > GO C_R | to run the task. |

The most direct flagging task is UVFLG, which puts commands into the flag table one at a time (or more than one when read from a disk text file). To use this task to flag channel 31 from 7 to 8 hours on the first day of observation from the second input (single-dish nomenclature) IF:

| | |
|---|---|
| > TASK 'UVFLG' ; INP C_R | to review the inputs. |
| > INDI *n* ; GETN *ctn* C_R | to select the disk and catalog entry of the sorted data set. |
| > OUTFGVER 1 C_R | to select the desired flag table. |
| > TIMERANG 0, 7, 0, 0, 0, 8, 0, 0 C_R | to set the time range from 7 to 8 hours. |
| > BCHAN 31 ; ECHAN 31 C_R | to flag only channel 31. |
| > BIF 0 ; EIF 0 C_R | to do all AIPS IFs. |
| > ANTEN 2, 0 ; BASELIN 2, 0 C_R | to select "baseline" 2-2, the 2$^{nd}$ IF in 12m nomenclature. |
| > APARM 0 C_R | to ignore amplitude in flagging. |
| > OPCODE 'FLAG' C_R | to flag the data. |
| > REASON 'Bad channel' C_R | to store away a reason. |
| > INP C_R | to check the full set of adverbs. |
| > GO C_R | to add one line to the flag table, creating one if needed. |

Multiple runs of UVFLG may be done to incorporate what you know about your data into the flagging table. Use PRTSD and the plot programs to help you find the bad data. If you have a long list of flagging commands, you may find it easier to use the INTEXT option of UVFLG to read in up to 100 flagging instructions at a time from a free-format text file.

The task CLIP is popular on interferometer data sets since it automatically flags all samples outside a specified flux range without interaction with the user. This blind flagging is often acceptable for interferometer data since each *uv* sample affects all image cells so that the damage done by a few remaining bad samples is attenuated by all the good samples. However, a bad sample in single-dish data affects only a few image cells and is hence not attenuated. Thus it is important to find and remove samples that are too small as well as those that are too large. For this reason, we do not recommend CLIP, but suggest that you look at your data and make more informed flagging decisions.

The best known of the interactive editing tasks is TVFLG (§ 4.4.3). This task is not suitable for single-dish data since it displays multiple baselines along the horizontal axis. The data on these baselines are related in interferometry, but, in single dish, they are from separate feeds or polarizations and hence neither numerous nor necessarily related. For spectral-line single-dish data, the task SPFLG is an ideal task to examine your data and to edit portions if needed. SPFLG is a menu-driven, TV display editing task in which spectral channel varies along the horizontal axis of the TV display and time along the vertical. (The spectral channels for each interferometer IF are displayed on the horizontal axis, but single-dish data in AIPS has only 1 of this sort of IF.) The data may be displayed with as much or as little time averaging as desired and is very useful for examining your data even if you do not think that editing is needed.

To run SPFLG, type

| | |
|---|---|
| > TASK 'SPFLG' ; INP C_R | to review the inputs. |
| > INDI *n* ; GETN *ctn* C_R | to select the disk and catalog entry of the sorted data set. |
| > FLAGVER 1 C_R | to select the use of a flag table *on the input data.* |
| > OUTFGVER 0 C_R | to write a new flag table including all flags applied to the input data. |

| | |
|---|---|
| > BCHAN 0 ; ECHAN 0 C_R | to view all spectral channels. |
| > DOCALIB FALSE C_R | to inhibit *interferometer* calibration of your data. |
| > IN2SEQ 0 ; DOCAT FALSE C_R | to create a new, but temporary "master file" each time. |
| > ANTEN 0 ; BASEL 0 C_R | to include all "baselines." |
| > DPARM 0, 1, 0, 0, 0, 0.1 C_R | to include autocorrelation data and to set the fundamental interval used to average data into the master file. The defaults for these parameters are not suitable for single-dish data. The other DPARM parameters may be ignored since they can be altered during the interactive session. |
| > INP C_R | to review the inputs. |
| > GO C_R | to begin the interactive display and editing. |

The task will then read your data to determine which times occur in the included portions (you may set TIMERANG, restrict autocorrelations, etc.) and then construct a master grid file with spectral channel as the first axis, pseudo-regular times on the second axis (gaps are mostly suppressed), and, if needed, baseline number on the third axis. SPFLG tells you the size of the resulting file, *e.g.*, `SPFLG1: Basic UV image is 128 14079 pixels in X,Y (Ch,T)`.

At this point, SPFLG selects an initial *display* smoothing time long enough to fit all of the master grid onto your TV window. It then averages the data to this interval and creates a display not unlike that seen in Figure 10.3. Move the TV cursor to any menu item (it will change color to show which has been selected) and press button D for on-line help information or press buttons A, B, or C to select the operation. Normally, you will probably begin by reducing the smoothing time (ENTER SMOOTH TIME menu option followed by typing in the new smoothing multiple on your AIPS window). Note that the display does not change other than to add an asterisk after the smoothing time to indicate that that will change on the next image load. This behavior is to allow you to alter a number of choices before doing the potentially expensive TV display. In this typical example, you would either ENTER BLC and ENTER TRC by hand and finally LOAD the sub-image or you can do this interactively with SET WINDOW + LOAD. You may examine data values (like CURVAL) and flag data with the options in the fourth column. Flagged data are removed from the display. You may review the flags you have prepared, undo any that you dislike, re-apply the remaining ones to make sure the display is correct, and modify the appearance of the display with the options in the first column. The image may be shown in zoom only during editing in order to give you greater accuracy in examining the data values and locations. If you are doing some time smoothing within SPFLG, the DISPLAY RMS option allows you to view images of the rms rather than the value of the time average. Such a display allows you to find excessively noisy portions of the data quickly.

Finally, when you are done, select EXIT. If you have prepared any flagging commands, SPFLG will ask you if you wish to enter them into your input data set. Answer yes unless you want to discard them or you have set DOCAT TRUE to catalog the master file in order to use it for multiple sessions. If you set OUTFGVER to zero, then the flag commands are put into a new flag table which can be deleted later if you wish.

SPFLG is not useful on continuum data; the interactive editor of choice for such data used to be the task IBLED, but is now EDITR. These tasks are also useful for spectral-line data in that they can display the average (and rms) of a selected range of channels. The spectral averaging should let you see more subtle level problems than can be seen on individual channels (*i.e.*, in SPFLG). EDITR is a menu-driven, TV display editing task, but it does not use grey-scales to show data values. Instead, it plots time on the horizontal axis and data value on the vertical axis. The full data set for the chosen baseline is displayed initially in a potentially crowded area at the bottom of the TV window. This area is available for editing. If DOTWO is true, then it also displays above the edit area a second observable (initially the difference between the amplitude and a running mean of the amplitude) for the primary baseline. EDITR allows you to display up to ten other "baselines" (*e.g.*, 12m-antenna IFs) in frames above the active editing frame. These should speed the process of editing and guide you in the choice of flagging one or all baselines at the time of the observation. A smaller time range or window into these full data sets may be selected interactively to enable more detailed editing. Be sure to set SOLINT to specify an appropriate averaging interval. Unlike SPFLG, no

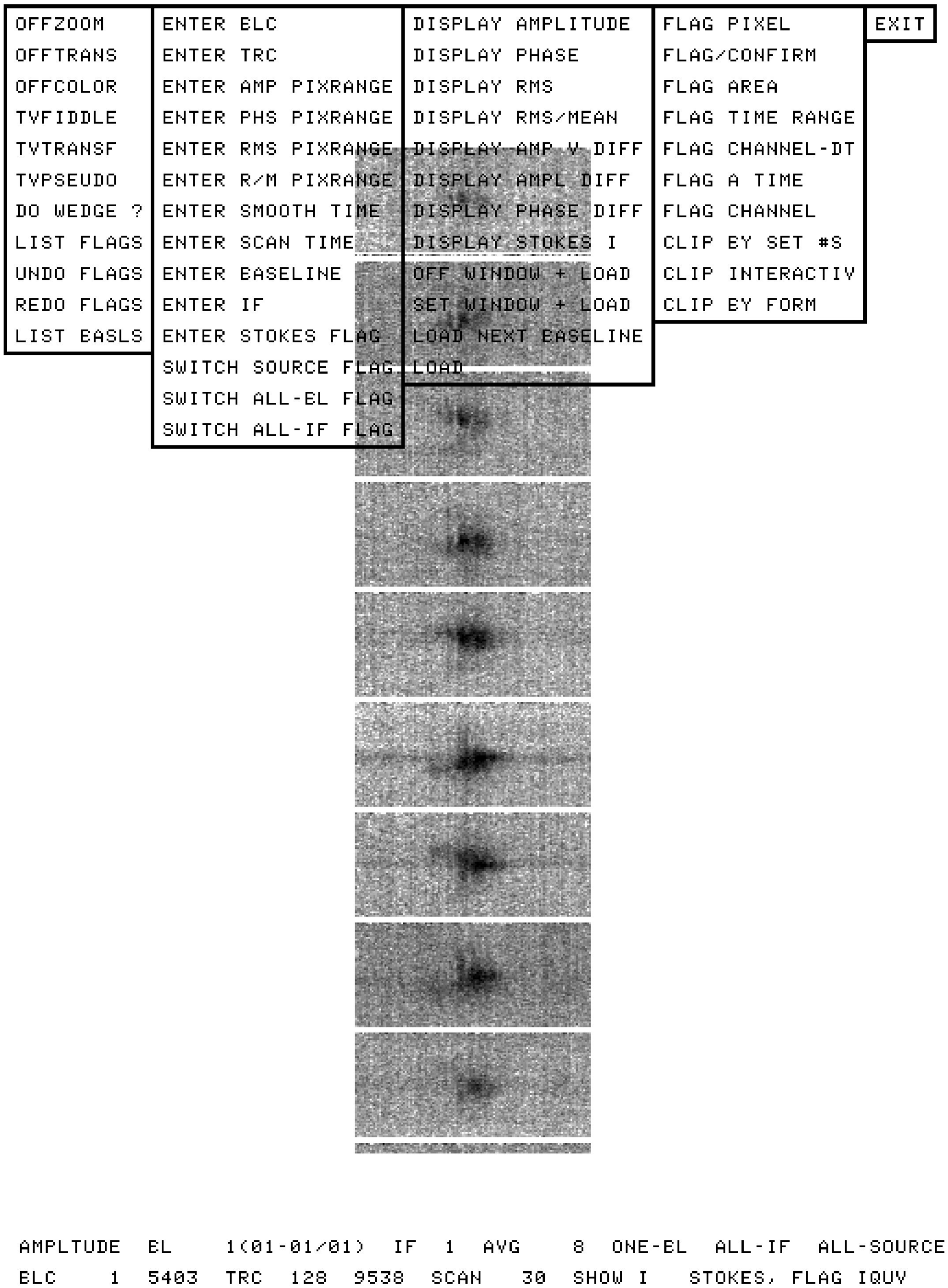



Figure 10.3: A display of a sample TV screen from SPFLG on single-dish data, made using the AIPS task TVCPS to produce a negative black-and-white display. The SPFLG menu (in the boxes) and status lines (at the bottom) are displayed in a graphics plane which is normally colored light green. The data are grey scales in a TV memory and may be enhanced in black-and-white or pseudo-colored. The data actually displayed range in intensity from -1.7 to 5.2 Kelvins (as stated during the image loading) and have been averaged to 0.8 seconds. The entire master grid contains 14079 times, but the current window includes only times 5403 through 9538. Flag commands generated at the moment illustrated will flag all source names, all IFs (in the AIPS sense), only the displayed baseline, and all Stokes. *Note that the menu displayed is now out of date, more options are available in the* `31DEC04` *and later versions.*

further time averaging is possible. The menu options allow you to work your way through all of your data, selecting time windows and baselines as desired. Consult § 5.5.2 for more details about EDITR.

EDITR has the ability to display a second data set for reference in parallel with the one being edited. This option is likely to prove useful for beam-switched continuum observations. Select one of the beam throws for editing and the other for reference display. Then, if editing is required, reverse the roles. It may also be useful to look at your beam-switched data in its differenced form. The task DIFUV may be used to difference the plus and minus throws, followed by EDITR (or any other AIPS uv-data task) to look at the differences. Be sure to tell DIFUV that the time difference between the plus and the minus beam throws should not be considered significant, *i.e.*, SOLINT = 1 / 8 / 60 or a little bit more to avoid round-off effects.

### 10.2.3 Using CSCOR and SDCAL to calibrate your data

The current calibration routines for single-dish data in AIPS are fairly rudimentary. The concept is similar to that used for interferometers. Corrections are developed in an extension table (called CS in single-dish, CL in interferometry) which can be applied to the data by some tasks. In particular, the single-dish tasks PRTSD and SDGRD are able to apply the CS table to the data without modifying the data as stored on disk. They do this using the DOCAL and GAINUSE adverbs. Other *uv* tasks, designed primarily for interferometry, also use these adverbs, but do not understand or apply CS tables. For such tasks, you should carefully turn off the calibration option. If you do not, such tasks will fail.

There are two tasks which can create CS tables: SDTUV discussed above and INDXR. To use the latter, enter

| | |
|---|---|
| > TASK 'INDXR' ; INP C_R | to review the inputs. |
| > INDI *n* ; GETN *ctn* C_R | to select the disk and catalog entry of the data set. |
| > CPARM $T_1$, $T_2$, $\Delta T$ C_R | to set the largest gap ($T_1$) and longest scan ($T_2$) times expected in the data set (for the index table) and to set the time interval ($\Delta T$) in the CS table, all in minutes. |
| > GO C_R | to run the task to create an index (NX) and a calibration (CS) table attached to the main data set. |

Note that this task requires the data to be in time order and expects an antenna (AN) table. You may set CPARM(5) to the maximum antenna number (beam number) in your data set and, with a few grumbles, INDXR will still create and initialize a CS table when you do not have an antenna table.

At this writing, the CS table may be used to correct the recorded right ascension and declination (*i.e.*, the pointing) and to correct the amplitudes for atmospheric opacity and other gain as a function of zenith angle effects. To add an atmospheric opacity correction to the CS table produced by INDXR, type:

| | |
|---|---|
| > TASK 'CSCOR' ; INP C_R | to review the inputs. |
| > TIMERAN 0 ; ANTENN 0 C_R | to do all times and antennas. |
| > GAINVER 1 ; GAINUSE 2 C_R | to modify the base table, producing a new table. |
| > OPCODE 'OPAC' C_R | to do the opacity correction. |
| > BPARM $O_z$, 0 C_R | to specify the zenith opacity in nepers. |
| > GO C_R | to run the task. |

Note that CSCOR only writes those records in the output file that you have selected via TIMERANG, ANTENNAS, etc. To make a new CS table to work for the full data set, you should first use TACOP to write the new table and then set GAINVER and GAINUSE to both point at the new table. CSCOR needs to compute the zenith angle and therefore needs to have an antennas file. If your data set does not have one, you may give the antenna longitude and latitude in the CPARM adverb. The other operations offered by CSCOR are GAIN, PTRA, and PTDC which apply as second-order polynomial functions of zenith angle corrections to the gain, right ascension, and declination, respectively. The format of the CS table allows for an additive flux correction as well. There are no tasks at this time to determine such a correction.

The basic single-dish tasks PRTSD and SDGRD can apply the CS table to the data as they read them in. Other *uv* tasks which are more directed toward interferometry data cannot do this. If you need to use such tasks with corrected data, then you must apply the corrections with SDCAL and write a new "calibrated" data set. To do this:

| | |
|---|---|
| > TASK 'SDCAL' ; INP C_R | to review the inputs. |
| > INDI *n* ; GETN *ctn* C_R | to select the disk and catalog entry of the data set. |
| > TIMERA 0 ; FLAGVER 1 C_R | to do all times and apply any flagging. |
| > BCHAN 1 ; ECHAN 0 C_R | to get all channels. |
| > DOCAL TRUE ; GAINUSE 0 C_R | to apply the highest numbered CS table. |
| > APARM 0 C_R | to do no averaging of spectral channels. |
| > GO C_R | to run the task. |

The output file from SDCAL can then be fed to UVPLT, SPFLG, or any other *uv*-data task including of course PRTSD and SDGRD.

### 10.2.4 Using SDLSF and SDVEL to correct your spectral-line data

It may be convenient to remove a spectral baseline from each sample before the imaging step. Doing so may allow you to skip the removal of a spectral baseline from the image cubes (as described in § 10.4.1). To do this, type:

| | |
|---|---|
| > TASK 'SDLSF' ; INP C_R | to review the inputs. |
| > INDI *n* ; GETN *ctn* C_R | to select the disk and catalog entry of the data set. |
| > NCOUNT 1 C_R | to solve for a slope as well as a constant in the baselines. |
| > DOALL 1 C_R | to fit a single baseline to all samples taken at a particular time. This is useful for single-beam, multi-polarization data, but, for multi-beam data, it is found that instrumental problems dominate weather and require DOALL = -1 C_R instead. |
| > DOOUT -1 C_R | to avoid writing a continuum data set. |
| > FLUX 0 ; CUTOFF 0 C_R | to write all data with no flagging. |
| > CHANSEL $s_1, e_1, i_1, s_2, e_2, i_2 \ldots$ C_R | to use every $i_1$ channel from $s_1$ through $e_1$, every $i_2$ channel from $s_2$ through $e_2$, and so forth to fit the baseline. Be sure to avoid dubious channels, if any, at the ends and any channels with real line signal. It is important to have regions at both ends of the spectrum to fit the slope. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the task. |

You may, and probably should, use FLUX and CUTOFF to flag those data having excessive noise or excessive signals in individual channels. These "excesses" are measured only in the channels selected by CHANSEL for fitting the baseline.

If you have observed a wide field with relatively narrow spectral channels, there is an effect which you should consider. The "velocity" corresponding to a particular frequency of observation depends on the velocity definition (*e.g.*, LSR or heliocentric), the direction at which the telescope pointed, the time of year, the time of day, and the location of the telescope. Most telescopes adjust the observing frequency to achieve the desired velocity for some reference time and position and many adjust the frequency periodically to account for time changes. However, few, if any, can adjust the observing frequency for every pointing direction and time in a rapidly scanned on-the-fly observing mode. The 12m telescope now sets the frequency once per image with respect to the reference coordinate (usually the image center). In this mode, the maximum velocity error in a 2 degree by 2 degree image is about 1.16 km/s (in LSR velocities) and 0.79 km/s (heliocentric). Since mm lines are often narrow, this can be a significant effect. Fortunately, single-dish OTF data may be fully corrected for this effect so long as your spectra are fully sampled in frequency. The task SDVEL shifts each spectrum so that the reference channel has the reference velocity for its pointing position. The DPARM adverb array is used to tell the task how the telescope set reference velocities and to ask the task to report any excessive shifts and even flag data having really excessive shifts. The latter are to detect and/or remove times in which the telescope pointing was significantly in error (*i.e.*, high winds). DPARM(1) should be set to 0 for 12m data taken after 5 May 1997 and to 2 for data taken before that date. The task VTEST was written to help you evaluate the magnitude of this effect.

### 10.2.5 Using SDMOD and BSMOD to model your data

It is sometimes useful to replace your actual data with a source model or, if your continuum levels are well calibrated, to add or subtract a model from your data. The task to do this is called SDMOD and allows up to four spatially elliptical Gaussians (or an image) to replace the data, or to be added to the data, with either a Gaussian or no frequency dependence. When the data are replaced, a random noise may also be added. SDMOD has options for modeling beam-switched continuum data (set BPARM(1) = 1) as well as for spectral-line data. For example, to see what a modestly noisy point source at the origin would look like after all of the imaging steps:

| | |
|---|---|
| > TASK 'SDMOD' ; INP C_R | to review the inputs. |
| > INDI *n* ; GETN *ctn* C_R | to select the disk and catalog entry of the data set. |
| > BCHAN *n* ; ECHAN *n* C_R | to get one channel only. |
| > NGAUSS 1 ; APARM 0 C_R | to get one Gaussian with no frequency dependence. |
| > GWIDTH 0 ; GPOS 0 C_R | to do a point source (convolved with the single-dish beamwidth in the header) at the coordinate center. |
| > GMAX 1, 0 ; FLUX 0.05 C_R | to do a 1 K object with rms noise of 0.05 K. |
| > GO C_R | to run the task. |

The output file from SDMOD can then be fed to SDGRD, BSGRD, or any other appropriate task as if it were regular data. The input model is convolved with the single-dish beamwidth given in the *uv* data header before being used to replace or add to the input data. The history file will show in detail what was done.

Beam-switched observations may be modeled with task BSMOD. No input data set is needed. Instead two regular grids of switched data are constructed from a specified model plus noise and a variety of instrumental defects.

## 10.3 Imaging single-dish data in *AIPS*

### 10.3.1 Normal single-dish imaging

The process of imaging in single-dish is a process of convolving the "randomly distributed" observations with some convolving function and then resampling the result on a regular image grid. Tasks SDGRD and SDIMG combine the data calibration, selection, projection, sorting, and gridding in one task capable of imaging all spectral channels into one output data "cube." They are relatively easy to run, but selecting the correct input adverb values is more difficult. Choose SDGRD for most single-dish applications; SDIMG is very similar but can handle larger output images at the cost of making a sorted copy of the entire input data set (which can be very large). Type:

| | |
|---|---|
| > TASK 'SDGRD' ; INP C_R | to review the inputs. |
| > INDI *n* ; GETN *ctn* C_R | to select the disk and catalog entry of the data set. |
| > TIMERA 0 ; FLAGVER 1 C_R | to do all times and apply any flagging. |

| | |
|---|---|
| > BCHAN 1 ; ECHAN 0 C_R | to get all channels. |
| > DOCAL FALSE C_R | to apply no calibration. |
| > OPTYPE '-GLS' C_R | to make the image on a "global sinusoidal" kind of projection. |
| > APARM 0 C_R | to use the observed right ascension and declination given in the header as the center of the image. For concatenated data sets, use APARM to specify a more appropriate center. |
| > REWEIGHT 0, 0.05 C_R | to have an "interpolated" or best-estimate image for output, cutting off any cells with convolved weight $<$ 0.05 of the maximum convolved weight. |
| > CELLSIZE $c$ C_R | to set the image cells to be $c$ arc seconds on a side. |
| > IMSIZE $N_x$ , $N_y$ C_R | to make the image of each channel be $N_x$ by $N_y$ pixels centered on the coordinate selected by APARM. |
| > XTYPE 16 ; XPARM 0,0,0,0,50 C_R | to select convolution function type 16 (a round Bessel function times Gaussian) with default parameters and 50 samples of the function per pixel. The default of 20 samples/cell is probably adequate. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the task. |

SDGRD begins by reading the data selecting only those samples which will fit fully on the image grid. It reports how many were read and how many selected. If you have made the image too small, with IMSIZE or CELLSIZE, then data will be discarded. Use PRTSD with a substantial XINC to determine the full spatial distribution of your data. It does not hurt to have the output image be a bit bigger than absolutely necessary. If you are uncertain about the parameters to use, try running SDGRD on a single channel to begin with since it will be much faster.

A number of these parameters require more discussion. REWEIGHT(1) selects the type of output image. The data are multiplied by their weights (which depend on the system temperature), convolved by the sampled convolving function and then summed at each image pixel. REWEIGHT(1) = 1 selects the result, which is not calibrated in any way since its scaling depends on the scaling of the data weights and the convolving function and on the distribution of data. While the program "grids" the actual data it also does the same process on the data replaced by 1.0. That result, the convolved weights may be obtained with REWEIGHT(1) = 2. The most meaningful image, which is obtained with REWEIGHT(1) = 0, is the ratio of the former to the latter. This is the interpolated or best-estimate image and will be similar to the convolved image in well-sampled regions except for having retained the calibration. REWEIGHT(1) = 3 tells SDGRD to compute an image of the expected noise (actually $1/\sigma^2$) in the output image of type 0; see WTSUM below (§ 10.4.2) for its use.

REWEIGHT(2) controls which pixels are retained in the output image and which are blanked by specifying a cutoff as a fraction of the maximum convolved weight. It is important to blank pixels which are either simple extrapolations of single samples or, worse, extrapolations of only a couple noisy samples. In the latter case, it is possible to get very large image values. Thus, if the output is $(W_1D_1+W_2D_2)/(W_1+W_2)$ where the $D$'s are data and the $W$'s are convolved weights and if, say $W_1 = 0.1001, D_1 = 1.0, W_2 = -0.1000, D_2 = -1.0$, then the output would be 2001. Such large and erroneous values will be obvious, but will confuse software which must deal with the whole image and will also confuse people to whom you may show the image. In simple cases, in which all data have roughly the same data weights (system temperatures), setting REWEIGHT(2) = 0.2 or even more is probably wise. However, if some portions of the data have significantly lower weights than others, then you may have to set a lower value in order to keep the low-weight regions from being completely blanked.

The choices of CELLSIZE and the widths of the convolving function are related to the spatial resolution inherent in your data, *i.e.*, to the single-dish beamwidth. If the pixels and function are too small, then data samples which are really from the same point in the sky will appear as if different in the output image. If, however, they are too large, then too much data will be smoothed together and spatial resolution will be lost. The latter may be desirable to improve signal-to-noise, but image smoothing can be done at a later stage as well. You may wish to experiment with these parameters, but it is usually good to start with a CELLSIZE about one-third of the beamwidth (fwhm) of your telescope. The default parameters (XPARMs) of all convolving functions may be used with this cell size. You may vary these parameters in units of cells or in units of arc seconds; enter HELP UV$n$TYPE C_R to look at the parameters for type $n$ ($n = 1$ through 6). If you give XTYPE = $n + 10$, then you get a round rather than square function which is perhaps better suited to this type of data. If you wish to change the cell size, but retain the same convolving function in angular measure on the sky, you may give XTYPE $< 0$ and specify the XPARMs in arc seconds rather than cells.

The choice of convolving function affects the noise levels and actual spatial resolution in the output image. In effect, the Fourier transform of the convolving function acts to modify the illumination pattern of the feed horn onto the aperture. Figure 10.4 shows slices through the Fourier transforms of six of the available convolving functions. The ideal function would be flat all the way across and then suddenly zero at the edges. Type 14 is the widest, but has a deep dip in the middle. This leaves out the center portion of the dish and illuminates the outer portions, effectively improving the spatial resolution of the image over that of the normal telescope, but with a noticeable loss of signal-to-noise ratio. The spheroidal functions, on the other hand, illuminate the center fully and leave out the outer portions. This degrades the spatial resolution, but noticeably improves the noise levels. Types 4 and 16 seem to be the best compromise. Type 16 is preferred since it is zero at the edges. Round functions require more computer memory than square ones, so type 4 would be preferred on computers with small memories.

Images may be built up from observations taken at significantly different times. The simplest way to do this is to concatenate the two "*uv*" data sets on disk with OTFUV or DBCON (§ 10.1.1.2) and then use SDGRD once to make the image. Some single-dish data sets are so large — or the time interval so great — that this is not practical. SDGRD combines observations taking into account the data weights which are based on the measured system temperatures. You can get the same weighted averaging in the image plane if you first compute a "weight" image and then use the task WTSUM to do the averaging. To get a weight image:

| | |
|---|---|
| > TGET SDGRD C_R | to get the inputs used for the actual image cube. |
| > REWEIGHT(1) 3 C_R | to get the weight image which is proportional to $1/\sigma^2$ expected from the actual gridding done on the data whose weights are assumed proportional to their $1/\sigma^2$. |
| > BCHAN $n$ ; ECHAN BCHAN C_R | to image a single channel when there is no channel-dependent data weights and flagging. |
| > GO C_R | to get the weight image. |

See § 10.4.2 for details about WTSUM.

### 10.3.2 Beam-switched continuum imaging

The construction of images from beam-switched on-the-fly continuum observations is more properly a research question than one of production software. Observers in this mode should be aware that the optimal methods of data reduction are probably not yet known and that the methods currently provided require the user to determine three critical correction parameters. In this mode, the telescope is moved in a raster of offsets in azimuth and elevation with respect to the central coordinate. The beam is switched rapidly from a "plus" position to a "minus" position at constant elevation. On the 12m, there are four plus samples and four minus samples taken each second, all taken while the telescope is being driven rapidly in azimuth at a constant (relative to the central source) elevation. In principle, each pair of plus and minus points contain the same instrumental bias but different celestial signals. It is then the job of the software to disentangle the time variable bias from the two beams' estimates of the sky brightness.

A technique for doing the disentangling was first described by Emerson, Klein, and Haslam (Astronomy and

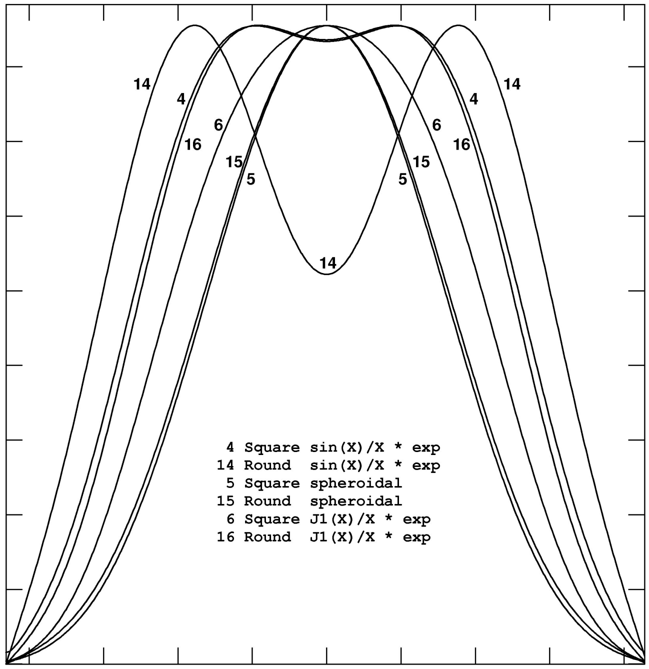



Figure 10.4: Slices through the Fourier transforms of six convolving functions using the XTYPE numbers shown on the plot with default values of the XPARMs.

Astrophysics, 76, 92–105, 1979). The plus and minus samples are differenced removing the instrumental bias and creating two images of the sky, one positive and one negative. Problems arise because the two images potentially can overlap and because, in the OTF mode of observing, the telescope positioning is not exactly along rows of the output image and the relative positioning of the plus and minus beams varies both due to the wobbles in the telescope pointing and due to the reversing of the direction of telescope movement. The Emerson *et al.* technique involves a convolution of each row in the differenced image with a function which is a set of positive and negative delta functions (or $\frac{\sin x}{x}$ functions when the total beam throw is not an integer number of image cells). It turns out that the problem of image overlap is largely solved by this technique. Unfortunately, differences in the position of the plus and minus beam with respect to the source and to the image cells appear to limit the quality of the images produced with this technique.

The principal task used to produce images from  data is called BSGRD. It makes two images from the two "uv" data sets written by OTFBS, gridding each sample at the coordinate at which it was observed (neglecting the throw but not the telescope movement between plus and minus). If the beam throw was not exactly along constant elevation, it then shifts the two images. Then it applies the Emerson *et al.* technique, fitting and removing baselines, differencing the two images, and convolving the difference image with an appropriate $\frac{\sin x}{x}$ function. Finally, BSGRD regrids the data from relative azimuth-elevation coordinates onto a grid in normal celestial coordinates. This task is a combination of four tasks, SDGRD described above to make the images, OGEOM to do the rotation correction, BSCOR to apply the Emerson *et al.* technique, and BSGEO to regrid the data onto normal celestial coordinates.

To use BSGRD, type

| | |
|---|---|
| > TASK 'BSGRD' ; INP C<sub>R</sub> | to review the inputs. |
| > INDI *n* ; GETN *ctn* C<sub>R</sub> | to select the disk and catalog entry of the data set. Note that the class name is assumed to have a plus sign in the sixth character for the plus throw data set and a minus sign in that character for the minus throw data set. |

> TIMERA 0 ; FLAGVER 1 C_R — to do all times and apply any flagging.
> DOCAL FALSE C_R — to apply no calibration.
> OPTYPE '-GLS' C_R — to make the image on a "global sinusoidal" kind of projection.
> APARM 0 C_R — to use the observed right ascension and declination given in the header as the center of the image. For concatenated data sets, use APARM to specify a more appropriate center.
> REWEIGHT 0, 0.05 C_R — to have an "interpolated" or best-estimate image for output, cutting off any cells with convolved weight < 0.05 of the maximum convolved weight.
> CELLSIZE $c$ C_R — to set the image cells to be $c$ arc seconds on a side.
> IMSIZE $N_x$ , $N_y$ C_R — to make the image of each throw be $N_x$ by $N_y$ pixels centered on the coordinate selected by APARM.
> XTYPE 16 ; XPARM 0,0,0,0,50 C_R — to select convolution function type 16 (a round Bessel function times Gaussian) with default parameters and 50 samples of the function per pixel. The same function is used in both convolutions.
> FACTOR $f$ C_R — to multiply the recorded throw lengths by $f$ in doing the Emerson *et al.* correction.
> ROTATE $\rho$ C_R — to correct the throws for being $\rho$ degrees off from horizontal.
> DPARM $1, 1, x_1, x_2, x_3, x_4$ C_R — to specify that the two beams have the same relative amplitude and to give the pixel numbers to be used to fit baselines in *both* images.
> ORDER 1 C_R — to fit a slope as well as a constant in the horizontal baseline in each row.
> DOCAT -1 C_R — to delete the intermediate images created by BSGRD.
> INP C_R — to review the inputs.
> GO C_R — to run the task.

BSGRD takes three correction parameters which you must supply: the throw length error FACTOR, the throw angle error ROTATE, and the relative beam gain error DPARM(1). To estimate these, you will need data on a relatively strong point source. Use SDGRD to make an image of each throw of these data, setting ROTATE = 0 since rotation *must* be done later and setting ECHAN = 1 to eliminate the coordinate information which is confusing to MCUBE and used only by BSGEO. The tasks IMFIT and/or JMFIT (§ 7.5.2) may be useful in fitting the location and peak of the two beams. Since there is likely to be a significant offset from zero in these images, be sure to fit for the offset using a second component of CTYPE = 4. For reasons that are not clear, these tasks may not provide sufficiently accurate positions. Another approach then is to take the two images produced by SDGRD and then run OGEOM and BSCOR for a range of rotations and factors. Find the image that is most pleasing and put its parameters into BSGRD for the program source. Of course, it is not clear that these correction factors are constant with time or pointing, so this could all be bologna.

For example,

> TASK 'OGEOM' ; INP C_R — to review the inputs.
> INDI $n$ ; GETN $ctn_+$ C_R — to select the disk and catalog entry of the plus image.
> APARM 0 C_R — to do no shifts or rescaling.
> DOWAIT 1 C_R — to wait for a task to finish before resuming AIPS.
> OUTCLA 'OGEOM+' C_R — to set the output class to show the throw sign.
> FOR APARM(3) = -2 , 2.01 BY 0.1 ; GO; END C_R — to produce 41 plus images each with a slightly different rotation.
> GETN $ctn_-$ ; OUTCLA 'OGEOM-' C_R — to select the minus image as input and specify the output class.

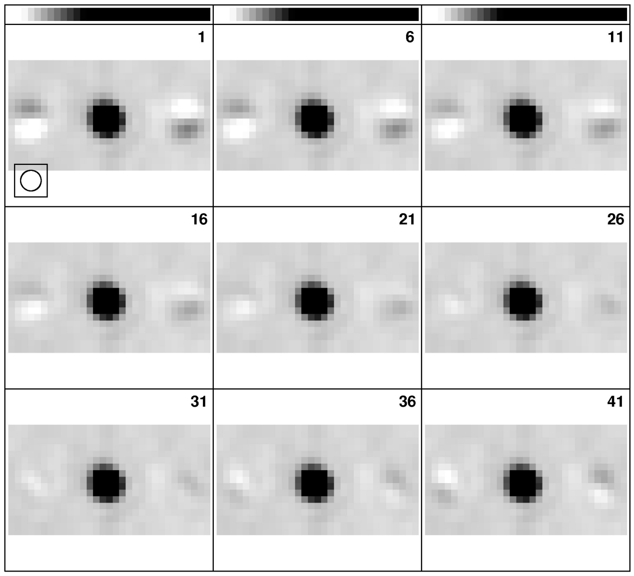



Figure 10.5: Images at selected rotations from 2.0 to -2.0 by -0.5 degrees. Rotations between -0.5 and -1.0 appear to minimize the artifacts due to the incomplete cancellation of the plus and minus beams.

> FOR APARM(3) = -2 , 2.01 BY 0.1 ; GO; END C_R — to produce 41 minus images each with a slightly different rotation.

Then apply the Emerson *et al.* corrections to each of the 41 with

> TASK 'BSCOR' ; INP C_R — to review the inputs.

> INDI *n* ; GETN $ctn_+$ C_R — to select the disk and catalog entry of one of the rotated plus images.

> IN2DI *n* ; GET2N $ctn_-$ C_R — to select the disk and catalog entry of one of the rotated minus images.

> FACTOR *f* C_R — to multiply the recorded throw lengths by *f* in doing the Emerson *et al.* correction. Use 1.0 as an initial guess.

> DPARM $1, 1, x_1, x_2, x_3, x_4$ C_R — to specify that the two beams have the same relative amplitude and to give the pixel numbers to be used to fit baselines in *both* images. The choice of the $x_n$ is significant.

> ORDER 1 C_R — to fit a slope as well as a constant in the horizontal baseline in each row.

> FOR INSEQ = 1 : 41; IN2SEQ = INSEQ ; GO ; END C_R — to produce 41 "corrected" images.

It is convenient to look at the images with tools such as `TVMOVIE` (§ 8.5.4) and `KNTR` (§ 10.4.5). To build the "cube", use `MCUBE` as:

> TASK 'MCUBE' ; INP C_R — to review the inputs.

> INDI *n* ; GETN *ctn* C_R — to select the disk and catalog entry of the first of the corrected images.

> IN2SEQ 41 ; IN3SEQ 1 C_R — to set the sequence number loop limit and increment.

> AXREF 0 ; AX2REF 41 ; NPOINTS 41 C_R — to set the locations of the images in the cube explicitly.

> DOALIGN -2 C_R — to have `MCUBE` ignore the differing image rotations.

> DOWAIT -1 ; GO C_R — to resume normal task functioning and to build the data cube.

Examine the cube to find the "best" plane and use the rotation of that plane to run similar tests varying the throw length correction factor. One of these cubes, testing rotation, is illustrated in Figure 10.5.

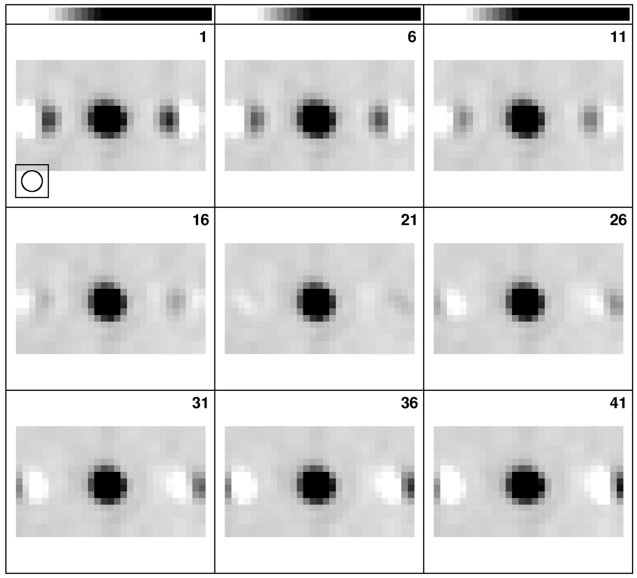



Figure 10.6: Images at selected beam throw corrections from 0.9 to 1.1 by -0.5. Note that rotation errors cause vertical separations of the plus and minus images while throw length errors cause horizontal separations (and hence incomplete cancellation) of the beams.

The determination of throw length is similar:

| | |
|---|---|
| > TASK 'BSCOR' ; INP CR | to review the inputs. |
| > INDI $n$ ; GETN $ctn_+$ CR | to select the disk and catalog entry of the plus image at the best rotation. |
| > IN2DI $n$ ; GET2N $ctn_-$ CR | to select the disk and catalog entry of one of the corresponding rotated minus image. |
| > OUTNA 'ROTATE TEST' CR | to assign a new output name. |
| > DPARM $1, 1, x_1, x_2, x_3, x_4$ CR | to specify that the two beams have the same relative amplitude and to give the pixel numbers to be used to fit baselines in *both* images. The choice of the $x_n$ is significant. |
| > ORDER 1 CR | to fit a slope as well as a constant in the horizontal baseline in each row. |
| > DOWAIT 1 CR | to run the task in wait mode. |
| > FOR FACTOR = 0.9 ; 1.101 BY 0.005; GO ; END CR | to produce 41 "corrected" images. |

It is convenient to look at the images with tools such as TVMOVIE (§ 8.5.4) and KNTR (§ 10.4.5). To build the "cube", use MCUBE as:

| | |
|---|---|
| > TASK 'MCUBE' ; INP CR | to review the inputs. |
| > INDI $n$ ; GETN $ctn$ CR | to select the disk and catalog entry of the first of the new corrected images. |
| > IN2SEQ 41 ; IN3SEQ 1 CR | to set the sequence number loop limit and increment. |
| > AXREF 0 ; AX2REF 41 ; NPOINTS 41 CR | to set the locations of the images in the cube explicitly. |
| > DOWAIT -1 ; GO CR | to resume normal task functioning and to build the data cube. |

Examine the cube to find the "best" plane and use the scaling factor of that plane in later imaging. One of these cubes, testing throw length, is illustrated in Figure 10.6.

BSGRD is in fact a deconvolution algorithm to remove the plus-minus beam from the difference image. An experimental Clean algorithm has been made available in BSCLN. Although initial tests seemed promising, it appears to converge to the EKH solution after very many iterations and to have systematic problems before that point. The one-dimensional display task BSTST will allow you to evaluate and compare the two algorithms on model (one-dimensional) data.

## 10.4 Analysis and display of single-dish data

The analysis and display of images produced from single-dish data are not, in general, different from those produced by interferometers. See Chapter 6 for a discussion of display tools, Chapter 7 for a variety of analysis tasks, and § 8.5 and § 8.6 for spectral-line analysis and display. Some matters of particular interest to single-dish users will be discussed below.

### 10.4.1 Spectral baseline removal

As the SPFLG display in § 10.2.2 shows, one of the first things most users will want to do is remove a spectral baseline at each pixel in the their image. This is frequently done with SDLSF (§ 10.2.4). To do this in the image plane, you must first transpose the data cube to make the frequency axis be first:

| | |
|---|---|
| > TASK 'TRANS' ; INP C_R | to review the task's parameters. |
| > INDI $n_1$ ; GETN $ctn_1$ C_R | to select the input image from disk $n_1$ catalog slot $ctn_1$. |
| > TRANSCOD '312' ; OUTCL 'VXY' C_R | to move the frequency axis from 3rd to 1st. |
| > GO C_R | to transpose the cube. |

You must also determine, using this input image if needed, which spectral channels are completely free of real emission or absorption. TVMOVIE is often useful; see § 8.5.4. Then:

| | |
|---|---|
| > TASK 'IMLIN' ; INP C_R | to review the task's parameters. |
| > INDI $n_2$ ; GETN $ctn_2$ C_R | to select the input image (output from TRANS) from disk $n_2$ catalog slot $ctn_2$. |
| > ORDER 1 C_R | to subtract linear baselines; up to 4th are allowed. |
| > NBOXES $n$ C_R | to select $n$ contiguous regions along the spectral axis to be used in fitting the channels. |
| > BOX $c_{11}$, $c_{12}$, $c_{21}$, $c_{22}$, ... $c_{n1}$, $c_{n2}$ C_R | to use spectral channels $c_{11} - c_{12}$, $c_{21} - c_{22}$, up to $c_{n1} - c_{n2}$ to fit the baselines at each pixel. |
| > INP C_R | to review the inputs. |
| > GO C_R | to fit the baselines, writing a new data cube. |

It is sometimes useful to specify DOOUT TRUE to obtain images of the fit parameters and of their uncertainties. The uncertainty in the DC offset is a good measure of the uncertainty in the image.

The output from IMLIN is the baseline-corrected image in the familiar position-velocity form, with a third axis giving multiple positions on the second celestial coordinate. To go back to sky images as a function of frequency:

| | |
|---|---|
| > TASK 'TRANS' ; INP C_R | to review the task's parameters. |
| > INDI $n_3$ ; GETN $ctn_3$ C_R | to select the input image (output from IMLIN) from disk $n_3$ catalog slot $ctn_3$. |
| > TRANSCOD '231' ; OUTCL 'XYV' C_R | to move the frequency axis from 1st to 3rd. |
| > GO C_R | to transpose the cube back again. |

### 10.4.2 Using WTSUM and BSAVG to combine images

To do a weighted average of multiple images of the same field, be sure to make all images with the same geometry type, the same cell size, and the same center coordinate. If you have two images,

| | |
|---|---|
| > TASK 'WTSUM' ; INP C_R | to review the inputs. |
| > INDI $n_1$ ; GETN $ctn_1$ C_R | to select the first input image from disk $n_1$ catalog slot $ctn_1$. |
| > INDI $n_2$ ; GET2N $ctn_2$ C_R | to select the second input image from disk $n_1$ catalog slot $ctn_2$. |
| > INDI $n_3$ ; GET3N $ctn_3$ C_R | to select the first weight image from disk $n_3$ catalog slot $ctn_3$. |
| > INDI $n_4$ ; GET4N $ctn_4$ C_R | to select the second weight image from disk $n_4$ catalog slot $ctn_4$. |
| > DOINVER FALSE C_R | to state that the weight images are weights rather than rms's. |
| > GO C_R | to compute an averaged image cube and a new weight image. |

The weight images can be either a single plane or a cube that matches the corresponding image cube. All must be on the same spectral and celestial coordinate system.

If you have more than two images of the same field, then all images must have the same name parameters, differing only by having consecutive sequence numbers. All weight images must have the same name parameters with corresponding consecutive sequence numbers. The verb RENAME may be used to correct problems in naming. Then

| | |
|---|---|
| > TASK 'WTSUM' ; INP C_R | to review the inputs. |
| > INDI $n_1$ ; GETN $ctn_1$ C_R | to select the first input image from disk $n_1$ catalog slot $ctn_1$. |
| > CLR2NAME ; IN2SEQ $m_2$ C_R | to select the looping mode and set the highest image sequence number. |
| > INDI $n_3$ ; GET3N $ctn_3$ C_R | to select the first weight image from disk $n_3$ catalog slot $ctn_3$. |
| > CLR4NAME C_R | to clear the unused fourth name set. |
| > DOINVER FALSE C_R | to state that the weight images are weights rather than rms's. |
| > GO C_R | to compute an averaged image cube and a new weight image. |

If $m_1$ is the sequence number of the first image (in $ctn_1$) and $w_1$ is the sequence number of the first weight image (in $ctn_3$), then images of sequence numbers $m_1$ through $m_2$ will be weighted with corresponding weight images of sequence number $w_1$ through $w_1 + m_2 - m_1$. All weight images must be a single plane or all weight images must be a full cube matching the images.

BSAVG is a special task written to average beam-switched continuum images. Each image is Fourier transformed and weighted to give no weight to Fourier components at the beam switching spatial frequency and direction (since the images lack any non-noise information at these lines in the Fourier domain). Images made at different parallactic angles (*i.e.*, different hour angles) have these zero-weight lines at different angles while images made with different throw lengths have these zero-weight lines at different spatial frequencies. Thus, averaging images in this way (and Fourier transforming them back) should produce images with less noise and more information content. This algorithm works only on images that are made very quickly. If there is a significant rotation of the parallactic angle during the observation of one image, then the zero-weight "line" is actually curved and smeared away from the center (in Fourier space). The failure of this algorithm when observations are made with constant-elevation throws is one reason why some telescopes are designed to beam-switch in celestial coordinates.

### 10.4.3 Spectral moment analysis

A data cube may be reduced to a line-sum and a predominant-velocity image when the spectral shape is fairly simple at all points of the image. The simplest task to do this is:

| | |
|---|---|
| > TASK 'XMOM' ; INP C<sub>R</sub> | to review the inputs. |
| > INDI *n* ; GETN *ctn* C<sub>R</sub> | to select the input image from disk *n* catalog slot *ctn* — use the output from IMLIN with velocity as the first axis. |
| > FLUX *x* C<sub>R</sub> | to include only pixels $> x$ in brightness when computing the moments. |
| > GO C<sub>R</sub> | to compute images of the $o^{\text{th}}$ through $3^{\text{rd}}$ moments plus an image of the number of pixels used at each position. |

This simple prescription will produce a result which should tell you whether this mode of analysis is interesting. If it is, then the regions of signal should be separated from regions of no signal so that the latter do not contribute to the noise in the moment images. See the discussions in § 7.4 and § 8.6 for methods of doing this. After the non-signal regions are blanked, the moments should be recomputed.

### 10.4.4 Source modeling and fitting

Gaussian fitting of images is discussed in some detail in § 7.5 while source modeling may be done in the "*uv*" data domain with SDMOD (§ 10.2.5) and in the image domain with IMMOD. The task SAD will find, and fit Gaussians to, sources in your image. Although it works on a plane of the image at a time, it records the plane number in its output model-fit (MF) table. This will allow you to examine the fits to your sources as a function of frequency. To run SAD on a number of image planes:

| | |
|---|---|
| > TASK 'SAD' ; INP C<sub>R</sub> | to review the inputs. |
| > INDI *n* ; GETN *ctn* C<sub>R</sub> | to select the image cube from disk *n* catalog slot *ctn* |
| > BLC 0 ; TRC 0 C<sub>R</sub> | to search for sources over the full plane. |
| > DORESID FALSE C<sub>R</sub> | to delete the residual image after fitting; the fit results are kept in an MF file attached to the input image. |
| > NGAUSS 10 C<sub>R</sub> | to allow up to 10 possible sources to be fit; make this enough to allow for a noise spike or two. |
| > CUTOFF *x* C<sub>R</sub> | to fit "islands" of flux $> x$ only — this is probably the most important parameter. |
| > DOCRT 132 C<sub>R</sub> | to display results on your workstation rather than the line printer. |
| > DOALL 1 ; DOWIDTH 1 C<sub>R</sub> | to allow the task to fit multiple sources to an island and to fit the source widths. |
| > OUTVERS -1 C<sub>R</sub> | to suppress writing of CC files. |
| > INVERS 1 C<sub>R</sub> | to use one MF file for all fits. |
| > DOWAIT TRUE C<sub>R</sub> | to resume AIPS only when the task finishes; this allows looping without tripping over ourselves. |
| > INP C<sub>R</sub> | to recheck the inputs. |
| > FOR BLC(3) = $c_1$ TO $c_2$ ; GO; END C<sub>R</sub> | to fit channels $c_1$ through $c_2$. |

SAD will reject dubious solutions for a variety of reasons. The DPARM adverb allows you to control these reasons and PRTLEV controls how much of an explanation you get.

SAD offers a printer option to provide a detailed account of each execution. To view a simpler summary of the current contents of one or more MF files, use

| | |
|---|---|
| > TASK 'MFPRT' ; INP C<sub>R</sub> | to review the inputs. |
| > INDI *n* ; GETN *ctn* C<sub>R</sub> | to select the image cube from disk *n* catalog slot *ctn* as input to SAD. |
| > INVER $n_1$ ; IN2VER $n_2$ ; XINC 1 C<sub>R</sub> | to view MF file versions $n_1$ through $n_2$. |
| > DOCRT 132 C<sub>R</sub> | to see the display on your monitor. |

| | |
|---|---|
| > FLUX 0 ; IMSIZE 0 C_R | to see all components. |
| > SORT 'C' C_R | to see the file in channel number order. |
| > GO C_R | to run the task. |

Setting DOCRT FALSE and specifying OUTPRINT will produce a file suitable for some non-*AIPS* modeling programs.

### 10.4.5 Image displays

The subject of displays in *AIPS* has been treated extensively in earlier chapters. To make a printer representation of your image, see § 6.2.2 for a discussion of PRTIM. See § 6.3.2 for a discussion of plotter displays of images including tasks CNTR, PCNTR, GREYS, PLROW, PROFL, IMVIM, and IMEAN. Spectral-line displays are described in some detail in § 8.5.4 including tasks KNTR and PLCUB and the TV-movie display verbs TVMOVI and TVCUBE. The use of the TV for display, image enhancement, parameter setting, data examination, image comparison, and the like is described in detail in §§ 6.4.

For tutorial purposes, we will include one example here. The contouring task of choice is now KNTR since it can display images in grey-scales and/or contours with one or more planes per display and with an optional beam display. It also can plot polarization and has several "coloring" options. For example, to display several spectral channels as contours with the $0^{\rm th}$-moment (total CO) image as a grey scale on each display, enter

| | |
|---|---|
| > TASK 'KNTR' ; INP C_R | to review the inputs. |
| > INDI $n_1$ ; GETN $ctn_1$ C_R | to select the image cube from disk $n_1$ catalog slot $ctn_1$. |
| > IN2DI $n_2$ ; GET2N $ctn_2$ C_R | to select the $0^{\rm th}$-moment image plane from disk $n_2$ catalog slot $ctn_2$. |
| > DOCONT 1 ; DOGREY 2 ; DOVECT -1 C_R | to have contours drawn of the first image, grey-scale of the second image, and no polarization. |
| > BLC 0 , 0 , $c_1$ ; TRC 0 , 0 , $c_1$ C_R | to draw the full plane from channels $c_1$ through $c_2$. |
| > ZINC $\Delta c$ C_R | to display every $\Delta c^{\rm th}$ channel. |
| > PIXRANGE $B_1$, $B_2$ C_R | to do grey scales from $B_1$ through $B_2$ only, clipping the most negative and positive values if desired. The default is the full range of image DOGREY. |
| > FUNCTYPE 'SQ' C_R | to use a square-root transfer function on the grey scales to emphasize the lower levels. |
| > OFMFILE ' ' C_R | to do no pseudo-coloring in KNTR. |
| > DOWEDGE 1 C_R | to plot a step wedge along the top. |
| > CLEV 0.1 C_R | to plot 0.1 K as the basic contour level. |
| > LEVS 2.7, 7.4, 20.1, 54.6, 148.4, 403.4 C_R | to do logarithmic contours, starting at 0.27 K. |
| > CBPLOT 18 C_R | to plot a half-power beam contour in the upper right corner and fill it in. |
| > LABEL 1 C_R | to label each pane with its coordinate (velocity usually). |
| > DOTV -1 ; INP | to make a plot file and to review the inputs. |
| > GO C_R | to run the task. |

Beginning with the 31DEC02 release, the contour lines will be drawn in a contrasting color when the background grey-scale intensity is high. When KNTR has finished:

| | |
|---|---|
| > PLVER 0 C_R | to plot the most recent plot file for the image. |
| > OUTFILE ' ' C_R | to print the plot immediately rather than saving it in a file. |
| > GO LWPLA C_R | to translate the plot file into PostScript on a suitable printer. |

LWPLA offers additional control over fonts, paper size, line width, the grey-scale plotting (if PIXRANGE was not quite right), image pseudo-coloring, coloring of lines and backgrounds, and number of copies. It can make an "encapsulated" PostScript file for inclusion in other documents, such as this *CookBook*. See HELP POSTSCRIPT for information on other things that can be done with PostScript plot files.

### 10.4.6 Backing up your data

The next chapter describes how to help the *AIPS* programming team (with "GRIPEs"), to exit AIPS (with EXIT), to delete your data (with ZAP and ALLDEST), and, most importantly, to back up your data to magnetic tape. Do not assume that data on disk is permanent. Many single-dish data sets are very large even by modern computer standards and only 1–3 can be on disk at a time. Disks can fail and users can make mistakes, so it it is wise to make backups to tape. Read § 3.9 for details on mounting and positioning tapes. Run FITTP or FITAB (§ 11.2.1) on all *uv* data and image files that you wish to keep. Then run PRTTP on your tape to make a record of —and double check — its contents.

## 10.5 Combining single-dish and interferometer data

We add this section to this chapter with some trepidation since the combination of single-dish data into interferometric imaging is still an area more suited to research than to production. In principle, the problem is fairly simple. You begin by observing a region of sky with a single-dish telescope rather larger than the individual telescopes of the interferometer. From these observations, you make an image which you correct if necessary (*e.g.*, by removing spectral baselines). Then you deconvolve the image removing the convolution of the sky with the beam of the large single-dish telescope. The "sky" observed with the interferometer is the product of the real sky (estimated by your deconvolved image) and the beam of the individual telescopes of the interferometer. Therefore, you multiply your deconvolved image with an image of the single-dish beam and Fourier transform the result. Adjusting the flux scales (usually of the single-dish data), you append or "feather in" the "visibilities" produced by the Fourier transform.

This is a lot of steps and contains several dangers, namely pointing, image alignment, the deconvolution, and the flux re-calibration. *AIPS* can provide you with some help. The imaging and image correction software is described earlier in this chapter. The deconvolution is tricky. Try DCONV first. It attempts an iterative solution of the deconvolution problem in the image plane. If that is not acceptable, try CONVL with OPCODE 'DCON' (in 15JAN96 and later releases). This is a brute force deconvolution that will be very noisy at high spatial frequencies, but these frequencies will be tapered or truncated away later. A third approach is to use PATGN (OPCODE 'GAUS') to make an image of the single-dish beam of the large telescope. APCLN (§ 5.3.7) can then be persuaded to do a Clark image-based Clean; use a small restoring beam. Remember that this image will (must) be tapered in the *uv* plane. It does not have to be beautiful in detail in the image plane.

The next step is to make an image of the interferometer single-dish beam on the same cell size and center as your deconvolved image. Use PATGN with OPCODE 'BEAM' for this. Then multiply the result by the deconvolved image with COMB using OPCODE 'MULT' (§ 7.1). If this produces an image with any blanked pixels, run REMAG to convert the blanks to zeros. Then start trying IM2UV to produce a *uv* data set. Use UVTAPER to weight down longer spacings, FLUX to scale the visibilities, and UVRANGE to omit the outer spacings. (The first two options appear only in 15JAN96 and later releases.) You should use PRTUV, UVPLT, and even UVFLG on the output of IM2UV to make sure that the visibility phases and amplitudes of your single-dish and interferometer data are in reasonable agreement. Finally, combine the two data sets with DBCON and have fun with IMAGR (Chapter 5).

# 11 EXITING FROM, AND SOLVING PROBLEMS IN, *AIPS*

This chapter contains a grab-bag of miscellaneous advice on exiting from *AIPS* and on solving a variety of common problems that may arise. The latter are also addressed in § Z.1.5.

## 11.1 Helping the *AIPS* programmers

Comments, suggestions and bug reports about any facet of *AIPS* are very useful to the *AIPS* programming and management group. Note that "gripes" are only useful when they are informative — *e.g.*, giving details of the circumstances under which a task failed with accompanying system error messages (if any). Terse gripes along the lines of "UVCOP doesn't work!" whilst perhaps true in some circumstances, are unlikely to arouse the *AIPS* programmers' enthusiasm. In many cases, it may be necessary for the programmer to use your data to fix the bug. A FITS-disk file read over the net is a common means to this end. The *AIPS* group may often seem unresponsive to your gripe. This is an unavoidable consequence of the breadth of the *AIPS* project combined with the small size of the group. Nonetheless, if you do not tell the programmers that there is a problem or a good idea, then you are almost certain to encounter the same problem years later and never to see your good idea put into practice. The *AIPS* group depends on help from users.

Gripes can be entered into a site-wide "GR" file and automatically mailed to daip@nrao.edu by typing:

\> GRIPE C<sub>R</sub>

while in AIPS. Follow the directions to record your comment. Current gripes in the file may be read via

| | |
|---|---|
| > GRINDEX C_R | to display an index of all gripes in the file. |
| > JOBNUM *n* ; GRLIST C_R | to list the $n^{\rm th}$ gripe in the file. |

and a gripe may be deleted with

| | |
|---|---|
| > JOBNUM *n* ; GRDROP C_R | to delete the $n^{\rm th}$ gripe in the file and notify daip. |

Note that the deleted gripe has already been e-mailed to the *AIPS* group in Socorro, so dropped ones get sent too. Do not do a GRDROP unless you realize that the gripe was erroneous. (An explanatory "gripe" would be appreciated.) If you change your mind about a gripe before you finish it, type _forget or _FORGET (case sensitive!) to stop the gripe before it is mailed and entered in the file. The addition of automatic e-mail gives immediacy to all gripes and provides, for the first time, real access to the gripe system for sites outside of the NRAO.

## 11.2 Exiting from *AIPS*

Before ending a period of data reduction with *AIPS*, you should back up those data files which you wish to keep, delete all of your disk data files, tidy up your work area, and then issue the KLEENEX (to stop the TV, tek, and message servers too) or EXIT (to leave the servers running) command to the AIPS program. Of course, if the computer and disks are part of your very own workstation in your office, you may ignore all this advice. The tape back-ups are a very good idea in any case. Disk files are easily deleted due to software or user malfunction, or lost due to disk hardware malfunction.

### 11.2.1 Backups

While processing and particularly just before exiting from *AIPS*, please delete as many of your own data sets as possible. Images and *uv* data may be backed up on tape in FITS format using the task FITTP. This task can write more than one *AIPS* file on tape in a single execution. For example, to backup all sorted *uv* files (class UVSRT), type

| | |
|---|---|
| > TASK 'FITTP' ; INP C_R | to review the inputs. |
| > DOALL TRUE C_R | to specify that all files with the allowed name parameters are to be written. |
| > CLRNAME C_R | to allow any name, class sequence number and disk. |
| > INTYP 'UV' C_R | to restrict to *uv* files. |
| > INCLASS 'UVSRT' C_R | to restrict to class UVSRT files. |
| > INP C_R | to check the inputs. |
| > GO C_R | to write the tape. |

Then, for example, to write all 3C123 files on disk 2 after the sorted *uv* data files, type:

| | |
|---|---|
| > INTYP ' ' ; INCLASS ' ' C_R | to allow any class and type. |
| > INNA '3C123' ; INDISK 2 C_R | to restrict things to 3C123 files on disk 2. |
| > WAIT ; GO C_R | to have AIPS wait for the FITTP execution started above to finish and then to run FITTP with the new inputs. |

Note that this sequence will write two copies of any 3C123 UVSRT files to be found on disk 2.

Task FITAB also writes FITS tapes. For *uv* data it has the advantage of being able to write the data in compressed form, saving disk or tape, and of writing the data in multiple "pieces" for increased reliability. Unfortunately, the table form of data used may not be read by older *AIPS* versions and is not understood by other software systems. FITAB was revised in October 2007 and subsequent output can only be read by versions of UVLOD and FITLD revised in a corresponding manner, current to end of October, 2007 in version 31DEC07. Note that FITAB is used for processed *uv* data by the NRAO archive — it will matter to many users to update to the final 31DEC07 or later releases. FITAB may apply a quantization to images on output that allow the FITS files to be compressed very much more efficiently. If the quantization level is set below 1/4 of the image noise, then the noise in the output image will only be 1–2% larger than in the input image.

### 11.2.2 Deleting your data

Please delete redundant images and data as soon as possible to preserve disk space for yourself and other users. It is tempting to work on many sets of data at the same time, but this generally takes a lot of disk space and users should limit the amount of data resident on disk to that which will be processed during the session. A data set and all extension files can be deleted by:

| | |
|---|---|
| > IND *n* ; GETN *ctn* C_R | where *n* and *ctn* select the disk and catalog numbers of the data set to be deleted. |
| > ZAP C_R | to do the deletion. |

To delete data in contiguous slots from *n* to *m* in a catalog, set the INDISK and use the loop:

> FOR I = *n* TO *m* ; GETN I ; ZAP ; END C_R

For massive deletions — the kind we hope you will use when you leave an NRAO site — use:

| | |
|---|---|
| > ALLDEST C_R | to destroy all data files consistent with the inputs to ALLDEST. |

And to compress your message file, after using PRTMSG to print any you want to keep, use:

| | |
|---|---|
| > PRNUM -1 ; PRTASK ' ' ; PRTIME 0 C_R | to do all messages. |
| > CLRMSG C_R | to do the clear and compress. |

DO NOT DELETE OTHER USERS' DATA OR MESSAGES WITHOUT THE EXPLICIT PERMISSION EITHER OF THE OTHER USER OR OF THE AIPS MANAGER.

### 11.2.3 Exiting

To exit from AIPS type:

| | |
|---|---|
| > EXIT C_R | to leave TV, message, and graphics servers running, or |
| > KLEENEX C_R | to kill server processes as well as AIPS. |

Please clean up any papers, tapes, etc. in the area around your terminal before you go.

## 11.3 Solving problems in using AIPS

On all computer systems things go wrong due to user error, program error, or hardware failure. Unfortunately, AIPS is not immune to this. The section below reviews several general problem areas and their generalized solutions. Refer to § Z.1.5 for the details appropriate to NRAO's computer systems. Some well-known possibilities follow.

### 11.3.1 "Terminal" problems

If your workstation window is alive, but AIPS has "disappeared" you may have "suspended" it by typing CTRL Z. The AIPS can be left in a suspended state, placed into the "background" with bg, or returned to the "foreground" again with fg after which it will resume accepting terminal input. If your AIPS appears to be "suspended", try typing jobs to see which jobs are attached to your window and then use fg %*n* to bring back job *n* where *n* is the job number of the suspended AIPS. If no AIPS job is suspended from the current window, check all other windows you have running on the workstation for the missing simian before starting a new AIPS. Otherwise, you may run out of allowed AIPSes and/or encounter mysterious file locking problems.

If your workstation window (or terminal on obsolete systems) is "dead", *i.e.*, refuses to show signs of talking to your computer, you have a problem. There are numerous possible causes. If typed characters are shown on the screen, but not executed, then

1. Are you executing a long verb, *e.g.*, REWIND, AVFILE, RESCALE? If so, be patient.
2. Are you executing some interactive TV or TEK verb which is waiting for input from the cursor or buttons? If so, provide the input.
3. Have you started a task with DOWAIT set to TRUE (+1.0)? If so, wait for the task to finish. Most tasks report their progress on the message monitor window (or your input window).
4. Is AIPS waiting while a tape rewinds or skips files or is it waiting to open some disk file currently being used by one of your tasks? Be patient.

If typed characters do not appear, then

1. Have you stopped output to your window accidentally by hitting the appropriate NO SCRL or other XOFF control sequence? If so, hit the XON control sequence. (These are CTRL S and CTRL Q, respectively.)

2. Do other windows connected to the computer appear to be "alive"? If so, use one of them and inquire about the status of your `AIPS` program and tasks; on Linux and Berkeley Unix try `ps aux` C_R and on Linux, Solaris and other Bell Unix try `ps -elf` C_R. It might be necessary to stop your old `AIPS` session from your new window and then use that window to start a new `AIPS`.

3. Can you abort `AIPS` at your window using the appropriate system commands (*i.e.*, `CTRL C` on Unix machines)?

4. If all windows appear dead, then your computer or its X-Windows server may have "crashed." Try a remote login from another computer. If that works, check on your processes and try to kill the server and other tasks. This should return your computer to a login state. Otherwise, report the problem to your AIPS Manager or System Administrator. If you feel you must reboot the system, do so *only* after checking that all current users and the System Administrator (if available) agree that that action is required.

5. If even a reboot fails, report the problem to the System Administrator or hardware experts and go do something else. UNDER NO CIRCUMSTANCES SHOULD YOU ATTEMPT TO REPAIR ANY HARDWARE DEVICES. Such repairs must be performed by trained personnel.

### 11.3.2 Disk data problems

If you encounter the message `CATOPN: ACCESS DENIED TO DISK` *n* `FOR USER` *mmm*, it means that user *mmm* has not been given access to write (or read) on limited-access disk *n*. The access rights for all disks can be checked by typing `FREESPAC` in the `AIPS` session. In the list of mounted disks, the `Access` column can say `Alluser`, `Scratch` (scratch files only), `Resrved` (limited access including you), and `Not you` (limited access not including you). If you feel that you should have access to that particular disk, resume using your correct user number or see your AIPS Manager about enabling your user number.

If your data set seems to have disappeared, consider

1. Have you set `INDISK` *et al.* (especially `INTYPE`) correctly before running `CAT`? Type `INP CAT` C_R to check. Is `USERID` not set to 0 or your user number?

2. Are you connected to the right AIPS computer, if your site has more than one?

3. Are the desired disks mounted for your `AIPS` session? Type `FREE` C_R to see which disks are currently running and which numbers they are assigned in this session. When you attach disks from other computers (using the `da=` option of the `aips` command — § 2.2.3), they are assigned numbers which depend on the list of computers and which may thus vary from session to session.

4. Did you leave your file untouched for a "long" time on a public disk? System managers may have had to delete "old" files to make room for new ones. In this case your data are gone and we hope you made a backup on tape.

The message **`write failed, file system is full`** will appear when the search for scratch space encounters a disk or disks without enough space. (AIPS usually emits messages at this time as well.) This is only a problem when none of the disks available for scratch files has enough space, at which point the task will "die of unnatural causes." Run the verb `FREESPAC` to see how much disk is available and then review the inputs to the task to make sure that `OUTDISK` and `BADDISK` are set properly. Change them to include disks with space. Check the other adverbs to make sure that you have not requested something silly, such as a 2000-channel cube 8096 on a side. Then try again.

If there simply is not enough space, try some of the things suggested in § 3.6, such as `SCRD` to delete orphan scratch files, `DISKU` to find the disk hogs, and, if all else fails, `ZAP` to delete some of your own files. Your

*AIPS* Manager may help you by removing non-*AIPS* files from the *AIPS* data disks. Do not do this yourself unless they are your files.

### 11.3.3 Printer problems

All *AIPS* print operations now function by writing the output to a disk text file, then queuing the file to a printer, and then sometime later, deleting the file. After the job is queued, the *AIPS* task or verb will display information about the state of the queue. Read this carefully to be sure that the operation was successful and to find out the job number assigned to your print out. If you are concerned that your print job may be lengthy, or expect that you will only need a few numbers from the job, please consider using the `DOCRT` option to look at the display on your terminal or the `OUTPRINT` option to send the display to a file of your choosing without the automatic printing. See § Z.1.5.3 for information about printing such files later.

To find out what jobs are in the spooling queue for the relevant printer, type, at the monitor level:

| | |
|---|---|
| $ lpq -P*ppp* C<sub>R</sub> | to show printer *ppp*. |
| $ lpstat *ppp* C<sub>R</sub> | to show printer *ppp* under Solaris, HP, SGI (Sys V systems). |

where *ppp* is the name of the printer assigned to you when you began `AIPS`. If the file is still in the queue as job number *nn*, you can type simply

| | |
|---|---|
| $ lprm -P*ppp* *nn* CR | to remove the job. |
| $ cancel *nn* CR | to remove the job under Sys V systems. |

`lprm` and `cancel` will announce the names of any files that they remove and are silent if there are no jobs in the queue which match the request.

Since modern printers are capable of swallowing large amounts of input, your job may still be printing even though it is no longer visible in the queue. If you turn off the printer at this stage, you are likely to kill the remainder of your print job and quite possibly one or more other print jobs that followed yours. Use discretion. Do not turn the printer back on if the job is still in the queue. Most systems will start the print job over again after you turn the power back on without doing a `lprm` or `cancel`.

If your printout fails to appear

1. Did the print queuing actually work? Review the messages at the end of the verb or task.
2. Did the printout go to a printer other than the one you expected? Was it diverted to a printer used for especially long print jobs or one used for color plots? The messages at the end of the verb or task should show this.
3. Was the printer not working or backed up for so long that the file was deleted before it could be printed? The delay time for deletion is shown at the end of the verb or task. It can be changed by your *AIPS* Manager for future jobs.
4. Was your print job, or that of a user in the queue ahead of you, a large plot? These can take a long time in some PostScript printers (usually indicated by a blinking green light), so be patient.

### 11.3.4 Tape problems

When `AIPS` does a software `MOUNT` of a magnetic tape, it actually reads the device on most systems. An error messages along the lines of `ZMOUN2: Couldn't open tape device` ... usually means that you have attempted the `MOUNT` before the device was ready. Wait for all whirring noises and blinking lights to subside and try again. Remote tape mounts are more fragile. If you get a message such as `ZVTPO2 connect (INET):`

`Connection refused`, then the tape dæmon `TPMON` is probably not running on the remote host. `EXIT` and restart `AIPS`, specifying the remote host in the `tp=` option (see § 2.2.3). If you are told `AMOUNT: TAPE IS ALREADY MOUNTED BY TPMON`, then there is a chance that you are trying to mount the wrong tape or that someone left the tape device in a mounted state. See § Z.1.5.7 for advice on curing this stand-off between `AIPS`, which knows that the tape is not mounted, and `TPMON` which knows that it is.

If you are having problems reading and writing a tape, consider

1. Did you actually mount the tape in software from the *AIPS* level with the `MOUNT` verb. A message like `ZTPOPN: NO SUCH LOGICAL DEVICE = AMT0`*n*`:` indicates that you have not.
2. Have you specified the `INTAPE` or `OUTTAPE` number to correspond with the drive you mounted the tape on?
3. Does your computer have access to tapes on the remote host? The message `AIPS TAPE PERMISSION DENIED ON REMOTE HOST` suggests not. See the *AIPS* Manager for the remote host.
4. Is the tape correctly loaded in the drive and is the drive "on line" (check the `ON LINE` light)?
5. Have you set the density correctly? Some drives need the density to be set by a switch, others have software control. Some try to read the tape and sense the density automatically. Be aware that some drives do not set the density until you actually read or write the tape. Under these circumstances, the density indication on the drive can be misleading. If in doubt, consult your local *AIPS* Manager about the meaning of the tape density indicator lights on the drive you are using.
6. Are you using the correct program to read the tape? If you are unsure of the format of a tape, use the task `PRTTP` to diagnose it for you. It will recognize any format that *AIPS* is able to read.
7. Are you writing to a completely blank tape? This fails sometimes. Or are you writing to an old tape which is new to you? In both cases, try specifying `DOEOT FALSE` C<sub>R</sub> and then rerunning the tape-writing program.
8. Has the drive been cleaned recently? Do *not* attempt to clean a drive yourself. Using the wrong cleaning fluid or cleaning the wrong parts of a drive can do serious damage. If you have any doubts, use another drive.
9. Is your tape defective? Tapes can lose oxide or become stretched, creased, or dirty, all of which will cause problems. Try using another tape, if possible.

## 11.4 Additional recipe

### 11.4.1 Banana coffeelate

1. Peel and mash 2 ripe **bananas**.
2. Blend in 1/2 teaspoon **vanilla extract**, a few grains **salt**, 1/4 cup **chocolate syrup**, 2 teaspoons **sugar**, and 2 teaspoons instant powdered **coffee**.
3. Add $1\frac{1}{2}$ cups **milk**.
4. Beat with rotary beater or electric mixer until smooth and creamy. Chill.

# 12 *AIPS* FOR THE MORE SOPHISTICATED USER

The program AIPS uses the *POPS* language to communicate with you. *POPS* has many capabilities that have been hidden or taken for granted in the previous sections. Once you start to become familiar with *AIPS*, you will need to know more about *POPS* to take full advantage of the powerful features which are available. The first section below describes some of the shortcuts and conventions of *AIPS* while the second section describes program flow control options.. The third section describes multiple features of the *POPS* language including the constructions of procedures. The fourth section addresses the needs of "remote" users of *AIPS*, while the last section discusses how to begin writing your own *AIPS* tasks.

## 12.1 *AIPS* conventions

### 12.1.1 AIPS shortcuts

Some niceties of using *POPS* syntax in *AIPS* are:

1. More than one expression can be put on a line. These expressions must be separated by a semicolon ( ; ). Exceptions are RESTORE, GET, RUN and a few other "pseudoverbs" which, with their arguments, must stand alone. For example, GET MYIMAGE ; INDISK = 1 C_R will ignore the INDISK = 1. When in doubt, see the HELP files for the pseudoverb to find the restrictions on its use.
2. As in many other systems, recognized keywords in AIPS do not need to be typed in full. You must type only enough of the leading characters to get a unique match. This "minimum-matching" has been exploited throughout this *CookBook*. If in doubt, hit the Tab key. The keyword will be completed if it is unique or the screen will blink. Hit the Tab key a second time to see your choices.
3. The parameter variables in AIPS are called "adverbs." They are assigned values by the equals verb ( = ), *e.g.*, INTAPE = 2 C_R. The equals sign may usually be replaced by a space. The exception arises when the variable on the left is a subscripted array element and the expression on the right involves a unary minus or other function reference (*e.g.*, APARM(3) = -1 ; APARM(4) = SIN(X) C_R).
4. Array adverbs are set to a constant value by putting a single value on the right hand side of the equals sign, *e.g.*, CELLSIZE = 1.5 C_R. A list of values may be put in the array by putting the list on the right hand side of the = sign separated by commas ( , ), *e.g.*, LEVS = -1, 1, 2, 3, 6, 9 C_R. The commas may be replaced by spaces in most cases. An exception occurs if an element is negative or some other arithmetic expression. Thus, SHIFT = -19 -2 C_R will produce SHIFT = -21, -21.
5. A list of values may also be put in a sequence of scalar adverbs with the ~ (tilde sign) adverb. The main use of this is to overcome the 80-character limit for input lines to *POPS* in assigning values to an array. Thus, for example,
   RASHIFT = -3000, -2500, -2000, -1500, -1000, -500, 0, 500, 1000 C_R
   RASHIFT(10) ~ 1500, 2000, 2500, 3000 C_R
6. Adverbs can be used in arithmetical expressions or set equal to other adverbs, *e.g.*, OUTNAME = INNAME ; OUTSEQ = 2.5 * INSEQ + 3.
7. Both upper and lower case letters may be entered by the user; with one exception, *AIPS* is case insensitive. That exception is in adverb character string values, which are converted to upper case by

the trailing quote sign. If you omit the trailing quote — and make that the last command on the input line — then case is preserved (and used) in the string.

As an example, these shortcuts allow the following AIPS command sequence:

```
> INNAME = '3C138' CR
> INCLASS = 'IMAGE' CR
> INSEQ = 0 CR
> BLC = 200 , 200 CR
> TRC = 300 , 300 CR
> OUTNAME = '3C138' CR
> OUTSEQ = 5 CR
> GO PRTIM CR
```

to be shortened to:

```
> Inn '3c138' ; INC 'image' ; blc 200 ; Trc 300 CR      (Note use of upper and lower case.)
> OUTN INN ; OUTS INS + 5 CR
> go prti CR                                          (Task name can be in either case, too.)
```

### 12.1.2 Data-file names and formats

The physical name of the data file is generated internally, depends on the type of computer, and will not often concern you as a user. You will refer to an image by specifying its disk number, the type of image ('MA' for images, 'UV' for *uv* data), and the following three parts of the image designation:

1. Name — A string of up to 12 legal characters.
2. Class — A string of up to 6 legal characters.
3. Seq — A number between 0 and 9999.

Each of these parts corresponds to separate input adverbs called INNAME, INCLASS, and INSEQ (and their variations). You can choose the image name arbitrarily and sensible choices will reduce other book-keeping. Many programs will choose a reasonable image name if you do not specify one.

A common set of conventions for the name adverbs is used throughout AIPS. INNAME ' ' CR means "accept any image name with the specified class and sequence." INSEQ 0 CR means "accept any image with the specified name and class" or, if only one image is to be used, "accept the image with the specified name and class having the highest sequence number." OUTNAME ' ' CR means "use the actual INNAME." OUTCLASS ' ' CR means "use the task name," except for tasks that write more than one output image, in which case task-based defaults will be used. OUTSEQ 0 CR means "use a sequence number that is one higher than that of any files currently on disk with the same name and class as the requested output file." The name and class strings also support "wild-card" characters for input and output. This feature is especially powerful in tasks, such as FITTP, that can be told to operate on *all* images that match the specified name parameters. Type HELP INNAME CR and HELP OUTNAME CR for details.

Only the array data, in the form of 4-byte floating-point numbers, are stored in the image or *uv* data file. The header information is stored separately for each image or *uv* data set. Directory information is stored in a special file, called the Catalog File. Each disk has one such file for each user and it contains directory information for all images and *uv* data sets belonging to that user.

Extension files may be associated with any image data file. Each image can have (in principle) up to fifty types of extension files and up to 46655 "versions" of each type. These subordinate files contain additional information associated with the image and are designated by a two-letter type code. 'HI' is a history file, 'CC' is a Clean components file, 'PL' is a plot file, 'AN' is an antennas file, 'SL' is a slice file. In *AIPS*, an extension file associated with an image is uniquely specified by the usual file-naming adverbs plus the extension file type (adverb INEXT) and the version number (adverb INVERS). The default convention for INVERS is reasonable — on input, zero means the highest (*i.e.*, most recent) version and, on output, the highest plus one.

Array elements in an image are designated by their pixel coordinates (counts). If $M(i, j, k, l, m, n, o)$ is a seven-dimensional array, the (1,1,1,1,1,1,1) pixel will be associated with the lower left hand corner of the image. The $i^{\rm th}$ (first) coordinate increments fastest and is associated with a column in each plane of the image. The $j^{\rm th}$ (second) coordinate is associated with a row in each plane. The other coordinates allow the image to be generalized to cover up to seven dimensions, *i.e.*, "cubes" and the like. The two adverbs BLC for bottom left corner and TRC for top right corner let you specify the desired sub-array in up to seven dimensions. When a sub-image is taken from an image, the pixel designation of any image element will usually change.

## 12.2 Process control features of *AIPS*

There are a number of tools available to assist you in scheduling and controlling the execution of *AIPS* tasks. They include taking the input from a text file rather than an interactive terminal, special adverbs to the verb GO, and even one or more detached, batch processing queues.

### 12.2.1 RUN files

If you have some lengthy sequence of commands to give to AIPS, especially if you will have to give essentially the same sequence more than once, you may find it helpful to prepare the sequence in a text file using your favorite and flexible text editor. In particular, it is cumbersome to write and edit procedures more than about five lines long in *AIPS* because of its primitive internal editor. Long procedures are best written as text files at your computer's monitor level, where the editing facilities will usually be much better. These text files can be transferred to AIPS easily using the RUN file facility.

Any commands that can be typed on the terminal to AIPS can be stored in your text file. The text files may be stored in a disk area of your choosing or in a public area identified by the logical name $RUNFIL. The name of the file must be all upper case letters, followed by a period, followed by your user number as a three-digit "extended-hexadecimal" number with leading zeros. (To translate between decimal and extended hexadecimal, use the *AIPS* procedures or the AIPS verbs called EHEX and REHEX.) To use the RUN file from your own disk area, define a logical name before starting AIPS to point to the area (see § 3.10.1). Then start up AIPS under your user number and enter

| | |
|---|---|
| > VERSION = 'MYAREA' C_R | where MYAREA is your disk area, or |
| > VERSION = ' ' C_R | if $RUNFIL is to be used |
| > RUN *FILE* C_R | to execute the file named *FILE.uuu* |

where *uuu* is your user number in extended hexadecimal with leading zeros to make three digits. The file *FILE.uuu* or, if it does not exist, *FILE.001* will be executed by the above command. Note that minimum match also applies to RUN file names.

The first line of a RUN file is ignored by AIPS. You should type comments into your RUN files to remind you what they are doing. The first line, any line which begins with an * in column one, and all text following a $ sign (in any line) are treated as comments which will not be compiled or executed by AIPS. All facilities in AIPS such as GET, SAVE, and TGET can be used in RUN files, with the sole exceptions of RUN itself and the pseudoverb COMPRESS which makes use of the RUN process. The full contents of a SAVE area may be put in a RUN file in 31DEC02 and later using SG2RUN.

AIPS programmers also provide a few RUN files for general use in each release *e.g.*, VLACALIB, VLACLCAL and VLARESET. They are normally used to create procedures helpful to some, but not all, AIPS users. These are stored under user number 1, but are available automatically to everyone. To use a procedure from one of them, type, for example:

> RUN VLAPROCS C_R — to read and execute file VLAPROCS in AIPS. The text will be listed as it is read.

This file contains a number of procedure definitions including those named above. To execute the procedure, prepare the input adverbs as needed, and then type

> VLACALIB C_R — to execute the calibration sequence of the simplified procedure.

AIPS programmers will provide a file with the inputs and help information for all canned procedures. Thus you can do

> HELP VLACAL C_R — to see help information on the procedure.

> INP VLACAL C_R — to see the current inputs to the procedure.

The help and inputs functions may require the RUN if special adverbs are used by the procedure, but you must do the RUN to compile the procedure before you can use it.

### 12.2.2 More about GO

The verb GO is shown in examples throughout this *CookBook*. Don't overlook the fact that GO, like all other AIPS verbs, has its own inputs. You will be familiar with the ability to specify which task you want to execute either by an immediate argument, *e.g.*, GO UVSRT C_R, or by the parameter TASK, *e.g.*, TASK 'UVSRT' ; GO C_R. GO has two further parameters, DOWAIT and VERSION. The value of DOWAIT is passed to the task and instructs it to resume AIPS as soon as possible (DOWAIT FALSE C_R) or to resume AIPS only after completing its operations (DOWAIT TRUE C_R). The latter option lets the task return a meaningful error code to which AIPS may respond by aborting the current input line, procedure, FOR loop, etc. Note that the verb WAIT '*taskname*' also forces AIPS to wait for a task to complete, but it cannot respond to some failure in that task. For example, the line:

> GO UVSRT ; WAIT UVSRT ; GO UVMAP C_R

may cause unwanted images to be generated by UVMAP if UVSRT fails for lack of disk space or some other reason. However, the line:

> DOWAIT TRUE ; GO UVSRT ; GO UVMAP C_R

will not attempt to execute UVMAP if UVSRT fails. Note that AIPS will not get hung up when a task aborts even if DOWAIT is true. *This consideration is particularly important when you do multiple runs of* FITTP *to write your output tape. If one fails, the tape may even be rewound. If the next scheduled* FITTP *actually runs, it may write at the beginning of tape, destroying all previous data on the tape!*

VERSION, the last input to GO, is used to specify which version of the program you wish to execute. You might use this to select the TST or OLD versions of a task from the NEW version of AIPS, for example. VERSION also allows you to execute private versions of programs and even to check a list of areas for versions of your program. Type HELP VERSION C_R for details.

GO has another useful capability. Normally, in order to invoke a verb, you simply type its name, *e.g.*,:

> PRTMSG C_R — to print the message file contents.

However, if you type, instead:

> GO PRTMSG C_R

having forgotten that PRTMSG is a verb, then AIPS will actually execute:

| | |
|---|---|
| > TPUT PRTMSG ; PRTMSG CR | to save the current PRTMSG inputs and then print the contents of the message file. |

You can recover those inputs at a later time with TGET PRTMSG CR.

### 12.2.3 Batch jobs

The *AIPS* batch processor can be used to run jobs outside interactive *AIPS*. The job consists of a set of *AIPS* instructions which do not need user interaction. This excludes the TV, the Tektronix, and the tape-drive oriented tasks and verbs. RUN files may be used in batch jobs — as the batch editor facility is also primitive, they are particularly attractive to batch users. Older restrictions on which tasks may be run in queue 1 have been removed in the 15JAN96 release.

The instructions to be executed in the batch processor are prepared in a "workfile." The workfile can be made while in AIPS and detailed instructions are given by typing:

> HELP BATCHJOB CR

A simple example is given here:

| | |
|---|---|
| > BATQUE = 2 ; BATCLEAR CR | to select queue 2 and clear its workfile. |
| > BATCH CR | to enter batch preparation mode. |
| < TASK = 'UVSRT' CR | (Notice < prompt. Begin typing as in AIPS.) |
| < INN = '3C16' ; INCL = 'UVDATA' CR | |
| < INSEQ 1 ; OUTN INN ; OUTCL INCL CR | |
| < OUTSEQ = 0 ; SORT = 'XY' CR | |
| < GO CR | (Batch AIPS always waits for a task to finish before continuing.) |
| < RUN XXXXX CR | (RUN files are good to use in a batch job.) |
| < GO CR | |
| < ENDBATCH CR | to leave batch preparation mode type in ENDBATCH spelled out in full. |
| > | (Resume normal interactive processing.) |

To list a batch file, type:

> BATFLINE = 0 ; BATLIST CR

To edit line $n$ in a batch file, type:

| | |
|---|---|
| > BATEDIT $n$ CR | |
| < *put text here* CR | to replace old line $n$. |
| < *some more text* CR | to insert more commands between old lines $n$ and $n$+1. |
| < ENDBATCH CR | (spelled out in full.) |
| > | (Resume normal interactive processing.) |

As with procedures (§ 12.3.2), if $n$ is an integer, the existing line $n$ is overwritten with the line or lines typed before ENDBATCH. If $n$ is not an integer, the new lines are simply inserted between lines $n$ and $n$+1. BAMODIFY provides, for workfiles, the same functions as MODIFY does for procedures.

Finally, the workfile can be submitted to the batch processor by typing:

> SUBMIT CR

The instructions are sent to a checking program which checks that the input is free of obvious errors. All RUN files are expanded and checked. If Checker (the task AIPSC$m$ where $m$ is some extended hexadecimal number $<$ Z) approves, the job goes into the *AIPS* job queue, which is managed by QMNGR$n$. If you change your mind, the job can be removed from the queue and returned to the workfile with the verb UNQUE. Beginning with 31DEC10, the batch job may be submitted to any local computer, not just the one on which the current

*AIPS* session is running. Adverbs REMHOST and REMQUE control this option. The remote host must be one sharing the same *AIPS* installation as the current session. Note that the data must also be available to the remote host, but verb ADDDISK may be useful either within the batch job or in preparing the data files for the job. REMOST is supported by all relevant batch-related verbs.

Batch has several limitations. First, devices which require interactive use (TV device, Tektronix device, and the tape drives) cannot be used in batch. Also, batch uses a different set of TPUT and TGET files. Thus, a TGET in batch does not get the adverbs from your last interactive use of the specified task. However, the AIPS facilities GET and SAVE are particularly useful for batch. You can use interactive AIPS to set up and test set(s) of procedures and adverb values and SAVE them in named files. These files may then be recovered by batch for the routine processing of large sets of data. This is considerably more convenient than using the batch editor. Note that SAVE / GET files may become obsolete with new *AIPS* releases, but that improvements to the *POPS* language have made this quite unlikely.

At present, batch jobs are run after a short delay, on a first-come, first-served basis. After your job has been submitted successfully, type:

`> QUEUES` C_R to list jobs in the queue.

Note the SUBMIT TIME for your job. It will not start before that time. The messages generated by your batch job will be printed automatically into a text file. They are kept in your message file, however, and can be reprinted or examined later via PRTMSG with PRNUMB set to the *AIPS* number of the batch queue. Printer output for batch jobs is concatenated into a file either specified by the user with OUTPRINT or a file named PRTFIL:BATCH*jjj*.*nnn*, where *jjj* is the job number and *nnn* the user number both in extended hexadecimal. Note, this means batch job printouts are concatenated in (normally) one file and are not automatically printed. An interactive AIPS can interact with a batch job via TELL; see § 5.3.1.

## 12.3 AIPS language

AIPS contains a basic set of symbols and keywords which are needed to construct a computer language, as well as the symbols needed by the application code. A list of the basic symbols is given in the help file called POPSYM, reproduced below:

```
Type:  Symbols used in the POPS interpretive language

    VERB      USE        COMMENTS

                   ----Arithmetic expressions

     +       A + B       Add the expression A to B
     -       A - B       Subtract the expression B from A
     *       A * B       Multiply the expression A with B
     /       A / B       Divide the expression A by B
     **      A ** B      Calculate A to the power B
     ( )     (A+B)*C     Grouping expressions as desired
     =       A = B       Store the value of B into A
     ,       A = 3,5,4   Separator of elements in an array
     ~       A(i) ~ 1,2,3  Store values in A(i),A(i+1)...
                         (change only as many as on RHS)
     :       TO          Equivalent to the verb TO
     ;                   Separator between AIPS statements

                   ----Logical expressions
```

```
     >       A > B       A greater than B
     <       A < B       A less than B
     =       A = B       A equal B (numeric or string)
     >=      A >= B      A equal to or greater than B
     <=      A <= B      A equal to or less than B
     <>      A <> B      A not equal to B (numeric or string)
     !       A ! B       A or B
     &       A & B       A and B
     ^       ^ A         not A

                 ----String expressions

   !!       A !! B        string = string A followed by string B
   SUBSTR   SUBSTR(A,i,j) string = chars i through j of string A
   LENGTH   LENGTH(A)     position last non-blank in A
   CHAR     CHAR(A)       convert number A to string
   VALUE    VALUE(A)      convert string A to number


                 ----Looping constructions

   (FOR-TO-BY-END)        FOR I=1 TO 7 BY 2
                          <any valid set of AIPS syntax>
                          END

   (WHILE-END)            WHILE <any logical expression>
                          <any valid set of AIPS syntax>
                          END

   (IF-THEN-ELSE-END)     IF <any logical expression>
                          THEN <any valid set of AIPS syntax>
                          ELSE <any valid set of AIPS syntax>
                          END

                 ----Built-in functions

   ACOS          Arc-cosine - output in degrees
   ASIN          Arc-sine - output in degrees
   ATAN          Arc-tangent (one argument) - output in degrees
   ATAN2         Arc-tangent (two arguments) - output in degrees
   COS           Cosine (degrees)
   SIN           Sine (degrees)
   TAN           Tangent (degrees)
   EXP           Exponential
   LN            Log base e
   LOG           Log base 10
   SQRT          Square-root
   MAX           Maximum i.e. X = MAX (A, B)
   MIN           Minimum i.e. X = MIN (A, B)
   MODULUS       Root-square sum of two arguments
   MOD(A,B)      A - (A/B) * B  i.e. remainder of A/B
   CEIL(A)       Lowest integer >= A
   FLOOR(A)      Highest integer <= A
```

```
                  ----Procedure building verbs

  PROC       PV  Begin building a procedure
  PROCEDUR   PV  Begin building a procedure
  LIST       pV  List a procedure
  EDIT       PV  Edit a procedure
  ENDEDIT    PV  End editing a procedure
  ERASE      PV  Delete line(s) of a procedure
  MODIFY     PV  Modify a line in a procedure
  RETURN     V   Last statement in a procedure
  FINISH     PV  End procedure building

                  ----Variable declarations

  SCALAR     pV  Declare scalars
  ARRAY      pV  Declare arrays
  STRING     pV  Declare strings

                  ----Input/Output functions

  PRINT      V   Print the following keyword value(s)
  TYPE       V   Print the following keyword value(s)
  READ       V   Read value(s) from terminal after # prompt

                  ----Other information

  CORE       pV  Amount of core left in POPS
  COMPRESS   PV  Compress the core area, recovering lost space
                 and acquiring any new vocabulary
  CLRTEMP    V   Clear the temp data array
  DEBUG      pV  Debug: turns on compiler debug information
  DUMP       V   Dump K array on terminal screen
  SCRATCH    PV  Remove procedures in POPS
  $          PV  Makes rest of input line a comment
```

### 12.3.1 Using *POPS* outside of procedures

*POPS* variables are either numeric or character valued and may be multi-dimensional arrays. Once created, all variables are available everywhere, *i.e.*, they are global. You may manipulate these variables on the command line using most of the symbols listed above. In fact, you have been doing this while setting the adverbs for all the tasks and verbs described in preceding chapters. The more advanced user may wish to use some of the language features in order to simplify repetitive data processing. Here are some simple examples of uses of the AIPS language:

| | |
|---|---|
| > TYPE (2 + 5 * 6) C_R | 32 is written on the terminal. |
| > TYPE 'X =', ATAN (1.0) C_R | X = 45 is written on the terminal. |
| > TYPE 'MAPNAME ', INNAME, INCLASS, INSEQ C_R | MAPNAME 3C138 IMAGE 1 is written on the terminal. |

The simplest loop capability in AIPS uses the pseudoverbs FOR, TO, and BY for repetitive operations. Such loops are primarily intended for use in "procedures" (see § 12.3.2). If a FOR loop can be typed fully on one input line, it will also work outside the procedure mode. The following example shows how to delete a series of images with the same name and class and with consecutive sequence numbers 1 through 10:

| | |
|---|---|
| > INNA 'TEST' ; INCL 'IMAGE' C_R | to set (fixed) name parts. |
| > INDI 1 C_R | to set (fixed) disk number. |
| > FOR INSEQ = 1 TO 10 ; ZAP ; END C_R | to delete the files. |

FOR loops must be terminated with an END. The following example shows how to delete every other file in a catalog with 20 entries:

> FOR INSEQ = 1 TO 20 BY 2 ; GETN(I) ; ZAP ; END C_R

More extensive examples are shown in the sections below on procedures.

In some cases, you may wish to manipulate character strings to give your files meaningful names — particularly if your RUN file or procedure operates repetitively on many similar files. The verbs for character manipulation are listed above. As an example,

| | |
|---|---|
| > OUTNAME = 'CLEAN' !! CHAR(BLC(3)) C_R | to name each output file after the input image plane. |

Note that trailing blanks are ignored. If you wanted a space after CLEAN before the plane number, use

| | |
|---|---|
| > OUTNAME = 'CLEAN' C_R | to set the basic form. |
| > SUBSTR (OUTNAME , 7 , 12) = CHAR (BLC(3)) C_R | to alter only the last six characters of OUTNAME. |

### 12.3.2 Procedures

Procedure building is a way to combine keywords in AIPS in any convenient way to obtain useful constructs. For complicated sequences, it is easier to prepare and debug procedures in RUN files (§ 12.2.1) than to prepare them in interactive *AIPS*. A procedure is given a name, with or without arguments, and then can be treated as an *AIPS* verb. As an example, consider a procedure to load an image on the TV, set the cursor, and fit for the maximum intensity. You could type the following on your terminal:

| | |
|---|---|
| > PROC MFIT (I) C_R | to define procedure MFIT with one argument I. (I and J are two dummy adverbs which are already defined in AIPS.) |
| : GETNAME(I) C_R | (Notice the prompt symbol : . This means that we are in the procedure-building mode.) |
| : TVLOD ; IMXY ; MAXFIT C_R | to load the image, produce and read the cursor, and fit the maximum near the cursor position when a TV button is pressed |
| : RETURN C_R | to designate a return point in the procedure — normally not required at the end of a procedure unless a value is to be left on the stack, *i.e.*, a function. |
| : FINISH C_R | to designate the end of the procedure-building mode and to get back into the normal (prompt >) mode. |
| > | Notice the prompt symbol, you are back to interactive input mode. |

When you type such a procedure into AIPS, the code is compiled as you type. Most syntax errors are spotted immediately and will unceremoniously dump you out of procedure mode. However, all lines written before the detected error are kept and the procedure editor can be used to continue.

The *AIPS* procedure editing capabilities are quite primitive. If you want to build procedures longer than about five lines, we therefore recommend using permanent storage files in the "RUN" area, as discussed in § 12.2.1 above.

To list the procedure MFIT, type:

> LIST MFIT C_R

This will produce the following:

```
1PROC MFIT(I)
2GETNAME(I)
3TVLOD ; IMXY ; MAXFIT
4RETURN
5FINISH
```

The procedure is identical to what you typed, with line numbers added.

Procedures are edited line by line. To edit line 2 in the above procedure, type:

| | |
|---|---|
| > EDIT MFIT 2 C_R | to enter Procedure editing mode. |
| ; GETNAME(I) ; TVLOD C_R | (Notice prompt symbol ; for procedure-editing mode.) This change replaces the old line 2 adding a TVLOD. |
| ; IMXY ; MAXFIT C_R | to add a line between the changed line 2 and old line 3. |
| ; GETNAME(I+1) C_R | to add yet another line after 2. |
| ; ENDEDIT C_R | to terminate procedure editing. |

> LIST MFIT C_R

Listing the modified procedure will give:

```
1PROC MFIT(I)
2GETNAME(I) ; TVLOD
3IMXY ; MAXFIT
4GETNAME(I+1)
5TVLOD ; IMXY; MAXFIT
6RETURN
7FINISH
```

To delete lines $n$ through $m$ from a procedure, type:

> ERASE *xxxxxxxx* $n : m$ C_R    where *xxxxxxxx* is the name of the procedure.

To insert one or more lines between lines 3 and 4 of a procedure, type:

> EDIT *xxxxxxxx* 3.5 C_R

; *(Type additional lines as needed.)*

; ENDEDIT C_R

Notice that the lines are renumbered after any EDIT or ERASE. Use LIST to determine the new line numbers.

The pseudoverb MODIFY lets you modify characters within a line of a procedure to correct the line or change its meaning. The grammar is:

> MODIFY *proc-name line-number*    where *proc-name* is the name of the procedure and *line-number* is the line number in the procedure as shown by LIST.

MODIFY begins by showing the existing line with a ? as a prefix. Then it prompts for input with a ? To keep the character of the original line immediately above the cursor, type a blank (space-bar). To delete that character, type a $ (dollar-sign). To replace that character, type the new character (to get a new blank character, type an @ sign). Insertions complicate things. To insert text prior to the character immediately above the cursor, type a \ followed by the desired text followed by another \. You may continue to MODIFY the remainder of the line, but you must remember that the current character position in the old line is to the left of the current cursor position by the number of inserted characters (including the 2 \'s). MODIFY will display the resulting line of code after you hit a carriage return ( C_R) and does not change the line number. Example:

```
> MODIFY  ED  2 |CR
?TYPE 'THIS IS EDS PROC'
?              MY@\NEW\     @FOR@EXAMPLE' |CR
TYPE 'THIS IS MY NEW PROC FOR EXAMPLE'
> MODIFY  ED  2 |CR
?TYPE 'THIS IS MY NEW PROC FOR EXAMPLE'
?                 $$$$    \EDURE,\ |CR
TYPE 'THIS IS MY PROCEDURE, FOR EXAMPLE'
```

More information about procedure building and editing can be found by typing:

> HELP PROCEDUR C_R

Procedure creation and editing uses up the limited memory of the *POPS* processor. When the memory is gone, the message BLEW CORE! will appear and you can do no more procedure writing without starting over (*i.e.*, RESTORE 0 C_R). CORE C_R will tell you how much memory is left. If the memory remaining appears small, try COMPRESS to recover the lost memory (in 15JAN96 and later releases). COMPRESS might even work after a BLEW CORE! if you are lucky.

The procedure MFIT can be executed by:

> MFIT($n$) C_R where $n$ is the slot number of the appropriate image.

(It is assumed that the correct disk unit number has already been set.) This procedure can also be part of another procedure or put in a loop. For example:

> FOR I= 1 TO 10 BY 2; MFIT(I) ; END C_R

will load the TV and fit the maximum for the first ten images on the appropriate disk.

All the syntax available in AIPS is available for use inside procedures *except for certain pseudoverbs*. The "prohibited" pseudoverbs include SAVE, GET, STORE, RESTORE, PROCEDURE, EDIT, ENDEDIT, MODIFY, LIST, CORE, SCRATCH and COMPRESS. Others do not make much sense in procedures, including MSGKILL, DEBUG, and ABORTASK. Other pseudoverbs are, however, particularly useful in procedures. These include TGET, TPUT, and GO.

Several verbs are extremely useful in procedures. To set the image name adverbs to those visible on the TV, use TVNAME. When GETN accesses an empty slot, an error condition is raised and the procedure dies. To handle this error condition in your procedure, use EGETN $n$ instead and test the adverb ERROR which will be "true" if the slot is empty. CHKNAME may be used similarly to check on the existence of files with computed names. Some tasks require image-data dependent inputs. To help handle this in general procedures, the verb GETHEAD allows all header parameters to be fetched into adverbs. Type EXPLAIN GETHEAD C_R for details. Verbs GETTHEAD and TABGET perform similar functions for data in table extension files. Beginning in 31DEC06 the verb GETPOPSN fetches the current *POPS* number for use in procedures, for example, to allow the same procedure to run concurrently in multiple *AIPS* sessions. The verb DELAY will cause AIPS to pause for a specified period of time — MFIT above would benefit by pausing to allow the user to see his images. There are numerous arithmetic functions, useful looping constructions, and powerful methods of building arithmetic, logical, and string expressions in *POPS*. See § 12.3 above for a list of these. CLRTEMP may be used in procedures which do a lot of looping. It clears the temporary space used to hold substrings and other temporary constants. A procedure that does much string manipulation is likely to overflow this area after a number of iterations. The message BLEW TEMP C! usually accompanies the overflow.

Once a procedure is written and edited, it can be stored in a SAVE file for later use. Procedures are lost when another GET file is obtained. Procedures can be stored more permanently in RUN files which are described in § 12.2.1 above. To list the names of all procedures currently in your AIPS environment, type:

> HELP PROCS C_R

This will list internal *AIPS* procedures as well as your own.

Several procedures have been built into *AIPS*. In particular, some procedures are defined in the system

RUN file VLAPROCS to aid *routine* calibration of VLA data. Currently, these are VLACALIB, VLACLCAL and VLARESET. Similarly, VLBA reductions are aided by the procedures in the file named VLBAUTIL. They may be useful templates for your own procedures. If you are unfamiliar with the use of *AIPS* procedures, looking at these system-supplied ones will help you to understand, and see the power of, this feature of *AIPS*.

### 12.3.3 Writing your own programs with *POPS*

You may want to add your own programs to *AIPS*. It is not a trivial matter to generate an *AIPS*-standard FORTRAN program (see HELP NEWTASK CR, the *Going AIPS* manuals, and § 12.6 below). Simple but powerful programs may however be built as procedures that use existing verbs and tasks.

Consider a the following example. (This example is presented as if it were typed into an interactive AIPS. In practice, you will probably prefer to prepare such a complicated procedure as a RUN file.) We wish to determine the average value and rms scatter at any pixel location in a set of $n$ images. We shall demand that the $n$ images all have the same INNAME and INCLASS with sequence numbers between 1 and $n$. The RENAME verb can be used to name the images appropriately. We could call this procedure:

```
AVGRMS (PIXXY, N, AVG, RMS)
```

where

| | |
|---|---|
| PIXXY | is the pixel location in the images, |
| N | is the number of images, |
| AVG | is the average value at the pixel location, and |
| RMS | is the rms value at the pixel location. |

The array adverb PIXXY is a standard AIPS adverb, but the variables N, AVG, and RMS are unknown to AIPS. These must be defined before we can write the procedure AVGRMS. This is done by a short dummy procedure which we will call DAVGRMS:

| | |
|---|---|
| > PROC DAVGRMS CR | to define dummy procedure. |
| : SCALAR N, AVG, RMS CR | to define scalar adverbs. |
| : FINISH CR | to exit from dummy procedure. |

Now begin the procedure AVGRMS:

| | |
|---|---|
| > PROC AVGRMS (PIXXY, N, AVG, RMS) CR | to enter procedure building mode. |
| : SCALAR SUM, SUM2 CR | to define more variables. |
| : ARRAY VAL(20) CR | to define an array. |
| : RMS = 0 ; SUM = 0 ; SUM2 = 0 CR | to zero some variables. |
| : FOR INSEQ =1 TO N CR | to begin summing loop. |
| : QIMVAL CR | to get pixel value at PIXXY in image INNAME INCLASS INSEQ. |
| : VAL(INSEQ) = PIXVAL CR | to save pixel value (placed in PIXVAL by IMVAL) in our array. |
| : SUM = SUM + PIXVAL CR | to sum for averaging. |
| : SUM2 = SUM2 + PIXVAL * PIXVAL CR | to sum for rms. |
| : END CR | to mark end of FOR loop. |
| : AVG = SUM / N CR | to get average value. |
| : IF N > 1.5 THEN CR | to check if N > 1. |
| : RMS = SQRT((SUM2 - N*AVG*AVG) / (N * (N-1))) CR | to calculate rms if N > 1. |
| : ELSE ; TYPE 'N TOO SMALL', N CR | to warn the user. |
| : END CR | to mark end of IF clause. |

```
: TYPE 'AVG=',AVG,'RMS=',RMS,'AT PIXEL',PIXXY CR
: TYPE ' # ',' VAL ',' ERROR ' CR                  to print a heading.
: FOR INSEQ = 1 TO N CR                            to begin another loop.
:     SUM = AVG - VAL(INSEQ) CR                    to get residual.
:     TYPE INSEQ, VAL(INSEQ), SUM CR               to print data and residual.
:     END CR                                       to mark end of FOR loop.
: FINISH CR                                        to return to regular AIPS mode.
>
```

The above procedure could be run as follows. First fill in the adverbs INNAME, INCLASS and PIXXY with the desired values. Then type:

> AVGRMS (PIXXY, $n$, AVG, RMS) CR

where $n$ is the number of images to average. The average and rms will be calculated and written on the terminal and in the message file. This procedure could be used by another procedure. Suppose we wanted to determine the average and rms of the pixels within a rectangular area. If we set BLC and TRC in the usual way to define the rectangular boundary, then the procedure:

```
> PROC AVGARRAY (BLC, TRC) CR                     to define new proc.
: FOR I = BLC(1) TO TRC(1) CR                     to loop over x-coordinate
:     FOR J = BLC(2) TO TRC(2) CR                 to loop over y-coordinate.
:         PIXXY = I , J CR                        to set pixel coordinates for AVGRMS.
:         AVGRMS (PIXXY, N, AVG, RMS) CR
:         END ; END CR                            to end y loop, then x loop.
: FINISH CR                                       to end the proc., RETURN not needed.
>
```

will calculate the average value and rms at this array of pixel locations. Please note that this is just an example. The verb IMSTAT performs this function much more efficiently.

#### 12.3.3.1 Special facilities for use in procedures

When a task or verb encounters an error condition, it sets an error flag which normally causes *POPS* to terminate the line or procedure it was executing. You can avoid the termination due to task failure by setting DOWAIT FALSE and then doing a WAIT on the task. This does not let your procedure know that an error in the task occurred, but it does let you ignore any possible error. Certain verbs have a second version which sets the ERROR adverb, rather than the automatic termination flag. These include CHKNAME which checks for the existence of an *AIPS* file with specified name parameters, EGETHEAD which returns a keyword value from a header or ERROR if the keyword is not present, EGETNAME which returns ERROR if the catalog slot is empty, COPIXEL which returns ERROR if the coordinate is not in the image, and SYSTEM which returns ERROR if the function fails. Several fitting verbs, IMVAL, MAXFIT, QIMVAL, TVFLUX, and TVMAXFIT, return ERROR if the fit fails. Your procedure can test ERROR after these verbs and take appropriate action.

Numerous verbs return adverb values which may be used in your procedures. These include COPIXEL, COWINDOW, EGETHEAD, EGETNAME, EPOCONV, GAMMASET, the various GETNAMEs, GETHEAD, GETTHEAD, GREAD, IN2TV, IMDIST, IMPOS, IMSTAT, IMVAL, IMMXY, MAXFIT, QIMVAL, REBOX, SET1DG, SETSLICE, SETXWIN, TABGET, TK1SET, TKBOX, TKNBOXS, TKSET, TKVAL, TKWIN, TV1SET, TVBOX, TVCOLORS, TVDIST, TVFLUX, TVMAXFIT, TVNAME, TVPOS, TVSET, TVSTAT, and TVWINDOW. GETHEAD and the table functions GETTHEAD and TABGET are particularly useful in procedures.

The RUN file VLBAUTIL provides interesting procedures such as MAXTAB which returns the maximum table number of a specified table type. Other procedures in that RUN file include ones that return antenna number corresponding to a specific name and ones that test whether a data set appears to be new and appears to contain only VLBA antennas.

Several tasks now return adverb values. These values can then be used for later computation. These tasks include CUBIT, GAL, FINDR, IMEAN, IMFIT, JMFIT, RLDIF, and SETFC. The first two of these return image fit parameters, the next two return *uv* and image statistics, the next two return the results of Gaussian fitting, RLDIF returns the phase difference between RL and LR polarizations for polarization calibration, and SETFC returns imaging parameters including number of facets, cell size, and image size.

There is also a new verb in 31DEC04 named SYSTEM which allows the *AIPS* user to fork a command to the host operating system from within AIPS including from within procedures. This may be used to delete unwanted text or FITS files, to run `ftp` to fetch data files from the web, to run another copy of AIPS, or any of a very large number of other commands. In 31DEC09, the verb FILEZAP will allow you to delete non*AIPS* files without use of the SYSTEM verb.

## 12.4 Remote use of *AIPS*

*AIPS* users do not always find themselves seated in front of the main display screen of the computer which they intend to use for their data analysis. *AIPS* provides facilities for such users which depend to some extent on the nature and location of the workstation or terminal at which the user is seated. Nearly seamless function is provided to a user seated at a workstation on the local Ethernet well known to the *AIPS* installation. Substantial capabilities are still available to the user at a more distant workstation capable of X-Windows display, especially if that workstation can also run *AIPS* programs such as the TV server and remote tape server. Even the user at a simple terminal or workstation, capable of emulating a Tektronix 4010, can still get some interactive displays. It is only the users at very simple (and now antique) terminals who will be rather limited in their interactive use of *AIPS*.

### 12.4.1 Connections via X-Windows

In the following discussion, we will assume that you need to do your computing on a computer called *Server* and that you are sitting in front of a workstation called *MyHost*.

If *Server* and *MyHost* are both on the same local area network and both have the same byte ordering, then they should have *AIPS* installed with both of them shown as being at the same *AIPS* "site." In this case, you simply `slogin`, `rlogin`, or `telnet` into *Server* from a window on *MyHost* and issue the `aips` command as described in § 2.2.3. The `aips` command will recognize that you are coming in from *MyHost* only if the `$DISPLAY` environment variable is correct (*MyHost*:0). In that case, or if you add `tv=`*MyHost* to the `aips` command line, the procedure will start the message, graphics, and TV servers on *MyHost* if needed. If you want to share data areas between the two computers, you may add a `da=`*MyHost* on the command line and AIPS will run with all data areas from both machines. (The disk systems must be auto-mountable between the two computers.) There are two verbs within 31DEC10 AIPS which will allow you the equivalent of `da=`. They are ADDDISK which will add the disks of a selected computer to the current list of data disks and REMDISK which will remove the disks of a selected computer from the current list. The `aips` command also lets you select the most convenient printer within your local area network for use in your *AIPS* session. Other forms of data transfer, including magnetic tapes, will be discussed later.

If *Server* and *MyHost* have different byte orders or are not both on the same local area network, then they cannot be at the same *AIPS* site. If both machines have *AIPS* installed and the versions are compatible, then you may run on *Server* with *MyHost* treated as a "guest." Again, `slogin`, `rlogin`, or `telnet` into *Server* from a window on *MyHost*. Make sure that the environment variable DISPLAY on *Server* is set to *MyHost*:0 and that *Server* is mentioned in your .rhosts file on *MyHost*. Then issue the usual aips command. You do not have to give the tv= option, but you may give tv=*MyHost* if you wish.. This will start the message, graphics, and TV servers on *MyHost* if needed. If the servers fail to start and messages such as "Cannot start remote TV servers..." appear, then you must start the servers using the aips command on *MyHost*. The displays will work without restarting AIPS on *Server*. Thereafter, give the aips option tvok to *Server* (rather than tv=) to suppress the annoying messages. There is no drawback to being a guest TV; all catalogs and device information are now maintained by XAS itself. Since the display refreshing is handled locally by programs running in *MyHost*, this level of connection supports nearly full interactivity including such demanding displays as TVBLINK and TVMOVIE.

If *MyHost* does not have *AIPS* installed, then you may run the message, graphics, and TV servers on *Server*, with the X-Windows $DISPLAY set to *MyHost*:0. You may do this with internet sockets, but this ties up the one instance of the servers allowed to use such sockets. The socially acceptable method uses local Unix sockets so that only current *AIPS* session(s) on *Server* may talk to the windows in *MyHost*. You must ask for this explicitly, setting tv=local. This mode of operation is not encouraged since the display refreshing has to be transmitted over the network, making some of the interactive displays too slow to be useful. Nonetheless, there are circumstances in which this mode of operation is the only one available. You will have to add *Server* as an allowed X host (xhost +*Server*) to use this option. See HELP AIPS C$_R$ for more information on "local" TVs which, among other things, allow for multiple TVs on a single display screen.

### 12.4.2 Connections to a terminal

You may do some interactive *AIPS*ing if your workstation window is able to emulate a Tektronix 4010 terminal, or you are at a terminal capable of this emulation. (Note that most xterm displays may be switched between a "Tek mode" and the normal "VT mode" by pressing the Control key and the middle mouse button.) To operate in this mode, log in to *Server* from your terminal or workstation window and start AIPS with the command-line option REMOTE. This option will disable all TV functions, will cause all task messages to come to your terminal or window, and will cause any graphics ("TK") displays to be sent to your terminal or window. You may display an "image" by creating a contour drawing with CNTR and then displaying the plot file with TKPL Interactive cursor verbs and procedures such as TKXY, TKPOS, and TKWIN may then be used. The old 4010 Tektronix display mixed plotting and text in a less than elegant fashion which is slavishly honored by most emulations. This is unfortunate, but usually does not prevent the display from being used for simple position selection and the like.

The *AIPS* task TXPL is a powerful tool for remote users without any, or correct, Tektronix 4010 emulation. It reads an extension file of type PL and translates the graphics commands in that file to an alphanumeric display for a "dumb" terminal. TXPL may be exactly what you need for *AIPS* applications that depend on scanning the *shape* of a plot rather than its fine detail. Common examples are viewing the shape of visibility functions produced by UVPLT (to guide self-calibration or to diagnose interference) or examining calibration solution plots from SNPLT. TXPL can also usefully interpret simple contour plots or even grey scales(!) for a remote user. It is often much faster to use TXPL to diagnose the state of your *AIPS* data processing over a low-bandwidth link than to use TKPL to execute a stream of Tektronix graphics instructions (even if you have full Tektronix 4010 emulation).

### 12.4.3 Remote data connections

Like the message, graphics, and TV servers, there is also a remote data server in *AIPS* in the form of a remote "tape" dæmon called TPMON. All computers that run *AIPS* run a copy of TPMON to serve FITS-disk files plus a copy of TPMON for each real *AIPS* tape device on the computer. Some computers start these TPMONs when the are booted while others wait until someone runs AIPS on them or orders the tape servers to run by using the `tp=` option for the computer from some other computer (§ 2.2.3). If you are computing on the remote *Server* and wish to use an *AIPS* tape drive on your computer, type on *Server*:

| | |
|---|---|
| % aips tp=*MyHost* C_R | to start `AIPS` on *Server* and to start the `TPMON`s on *MyHost*. |

Then, within `AIPS`, enter:

| | |
|---|---|
| > REMHOST '*MyHost*' C_R | to specify your computer as the tape server. |
| > REMTAPE *n* C_R | to specify the $n^{\text{th}}$ *AIPS* tape device on *MyHost*. |
| > INTAPE *m* C_R | to specify a *Server* tape number one or two higher than the number of real tape devices on *Server*. These match those shown for `REMOTE` as you started `AIPS`; see § 3.9 for an example. |
| > MOUNT C_R | to mount the remote tape. |

You may then use the remote tape as you would any other tape in *AIPS*. See § 3.9, § 4.1, § 5.1, and § 6.1 for examples of normal tape usage. The verb `TAPES` is even able to use `TPMON` to tell you what tape devices are available on the remote host.

If you have a FITS-disk file (§ 3.10.3) on *MyHost* which you wish to read into *Server*, then you may set `DATAIN` to *MyHost*::*logical*:*filename*. Note that double colons connect the host name to the logical name for the disk area and a single colon connects the logical name to the name of the file within that disk area. Note also that the logical name must be one known to `TPMON` when it is started. Put your file in a standard area such as `FITS`, which is known to all of *AIPS*, or create the logical variable in a window on *MyHost* (*e.g.*, with `setenv` or `export` — see § 3.10.1)and then start the `TPMON`s from that window with the `aips` command. Similarly, you may use `FITTP` to write a FITS-disk file onto *MyHost* of an *AIPS* image or *uv* data set. Enter `DATAOUT` with the form shown above for `DATAIN`.

Unlike the display servers, `TPMON` can read and write disk files and magnetic tape devices. Given the hostile environment now found on the Internet, this poses a security problem. Therefore, `TPMON` checks every connection request to see if the remote computer has permission to use its services. To do the remote tape operations described above, you must have the *AIPS* Manager for *MyHost* alter the appropriate files to give *Server* permission to use the `TPMON`s on *MyHost*. This should have been done already if *Server* and *MyHost* are on the same *AIPS* "site" or are routinely used together.

### 12.4.4 File transfer connections

The techniques discussed above apply to many computer configurations and to most tools within *AIPS*. They do not, however, handle the outputs of printing and plotting tasks. Nor do they provide much support for small computer systems that have no *AIPS* capability of their own. For these situations, the results of your computations will need to be written onto disk on *Server* and then transferred over the network to *MyHost*.

*AIPS* does not support remote printers explicitly. However, all *AIPS* tasks and verbs which generate printer output support the `OUTPRINT` adverb. With this adverb, you may specify a disk text file to receive the printer text. If you specify the same file for successive printer verbs or tasks, the outputs will be concatenated. (*AIPS* batch jobs do this automatically to concatenate all printer displays for the job.) You may then copy the text file to *MyHost* for editing, printing, or whatever. If you wish to print the whole file on a PostScript printer on *MyHost*, you may wish to run `F2PS` on the text file on *Server* and copy the result to *MyHost*. *AIPS* provides a "filter" program to convert plain (or Fortran) text files to PostScript for printing on PostScript printers. The command

$ F2PS -*nn* < *file* > *outfile*

will convert text file *file* to PostScript format file *outfile*. The parameter *nn* is the number of lines per page used inside *AIPS*; use 97 for a small font in "portrait" form or 61 for a larger font in "landscape" form.

The AIPS task LWPLA also has an option to write its output to a disk file in encapsulated PostScript form using the OUTFILE parameter. Similarly, TVRGB and TVCPS use the same adverb to write PostScript text files containing their three-color displays. Numerous other AIPS tasks offer the option to write details of the operation to a text file specified with OUTTEXT. These include SLICE (slice), IMEAN (histogram), GAL (fit results), POSSM (spectrum), FRPLT (spectrum), HITEXT (history), UVCRS (*uv*-plane crossings), CONPL (convolving functions), etc.

FITS-disk files may be written with FITTP and FITAB and read with FITLD, UVLOD and IMLOD. For efficiency reasons, these are binary files rather than the text files produced by everything else. AIPS table files will have their contents transferred by these tasks along with the main data files. To put an AIPS table in a disk file in text form, use TBOUT to write a simple text file or EXTAB to write a file suitable for database and spreadsheet programs. Files in the form written by TBOUT may be read back into AIPS with TBIN.

To transfer the FITS-disk files and text files between *MyHost* and *Server*, some standard network file transfer must be used. For example, use `ftp` on *MyHost* with

| | |
|---|---|
| `%` cd *MyArea* C_R | to switch to the disk area on *MyHost* used for your files. |
| `%` ftp *Server* C_R | to start `ftp` to the remote system. |
| `Name (`*Server*`:...):` *loginame* C_R | to log in to account *loginame*. |
| `Password:` *password* C_R | to give the account's password. |
| `ftp>` cd *directory* C_R | to change to the *directory* name containing the file on *Server*. |
| `ftp>` binary C_R | to allow reading of a binary file — required for FITS-disk files, okay for text files. |
| `ftp>` hash C_R | to get progress symbols as the copy proceeds — a good idea for large files. |
| `ftp>` put *filename* C_R | to send *filename* from *MyHost* to *Server*. |
| `ftp>` get *anothername* C_R | to send *anothername* from *Server* to *MyHost*. |
| `ftp>` quit C_R | to exit from `ftp`. |

The files should then be in the desired directories. You may have to rename them, however, to a name in all upper-case letters unless you use the "trick" mentioned in § 3.10.1. The secure copy (`scp`) is preferable if you have a secure connection set up. The files may be compressed with `gzip` before copying and then uncompressed with `gunzip` at the other end. This is particularly effective on text files and images written by FITAB with quantization.

## 12.5 Moving data to a new computer

Lucky users who get a new computer frequently ask "how do I move my data to my new, better machine?" The easiest thing to do is first to install AIPS on the new computer, release 31DEC07 or later. Create at least as many data areas on the new machine as there were on the old. If you are moving between machines of the same byte order (same architecture or Solaris to Mac PPC, Linux to Mac Intel, or vice versa), then do a network `scp` copy (or easier yet a cp from cross-mounted disks) to move all data files from AIPS disk 1 on the old machine to AIPS disk 1 on the new machine. Repeat for the other AIPS disks. Note that AIPS disk 1 is different; it contains message, SAVE/GET, and other special files as well as normal data files. The other data areas may be rearranged if you want, but do not copy two old data areas to one new data area. That will cause extreme confusion and loss of data. Now you are ready to resume AIPSing.

But if you are moving from Solaris or Mac PPC to Linux or Mac Intel, or vice versa, then you have more to do. Mount the AIPS disks of the old machine from the new machine if possible. Otherwise copy the data from the old machine to new, temporary data areas on the new machine (not the new AIPS data areas) being careful to keep each data area separate. Outside of AIPS, setup the AIPS environment:

| | |
|---|---|
| % cd $AIPS_ROOT C_R | to move to the root of all AIPS. |
| % source LOGIN.CSH C_R | to set the basic environment under C-shell, or |
| % . LOGIN.SH C_R | to set the basic environment under bash — note the dot. |
| % $CDTST C_R | to set the full environment. |
| % RUN REBYTE C_R | to run a format converter once for each AIPS data area. |

Answer the question about range of user number (0 0 C_R will get you all possible numbers) and then enter the full pathname of the input (old) data area and the corresponding new AIPS data area. The program will convert the format of all files. The program — barring software error — will produce correct output for almost all files. There is a small danger that the SAVE/GET and TPUT/TGET files may have some errors since it is way beyond the scope of REBYTE to understand the format of these files.

The traditional way to move between computer architectures is more time consuming. On the old computer, use procedure WRTDISK to write a data area out as FITS files. The FITS file names encode the old AIPS disk and catalog numbers so that more than one disk can be written into the same FITS area. Copy the files to the new computer (or better yet, cross mount the disks) and then use procedure READISK on the new computer to read them into the new data area(s). These procedures are obtained via a RUN WRTPROCS. Plot and slice files are lost in this process. You can move the SAVE/GET files with the verb SG2RUN which converts an SG file to a text file which can be RUN on the new computer and then SAVEd. This traditional method works fairly well and can deal with the new computer having fewer AIPS data areas than the old one. It also offers the opportunity to do a probably overdue backup of your data. However, the loss of message, plot, and slice files and the added overhead in disk space may matter to you.

## 12.6 Adding your own tasks to *AIPS*

This Section is a brief guide for the user who wants to modify an existing task in *AIPS* or to write a new task. While it is difficult to write an *AIPS* task from scratch, *AIPS* contains several template tasks that are designed to hide most of the work from the "occasional" programmer. Anyone familiar with FORTRAN and a little of the system services of their local computer should be able to add convenient tasks to their local version of *AIPS* with a little practice and patience. The growing use of binary installations makes this more difficult since local sites are unlikely to have the relevant compilers.

### 12.6.1 Initial choices to make

The simplest way to write an *AIPS* task is to modify one of the four template tasks, TAFFY, CANDY, FUDGE or UVFIL. These tasks handle the *AIPS* I/O, contain extensive documentation, need to be modified in only a few well-defined places, and can be easily interfaced to user subroutines. They are limited in their ability to handle many input and output images, however, and generally operate on one image row or one visibility point at a time. Softening of these limitations will be discussed in § 12.6.5.

TAFFY — This template task reads an existing image in *AIPS* line by line, modifies the line of data as desired and then creates and writes the modified image in *AIPS*. This template task might, for example, be used to blank pixels in an input image in some specified manner.

CANDY — This task is similar to TAFFY except the input data are contained in an auxiliary file which is FORTRAN readable and outside *AIPS*. The task can transfer an image in any reasonable format outside *AIPS* into the *AIPS* data structure.

FUDGE — This template task reads an existing *AIPS* *uv* database optionally applying calibration, editing, and data selection, modifies the results point by point, and then creates and writes this modified output *uv* database in the AIPS catalog. This template task might, for example, be used to modify a *uv* data base for which the time parameter has been incorrectly written.

UVFIL — This task is similar to FUDGE without calibration and editing, except that the input *uv* data are contained in one or two auxiliary files, which are FORTRAN readable and outside AIPS. The task is useful for translating visibility data in an arbitrary format into an AIPS cataloged *uv* data set, or for computing a *uv* data set from model sources.

If you wish to make a minor change in an existing AIPS task, it will be simpler to copy the AIPS task itself and modify it as needed. For example, if you wanted to add a option in COMB to combine two input images in a new way to obtain a resultant image, it would be better to start with COMB itself than with one of the templates. However, non-trivial changes to major tasks will require a careful look at the code, which is generally well documented and segmented.

Changes to tasks that make plots and/or use the TV and other graphics devices can be tricky, but are useful sometimes. Changes to imaging and deconvolution software should not be attempted unless the changes are almost trivial. Modifying existing verbs or creating new ones require you to find which AU*xx*.FOR routine is involved and then require the entire AIPS program to be relinked. *Going AIPS* describes some of the considerations. The new pseudoverbs VERB and PSEUDOVB allow you to update your AIPS vocabulary using your own procedure rather than by changing the supplied vocabulary files and executing POPSGN as described in *Going AIPS*. In all cases, do not put your modified code into the standard AIPS code areas unless your local AIPS Manager agrees and has made a backup copy of the original code and executables. Such modified files may well disturb the AIPS updates done by the so-called "Midnight Job."

### 12.6.2 Getting started

Even if you have special privileges in AIPS, it is wise to generate and link new code in your own user directory rather than in your installation's designated local AIPS directory. After the code has been written and tested, check with your local AIPS Manager about installing it in a public area. Decide which template task or other AIPS task you want to modify, then follow these instructions after logging into your private area.

Under Unix

| | |
|---|---|
| % source /AIPS/LOGIN.CSH C_R | to get the basic AIPS system logicals under a c-shell, or |
| % . /AIPS/LOGIN.SH C_R | to get the basic AIPS system logicals under a korn, bourne, or bash shell. (These assume that your AIPS system home directory is called /AIPS). |
| % $CDTST (or $CDNEW) C_R | to set up the logical assignments for programming. |
| % PROG *TASK* C_R | to locate the task called *TASK*. |
| % LIBS $*AREA* > *NTASK*.OPT C_R | to create a file of linking information for a task found in area *AREA*, *e.g.*, APLPGM for TAFFY, APGNOT for FUDGE, CANDY and UVFIL, YPGM for IMEAN, etc. |
| % cp $*AREA*/*TASK*.FOR *NTASK*.FOR C_R | to copy code for *TASK* into your area and to give it a new name (≤ 5 letters). |
| % cp $HLPFIL/*TASK*.HLP *NTASK*.HLP C_R | to copy and rename the inputs/help file for the task. |
| % setenv MYAIPS 'pwd' C_R | to define MYAIPS (must be uppercase) as your disk area for AIPS programs, or |
| % export MYAIPS='pwd' C_R | to define the MYAIPS environment variable under korn, bash, and bourne shells. |

### 12.6.3 Initial check of code and procedures

Before modifying the task in any way, it is wise to compile, link and execute the unchanged task to check that the original code is sound and that all of the *AIPS* logical assignments have been properly set. The duplicated *AIPS* task should run identically to the original; the template tasks are set up to duplicate the input data set with no changes and default parameters. In this way errors or other problems associated with the generation of new tasks can be found and corrected before getting into the quagmire of bugs that you are about to add. Note that CANDY and UVFIL require external data files and are therefore not so easily checked.

One change is needed in the FORTRAN program before checking. In the main program, about 60 lines down, there is a data statement which identifies the task.

DATA PRGM /'*TASK* '/

Change this to

DATA PRGM /'*NTASK*'/

The maximum number of characters in a task name is five and the DATA statement must be in the above form. There is no need to change the help file yet, as long as it is named NTASK.HLP.

To compile and link the task, type:

% COMLNK *NTASK* *NTASK*.OPT C_R

To compile the task for debugging, add the DEBUG NOOPT options to the COMLNK line. There should be no error messages and no significant warnings.

After successful compilation and linking, try executing the task. Under Unix, stay logged in to your area. To initiate the AIPS program, type:

| | |
|---|---|
| % aips C_R | or |
| % aips debug C_R | to use the debugger (*e.g.*, dbx) on tasks compiled with the DEBUG option. You will have to tell the procedure which debugger you want and that you do not want to start AIPS itself under that debugger. |

Your *AIPS* Manager may have to make some arrangements for you to activate *AIPS* from your login. Once you have started *AIPS*, type

| | |
|---|---|
| > VERSION 'MYAIPS' C_R | to specify the location of inputs and help information and of the task executable. |

Set up the input parameters, then

| | |
|---|---|
| > INP C_R | to review the input parameters. You should be told AIPS 1: Found in Version=MYAIPS at the start of the inputs display. If not, there is something wrong with the logical or task name or the location of the inputs/help file. |
| > GO C_R | to run the task. The Found ... line should appear again. |

### 12.6.4 Modifying an *AIPS* task

If you are modifying an existing task, the only ground rules are to read the task carefully and note the locations where changes must be made. Unlike the template tasks which are organized so that additional code need be inserted in only one or two places, an *AIPS* task may need revisions in a variety of places. Some guidelines are:

1. Change the data statement DATA PRGM ... near the beginning of the program and the PROGRAM statement at the very beginning, if you have not already done this.

2. Make changes in the introductory text which describes the task. This is particularly important if you are adding or removing adverbs.
3. The subroutine `GTPARM` obtains the adverb values from the input table in order. If you add or subtract adverbs, change `INPRMS`, the amount of input information. Be careful in the translation of the adverbs, which are usually listed in a `COMMON` named `/INPARM/`.
4. Change code as desired. Try to modify `HI`story file entries as well.
5. Liberally sprinkle `PRINT` statements in crucial places to help debug the program. If much of the new code can be put in a subroutine, write and debug the subroutine outside *AIPS*. Then, add it to the task.
6. Revise the file `NTASK.HLP`. At least, change all references to `TASK` to `NTASK`! If there are any changes in the adverb list, look at these changes carefully. Further changes in the `HELP` and `EXPLAIN` portions of the file may be needed to document your work for for others and for yourself at a later date.
7. Compile and link the modified task following the instructions in the previous section. When it compiles and links without errors, try it out in *AIPS*.

### 12.6.5 Modifying an *AIPS* template task.

The template tasks are:

1. `TAFFY` — modifies an existing image file and writes a new image.
2. `CANDY` — writes a new image. Input data from outside *AIPS*.
3. `FUDGE` — modifies an existing *uv* database and writes a new database.
4. `UVFIL` — writes a new *uv* database taking input data from outside *AIPS*.

These tasks are described in detail in Chapter 2 of *Going AIPS*. The template tasks and the code for each are extensively documented there, so only the major points are discussed here.

`TAFFY` reads a selected subset of an image, one row at a time, to a user interface subroutine `DIDDLE`. An output image is created, cataloged and filled with values calculated in `DIDDLE` (or attached subroutines). The dimensionality of the output image need not be the same as the input image.

1. If the output image has identical dimensions to the input image, and an output image row can be generated from each input image row, then `TAFFY` is relatively straight-forward to use and the accompanying documentation should suffice.
2. `TAFFY` has the option of deferring the writing of an output row until some number of input rows have been read. This would allow the output to depend on some function of several, or even all, input rows. Examples would include smoothing in $x$ and $y$ and other sorts of spatial filtering.
3. It is possible to handle several input images and several output images with `TAFFY` by using multi-dimensional images and the axis transposing task, `TRANS`. Suppose you want to calculate the spectral index from a set of four images. First, use `FQCUBE` to put the four images into one data cube. (`FQUBE` lets you avoid re-defining the frequency axis as `MCUBE` would require.) Then, transpose the cube so that the frequency axis is first with right ascension and declination as the second and third axes. Use this image as the input to `TAFFY` and use `CPARM` to specify the frequency values. Each input row will then be the intensity at a pixel for the four frequencies — from which the spectral index and other parameters can be calculated. The output dimension can be specified arbitrarily. For example, you might want to

write out the spectral index, the error, the curvature and the flux intercept at some fiducial frequency. When the task has completed, transpose the output cube so that the celestial coordinates are again the first two axes and the spectral index and friends are the third axis.

4. Subroutine NEWHED may be modified to require certain axis types, operation codes, etc. It must be used to change the output image dimensions if they are not to be the same as the input. An option to omit from the output image the first input axis is available and must be selected in NEWHED.
5. If you can write and debug outside *AIPS* any subroutines that DIDDLE will call in calculating the output image, you may speed up the debugging of your algorithms.

CANDY lets you create an image one row at a time. Input information is obtained through a file which is external to *AIPS*.

1. Subroutine NEWHED shows an example of how the external file may be defined and how it can be used. The first few records of the external file should contain information for defining the header of the output image and updating the appropriate catalog blocks. The pointers to the *AIPS* catalog are given in Chapter 5 of *Going AIPS*.
2. The subroutine MAKMAP reads further records from the external file until a full row of the output image is obtained.
3. Many adverbs are built into CANDY. If you need more or wish to change them, read the information at the beginning of subroutine CANIN.

FUDGE reads an existing *uv* database point by point and creates a new *uv* database with the modified data. It can easily be used to make simple changes in a *uv* database; for example, if the $u$, $v$, or $w$ terms are to be recalculated, if all phases are to be changed in sign, etc.

1. If the output data set has different dimensions than the input data set (*e.g.*, by combining several spectral-line channels), changes must be made in the subroutine FUDGIN.
2. To combine several input data points, use the task UVSRT to put the data points adjacent in the file.
3. If you wish to calculate quantities from an input *uv* data set without creating an output file, use this task. In the subroutine DIDDLE set IRET = -1 to avoid writing an the output *uv* data set.

UVFIL reads input from one or two FORTRAN-readable files which are outside *AIPS* to create, catalog, and fill a *uv* database into *AIPS*. This task is useful for transcribing *uv* data in an arbitrary format into an *AIPS* database.

1. The task code has copious notes to help the user. The first auxiliary file should contain header information about the observations and the telescopes. This file is read in the subroutine NEWHED.
2. The second auxiliary file contains the actual *uv* data in some format and it is converted into an *AIPS uv* database, point by point, in the subroutine FIDDLE. The comments are extensive and an example is given in the code.

### 12.6.6 Further remarks

1. Try to use the *AIPS* coding standards as described in *Going AIPS*. This will make your code more readable and more portable. It will also save other *AIPS* programmers lots of work if your new task comes into general use.

2. Declare all variables that you use.

3. While debugging, use the FORTRAN `PRINT *, ...` statement in your code to obtain temporary output on your terminal during execution. If you want more permanent output, use the *AIPS* message file facilities with the appropriate message level (4 is recommended for information, 6 for warnings, 8 for errors).

4. You may use a debugger (such as `dbx`) on *AIPS* tasks by specifying `DEBUG` to the `COMLNK` and `aips` procedures. Inside `AIPS`, set the "hidden" adverb `SETDEBUG` to 0 for normal operation and to 20 to run tasks with your specified debugger.

## 12.7 Additional recipes

### 12.7.1 Going bananas with bananas

1. Garnish a baked ham or ham steak with bananas.
2. Make a quick, rich desert with bananas and cream.
3. Bananas are perfect for lunch boxes. They come in their own wrapper, are easy to eat and mess-less.
4. Slice a banana in half lengthwise, brush with melted butter and bake it until tender; serve it as a "vegetable" with roasted meats or fish. Very Caribbean.
5. Don't forget old favorites like bananas sliced over cereal, diced in pancake batter, or buried midst the ice cream in a banana split.
6. Slice and stir-fry bananas with carrots, tomatoes and ground beef for a super-quick main dish.

### 12.7.2 Banana caramel pie

1. Mix 1 cup **dark brown sugar**, 1/4 cup **all-purpose flour**, 1/4 teaspoon **salt** in a saucepan. Stir in 1/4 cup **cold water** and 2 **egg yolks**. Beat until smooth.
2. Gradually stir in 1 cup **boiling water**. Then cook, stirring constantly, about 3 minutes until smoothly thickened.
3. Stir in 1 tablespoon **butter**, 1/2 teaspoon **vanilla**, and 1/4 cup **evaporated milk**. Cool slightly.
4. Pour into pre-baked, cooled 8 or 9 inch **pastry pie shell**.
5. Slightly before serving, slice 4 ripe **bananas** and arrange over filling. Top with whipped cream or with a meringue made out of the 2 left-over egg whites.

### 12.7.3 Curried shrimp

1. Cook 2 1/2 pounds **shrimp** for 3 minutes. Peel and devein.
2. Heat 1/3 pound **butter** or margarine in large saucepan. Saute 4 chopped **scallions** and 2 cups chopped, peeled **apples** until tender. Stir in 2 tablespoons **curry poweder**, 1 tablespoon **ground ginger**, and 1/3 cup **flour**. Stir for 2 minutes. Remove from heat and blend in 3 cups **chicken broth**. Return to heat, cook stirring until mixture boils and thickens.
3. Add 1 pound roasted **cashews**, 1 pound **Turkish apricots**, and, if desired, 2 ounces diced **crystalized ginger** and **raisins**. Cook over low heat for 15 minutes.
4. Add shrimp and mix in.
5. Cut 3 **bananas** into thick slices and add to mixture. Serve over cooked white or curried rice.

Thanks to Chiquita Bananas. See `http://www.jaetzel.de/tim/chiquit.htm`.

### 12.7.4 Banana Bombay salad

1. Puree 3 **bananas**.
2. Whisk with 1/4 cup **lemon juice**, 1/4 cup **mayonnaise**, 1/4 cup **plain yogurt**, and 1/8 – 1/4 ounce **taragon**. Refrigerate at least 2 hours.
3. Cut 2 pounds cooked **turkey** or **chicken breast** into bitesize pieces.
4. Add 1/2 cup **raisins**, 3 **green apples** cut into pieces, and 1/2 cup chopped **walnuts**. Mix.
5. Add banana puree and mix. Cut 2 **bananas** into thick chunks and add. Serve chilled.

Thanks to Chiquita Bananas. See `http://www.jaetzel.de/tim/chiquit.htm`.

### 12.7.5 Roasted turkey quesadillas with banana

1. Place 6 corn or whole wheat flour **tortillas** flat.
2. Sprinkle with 6 ounces grated low-fat **Jack** or **cheddar cheese**, 2 tablespoons chopped fresh **cilantro** or **parsley**, 1/2 pound shredded roasted **turkey** or **chicken** meat, 2 seeded and minced **jalapeño peppers**, 1 cup **alfalfa sprouts**, and 2 medium **bananas**, sliced into thin circles.
3. Place 6 **tortillas** on top and press firmly.
4. Place on a lightly oiled cookie sheet; cover with another cookie sheet of similar size. Bake in a pre-heated 350° F oven for 15 minutes until soft and melted. Cut into wedges and serve with hot sauce and salad.

Thanks to Chiquita Bananas. See `http://www.jaetzel.de/tim/chiquit.htm`.

# 13 CURRENT *AIPS* SOFTWARE

The complete lists of software in *AIPS* are kept up-to-date in certain special files which may then be accessed with the AIPS verb ABOUT. Semi-automatic software makes these listing files using the primary and secondary keywords entered by *AIPS* programmers in the numerous help files. The explanations given for each symbol are also those entered by the programmers as the "one-liner" descriptions of the symbol for which the help file is written. The lists of primary and secondary keywords may be viewed directly by typing:

\> HELP CATEGORY C_R    to view primary keywords

\> HELP SECONDARY C_R    to view secondary keywords

The help file for ABOUT is more explanatory, however. The general help file (for HELP itself) lists a number of general help files which will be of interest. These are also mentioned in the section called INFORMATION below.

The following sections are verbatim reproductions of the various listing files used by ABOUT and are roughly current to the 15JAN95 release of *AIPS*. Each section title is the name of the keyword which is used as the ABOUT topic. Each line within a section lists a task, verb, pseudoverb, procedure, adverb, or RUN file with a very brief description of its function. Pseudoverbs come in two flavors: those that act roughly like verbs and those that must be treated specially, *i.e.*, that must appear alone on a line or only in certain contexts. The help file for each pseudoverb should clarify the its grammatical limits. Typing

\> HELP *name* C_R

where *name* is one of the entries in the left-hand column, will give more useful information about that *AIPS* symbol.

## 13.1 ADVERB

```
ADVERB
Type:  General type of POPS symbol
Use:   Adverbs are the symbols used to address values.  They
       may be REAL (single-precision floating point), ARRAY
       (multiply-dimensioned REALs), or STRING (character
       strings with or without subscripts).  The user may
       create new adverbs by defining them while typing or
       editing procedures.
Grammar:   Adverb names may be used either in compile mode
       or in regular execute mode.  In the former, their
       pointers are compiled with the procedure and their
       values, at the time the procedure is invoked, are
       used during the execution of the procedure.
Usage examples:
       ARRAY2 = ARRAY1
       ARRAY3(I,J) = 23.6
       CHAN = 4
       STRARRY = 'STR1','STR2','STR3',STRAR2
       DUM3 (24, I, STRARRY)
    =====>  Character string data must be enclosed in quotes!
    =====>  This allows the compiler to tell data from adverb
            names and allows embedded special characters.
****************************************************************
ALIAS      adverb to alias antenna numbers to one another
ALLOKAY    specifies that initial conditions have been met.
```

| | |
|---|---|
| ANTENNAS | Antennas to include/exclude from the task or verb |
| ANTNAME | A list of antenna (station) names |
| ANTUSE | Antennas to include/exclude from the task or verb |
| ANTWT | Antenna Weights for UV data correction in Calibration |
| APARM | General numeric array adverb used many places |
| ARRAY1 | General scratch array adverb |
| ARRAY2 | General scratch array adverb |
| ARRAY3 | General scratch array adverb |
| ASPMM | Plot scaling parameter - arc seconds per millimeter on plot |
| AVGCHAN | Controls averaging of spectral channels |
| AVGIF | Controls averaging of IF channels |
| AVOPTION | Controls type or range of averaging done by a task |
| AX2REF | Second reference pixel number |
| AXINC | Axis increment - change in coordinate between pixels |
| AXREF | Reference pixel number |
| AXTYPE | Type of coordinate axis |
| AXVAL | Value of axis coordinate at reference pixel |
| BADDISK | specifies which disks are to be avoided for scratch files |
| BAND | specifies the approximate frequency of UV data to be selected |
| BANDPOL | specifies polarizations of individual IFs |
| BASELINE | specifies which antenna pairs are to be selected/deselected |
| BATFLINE | specifies starting line in a batch work file |
| BATNLINE | specifies the number of lines to process in a batch work file |
| BATQUE | specifies the desired batch queue |
| BCHAN | sets the beginning channel number |
| BCOMP | gives beginning component number for multiple fields |
| BCOUNT | gives beginning location for start of a process |
| BDROP | gives number of pooints dropped at the beginning |
| BIF | gives first IF to be included |
| BITER | gives beginning point for some iterative process |
| BLC | gives lower-left-corner of selected subimage |
| BLOCKING | specifies blocking factor to use on e.g. tape records |
| BLVER | specifies the version of the baseline-calibration table used |
| BMAJ | gives major axis size of beam or component |
| BMIN | gives minor axis size of beam or component |
| BOXFILE | specifies name of Clean box text file |
| BOX | specifies pixel coordinates of subarrays of an image |
| BPA | gives position angle of major axis of beam or component |
| BPARM | general numeric array adverb used too many places |
| BPASSPRM | Control adverb array for bandpass calibration |
| BPRINT | gives beginning location for start of a printing process |
| BPVER | specifies the version of the bandpass table to be applied |
| BWSMEAR | amount of bandwidth smearing correction to use |
| CALCODE | specifies the type of calibrator to be selected |
| CALIN | specifies name of input disk file usually with calibration data |
| CALSOUR | specifies source names to be included in calibration |
| CATNO | Specifies AIPS catalog slot number range |
| CBPLOT | selects a display of a Clean beam full width at half maximum |
| CCBOX | specifies pixel coordinates of subarrays of an image |
| CELLSIZE | gives the pixel size in physical coordinates |
| CHANNEL | sets the spectral channel number |
| CHANSEL | Array of start, stop, increment channel numbers to average |
| CHINC | the increment between selected channels |
| CLBOX | specifies subarrays of an image for Clean to search |
| CLCORPRM | Parameter adverb array for task CLCOR |
| CLEV | Contour level multiplier in physical units |
| CLINT | CL table entry interval |
| CMETHOD | specifies the method by which the uv model is computed |

| | |
|---|---|
| CMODEL | specifies the method by which the uv model is computed |
| CODETYPE | specifies the desired operation type |
| COLORS | specifies the desired TV colors |
| COMMENT | 64-character comment string |
| CON3COL | Controls use of full 3-color graphics for contouring |
| COOINC | Celestial axes increment: change in coordinate between pixels |
| COORDINA | Array to hold coordinate values |
| COOREF | Reference pixel number for two coordinate axes |
| COOTYPE | Celestial axes projection type |
| COPIES | sets the number of copies to be made |
| CPARM | general numeric array adverb used many places |
| CROWDED | allows a task to perform its function in a crowded fashion |
| CTYPE | specifies type of component |
| CUTOFF | specifies a limit below or above which the operation ends |
| DARKLINE | The level at which vectors are switched from light to dark |
| DATA2IN | specifies name of input FITS disk file |
| DATAIN | specifies name of input FITS disk file |
| DATAOUT | specifies name of output FITS disk file |
| DCODE | General string adverb |
| DDISK | Deterimins where input DDT data is found |
| DDTSIZE | Deterimins which type of DDT is RUN. |
| DECSHIFT | gives Y-coordinate shift of an image center from reference |
| DEFER | Controls when file creation takes place |
| DELCORR | specifies whether VLBA delay corrections  are to be used |
| DELTAX | Increment or size in X direction |
| DELTAY | Increment or size in Y direction |
| DENSITY | gives the desired tape density |
| DENUMB | a scalar decimal number |
| DETIME | specifies a time interval for an operation (destroy, batch) |
| DIGICOR | specifies whether VLBA digital corrections are to be applied |
| DIST | gives a distance - PROFL uses as distance to observer |
| DO3COL | Controls whether full 3-color graphics are used in a plot |
| DO3DIMAG | specifies whether uvw's are reprojected to each field center |
| DOACOR | specifies whether autocorrelation data are included |
| DOALIGN | specifies how two or more images are aligned in computations |
| DOALL | specifies if an operation is done once or for all matching |
| DOALPHA | specifies whether some list is alphabetized |
| DOAPPLY | Flag to indicate whether an operation is applied to the data |
| DOARRAY | spcifies if subarrays are ignored or the information used |
| DOBAND | specifies if/how bandpass calibration is applied |
| DOBLANK | controls handling of blanking |
| DOBTWEEN | Controls smoothing between sources in calibration tables |
| DOCALIB | specifies whether a gain table is to be applied or not |
| DOCAT | specifies whether the output is saved (cataloged) or not |
| DOCELL | selects units of cells over angular unit |
| DOCENTER | selects a single, centered page or multiple pages of plots |
| DOCIRCLE | select a "circular" display (i.e. trace coordinates, ...) |
| DOCOLOR | specifies whether coloring is done |
| DOCONCAT | selects concatenated or indivudual output files |
| DOCONFRM | selects user confirmation modes of repetitive operation |
| DOCONT | selects a display of contour lines |
| DOCRT | selects printer display or CRT display (giving width) |
| DODARK | specifies whether "dark" vectors are plotted dark or light |
| DODELAY | selects solution for phase/amplitude or delay rate/phase |
| DOEBAR | Controls display of estimates of the uncertainty in the data |
| DOEOF | selects end-of-file writing or reading until |
| DOEOT | selects tape positioning before operation: present or EOI |
| DOFIT | Controls which antennas are fit by what methods |

| | |
|---|---|
| DOFLAG | Controls closure cutoff in gain solutions and flagging |
| DOGREY | selects a display of a grey-scale image |
| DOGRIDCR | selects correction for gridding convolution function |
| DOHIST | selects a histogram display |
| DOHMS | selects sexagesimal (hours-mins-secs) display format |
| DOIFS | controls functions done across IFs |
| DOINVERS | selects opposite of normal function |
| DOMAX | selects solutions for maxima of models |
| DOMODEL | selects display of model function |
| DONEWTAB | do we make new tables, use a new table format, etc. |
| DOOUTPUT | selects whether output image or whatever is saved / discarded |
| DOPOL | selects application of any polarization calibration |
| DOPOS | selects solutions for positions of model components |
| DORESID | selects display of differences between model and data |
| DOSLICE | selects display of slice data |
| DOSTOKES | selects options related to polarizations |
| DOTABLE | selects use of table-format for data |
| DOTV | selects use of TV display option in operation |
| DOTWO | do we make two of something |
| DOUVCOMP | selects use of compression in writing UV data to disk |
| DOVECT | selects display of polarization vectors |
| DOWAIT | selects wait-for-completion mode for running tasks |
| DOWEDGE | selects display of intensity step wedge |
| DOWEIGHT | selects operations with data weights |
| DOWIDTH | selects solution for widths of model components |
| DPARM | General numeric array adverb used many places |
| ECHAN | define an end for a range of channel numbers |
| ECOUNT | give the highest count or iteration for some process |
| EDGSKP | Deterimins border excluded from comparision or use |
| EDROP | number of points/iterations to be omitted from end of process |
| EHNUMB | an extended hexadecimal "number" |
| EIF | last IF number to be included in operation |
| EPRINT | gives location for end of a printing process |
| ERROR | was there an error |
| EXPERT | specifies an user experience level or mode |
| FACTOR | scales some display or CLEANing process |
| FGAUSS | Minimum flux to Clean to by widths of Gaussian models |
| FITOUT | specifies name of output text file for results of fitting |
| FLAGVER | selects version of the flagging table to be applied |
| FLDSIZE | specifies size(s) of images to be processed |
| FLMCOMM | Comment for film recorder image. |
| FLUX | gives a total intensity value for image/component or to limit |
| FMAX | specifies peak values of model components - results of fits |
| FORMAT | gives a format code number: e.g. FITS accuracy required |
| FPARM | General numeric array adverb used in modeling |
| FPOS | specifies pixel positions of fit model components |
| FQTOL | Frequency tolerance with which FQ entries are accepted. |
| FREQID | Frequency Identifier for frequency, bandwidth combination |
| FSIZE | file size in Megabytes |
| FUNCTYPE | specifies type of intensity transfer function |
| FWIDTH | gives widths of model components - results of fitting |
| GAINERR | gives estimate of gain uncertainty for each antenna |
| GAIN | specifies loop gain for deconvolutions |
| GAINUSE | specifies output gain table or gain table applied to data |
| GAINVER | specifies the input gain table |
| GCVER | specifies the version of the gain curve table used |
| GG | spare scalar adverb for use in procedures |
| GMAX | specifies peak values of model components |

| | |
|---|---|
| GPOS | specifies pixel positions of model components |
| GRADDRES | specifies user's home address for replies to gripes |
| GRCHAN | specifies the TV graphics channel to be used |
| GREMAIL | gives user's e-mail address name for reply to gripe entry |
| GRNAME | gives user's name for reply to gripe entry |
| GRPHONE | specifies phone number to call for questions about a gripe |
| GUARD | portion of UV plane to receive no data in gridding |
| GWIDTH | gives widths of model components |
| HIEND | End record number in a history-file operation |
| HISTART | Start record number in a history-file operation |
| ICHANSEL | Array of start, stop, increment channel #S + IF to average |
| ICUT | specifies a cutoff level in units of the image |
| I | spare scalar adverb for use in procedures |
| IM2PARM | Specifes enhancement parameters for OOP-based imaging: 2nd set |
| IMAGRPRM | Specifes enhancement parameters for OOP-based imaging |
| IMSIZE | specifies number of pixels on X and Y axis of an image |
| IN2CLASS | specifies the "class" of the 2nd input image or data base |
| IN2DISK | specifies the disk drive of the 2nd input image or data base |
| IN2EXT | specifies the type of the 2nd input extension file |
| IN2FILE | specifies name of a disk file, outside the regular catalog |
| IN2NAME | specifies the "name" of the 2nd input image or data base |
| IN2SEQ | specifies the sequence # of the 2nd input image or data base |
| IN2TYPE | specifies the type of the 2nd input image or data base |
| IN2VERS | specifies the version number of the 2nd input extension file |
| IN3CLASS | specifies the "class" of the 3rd input image or data base |
| IN3DISK | specifies the disk drive of the 3rd input image or data base |
| IN3EXT | specifies the type of the 3rd input extension file |
| IN3NAME | specifies the "name" of the 3rd input image or data base |
| IN3SEQ | specifies the sequence # of the 3rd input image or data base |
| IN3TYPE | specifies the type of the 3rd input image or data base |
| IN3VERS | specifies the version number of the 3rd input extension file |
| IN4CLASS | specifies the "class" of the 4th input image or data base |
| IN4DISK | specifies the disk drive of the 4th input image or data base |
| IN4NAME | specifies the "name" of the 4th input image or data base |
| IN4SEQ | specifies the sequence # of the 4th input image or data base |
| IN4TYPE | specifies the type of the 4th input image or data base |
| INCLASS | specifies the "class" of the 1st input image or data base |
| INDISK | specifies the disk drive of the 1st input image or data base |
| INEXT | specifies the type of the 1st input extension file |
| INFILE | specifies name of a disk file, outside the regular catalog |
| INLIST | specifies name of input disk file, usually a source list |
| INNAME | specifies the "name" of the 1st input image or data base |
| INSEQ | specifies the sequence # of the 1st input image or data base |
| INTAPE | specifies the input tape drive number |
| INTERPOL | specifies the type of averaging done on the complex gains |
| INTEXT | specifies name of input text file, not in regular catalog |
| INTPARM | specifies the parameters of the gain interpolation function |
| INTYPE | specifies the type of the 1st input image or data base |
| INVERS | specifies the version number of the 1st input extension file |
| IOTAPE | Deterimins which tape drive is used during a DDT RUN |
| J | spare scalar adverb for use in procedures |
| JOBNUM | specifies the batch job number |
| KEYSTRNG | gives contents of character-valued keyword parameter |
| KEYTYPE | Adverb giving the keyword data type code |
| KEYVALUE | gives contents of numeric-valued keyword parameter |
| KEYWORD | gives name of keyword parameter - i.e. name of header field |
| LABEL | selects a type of extra labeling for a plot |
| LEVS | list of multiples of the basic level to be contoured |

```
LPEN       specifies the "pen width" code # => width of plotted lines
LTYPE      specifies the type and degree of axis labels on plots
MAPDIF     Records differences between DDT test results and standards
MAXPIXEL   maximum pixels searched for components in Clark CLEAN
MDISK      Deterimins where input DDT data is found
MINAMPER   specifies the minimum amplitude error prior to some action
MINPATCH   specifies the minimum size allowed for the center of the beam
MINPHSER   specifies the minimum phase error prior to some action
NAXIS      Axis number
NBOXES     Number of boxes
NCCBOX     Number of clean component boxes
NCHAV      Number of channels averaged in an operation
NCOMP      Number of CLEAN components
NCOUNT     General adverb, usually a count of something
NDIG       Number of digits to display
NFIELD     The number of fields imaged
NFILES     The number of files to skip, usually on a tape.
NGAUSS     Number of Gaussians to fit
NITER      The number of iterations of a procedure
NMAPS      Number of maps (images) in an operation
NOISE      estimates the noise in images
NPIECE     The number of pieces to make
NPLOTS     gives number of plots per page or per job
NPOINTS    General adverb giving the number of something
NPRINT     gives number of items to be printed
NUMTELL    selects POPS number of task which is the target of a TELL
NX         General adverb referring to a number of things in the Y direction
NY         General adverb referring to a number of things in the Y direction
OBJECT     The name of an object
OBOXFILE   specifies name of output Clean box text file
OFFSET     General adverb, the offset of something.
OFMFILE    specifies the name of a text file containing OFM values
ONEBEAM    specifies whether one beam is made for all facets or one for each
OPCODE     General adverb, defines an operation
OPTELL     The operation to be passed to a task by TELL
OPTYPE     General adverb, defines a type of operation.
ORDER      Adverb used usually to specify the order of polynomial fit
OUT2CLAS   The class of a secondary output file
OUT2DISK   The disk number of a secondary output file.
OUT2NAME   The name of a secondary output file.
OUT2SEQ    The sequence of a secondary output file.
OUTCLASS   The class of an output file
OUTDISK    The disk number of an output file.
OUTFGVER   selects version of the flagging table to be written
OUTFILE    specifies name of output disk file, not in regular catalog
OUTNAME    The name of an output file.
OUTPRINT   specifies name of disk file to keep the printer output
OUTSEQ     The sequence of an output file.
OUTTAPE    The output tape drive number.
OUTTEXT    specifies name of output text file, not in regular catalog
OUTVERS    The output version number of an table or extension file.
OVERLAP    specifies how overlaps are to be handled
OVRSWTCH   specifies when IMAGR switches from OVERLAP >= 2 to OVERLAP = 1 mode
PBPARM     Primary beam parameters
PBSIZE     estimates the primary beam size in interferometer images
PCUT       Cutoff in polarized intensity
PDVER      specifies the version of the spetral polarization table to use
PHASPRM    Phase data array, by antenna number.
```

| | |
|---|---|
| PHAT | Prussian hat size |
| PHSLIMIT | gives a phase value in degrees |
| PIX2VAL | An image value in the units specified in the header. |
| PIX2XY | Specifies a pixel in an image |
| PIXAVG | Average image value |
| PIXRANGE | Range of pixel values to display |
| PIXSTD | RMS pixel deviation |
| PIXVAL | Value of a pixel |
| PIXXY | Specifies a pixel location. |
| PLCOLORS | specifies the colors to be used |
| PLEV | Percentage of peak to use for contour levels |
| PLVER | specifies the version number of a PL extension file |
| PMODEL | Polarization model parameters |
| POL3COL | Controls use of full 3-color graphics for polarization lines |
| POLANGLE | Intrinsic polarization angles for up to 30 sources |
| POLPLOT | specifies the desired polarization ratio before plotting. |
| PRIORITY | Limits prioroty of messages printed |
| PRNUMBER | POPS number of messages |
| PRSTART | First record number in a print operation |
| PRTASK | Task name selected for printed information |
| PRTIME | Time limit |
| PRTLEV | Specified the amount of information requested. |
| QUAL | Source qualifier |
| QUANTIZE | Quantization level to use |
| RADIUS | Specify a radius in an image |
| RASHIFT | Shift in RA |
| REASON | The reason for an operation |
| REFANT | Reference antenna |
| REFDATE | To specify the initial or reference date of a data set |
| REMHOST | gives the name of another computer which will provide service |
| REMQUE | specifies the desired batch queue on a remote computer |
| REMTAPE | gives the number of another computer's tape device |
| RESTFREQ | Rest frequency of a transition |
| REWEIGHT | Reweighting factors for UV data weights. |
| RGBCOLOR | specifies the desired TV graphics color |
| RGBGAMMA | specifies the desired color gamma corrections |
| RGBLEVS | colors to be applied to the contour levels |
| ROBUST | Uniform weighting "robustness" parameter |
| ROMODE | Specified roam mode |
| ROTATE | Specifies a rotation |
| RPARM | General numeric array adverb used in modeling |
| SAMPTYPE | Specifies sampling type |
| SCALR1 | General adverb |
| SCALR2 | General adverb |
| SCALR3 | General adverb |
| SCANLENG | an extended hexadecimal "number" |
| SEARCH | Ordered list of antennas for fring searches |
| SELBAND | Specified bandwidth |
| SELFREQ | Specified frequency |
| SHIFT | specifies a position shift |
| SKEW | Specifies a skew angle |
| SLOT | Specifies AIPS catalog slot number |
| SMODEL | Source model |
| SMOOTH | Specifies spectral smoothing |
| SMOTYPE | Specifies smoothing |
| SNCORPRM | Task-specific parameters for SNCOR. |
| SNCUT | Specifies minimum signal-to-noise ratio |
| SNVER | specifies the output solution table |

| | |
|---|---|
| SOLCON | Gain solution constraint factor |
| SOLINT | Solution interval |
| SOLMIN | Minimum number of solution sub-intervals in a solution |
| SOLMODE | Solution mode |
| SOLSUB | Solution sub-interval |
| SOLTYPE | Solution type |
| SORT | Specified desired sort order |
| SOUCODE | Calibrator code for source, not calibrator, selection |
| SOURCES | A list of source names |
| SPARM | General string array adverb |
| SPECINDX | Spectral index used to correct calibrations |
| SPECPARM | Spectral index per polarization per source |
| SPECTRAL | Flag to indicate whether an operation is spectral or continuum |
| SPECURVE | Spectral index survature used to correct calibrations |
| STFACTOR | scales star display or SDI CLEANing process |
| STOKES | Stokes parameter |
| STORE | Store current POPS environment |
| STRA1 | General string adverb |
| STRA2 | General string adverb |
| STRA3 | General string adverb |
| STRB1 | General string adverb |
| STRB2 | General string adverb |
| STRB3 | General string adverb |
| STRC1 | General string adverb |
| STRC2 | General string adverb |
| STRC3 | General string adverb |
| SUBARRAY | Subarray number |
| SYMBOL | General adverb, probably defines a plotting symbol type |
| SYS2COM | specifies a command to be sent to the operating system |
| SYSCOM | specifies a command to be sent to the operating system |
| SYSOUT | specifies the output device used by the system |
| SYSVEL | Systemic velocity |
| TASK | Name of a task |
| TAU0 | Opacities by antenna number |
| TBLC | Gives the bottom left corner of an image to be displayed |
| TCODE | Deterimins which type of DDT is RUN. |
| TDISK | Deterimins where output DDT data is placed |
| TIMERANG | Specifies a timerange |
| TIMSMO | Specified smoothing times |
| TMASK | Deterimins which tasks are executed when a DDT is RUN. |
| TMODE | Deterimins which input is used when a DDT is RUN. |
| TNAMF | Deterimins which files are input to DDT. |
| TRANSCOD | Specified desired transposition of an image |
| TRC | Specified the top right corner of a subimage |
| TRECVR | Receiver temperatures by polarization and antenna |
| TRIANGLE | specifies closure triangles to be selected/deselected |
| TTRC | Specifies the top right corner of a subimage to be displayed |
| TVBUT | Tells which AIPS TV button was pushed |
| TVCHAN | Specified a TV channel (plane) |
| TVCORN | Specified the TV pixel for the bottom left corner of an image |
| TVLEVS | Gives the peak intensity to be displayed in levels |
| TVXY | Pixel position on the TV screen |
| TXINC | TV X coordinate increment |
| TYINC | TV Y coordinate increment |
| TYVER | specifies the version of the system temperature table used |
| TZINC | TV Z coordinate increment |
| USERID | User number |
| UVBOX | radius of the smoothing box used for uniform weighting |

```
UVBXFN     type of function used when counting for uniform weighting
UVCOPPRM   Parameter adverb array for task UVCOP
UVFIXPRM   Parameter adverb array for task UVFIX
UVRANGE    Specify range of projected baselines
UVSIZE     specifies number of pixels on X and Y axes of a UV image
UVTAPER    Widths in U and V of gaussian weighting taper function
UVWTFN     Specify weighting function, Uniform or Natural
VCODE      General string adverb
VECTOR     selects method of averaging UV data
VELDEF     Specifies velocity definition
VELTYP     Velocity frame of reference
VERSION    Specify AIPS version or local task area
VLAMODE    VLA observing mode
VLAOBS     Observing program or part of observer's name
VLBINPRM   Control parameters to read data from NRAO/MPI MkII correlators
VNUMBER    Specifies the task parameter (VGET/VPUT) save area
VPARM      General numeric array adverb used in modeling
WEIGHTIT   Controls modification of weights before gain/fringe solutions
WGAUSS     Widths of Gaussian models (FWHM)
WTTHRESH   defines the weight threshold for data acceptance
WTUV       Specifies the weight to use for UV data outside UVRANGE
XAXIS      Which parameter is plotted on the horizontal axis.
X          spare scalar adverb for use in procedures
XINC       increment associated with an array of numbers
XPARM      General adverb for up to 10 parameters, may refer to X coord
XTYPE      Specify type of process, often the X axis type of an image
XYRATIO    Ratio of X to Y units per pixel
Y          spare scalar adverb for use in procedures
YINC       Y axis increment
YPARM      Specifies Y axis convolving function
YTYPE      Y axis (V) convolving function type
ZEROSP     Specify how to include zero spacing fluxes in FT of UV data
ZINC       Set the increment of the third axis
ZXRATIO    Ratio between Z axis (pixel value) and X axis
```

## 13.2 ANALYSIS

```
ACTNOISE   puts estimate of actual image uncertainty and zero in header
AHIST      Task to convert image intensities by adaptive histogram
AVOPTION   Controls type or range of averaging done by a task
BDEPO      computes depolarization due to rotation measure gradients
BLANK      blanks out selected, e.g. non-signal, portions of an image
BLSUM      sums images over irregular sub-images, displays spectra
BSCOR      Combines two beam-switched images
BSTST      Graphical display of solutions to frequency-switched data
BWSMEAR    amount of bandwidth smearing correction to use
COMB       combines two images by a variety of mathematical methods
CTYPE      specifies type of component
DOALIGN    specifies how two or more images are aligned in computations
DOINVERS   selects opposite of normal function
DOMAX      selects solutions for maxima of models
DOOUTPUT   selects whether output image or whatever is saved / discarded
DOPOS      selects solutions for positions of model components
DOWIDTH    selects solution for widths of model components
ECOUNT     give the highest count or iteration for some process
FARS       Faraday rotation synthesys based on the brightness vs wavelength
FLUX       gives a total intensity value for image/component or to limit
```

```
FMAX       specifies peak values of model components - results of fits
FPOS       specifies pixel positions of fit model components
FQUBE      collects n-dimensional images into n+1-dimensional FREQID image
FWIDTH     gives widths of model components - results of fitting
GAL        Determine parameters from a velocity field
GMAX       specifies peak values of model components
GPOS       specifies pixel positions of model components
GRBLINK    Verb which blinks 2 TV graphics planes
GWIDTH     gives widths of model components
HGEOM      interpolates image to different gridding and/or geometry
HOLGR      Read & process holography visibility data to telescope images
IMCENTER   returns pixel position of sub-image centroid
IMDIST     determines spherical distance between two pixels
IMEAN      displays the mean & extrema and plots histogram of an image
IMERG      merges images of different spatial resolutions
IMFIT      fits gaussians to portions of an image
IMLIN      Fits and removes continuum emission from cube
IMMOD      adds images of model objects to an image
IMSTAT     returns statistics of a sub-image
IMVAL      returns image intensity and coordinate at specified pixel
IMVIM      plots one image's values against another's
IRING      integrates intensity / flux in rings / ellipses
JMFIT      fits gaussians to portions of an image
LAYER      Task to create an RGB image from multiple images
LGEOM      regrids images with rotation, shift using interpolation
MATHS      operates on an image with a choice of mathematical functions
MAXFIT     returns pixel position and image intensity at a maximum
MCUBE      collects n-dimensional images into n+1-dimensional image
MEDI       combines four images by a variety of mathematical methods
MFPRT      prints MF tables in a format needed by modelling software
MINPATCH   specifies the minimum size allowed for the center of the beam
MOMFT      calculates images of moments of a sub-image
MOMNT      calculates images of moments along x-axis (vel, freq, ch)
MWFLT      applies linear & non-linear filters to images
NGAUSS     Number of Gaussians to fit
NINER      Applies various 3x3 area operaters to an image.
NNLSQ      Non-Negative-Least-Squares decomposition of spectrum
OMFIT      Fits sources and, optionally, a self-cal model to uv data
OUTTEXT    specifies name of output text file, not in regular catalog
PBCOR      Task to apply or correct an image for a primary beam
PRTIM      prints image intensities from an MA catalog entry
QIMVAL     Determines pixel value and coordinate at specified position
RM         Task to calculate rotation measure and magnetic field
RMSD       Calculate rms for each pixel using data at the box around the pixel
SAD        finds and fits Gaussians to portions of an image
SCLIM      operates on an image with a choice of mathematical functions
SERCH      Finds line signals in transposed data cube
SET1DG     Verb to set 1D gaussian fitting initial guesses.
SHADO      Calculate the shadowing of antennas at the array
SLCOL      Task to collate slice data and models.
SLFIT      Task to fit gaussians to slice data.
SLICE      Task to make a slice file from an image
SMOTH      Task to smooth a subimage from upto a 7-dim. image
SPIXR      Fits spectral indexes to each row of an image incl curvature
STFUN      Task to calculate a structure function image
SUMSQ      Task to sum the squared pixel values of overlapping,
TABGET     returns table entry for specified row, column and subscript.
TABPUT     replaces table entry for specified row, column and subscript.
```

```
TK1SET     Verb to reset 1D gaussian fitting initial guess.
TKAGUESS   Verb to re-plot slice model guess directly on TEK
TKAMODEL   Verb to add slice model display directly on TEK
TKASLICE   Verb to add a slice display on TEK from slice file
TKGUESS    Verb to display slice model guess directly on TEK
TKMODEL    Verb to display slice model directly on TEK
TKSET      Verb to set 1D gaussian fitting initial guesses.
TKSLICE    Verb to display slice file directly on TEK
TKVAL      Verb to obtain value under cursor from a slice
TKXY       Verb to obtain pixel value under cursor
TV1SET     Verb to reset 1D gaussian fitting initial guess on TV plot.
TVAGUESS   Verb to re-plot slice model guess directly on TV graphics
TVAMODEL   Verb to add slice model display directly on TV graphics
TVARESID   Verb to add slice model residuals directly on TV graphics
TVASLICE   Verb to add a slice display on TV graphics from slice file
TVBLINK    Verb which blinks 2 TV planes, can do enhancement also
TVCUBE     Verb to load a cube into tv channel(s) & run a movie
TVDIST     determines spherical distance between two pixels on TV screen
TVGUESS    Verb to display slice model guess directly on TV graphics
TVMAXFIT   displays fit pixel positions and intensity at maxima on TV
TVMODEL    Verb to display slice model directly on TV graphics
TVRESID    Verb to display slice model residuals directly on TV graphics
TVSET      Verb to set 1D gaussian fitting initial guesses from TV plot.
TVSLICE    Verb to display slice file directly on TV
UVADC      Fourier transforms and corrects a model and adds to uv data.
UVCON      Generate sample UV coverage given a user defined array layout
UVFIT      Fits source models to uv data.
UVHIM      Images statistics of uv data files.
UVMOD      Modify UV database by adding a model incl spectral index
UVSEN      Determine RMS sidelobe level and brightness sensitivity
UVSIM      Generate sample UV coverage given a user defined array layout
WARP       Model warps in Galaxies
XBASL      Fits and subtracts nth-order baselines from cube (x axis)
XGAUS      Fits 1-dimensional Gaussians to images
XMOM       Fits one-dimensional moments to each row of an image
```

## 13.3 AP

```
APCLN      Deconvolves images with CLEAN algorithm
APGS       deconvolves image with Gerchberg-Saxton algorithm
APVC       Deconvolves images with van Cittert algorithm
BLING      find residual rate and delay on individual baselines
BPASS      computes spectral bandpass correction table
BSGRD      Task to image beam-switched single-dish data
CALIB      determines antenna calibration: complex gain
CCRES      Removes or restores a CC file to a map with a gaussian beam.
COMAP      Procedure to MAP and Self-Calibrate a UVDATA set
COMAP_NA   Procedure to MAP and Self-Calibrate a UVDATA set
COMAP_UV   Procedure to MAP and Self-Calibrate a UVDATA set
CONPL      Plots AIPS gridding convolution functions
CONVL      convolves an image with a gaussian or another image
CPASS      computes polynomial spectral bandpass correction table
EDITA      Interactive TV task to edit uv data based on TY/SY/SN/CL tables
EDITR      Interactive baseline-oriented visibility editor using the TV
FFT        takes Fourier Transform of an image or images
FRCAL      Faraday rotation self calibration task
FRING      fringe fit data to determine antenna calibration, delay, rate
```

```
GUARD      portion of UV plane to receive no data in gridding
HLPCLEAN   Cleaning tasks  - internal help
HLPSCIMG   Cleaning tasks  - internal help
HLPSCMAP   Cleaning tasks  - internal help
HYB        RUN to set parameters for HYBRID (CALIB/MX) self-cal imaging
IM2UV      converts an image to a visibility data set
IMAGR      Wide-field and/or wide-frequency Cleaning / imaging task.
KRING      fringe fit data to determine antenna calibration, delay, rate
MAXPIXEL   maximum pixels searched for components in Clark CLEAN
NOBAT      Task to lock lower priority users out of the AP
RLDLY      fringe fit data to determine antenna R-L delay difference
RSTOR      Restores a CC file to a map with a gaussian beam.
SCIMG      Full-featured imaging plus self-calibration loop with editing
SCMAP      Imaging plus self-calibration loop with editing
SDGRD      Task to select and image random-position single-dish data
SDIMG      Task to select and image random-position single-dish data
SNEDT      Interactive SN/CL/TY/SY table editor using the TV
UVADC      Fourier transforms and corrects a model and adds to uv data.
UVMAP      makes images from calibrated UV data.
WFCLN      Wide field and/or widefrequency  CLEANing/imaging task.
```

## 13.4 ASTROMET

```
ASTROMET   Describes the process of astrometric/geodetic reduction in AIPS
FRMAP      Task to build a map using fringe rate spectra
HF2SV      convert HF tables from FRING/MBDLY to form used by Calc/Solve
HFPRT      write HF tables from CL2HF
XTRAN      Create an image with transformed coordinates
```

## 13.5 BATCH

```
Type:  Operations to prepare, submit, and monitor batch jobs
Use:   There are two batch streams of AIPS, each capable of
   processing a queue of jobs.  To run a batch job, one must
   first prepare the text of the job in a work file.  This text
   may contain any normal AIPS/POPS statement including RUN,
   except for verbs and tasks related to batch preparation, the
   TV, the TEK4012 green screen, and the tape drives.  When the
   text is ready, it may be submitted to the batch AIPS.  On
   the way, it is tested for errors and is submitted only if
   none are found.  After successful submission, the work file
   and any RUN files involved may be altered without affecting
   the job.  Array processor tasks are allowed only in queue
   #2 and only at night.  They may be submitted at any time,
   however.  Line printer output should be directed to a user
   chosen file (via adverb OUTPRINT).  If OUTPRINT = ' ', all
   tasks and AIPS itself will write to a file named
   PRTFIL:BATCHjjj.nnn, where jjj is the job number in hex and
   nnn is the user number in hex.  Note that all print jobs
   are concatenated into the specified file(s).
Adverbs:
   BATQUE     Number of queue to be used ( 1 or 2 or more )
   JOBNUM     Job number involved (101 - 164, 201 -264, ...)
   BATFLINE   First line number to be editted or listed
   BATNLINE   Number of lines to be listed
Verbs:
```

```
   BATCH     Add text to BATQUE work file
   BATCLEAR  Initiate and clear BATQUE work file
   BATLIST   List BATNLINE starting with BATFLINE from BATQUE
             work file
   BATEDIT   Edit text in BATQUE work file starting with line
             BATFLINE (or immediate argument)
   BAMODIFY  Edit text in BATQUE work file in line BATFLINE (or
             immediate argument), character-mode editing.
   SUBMIT    Submit text in BATQUE work file as job for queue
             BATQUE
   JOBLIST   List BATNLINE starting with BATFLINE from text file
             of job JOBNUM
   QUEUES    List jobs submitted, running, and completed in
             queue BATQUE
   UNQUE     Remove JOBNUM from queue, copy text of job to work
             file BATQUE

Batch jobs may also be prepared and submitted outside of AIPS,
using the program BATER.  See HELP BATER.
****************************************************************

AIPSB      AIPS main program for executing batch jobs
AIPSC      AIPS main program for testing and queuing batch jobs
BAMODIFY   edits characters in a line of a batch work file
BATCH      starts entry of commands into batch-job work file
BATCLEAR   removes all text from a batch work file
BATEDIT    starts an edit (replace, insert) session on a batch work file
BATER      stand-alone program to prepare and submit batch jobs
BATFLINE   specifies starting line in a batch work file
BATLIST    lists the contents of a batch work file
BATNLINE   specifies the number of lines to process in a batch work file
BATQUE     specifies the desired batch queue
ENDBATCH   terminates input to batch work file
JOBLIST    lists contents of a submitted and pending batch job
JOBNUM     specifies the batch job number
QUEUES     Verb to list all submitted jobs in the job queue
REMQUE     specifies the desired batch queue on a remote computer
UNQUE      remove a given job from the job queue
```

## 13.6 CALIBRAT

```
For a lengthy description of the calibration of interferometric
data (VLA and VLB line and continuum) enter:
              HELP CALIBRAT
****************************************************************

ACCOR      Corrects cross amplitudes using auto correlation measurements
ACFIT      Determine antenna gains from autocorrelations
ANCAL      Places antenna-based Tsys and gain corrections in CL table
ANCHECK    Checks By sign in Antenna files
ANTAB      Read amplitude calibration information into AIPS
ANTENNAS   Antennas to include/exclude from the task or verb
ANTUSE     Antennas to include/exclude from the task or verb
ANTWT      Antenna Weights for UV data correction in Calibration
APCAL      Apply TY and GC tables to generate an SN table
APGPS      Apply GPS-derived ionospheric corrections
ATMCA      Determines delay/phase gradient from calibrator observations
```

```
BASELINE  specifies which antenna pairs are to be selected/deselected
BASFIT    fits antenna locations from SN-table data
BLAPP     applies baseline-based fringe solutions a la BLAPP
BLAVG     Average cross-polarized UV data over baselines.
BLCAL     Compute closure offset corrections
BLCHN     Compute closure offset corrections on a channel-by-channel basis
BLING     find residual rate and delay on individual baselines
BLVER     specifies the version of the baseline-calibration table used
BPASS     computes spectral bandpass correction table
BPASSPRM  Control adverb array for bandpass calibration
BPCOR     Correct BP table.
BPERR     Print and plot BPASS closure outputs
BPLOT     Plots bandpass tables in 2 dimensions as function of time
BPSMO     Smooths or interpolates bandpass tables to regular times
BPVER     specifies the version of the bandpass table to be applied
BSPRT     print BS tables
BSROT     modifies SD beam-switch continuum data for error in throw
CALCODE   specifies the type of calibrator to be selected
CALDIR    lists calibrator models available as AIPS FITS files
CALIB     determines antenna calibration: complex gain
CALIBRAT  describes the process of data calibration in AIPS
CALIN     specifies name of input disk file usually with calibration data
CALRD     Reads model-image FITS file
CALSOUR   specifies source names to be included in calibration
CHANSEL   Array of start, stop, increment channel numbers to average
CLCAL     merges and smooths SN tables, applies them to CL tables
CLCOP     copy CL/SN file calibration between polarizations
CLCOR     applies user-selected corrections to the calibration CL table
CLCORPRM  Parameter adverb array for task CLCOR
CLINT     CL table entry interval
CLINV     copy CL/SN file inverting the calibration
CLIP      edits data based on amplitudes, phases, and weights out of range
CLSMO     smooths a calibration CL table
CMETHOD   specifies the method by which the uv model is computed
CMODEL    specifies the method by which the uv model is computed
CONFI     Optimize array configuration by minimum side lobes
CPASS     computes polynomial spectral bandpass correction table
CSCOR     applies specified corrections to CS tables
CVEL      shifts spectral-line UV data to a given velocity
DECOR     Measures the decorrelation between channels and IF of uv data
DEFLG     edits data based on decorrelation over channels and time
DELCORR   specifies whether VLBA delay corrections  are to be used
DELZN     Determines residual atmosphere depth at zenith and clock errors
DFCOR     applies user-selected corrections to the calibration CL table
DIGICOR   specifies whether VLBA digital corrections are to be applied
DOACOR    specifies whether autocorrelation data are included
DOAPPLY   Flag to indicate whether an operation is applied to the data
DOBAND    specifies if/how bandpass calibration is applied
DOBTWEEN  Controls smoothing between sources in calibration tables
DOCALIB   specifies whether a gain table is to be applied or not
DODELAY   selects solution for phase/amplitude or delay rate/phase
DOFIT     Controls which antennas are fit by what methods
DOFLAG    Controls closure cutoff in gain solutions and flagging
DOPOL     selects application of any polarization calibration
DTSIM     Generate fake UV data
EDITA     Interactive TV task to edit uv data based on TY/SY/SN/CL tables
EDITR     Interactive baseline-oriented visibility editor using the TV
ELINT     Determines and removes gain dependence on elevation
```

| | |
|---|---|
| EVASN | Evaluates statistics in SN/CL tables |
| EVAUV | Subtracts & divides a model Into uv data, does statistics on results |
| FACES | makes images of catalog sources for initial calibration |
| FARAD | add ionospheric Faraday rotation to CL table |
| FGPLT | Plots selected contents of FG table |
| FINDR | Find normal values for a uv data set |
| FIXWT | Modify weights to reflect amplitude scatter of data |
| FLAGR | Edit data based on internal RMS, amplitudes, weights |
| FLAGVER | selects version of the flagging table to be applied |
| FLGIT | flags data based on the rms of the spectrum |
| FQTOL | Frequency tolerance with which FQ entries are accepted. |
| FRCAL | Faraday rotation self calibration task |
| FREQID | Frequency Identifier for frequency, bandwidth combination |
| FRING | fringe fit data to determine antenna calibration, delay, rate |
| GAINERR | gives estimate of gain uncertainty for each antenna |
| GAINUSE | specifies output gain table or gain table applied to data |
| GAINVER | specifies the input gain table |
| GCVER | specifies the version of the gain curve table used |
| GETJY | determines calibrator flux densities |
| GPSDL | Calculate ionospheric delay and Faraday rotation corrections |
| HLPCLEAN | Cleaning tasks - internal help |
| HLPEDICL | Interactive SN/CL table uv-data editor - internal help |
| HLPEDISN | Interactive SN/CL table (not UV) editor - internal help |
| HLPEDISS | Interactive SY table (not UV) editor - internal help |
| HLPEDISY | Interactive SY table uv-data editor - internal help |
| HLPEDITS | Interactive TY table (not UV) editor - internal help |
| HLPEDITY | Interactive TY table uv-data editor - internal help |
| HLPEDIUV | Interactive uv-data editor - internal help |
| HLPIBLED | Interactive Baseline based visibility Editor - internal help |
| HLPSCIMG | Cleaning tasks - internal help |
| HLPSCMAP | Cleaning tasks - internal help |
| HLPSPFLG | Interactive time-channel visibility Editor - internal help |
| HLPTVFLG | Interactive time-baseline visibility Editor - internal help |
| HYB | RUN to set parameters for HYBRID (CALIB/MX) self-cal imaging |
| IBLED | Interactive BaseLine based visibility EDitor |
| ICHANSEL | Array of start, stop, increment channel #S + IF to average |
| IMAGR | Wide-field and/or wide-frequency Cleaning / imaging task. |
| INDXH | writes index file describing contents of UV data base |
| INDXR | writes index file describing contents of UV data base |
| INTERPOL | specifies the type of averaging done on the complex gains |
| INTPARM | specifies the parameters of the gain interpolation function |
| KRING | fringe fit data to determine antenna calibration, delay, rate |
| LDGPS | load GPS data from an ASCII file |
| LISTR | prints contents of UV data sets and assoc. calibration tables |
| LOCIT | fits antenna locations from SN-table data |
| LPCAL | Determines instrumental polarization for UV data |
| MAPBM | Map VLA beam polarization |
| MBDLY | Fits multiband delays from IF phases, updates SN table |
| MINAMPER | specifies the minimum amplitude error prior to some action |
| MINPHSER | specifies the minimum phase error prior to some action |
| MSORT | Sort a UV dataset into a specified order |
| MULTI | Task to convert single-source to multi-source UV data |
| OMFIT | Fits sources and, optionally, a self-cal model to uv data |
| OOSRT | Sort a UV dataset into a specified order |
| OOSUB | Subtracts/divides a model from/into a uv data base |
| PBEAM | Fits the analytic function to the measured values of the beam |
| PCAL | Determines instrumental polarization for UV data |
| PCCOR | Corrects phases using PCAL tones data from PC table |

```
PCLOD      Reads ascii file containing pulse-cal info to PC table.
PDVER      specifies the version of the spetral polarization table to use
PEELR      calibrates interfering sources in multi-facet imges
PHASPRM    Phase data array, by antenna number.
POLANGLE   Intrinsic polarization angles for up to 30 sources
POLSN      Make a SN table from cross polarized fringe fit
REAMP      modifies UV data re-scaling the amplitudes
REFANT     Reference antenna
REFREQ     Allows changing of reference pixel
RESEQ      Renumber antennas
RFI        Look for RFI in uv data
RLDIF      determines Right minus Left phase difference
RLDLY      fringe fit data to determine antenna R-L delay difference
SCIMG      Full-featured imaging plus self-calibration loop with editing
SCMAP      Imaging plus self-calibration loop with editing
SDCAL      Task to apply single dish calibration
SDVEL      shifts spectral-line single-dish data to a given velocity
SEARCH     Ordered list of antennas for fring searches
SELBAND    Specified bandwidth
SELFREQ    Specified frequency
SETJY      Task to enter source info into source (SU) table.
SHOUV      displays uv data in various ways.
SMODEL     Source model
SMOTYPE    Specifies smoothing
SNCOR      applies user-selected corrections to the calibration SN table
SNCORPRM   Task-specific parameters for SNCOR.
SNDUP      copies and duplicates SN table from single pol file to dual pol
SNEDT      Interactive SN/CL/TY/SY table editor using the TV
SNFLG      Writes flagging info based on the contents of SN files
SNPLT      Plots selected contents of SN, TY, PC or CL files
SNSMO      smooths and filters a calibration SN table
SNVER      specifies the output solution table
SOLCL      adjust gains for solar data according to nominal sensitivity
SOLCON     Gain solution constraint factor
SOLINT     Solution interval
SOLMIN     Minimum number of solution sub-intervals in a solution
SOLMODE    Solution mode
SOLSUB     Solution sub-interval
SOLTYPE    Solution type
SOUCODE    Calibrator code for source, not calibrator, selection
SOUSP      fits source spectral index from SU table or adverbs
SPCAL      Determines instrumental polzn. for spec. line UV data
SPECINDX   Spectral index used to correct calibrations
SPECPARM   Spectral index per polarization per source
SPECTRAL   Flag to indicate whether an operation is spectral or continuum
SPECURVE   Spectral index survature used to correct calibrations
SPFLG      interactive flagging of UV data in channel-TB using the TV
SPLAT      Applies calibration and splits or assemble selected sources.
SPLIT      converts multi-source to single-source UV files w calibration
TASAV      Task to copy all extension tables to a dummy uv or map file
TAUO       Opacities by antenna number
TECOR      Calculate ionospheric delay and Faraday rotation corrections
TIMSMO     Specified smoothing times
TRECVR     Receiver temperatures by polarization and antenna
TRIANGLE   specifies closure triangles to be selected/deselected
TRUEP      determines true antenna polarization from special data sets
TVFLG      interactive flagging of UV data using the TV
TYAPL      undoes and re-does nominal sensitivity application
```

```
TYSMO     smooths and filters a calibration TY or SY table
TYVER     specifies the version of the system temperature table used
UNCAL     sets up tables for uncalibrating Australia Telescope data
USUBA     Assign subarrays within a uv-data file
UVCRS     Finds the crossing points of UV-ellipses.
UVFIT     Fits source models to uv data.
UVFLG     Flags UV-data
UVHOL     prints holography data from a UV data base with calibration
UVMLN     edits data based on the rms of the spectrum
UVPRT     prints data from a UV data base with calibration
UVSRT     Sort a UV dataset into a specified order
UVSUB     Subtracts/divides a model from/into a uv data base
VBCAL     Scale visibility amplitudes by antenna based constants
VLABP     VLA antenna beam polarization correction for snapshot images
VLACALIB  Runs CALIB and LISTR for VLA observation
VLACLCAL  Runs CLCAL and prints the results with LISTR
VLALIST   Runs LISTR for VLA observation
VLAMODE   VLA observing mode
VLANT     applies VLA antenna position corrections from OPs files
VLAOBS    Observing program or part of observer's name
VLAPROCS  Procedures to simplify the reduction of VLBA data
VLARESET  Reset calibration tables to a virginal state
VLARUN    calibrating amplitude and phase, and imaging VLA data
VLBACALA  applies a-priori amplitude corrections to VLBA data
VLBACPOL  Procedure to calibrate cross-polarization delays
VLBAEOPS  Corrects Earth orientation parameters
VLBAFQS   Copies different FQIDS to separate files
VLBAFRGP  Fringe fit phase referenced data and apply calibration
VLBAFRNG  Fringe fit data and apply calibration
VLBAKRGP  Fringe fit phase referenced data and apply calibration
VLBAKRNG  Fringe fit data and apply calibration
VLBAMCAL  Merges redundant calibration data
VLBAMPCL  Calculates and applies manual instrumental phase calibration
VLBAPANG  Corrects for parallactic angle
VLBAPCOR  Calculates and applies instrumental phase calibration
VLBAPIPE  applies amplitude and phase calibration procs to VLBA data
VLBATECR  Calculate ionospheric delay and Faraday rotation corrections
VLBAUTIL  Procedures to simplify the reduction of VLBA data
VLOG      Pre-process external VLBA calibration files
WEIGHTIT  Controls modification of weights before gain/fringe solutions
WETHR     Plots selected contents of WX tables, flags data based on WX
WRTPROCS  Procedures to simplify the reduction of VLBA data
WTTHRESH  defines the weight threshold for data acceptance
WTUV      Specifies the weight to use for UV data outside UVRANGE
```

## 13.7 CATALOG

```
ABACKUP   VMS procedure to back up data on tape
ACTNOISE  puts estimate of actual image uncertainty and zero in header
ADDBEAM   Inserts clean beam parameters in image header
ADDDISK   makes a computer's disks available to the current AIPS session
ALLDEST   Delete a group or all of a users data files
ALTDEF    Sets frequency vs velocity relationship into image header
ALTSWTCH  Switches between frequency and velocity in image header
ARESTORE  Restores back up tapes of users data
AX2REF    Second reference pixel number
AXDEFINE  Define or modify an image axis description
```

```
AXINC     Axis increment - change in coordinate between pixels
AXREF     Reference pixel number
AXTYPE    Type of coordinate axis
AXVAL     Value of axis coordinate at reference pixel
BAKLD     reads all files of a catalog entry from BAKTP tape
BAKTP     writes all files of a catalog entry to tape in host format
CATALOG   list one or more entries in the user's data directory
CATNO     Specifies AIPS catalog slot number range
CELGAL    switches header between celestial and galactic coordinates
CHKNAME   Checks for existence of the specified image name
CLR2NAME  clears adverbs specifying the second input image
CLR3NAME  clears adverbs specifying the third input image
CLR4NAME  clears adverbs specifying the fourth input image
CLRNAME   clears adverbs specifying the first input image
CLRONAME  clears adverbs specifying the first output image
CLRSTAT   remove any read or write status flags on a directory entry
COODEFIN  Define or modify an image axis coordinate description
COOINC    Celestial axes increment: change in coordinate between pixels
COOREF    Reference pixel number for two coordinate axes
COOTYPE   Celestial axes projection type
DISKU     shows disk use by one or all users
DOALPHA   specifies whether some list is alphabetized
DOCAT     specifies whether the output is saved (cataloged) or not
DOOUTPUT  selects whether output image or whatever is saved / discarded
EGETHEAD  returns parameter value from image header and error code
EGETNAME  fills in input name adverbs by catalog slot number, w error
EPOSWTCH  Switches between B1950 and J2000 coordinates in header
ERROR     was there an error
EXTDEST   deletes one or more extension files
EXTLIST   lists detailed information about contents of extension files
GET2NAME  fills 2nd input image name parameters by catalog slot number
GET3NAME  fills 3rd input image name parameters by catalog slot number
GET4NAME  fills 4th input image name parameters by catalog slot number
GETHEAD   returns parameter value from image header
GETNAME   fills 1st input image name parameters by catalog slot number
GETONAME  fills 1st output image name parameters by catalog slot number
HGEOM     interpolates image to different gridding and/or geometry
HIEND     End record number in a history-file operation
HINOTE    adds user-generated lines to the history extension file
HISTART   Start record number in a history-file operation
HITEXT    writes lines from history extension file to text file
IMDIST    determines spherical distance between two pixels
IMHEADER  displays the image header contents to terminal, message file
IMPOS     displays celestial coordinates selected by the TV cursor
IMVAL     returns image intensity and coordinate at specified pixel
IN2CLASS  specifies the "class" of the 2nd input image or data base
IN2DISK   specifies the disk drive of the 2nd input image or data base
IN2EXT    specifies the type of the 2nd input extension file
IN2NAME   specifies the "name" of the 2nd input image or data base
IN2SEQ    specifies the sequence # of the 2nd input image or data base
IN2TYPE   specifies the type of the 2nd input image or data base
IN2VERS   specifies the version number of the 2nd input extension file
IN3CLASS  specifies the "class" of the 3rd input image or data base
IN3DISK   specifies the disk drive of the 3rd input image or data base
IN3EXT    specifies the type of the 3rd input extension file
IN3NAME   specifies the "name" of the 3rd input image or data base
IN3SEQ    specifies the sequence # of the 3rd input image or data base
IN3TYPE   specifies the type of the 3rd input image or data base
```

```
IN3VERS    specifies the version number of the 3rd input extension file
IN4CLASS   specifies the "class" of the 4th input image or data base
IN4DISK    specifies the disk drive of the 4th input image or data base
IN4NAME    specifies the "name" of the 4th input image or data base
IN4SEQ     specifies the sequence # of the 4th input image or data base
IN4TYPE    specifies the type of the 4th input image or data base
INCLASS    specifies the "class" of the 1st input image or data base
INDISK     specifies the disk drive of the 1st input image or data base
INEXT      specifies the type of the 1st input extension file
INNAME     specifies the "name" of the 1st input image or data base
INSEQ      specifies the sequence # of the 1st input image or data base
INTYPE     specifies the type of the 1st input image or data base
INVERS     specifies the version number of the 1st input extension file
KEYSTRNG   gives contents of character-valued keyword parameter
KEYTYPE    Adverb giving the keyword data type code
KEYVALUE   gives contents of numeric-valued keyword parameter
KEYWORD    gives name of keyword parameter - i.e. name of header field
LGEOM      regrids images with rotation, shift using interpolation
MCAT       displays images in the user's catalog directory
MOVE       Task to copy or move data from one user to another
OUT2CLAS   The class of a secondary output file
OUT2DISK   The disk number of a secondary output file.
OUT2NAME   The name of a secondary output file.
OUT2SEQ    The sequence of a secondary output file.
OUTCLASS   The class of an output file
OUTDISK    The disk number of an output file.
OUTNAME    The name of an output file.
OUTSEQ     The sequence of an output file.
OUTVERS    The output version number of an table or extension file.
PCAT       Verb to list entries in the user's catalog (no log file).
PLVER      specifies the version number of a PL extension file
PRTHI      prints selected contents of the history extension file
PUTHEAD    Verb to modify image header parameters.
QHEADER    Verb to summarize the image header: positions at center
QUAL       Source qualifier
REASON      The reason for an operation
RECAT      Verb to compress the entries in a catalog file
REMDISK    removes a computer's disks from the current AIPS session
RENAME     Rename a file (UV or Image)
RENUMBER   Verb to change the catalog number of an image.
RESCALE    Verb to modify image scale factor and offset
SCRDEST    Verb to destroy scratch files left by bombed tasks.
SLOT       Specifies AIPS catalog slot number
STALIN     revises history by deleting lines from history extension file
TVDIST     determines spherical distance between two pixels on TV screen
UCAT       list a user's UV and scratch files on one or more data areas
USERID     User number
ZAP        Delete a catalog entry and its extension files
```

## 13.8 COORDINA

```
ALTDEF     Sets frequency vs velocity relationship into image header
ALTSWTCH   Switches between frequency and velocity in image header
COODEFIN   Define or modify an image axis coordinate description
COORDINA   Array to hold coordinate values
COPIXEL    Convert between physical and pixel coordinate values
COSTAR     Verb to plot a symbol at given position on top of a TV image
```

| | |
|---|---|
| COTVLOD | Proc to load an image into a TV channel about a coordinate |
| COWINDOW | Set a window based on coordinates |
| EPOCONV | Convert between J2000 and B1950 coordinates |
| EPOSWTCH | Switches between B1950 and J2000 coordinates in header |
| FRMAP | Task to build a map using fringe rate spectra |
| NAXIS | Axis number |
| OBEDT | Task to flag data of orbiting antennas |
| OBTAB | Recalculate orbit parameters and other spacecraft info |
| PIX2VAL | An image value in the units specified in the header. |
| PIX2XY | Specifies a pixel in an image |
| RASHIFT | Shift in RA |
| REGRD | Regrids an image from one co-ordinate frame to another |
| RESTFREQ | Rest frequency of a transition |
| ROTATE | Specifies a rotation |
| SHIFT | specifies a position shift |
| SKYVE | Regrids a DSS image from one co-ordinate frame to another |
| SYSVEL | Systemic velocity |
| VELDEF | Specifies velocity definition |
| VELTYP | Velocity frame of reference |
| XINC | increment associated with an array of numbers |
| XPARM | General adverb for up to 10 parameters, may refer to X coord |
| XTRAN | Create an image with transformed coordinates |
| XTYPE | Specify type of process, often the X axis type of an image |
| XYRATIO | Ratio of X to Y units per pixel |
| ZINC | Set the increment of the third axis |
| ZXRATIO | Ratio between Z axis (pixel value) and X axis |

## 13.9 EDITING

| | |
|---|---|
| CLIP | edits data based on amplitudes, phases, and weights out of range |
| CROWDED | allows a task to perform its function in a crowded fashion |
| DEFLG | edits data based on decorrelation over channels and time |
| DOFLAG | Controls closure cutoff in gain solutions and flagging |
| EDITA | Interactive TV task to edit uv data based on TY/SY/SN/CL tables |
| EDITR | Interactive baseline-oriented visibility editor using the TV |
| EXPERT | specifies an user experience level or mode |
| FINDR | Find normal values for a uv data set |
| FLAGR | Edit data based on internal RMS, amplitudes, weights |
| FLGIT | flags data based on the rms of the spectrum |
| HLPEDICL | Interactive SN/CL table uv-data editor - internal help |
| HLPEDISN | Interactive SN/CL table (not UV) editor - internal help |
| HLPEDISS | Interactive SY table (not UV) editor - internal help |
| HLPEDISY | Interactive SY table uv-data editor - internal help |
| HLPEDITS | Interactive TY table (not UV) editor - internal help |
| HLPEDITY | Interactive TY table uv-data editor - internal help |
| HLPEDIUV | Interactive uv-data editor - internal help |
| HLPWIPER | WIPER run-time help file |
| IBLED | Interactive BaseLine based visibility EDitor |
| OFLAG | uses on-line flag table information to write a flag table |
| OUTFGVER | selects version of the flagging table to be written |
| RFI | Look for RFI in uv data |
| SCIMG | Full-featured imaging plus self-calibration loop with editing |
| SCMAP | Imaging plus self-calibration loop with editing |
| SDLSF | least squares fit to channels and subtracts from SD uv data |
| SNEDT | Interactive SN/CL/TY/SY table editor using the TV |
| SPFLG | interactive flagging of UV data in channel-TB using the TV |
| TABED | Task to edit tables |

| | |
|---|---|
| TAFLG | Flags data in a Table extension file |
| TVFLG | interactive flagging of UV data using the TV |
| UVFLG | Flags UV-data |
| UVFND | prints selected data from UV data set to search for problems |
| UVLIN | Fits and removes continuum visibility spectrum, also can flag |
| UVLSD | least squares fit to channels and divides the uv data. |
| UVLSF | least squares fit to channels and subtracts from uv data. |
| UVMLN | edits data based on the rms of the spectrum |
| VPFLG | Resets flagging to all correlators whenever 1 is flagged |
| WETHR | Plots selected contents of WX tables, flags data based on WX |
| WIPER | plots and edits data from a UV data base using the TV |

## 13.10 EXT-APPL

| | |
|---|---|
| BSPRT | print BS tables |
| GETTHEAD | returns keyword and other values value from a table header |
| MF2ST | Task to generate an ST ext. file from Model Fit ext. file |
| PUTTHEAD | inserts a given value into a table keyword/value pair |
| TABGET | returns table entry for specified row, column and subscript. |
| TABPUT | replaces table entry for specified row, column and subscript. |

## 13.11 FITS

| | |
|---|---|
| CALRD | Reads model-image FITS file |
| CALWR | writes calibrator images w CC files to FITS disk files |
| DATAIN | specifies name of input FITS disk file |
| DATAOUT | specifies name of output FITS disk file |
| FILEZAP | Delete an external file |
| FIT2A | reads the fits input file and records it to the output ascii file |
| FITAB | writes images / uv data w extensions to tape in FITS format |
| FITDISK | writes images / uv data w extensions to disk in FITS format |
| FITLD | reads tape to load FITS images or FITS UV files to disk |
| FITTP | writes images / uv data w extensions to tape in FITS format |
| IMLOD | reads tape to load images to disk |
| READISK | writes images / uv data w extensions to tape in FITS format |
| TCOPY | Tape to tape copy with some disk FITS support |
| UVLOD | Read export or FITS data from a tape or disk |
| VLBALOAD | Loads VLBA data |
| WRTDISK | writes images / uv data w extensions to tape in FITS format |
| WRTPROCS | Procedures to simplify the reduction of VLBA data |

## 13.12 GENERAL

| | |
|---|---|
| ABORTASK | stops a running task |
| ABOUT | displays lists and information on tasks, verbs, adverbs |
| AIPSB | AIPS main program for executing batch jobs |
| AIPS | AIPS main program for interactive use |
| ANTNAME | A list of antenna (station) names |
| APARM | General numeric array adverb used many places |
| BADDISK | specifies which disks are to be avoided for scratch files |
| BATCHJOB | Information about BATCH |
| BCOUNT | gives beginning location for start of a process |
| BITER | gives beginning point for some iterative process |
| BLC | gives lower-left-corner of selected subimage |
| BPARM | general numeric array adverb used too many places |

```
CATEGORY   List of allowed primary keywords in HELP files
CLRMSG     deletes messages from the user's message file
COMMENT    64-character comment string
CPARM      general numeric array adverb used many places
CPUTIME    displays curren tcpu and real time usage of the AIPS task
CROWDED    allows a task to perform its function in a crowded fashion
DCODE      General string adverb
DDISK      Deterimins where input DDT data is found
DDT        verifies correctness and performance using standard problems
DDTSAVE    verifies correctness and performance using standard problems
DDTSIZE    Deterimins which type of DDT is RUN.
DETIME     specifies a time interval for an operation (destroy, batch)
DISKU      shows disk use by one or all users
DOALL      specifies if an operation is done once or for all matching
DOCONFRM   selects user confirmation modes of repetitive operation
DOWAIT     selects wait-for-completion mode for running tasks
DOWEIGHT   selects operations with data weights
DPARM      General numeric array adverb used many places
DRCHK      stand-alone program checks system setup files for consistency
ECOUNT     give the highest count or iteration for some process
EDGSKP     Deterimins border excluded from comparision or use
EHEX       converts decimal to extended hex
EXPERT     specifies an user experience level or mode
EXPLAIN    displays help + extended information describing a task/symbol
FILEZAP    Delete an external file
FPARM      General numeric array adverb used in modeling
FREESPAC   displays available disk space for AIPS in local system
GET        restores previously SAVEd full POPS environment
GNUGPL     Information about GNU General Public License for AIPS
GO         starts a task, detaching it from AIPS or AIPSB
GRADDRES   specifies user's home address for replies to gripes
GRDROP     deletes the specified gripe entry
GREMAIL    gives user's e-mail address name for reply to gripe entry
GRINDEX    lists users and time of all gripe entries
GRIPE      enter a suggestion or bug report for the AIPS programmers
GRIPR      standalone program to enter suggestions/complaints to AIPS
GRLIST     lists contents of specified gripe entry
GRNAME     gives user's name for reply to gripe entry
GRPHONE    specifies phone number to call for questions about a gripe
HELP       displays information on tasks, verbs, adverbs
HINOTE     adds user-generated lines to the history extension file
HITEXT     writes lines from history extension file to text file
IN2FILE    specifies name of a disk file, outside the regular catalog
INFILE     specifies name of a disk file, outside the regular catalog
INTEXT     specifies name of input text file, not in regular catalog
IOTAPE     Deterimins which tape drive is used during a DDT RUN
LSAPROPO   Data input to APROPO to find what uses what words
MAPDIF     Records differences between DDT test results and standards
MDISK      Deterimins where input DDT data is found
MSGKILL    turns on/off the recording of messages in the message file
MSGSERVER  Information about the X11-based message server
MSGSRV     Information about the X11-based message server
NBOXES     Number of boxes
NCCBOX     Number of clean component boxes
NCOUNT     General adverb, usually a count of something
NITER      The number of iterations of a procedure
NPOINTS    General adverb giving the number of something
OBJECT     The name of an object
```

```
OFFSET     General adverb, the offset of something.
OPCODE     General adverb, defines an operation
OPTELL     The operation to be passed to a task by TELL
OPTYPE     General adverb, defines a type of operation.
ORDER      Adverb used usually to specify the order of polynomial fit
OTFBS      Translates on-the-fly continuum SDD format to AIPS UV file
OTFUV      Translates on-the-fly single-dish SDD format to AIPS UV file
OUTFILE    specifies name of output disk file, not in regular catalog
OUTTEXT    specifies name of output text file, not in regular catalog
OUTVERS    The output version number of an table or extension file.
PANIC      Instructions for what to do when things go wrong
PIX2VAL    An image value in the units specified in the header.
PIXRANGE   Range of pixel values to display
PIXVAL     Value of a pixel
POSTSCRIP  General comments about AIPS use of PostScript incl macros
PRTAC      prints contents and summaries of the accounting file
PRTASK     Task name selected for printed information
PRTHI      prints selected contents of the history extension file
PRTMSG     prints selected contents of the user's message file
QUAL       Source qualifier
READLINE   Information about AIPS use of the GNU readline library.
REASON      The reason for an operation
REBYTE     service program to transform byte order of full data sets
REHEX      converts extended hex string to decimal
ROTATE     Specifies a rotation
RPARM      General numeric array adverb used in modeling
RTIME      Task to test compute times
SCALR1     General adverb
SCALR2     General adverb
SCALR3     General adverb
SECONDARY  List of allowed secondary keywords in HELP files
SECONDRY   List of allowed secondary keywords in HELP files
SOURCES    A list of source names
SPARM      General string array adverb
STALIN     revises history by deleting lines from history extension file
STRA1      General string adverb
STRA2      General string adverb
STRA3      General string adverb
STRB1      General string adverb
STRB2      General string adverb
STRB3      General string adverb
STRC1      General string adverb
STRC2      General string adverb
STRC3      General string adverb
SUBARRAY   Subarray number
SYMBOL     General adverb, probably defines a plotting symbol type
SYS2COM    specifies a command to be sent to the operating system
SYSCOM     specifies a command to be sent to the operating system
SYSOUT     specifies the output device used by the system
SYSTEM     Verb to send a command to the operating system
TCODE      Deterimins which type of DDT is RUN.
TDISK      Deterimins where output DDT data is placed
TELL       Send parameters to tasks that know to read them on the fly
TIMERANG   Specifies a timerange
TMASK      Deterimins which tasks are executed when a DDT is RUN.
TMODE      Deterimins which input is used when a DDT is RUN.
TNAMF      Deterimins which files are input to DDT.
TPMON      Information about the TPMON "Daemon"
```

| | |
|---|---|
| VCODE | General string adverb |
| VLAC | verifies correctness of continuum calibration software |
| VLACSAVE | verifies correctness of continuum calibration |
| VLAL | verifies correctness of spectral line calibration software |
| VLALSAVE | verifies correctness of continuum calibration |
| VLBDDT | Verification tests using simulated data |
| VPARM | General numeric array adverb used in modeling |
| WHATSNEW | lists changes and new code in the last several AIPS releases |
| XHELP | Accesses hypertext help system |
| XPARM | General adverb for up to 10 parameters, may refer to X coord |
| XTYPE | Specify type of process, often the X axis type of an image |
| Y2K | verifies correctness and performance using standard problems |
| Y2KSAVE | verifies correctness and performance using standard problems |
| YINC | Y axis increment |
| YTYPE | Y axis (V) convolving function type |

## 13.13 HARDCOPY

| | |
|---|---|
| BPRINT | gives beginning location for start of a printing process |
| BSPRT | print BS tables |
| EPRINT | gives location for end of a printing process |
| FACTOR | scales some display or CLEANing process |
| FLMCOMM | Comment for film recorder image. |
| HIEND | End record number in a history-file operation |
| HISTART | Start record number in a history-file operation |
| INTEXT | specifies name of input text file, not in regular catalog |
| ISPEC | Plots and prints spectrum of region of a cube |
| NPLOTS | gives number of plots per page or per job |
| NPRINT | gives number of items to be printed |
| OTFIN | Lists on-the-fly single-dish SDD format data files |
| OUTFILE | specifies name of output disk file, not in regular catalog |
| OUTPRINT | specifies name of disk file to keep the printer output |
| OUTTEXT | specifies name of output text file, not in regular catalog |
| POSTSCRIP | General comments about AIPS use of PostScript incl macros |
| PRINTER | Verb to set or show the printer(s) used |
| PRIORITY | Limits prioroty of messages printed |
| PRNUMBER | POPS number of messages |
| PRSTART | First record number in a print operation |
| PRTASK | Task name selected for printed information |
| PRTIME | Time limit |
| PRTLEV | Specified the amount of information requested. |
| PRTSD | prints contents of AIPS single-dish data sets |
| PRTUV | prints contents of a visibility (UV) data set |
| RGBGAMMA | specifies the desired color gamma corrections |
| RSPEC | Plots and prints spectrum of rms of a cube |
| TVCPS | Task to copy a TV screen-image to a PostScript file. |
| TVDIC | Task to copy a TV screen-image to a Dicomed film recorder. |
| UVFND | prints selected data from UV data set to search for problems |
| UVHOL | prints holography data from a UV data base with calibration |
| UVPRT | prints data from a UV data base with calibration |

## 13.14 IMAGE-UT

| | |
|---|---|
| BDROP | gives number of pooints dropped at the beginning |
| BSGEO | Beam-switched Az-El image to RA-Dec image translation |
| CALWR | writes calibrator images w CC files to FITS disk files |

| | |
|---|---|
| DOMODEL | selects display of model function |
| DORESID | selects display of differences between model and data |
| DOSLICE | selects display of slice data |
| EDROP | number of points/iterations to be omitted from end of process |
| FIT2A | reads the fits input file and records it to the output ascii file |
| FITAB | writes images / uv data w extensions to tape in FITS format |
| FITDISK | writes images / uv data w extensions to disk in FITS format |
| FITTP | writes images / uv data w extensions to tape in FITS format |
| HLPTVHUI | Interactive intensity-hue-saturation display - on-line help |
| HLPTVRGB | Interactive red-green-blue display - on-line help |
| IMCLP | Clip an image to a specified range. |
| IMLOD | reads tape to load images to disk |
| OGEOM | Simple image rotation, scaling, and translation |
| OHGEO | Geometric interpolation with correction for 3-D effects |
| READISK | writes images / uv data w extensions to tape in FITS format |
| WRTDISK | writes images / uv data w extensions to tape in FITS format |
| WRTPROCS | Procedures to simplify the reduction of VLBA data |

## 13.15 IMAGE

| | |
|---|---|
| CPYRT | replaces history with readme file, inserts copyright |
| IMRMS | Plot IMEAN rms answers |
| MAPBM | Map VLA beam polarization |
| PROFL | Generates plot file for a profile display. |
| STRAN | Task compares ST tables, find image coordinates (e.g. guide star ) |
| VLABP | VLA antenna beam polarization correction for snapshot images |
| XSMTH | Smooth data along the x axis |
| XSUM | Sum or average images on the x axis |
| XTRAN | Create an image with transformed coordinates |

## 13.16 IMAGING

| | |
|---|---|
| AHIST | Task to convert image intensities by adaptive histogram |
| ALLOKAY | specifies that initial conditions have been met. |
| APCLN | Deconvolves images with CLEAN algorithm |
| APGS | deconvolves image with Gerchberg-Saxton algorithm |
| APVC | Deconvolves images with van Cittert algorithm |
| AVOPTION | Controls type or range of averaging done by a task |
| BCOMP | gives beginning component number for multiple fields |
| BLC | gives lower-left-corner of selected subimage |
| BLWUP | Blow up an image by any positive integer factor. |
| BMAJ | gives major axis size of beam or component |
| BMIN | gives minor axis size of beam or component |
| BOX2CC | Converts CLBOX in pixels to CCBOX in arc seconds |
| BOXES | Adds Clean boxes to BOXFILE around sources from a list |
| BOXFILE | specifies name of Clean box text file |
| BOX | specifies pixel coordinates of subarrays of an image |
| BPA | gives position angle of major axis of beam or component |
| BSAVG | Task to do an FFT-weighted sum of beam-switched images |
| BSCLN | Hogbom Clean on beam-switched difference image |
| BSGRD | Task to image beam-switched single-dish data |
| BSMAP | images weak sources with closure phases |
| CANDY | user-definable (paraform) task to create an AIPS image |
| CCBOX | specifies pixel coordinates of subarrays of an image |
| CCEDT | Select CC components in BOXes and above mininum flux. |
| CCFND | prints the contents of a Clean Components extension file. |

```
CCGAU      Converts point CLEAN components to Gaussians
CCMOD      generates clean components to fit specified source model
CCMRG      sums all clean components at the same pixel
CCRES      Removes or restores a CC file to a map with a gaussian beam.
CELLSIZE   gives the pixel size in physical coordinates
CHKFC      makes images of Clean boxes from Boxfile
CLBOX      specifies subarrays of an image for Clean to search
CMETHOD    specifies the method by which the uv model is computed
CMODEL     specifies the method by which the uv model is computed
COHER      Baseline Phase coherence measurement
COMAP_DO   MX adverbs not changed by COMAP
COMAP      Procedure to MAP and Self-Calibrate a UVDATA set
COMAP_MX   MX adverbs not changed by COMAP
COMAP_NA   Procedure to MAP and Self-Calibrate a UVDATA set
COMAP_UV   Procedure to MAP and Self-Calibrate a UVDATA set
CONPL      Plots AIPS gridding convolution functions
CONVL      convolves an image with a gaussian or another image
CUTOFF     specifies a limit below or above which the operation ends
CXCLN      Complex Hogbom CLEAN
DCONV      deconvolves a gaussian from an image
DECSHIFT   gives Y-coordinate shift of an image center from reference
DELBOX     Verb to delet boxes with TV cursor & graphics display.
DFILEBOX   Verb to delete Clean boxes with TV cursor & write to file
DO3DIMAG   specifies whether uvw's are reprojected to each field center
DOGRIDCR   selects correction for gridding convolution function
DRAWBOX    Verb to draw Clean boxes on the display
DTSUM      Task to provide a summary of the contents of a dataset
EVAUV      Subtracts & divides a model Into uv data, does statistics on results
FACES      makes images of catalog sources for initial calibration
FACTOR     scales some display or CLEANing process
FETCH      Reads an image from an external text file.
FFT        takes Fourier Transform of an image or images
FGAUSS     Minimum flux to Clean to by widths of Gaussian models
FILEBOX    Verb to reset Clean boxes with TV cursor & write to file
FILIT      Interactive BOXFILE editing with facet images
FIXBX      converts a BOXFILE to another for input to IMAGR
FLATN      Re-grid multiple fields into one image incl sensitivity
FLDSIZE    specifies size(s) of images to be processed
FLUX       gives a total intensity value for image/component or to limit
FSIZE      file size in Megabytes
GAIN       specifies loop gain for deconvolutions
GUARD      portion of UV plane to receive no data in gridding
HISEQ      task to translate image by histogram equalization
HLPCLEAN   Cleaning tasks  - internal help
HLPSCIMG   Cleaning tasks  - internal help
HLPSCMAP   Cleaning tasks  - internal help
HOLGR      Read & process holography visibility data to telescope images
HYB        RUN to set parameters for HYBRID (CALIB/MX) self-cal imaging
IM2PARM    Specifes enhancement parameters for OOP-based imaging: 2nd set
IM2UV      converts an image to a visibility data set
IMAGR      Wide-field and/or wide-frequency Cleaning / imaging task.
IMAGRPRM   Specifes enhancement parameters for OOP-based imaging
IMERG      merges images of different spatial resolutions
IMSIZE     specifies number of pixels on X and Y axis of an image
IMTXT      Write an image to an external text file.
INLIST     specifies name of input disk file, usually a source list
LTESS      makes mosaic images by linear combination
MANDL      creates an image of a subset of the Mandlebrot Set
```

```
MAPPR      Simplified access to IMAGR
MAXPIXEL   maximum pixels searched for components in Clark CLEAN
MODVF      task to create a warped velocity field
MWFLT      applies linear & non-linear filters to images
NBOXES     Number of boxes
NCCBOX     Number of clean component boxes
NCOMP      Number of CLEAN components
NDIG       Number of digits to display
NFIELD     The number of fields imaged
NMAPS      Number of maps (images) in an operation
NOIFS      makes all IFs into single spectrum
NOISE      estimates the noise in images
OBOXFILE   specifies name of output Clean box text file
ONEBEAM    specifies whether one beam is made for all facets or one for each
OOSUB      Subtracts/divides a model from/into a uv data base
OUT2CLAS   The class of a secondary output file
OUT2DISK   The disk number of a secondary output file.
OUT2NAME   The name of a secondary output file.
OUT2SEQ    The sequence of a secondary output file.
OVERLAP    specifies how overlaps are to be handled
OVRSWTCH   specifies when IMAGR switches from OVERLAP >= 2 to OVERLAP = 1 mode
PADIM      Task to increase image size by padding with some value
PASTE      Pastes a selected subimage of one image into another.
PATGN      Task to create a user specified test or primary-beam pattern
PBCOR      Task to apply or correct an image for a primary beam
PBPARM     Primary beam parameters
PBSIZE     estimates the primary beam size in interferometer images
PGEOM      Task to transform an image into polar coordinates.
PHASE      Baseline Phase coherence measurement
PHAT       Prussian hat size
PIX2VAL    An image value in the units specified in the header.
PIX2XY     Specifies a pixel in an image
PIXAVG     Average image value
PIXRANGE   Range of pixel values to display
PIXSTD     RMS pixel deviation
PIXVAL     Value of a pixel
PIXXY      Specifies a pixel location.
PRTCC      prints the contents of a Clean Components extension file.
PUTVALUE   Verb to store a pixel value at specified position
QUANTIZE   Quantization level to use
REBOX      Verb to reset boxes with TV cursor & graphics display.
REGRD      Regrids an image from one co-ordinate frame to another
REMAG      Task to replace magic blanks with a user specified value
RMSD       Calculate rms for each pixel using data at the box around the pixel
ROBUST     Uniform weighting "robustness" parameter
RSTOR      Restores a CC file to a map with a gaussian beam.
SABOX      create box file from source islands in facet images
SCIMG      Full-featured imaging plus self-calibration loop with editing
SCMAP      Imaging plus self-calibration loop with editing
SDCLN      deconvolves image by Clark and then "SDI" cleaning methods
SDGRD      Task to select and image random-position single-dish data
SDIMG      Task to select and image random-position single-dish data
SETFC      makes a BOXFILE for input to IMAGR
SHADW      Generates the "shadowed" representation of an image
SHIFT      specifies a position shift
SIZEFILE   return file size plus estimate of IMAGR work file size
SKEW       Specifies a skew angle
SKYVE      Regrids a DSS image from one co-ordinate frame to another
```

```
SMODEL    Source model
SNCUT     Specifies minimum signal-to-noise ratio
SPECR     Spectral regridding task for UV data
SPIXR     Fits spectral indexes to each row of an image incl curvature
STEER     Task which deconvolves the David Steer way.
STESS     Task which finds sensitivity in mosaicing
STFACTOR  scales star display or SDI CLEANing process
STUFFR    averages together data sets in hour angle
SUBIM     Task to select a subimage from up to a 7-dim. image
SUMIM     Task to sum overlapping, sequentially-numbered images
TKBOX     Procedure to set a Clean box with the TK cursor
TKNBOXS   Procedure to set Clean boxes 1 - n with the TK cursor
TRANSCOD  Specified desired transposition of an image
TRANS     Task to transpose a subimage of an up to 7-dim. image
TRC       Specified the top right corner of a subimage
TVBOX     Verb to set boxes with TV cursor & graphics display.
UBAVG     Baseline dependent time averaging of uv data
UTESS     deconvolves images by maximizing emptiness
UVBOX     radius of the smoothing box used for uniform weighting
UVBXFN    type of function used when counting for uniform weighting
UVIMG     Grid UV data into an "image"
UVMAP     makes images from calibrated UV data.
UVPOL     modifies UV data to make complex image and beam
UVSIZE    specifies number of pixels on X and Y axes of a UV image
UVSUB     Subtracts/divides a model from/into a uv data base
UVWTFN    Specify weighting function, Uniform or Natural
VLARUN    calibrating amplitude and phase, and imaging VLA data
VTESS     Deconvolves sets of images by the Maximum Entropy Method
WFCLN     Wide field and/or widefrequency  CLEANing/imaging task.
WGAUSS    Widths of Gaussian models (FWHM)
WTSUM     Task to do a a sum of images weighted by other images
XMOM      Fits one-dimensional moments to each row of an image
YPARM     Specifies Y axis convolving function
ZEROSP    Specify how to include zero spacing fluxes in FT of UV data
```

## 13.17 INFORMAT

```
ASTROMET  Describes the process of astrometric/geodetic reduction in AIPS
BATCHJOB  Information about BATCH
BDF2AIPS  script access to obit task BDFIn to translate EVLA data to AIPS
BDFLIST   script access to obit task ASDMList to list contents of ASDM data
CALIBRAT  describes the process of data calibration in AIPS
CATEGORY  List of allowed primary keywords in HELP files
GNUGPL    Information about GNU General Public License for AIPS
LSAPROPO  Data input to APROPO to find what uses what words
MSGSERVER Information about the X11-based message server
MSGSRV    Information about the X11-based message server
NEWTASK   Information about installing a new task
NOADVERB  Information about the lack of a defined adverb or verb
PANIC     Instructions for what to do when things go wrong
POPSDAT   lists all POPS symbols, used to create them in MEmory files
POPSYM    Describes the symbols used in POPS
POSTSCRIP General comments about AIPS use of PostScript incl macros
PSEUDO    Description of POPS pseudoverbs - obsolete list file
READLINE  Information about AIPS use of the GNU readline library.
REBYTE    service program to transform byte order of full data sets
SECONDARY List of allowed secondary keywords in HELP files
```

| | |
|---|---|
| SECONDRY | List of allowed secondary keywords in HELP files |
| TEKSERVER | Information about the X-11 Tektronix emulation server |
| TEKSRV | Information about the X-11 Tektronix emulation server |
| TPMON | Information about the TPMON "Daemon" |
| USERLIST | Alphabetic and numeric list of VLA users, points to real list |
| UV1TYPE | Convolving function type 1, pillbox or square wave |
| UV2TYPE | Convolving function type 2, exponential function |
| UV3TYPE | Convolving function type 3, sinc function |
| UV4TYPE | Convolving function type 4, exponent times sinc function |
| UV5TYPE | Convolving function type 5, spheroidal function |
| UV6TYPE | Convolving function type 6, exponent times BessJ1(x) / x |
| WHATSNEW | lists changes and new code in the last several AIPS releases |
| XAS | Information about TV-Servers |
| XVSS | Information about older Sun OpenWindows-specific TV-Server |

## 13.18 INTERACT

| | |
|---|---|
| AIPS | AIPS main program for interactive use |
| DELBOX | Verb to delet boxes with TV cursor & graphics display. |
| DFILEBOX | Verb to delete Clean boxes with TV cursor & write to file |
| EDITA | Interactive TV task to edit uv data based on TY/SY/SN/CL tables |
| EDITR | Interactive baseline-oriented visibility editor using the TV |
| FILEBOX | Verb to reset Clean boxes with TV cursor & write to file |
| HLPCLEAN | Cleaning tasks  - internal help |
| HLPEDICL | Interactive SN/CL table uv-data editor - internal help |
| HLPEDISN | Interactive SN/CL table (not UV) editor - internal help |
| HLPEDISS | Interactive SY table (not UV) editor - internal help |
| HLPEDISY | Interactive SY table uv-data editor - internal help |
| HLPEDITS | Interactive TY table (not UV) editor - internal help |
| HLPEDITY | Interactive TY table uv-data editor - internal help |
| HLPEDIUV | Interactive uv-data editor - internal help |
| HLPFILIT | Interactive Clean box file editing with image display |
| HLPIBLED | Interactive Baseline based visibility Editor - internal help |
| HLPPLAYR | OOP TV class demonstration task - internal (on-line) help |
| HLPSCIMG | Cleaning tasks  - internal help |
| HLPSCMAP | Cleaning tasks  - internal help |
| HLPSPFLG | Interactive time-channel visibility Editor - internal help |
| HLPTVFLG | Interactive time-baseline visibility Editor - internal help |
| HLPTVHUI | Interactive intensity-hue-saturation display - on-line help |
| HLPTVRGB | Interactive red-green-blue display - on-line help |
| HLPWIPER | WIPER run-time help file |
| IBLED | Interactive BaseLine based visibility EDitor |
| IMAGR | Wide-field and/or wide-frequency Cleaning / imaging task. |
| MAPPR | Simplified access to IMAGR |
| OPTELL | The operation to be passed to a task by TELL |
| PLAYR | Verb to load an image into a TV channel |
| READ | Read a value from the users terminal |
| READLINE | Information about AIPS use of the GNU readline library. |
| REBOX | Verb to reset boxes with TV cursor & graphics display. |
| SCIMG | Full-featured imaging plus self-calibration loop with editing |
| SCMAP | Imaging plus self-calibration loop with editing |
| SETSLICE | Set slice endpoints on the TV interactively |
| SNEDT | Interactive SN/CL/TY/SY table editor using the TV |
| SPFLG | interactive flagging of UV data in channel-TB using the TV |
| TK1SET | Verb to reset 1D gaussian fitting initial guess. |
| TKBOX | Procedure to set a Clean box with the TK cursor |
| TKNBOXS | Procedure to set Clean boxes 1 - n with the TK cursor |

```
TKPOS     Read a position from the graphics screen or window
TKSET     Verb to set 1D gaussian fitting initial guesses.
TKWIN     Procedure to set BLC and TRC with Graphics cursor
TV1SET    Verb to reset 1D gaussian fitting initial guess on TV plot.
TVBOX     Verb to set boxes with TV cursor & graphics display.
TVFLG     interactive flagging of UV data using the TV
TVHELIX   Verb to activate a helical hue-intensity TV pseudo-coloring
TVSCROL   Shift position of image on the TV screen
TVSET     Verb to set 1D gaussian fitting initial guesses from TV plot.
TVSPLIT   Compare two TV image planes, showing halves
TVSTAT    Find the mean and RMS in a blotch region on the TV
TVTRANSF  Interactively alters the TV image plane transfer function
TVWINDOW  Set a window on the TV with the cursor
TVZOOM    Activate the TV zoom
WEDERASE  Load a wedge portion of the TV with zeros
WIPER     plots and edits data from a UV data base using the TV
```

## 13.19 MODELING

```
ACTNOISE  puts estimate of actual image uncertainty and zero in header
BOXES     Adds Clean boxes to BOXFILE around sources from a list
BSMOD     creates single-dish UV beam-switched data with model sources
BSTST     Graphical display of solutions to frequency-switched data
CMETHOD   specifies the method by which the uv model is computed
CMODEL    specifies the method by which the uv model is computed
CUBIT     Model a galaxy's density and velocity distribution from full cube
DIFUV     Outputs the difference of two matching input uv data sets
DOMODEL   selects display of model function
DORESID   selects display of differences between model and data
EVAUV     Subtracts & divides a model Into uv data, does statistics on results
FACES     makes images of catalog sources for initial calibration
FITOUT    specifies name of output text file for results of fitting
GLENS     models galaxy gravitational lens acting on 3 component source
IMFIT     fits gaussians to portions of an image
IMMOD     adds images of model objects to an image
INLIST    specifies name of input disk file, usually a source list
JMFIT     fits gaussians to portions of an image
MFPRT     prints MF tables in a format needed by modelling software
MODVF     task to create a warped velocity field
OMFIT     Fits sources and, optionally, a self-cal model to uv data
OOSUB     Subtracts/divides a model from/into a uv data base
RADIUS    Specify a radius in an image
SAD       finds and fits Gaussians to portions of an image
SDMOD     modifies single-dish UV data with model sources
SLFIT     Task to fit gaussians to slice data.
TK1SET    Verb to reset 1D gaussian fitting initial guess.
TKAMODEL  Verb to add slice model display directly on TEK
TKARESID  Verb to add slice model residuals directly on TEK
TKGUESS   Verb to display slice model guess directly on TEK
TKMODEL   Verb to display slice model directly on TEK
TKRESID   Verb to display slice model residuals directly on TEK
TKSET     Verb to set 1D gaussian fitting initial guesses.
TKSLICE   Verb to display slice file directly on TEK
TV1SET    Verb to reset 1D gaussian fitting initial guess on TV plot.
TVAGUESS  Verb to re-plot slice model guess directly on TV graphics
TVAMODEL  Verb to add slice model display directly on TV graphics
TVARESID  Verb to add slice model residuals directly on TV graphics
```

```
TVASLICE   Verb to add a slice display on TV graphics from slice file
TVGUESS    Verb to display slice model guess directly on TV graphics
TVMODEL    Verb to display slice model directly on TV graphics
TVRESID    Verb to display slice model residuals directly on TV graphics
TVSET      Verb to set 1D gaussian fitting initial guesses from TV plot.
TVSLICE    Verb to display slice file directly on TV
UVFIT      Fits source models to uv data.
UVMOD      Modify UV database by adding a model incl spectral index
UVSUB      Subtracts/divides a model from/into a uv data base
XGAUS      Fits 1-dimensional Gaussians to images
```

## 13.20 OBSOLETE

```
ABACKUP    VMS procedure to back up data on tape
ARESTORE   Restores back up tapes of users data
CLIPM
CODETYPE   specifies the desired operation type
HORUS      makes images from unsorted UV data, applying any calibration
MX         makes images & deconvolves using UV data directly - replaced
OFFROAM    Procedure to clear the TV from a Roam condition
PFT        The Perley-Feigelson Test; see PFTLOAD.RUN, PFTEXEC.RUN
PHCLN      PHCLN has been removed, use PHAT adverb in APCLN.
PSEUDO     Description of POPS pseudoverbs - obsolete list file
SAMPTYPE   Specifies sampling type
SETROAM    Verb use to set roam image mode, then do roam.  OBSOLETE
SNCUT      Specifies minimum signal-to-noise ratio
XVSS       Information about older Sun OpenWindows-specific TV-Server
```

## 13.21 ONED

```
PFPL2      Paraform Task to generate a plot file: (slice intensity)
PLCUB      Task to plot intensity vs x panels on grid of y,z pixels
PLROW      Plot intensity of a series of rows with an offset.
SETSLICE   Set slice endpoints on the TV interactively
SL2PL      Task to convert a Slice File to a Plot File
SLFIT      Task to fit gaussians to slice data.
SLICE      Task to make a slice file from an image
TK1SET     Verb to reset 1D gaussian fitting initial guess.
TKAMODEL   Verb to add slice model display directly on TEK
TKARESID   Verb to add slice model residuals directly on TEK
TKASLICE   Verb to add a slice display on TEK from slice file
TKGUESS    Verb to display slice model guess directly on TEK
TKMODEL    Verb to display slice model directly on TEK
TKRESID    Verb to display slice model residuals directly on TEK
TKSET      Verb to set 1D gaussian fitting initial guesses.
TKSLICE    Verb to display slice file directly on TEK
TV1SET     Verb to reset 1D gaussian fitting initial guess on TV plot.
TVAGUESS   Verb to re-plot slice model guess directly on TV graphics
TVAMODEL   Verb to add slice model display directly on TV graphics
TVARESID   Verb to add slice model residuals directly on TV graphics
TVASLICE   Verb to add a slice display on TV graphics from slice file
TVGUESS    Verb to display slice model guess directly on TV graphics
TVMODEL    Verb to display slice model directly on TV graphics
TVRESID    Verb to display slice model residuals directly on TV graphics
TVSET      Verb to set 1D gaussian fitting initial guesses from TV plot.
TVSLICE    Verb to display slice file directly on TV
```

```
XGAUS     Fits 1-dimensional Gaussians to images
XPLOT     Plots image rows one at a time on the graphics or TV screen
```

## 13.22 OOP

```
BLING     find residual rate and delay on individual baselines
BSCOR     Combines two beam-switched images
BSGEO     Beam-switched Az-El image to RA-Dec image translation
BSGRD     Task to image beam-switched single-dish data
CCEDT     Select CC components in BOXes and above mininum flux.
CCSEL     Select signifigant CC components
EDITA     Interactive TV task to edit uv data based on TY/SY/SN/CL tables
EDITR     Interactive baseline-oriented visibility editor using the TV
FILIT     Interactive BOXFILE editing with facet images
FINDR     Find normal values for a uv data set
FIXWT     Modify weights to reflect amplitude scatter of data
FLAGR     Edit data based on internal RMS, amplitudes, weights
FLATN     Re-grid multiple fields into one image incl sensitivity
FRCAL     Faraday rotation self calibration task
HLPCLEAN  Cleaning tasks  - internal help
HLPEDICL  Interactive SN/CL table uv-data editor - internal help
HLPEDISN  Interactive SN/CL table (not UV) editor - internal help
HLPEDISS  Interactive SY table (not UV) editor - internal help
HLPEDISY  Interactive SY table uv-data editor - internal help
HLPEDITS  Interactive TY table (not UV) editor - internal help
HLPEDITY  Interactive TY table uv-data editor - internal help
HLPEDIUV  Interactive uv-data editor - internal help
HLPFILIT  Interactive Clean box file editing with image display
HLPPLAYR  OOP TV class demonstration task - internal (on-line) help
HLPSCIMG  Cleaning tasks  - internal help
HLPSCMAP  Cleaning tasks  - internal help
IM2PARM   Specifes enhancement parameters for OOP-based imaging: 2nd set
IMAGR     Wide-field and/or wide-frequency Cleaning / imaging task.
IMAGRPRM  Specifes enhancement parameters for OOP-based imaging
IMCLP     Clip an image to a specified range.
MAPBM     Map VLA beam polarization
MBDLY     Fits multiband delays from IF phases, updates SN table
MULIF     Change number of IFs in output
OGEOM     Simple image rotation, scaling, and translation
OHGEO     Geometric interpolation with correction for 3-D effects
OMFIT     Fits sources and, optionally, a self-cal model to uv data
OOSRT     Sort a UV dataset into a specified order
OOSUB     Subtracts/divides a model from/into a uv data base
PASTE     Pastes a selected subimage of one image into another.
PLAYR     Verb to load an image into a TV channel
RFI       Look for RFI in uv data
SABOX     create box file from source islands in facet images
SCIMG     Full-featured imaging plus self-calibration loop with editing
SCMAP     Imaging plus self-calibration loop with editing
SDGRD     Task to select and image random-position single-dish data
SNEDT     Interactive SN/CL/TY/SY table editor using the TV
UV2MS     Append single-source file to multi-source file.
VLABP     VLA antenna beam polarization correction for snapshot images
WFCLN     Wide field and/or widefrequency  CLEANing/imaging task.
```

## 13.23 OPTICAL

| | |
|---|---|
| COSTAR | Verb to plot a symbol at given position on top of a TV image |
| GSTAR | Task to read a Guide Star (UK) table and create an ST table. |
| IMFLT | fits and removes a background intensity plane from an image |
| STFND | Task to find stars in an image and generate an ST table. |
| STRAN | Task compares ST tables, find image coordinates (e.g. guide star ) |
| TVSTAR | Verb to plot star positions on top of a TV image |
| XTRAN | Create an image with transformed coordinates |

## 13.24 PARAFORM

| | |
|---|---|
| CANDY | user-definable (paraform) task to create an AIPS image |
| DTCHK | Task to check results of a test using simulated data. |
| FUDGE | modifies UV data with user's algorithm: paraform task |
| NEWTASK | Information about installing a new task |
| PFPL1 | Paraform Task to generate a plot file: (does grey scale) |
| PFPL2 | Paraform Task to generate a plot file: (slice intensity) |
| PFPL3 | Paraform Task to generate a plot file: (does histogram) |
| TAFFY | User definable task to operate on an image |
| TBTSK | Paraform OOP task for tables |
| UVFIL | Create, fill a uv database from user supplied information |

## 13.25 PLOT

| | |
|---|---|
| ALIAS | adverb to alias antenna numbers to one another |
| ANBPL | plots and prints uv data converted to antenna based values |
| ASPMM | Plot scaling parameter - arc seconds per millimeter on plot |
| AVGCHAN | Controls averaging of spectral channels |
| AVGIF | Controls averaging of IF channels |
| BDROP | gives number of pooints dropped at the beginning |
| BLSUM | sums images over irregular sub-images, displays spectra |
| BPERR | Print and plot BPASS closure outputs |
| BPLOT | Plots bandpass tables in 2 dimensions as function of time |
| CANPL | translates a plot file to a Canon printer/plotter |
| CAPLT | plots closure amplitude and model from CC file |
| CBPLOT | selects a display of a Clean beam full width at half maximum |
| CCNTR | generate a contour plot file from an image |
| CIRCLEVS | Sets RGBLEVS to fill LEVS with a circular color scheme |
| CLEV | Contour level multiplier in physical units |
| CLPLT | plots closure phase and model from CC file |
| CNTR | generate a contour plot file or TV plot from an image |
| CON3COL | Controls use of full 3-color graphics for contouring |
| CONPL | Plots AIPS gridding convolution functions |
| COPIES | sets the number of copies to be made |
| COSTAR | Verb to plot a symbol at given position on top of a TV image |
| DARKLINE | The level at which vectors are switched from light to dark |
| DFTPL | plots DFT of a UV data set at arbitrary point versus time |
| DIST | gives a distance - PROFL uses as distance to observer |
| DO3COL | Controls whether full 3-color graphics are used in a plot |
| DOALIGN | specifies how two or more images are aligned in computations |
| DOBLANK | controls handling of blanking |
| DOCELL | selects units of cells over angular unit |
| DOCENTER | selects a single, centered page or multiple pages of plots |
| DOCIRCLE | select a "circular" display (i.e. trace coordinates, ...) |
| DOCOLOR | specifies whether coloring is done |
| DOCONT | selects a display of contour lines |

```
DOCRT      selects printer display or CRT display (giving width)
DODARK     specifies whether "dark" vectors are plotted dark or light
DOEBAR     Controls display of estimates of the uncertainty in the data
DOGREY     selects a display of a grey-scale image
DOHIST     selects a histogram display
DOHMS      selects sexagesimal (hours-mins-secs) display format
DOMODEL    selects display of model function
DORESID    selects display of differences between model and data
DOSLICE    selects display of slice data
DOVECT     selects display of polarization vectors
DOWEDGE    selects display of intensity step wedge
EDROP      number of points/iterations to be omitted from end of process
EXTAB      exports AIPS table data as tab-separated text
EXTLIST    lists detailed information about contents of extension files
FACTOR     scales some display or CLEANing process
FGPLT      Plots selected contents of FG table
FLAMLEVS   Sets RGBLEVS to fill LEVS with a red flame color scheme
FRPLT      Task to plot fringe rate spectra
FUNCTYPE   specifies type of intensity transfer function
GREYS      plots images as contours over multi-level grey
GSTAR      Task to read a Guide Star (UK) table and create an ST table.
HLPWIPER   WIPER run-time help file
ICUT       specifies a cutoff level in units of the image
IMEAN      displays the mean & extrema and plots histogram of an image
IMRMS      Plot IMEAN rms answers
IMVIM      plots one image's values against another's
IRING      integrates intensity / flux in rings / ellipses
ISPEC      Plots and prints spectrum of region of a cube
KNTR       make a contour/grey plot file from an image w multiple panels
LABEL      selects a type of extra labeling for a plot
LAYER      Task to create an RGB image from multiple images
LEVS       list of multiples of the basic level to be contoured
LPEN       specifies the "pen width" code # => width of plotted lines
LTYPE      specifies the type and degree of axis labels on plots
LWPLA      translates plot file(s) to a PostScript printer or file
MF2ST      Task to generate an ST ext. file from Model Fit ext. file
NPLOTS     gives number of plots per page or per job
NX         General adverb referring to a number of things in the Y direction
NY         General adverb referring to a number of things in the Y direction
OBPLT      Plot columns of an OB table.
OFMFILE    specifies the name of a text file containing OFM values
PCNTR      Generate plot file with contours plus polarization vectors
PCUT       Cutoff in polarized intensity
PFPL1      Paraform Task to generate a plot file: (does grey scale)
PFPL2      Paraform Task to generate a plot file: (slice intensity)
PFPL3      Paraform Task to generate a plot file: (does histogram)
PLCOLORS   specifies the colors to be used
PLCUB      Task to plot intensity vs x panels on grid of y,z pixels
PLEV       Percentage of peak to use for contour levels
PLGET      gets the adverbs used to make a particular plot file
PLOTR      Basic task to generate a plot file from text input
PLROW      Plot intensity of a series of rows with an offset.
PLVER      specifies the version number of a PL extension file
POL3COL    Controls use of full 3-color graphics for polarization lines
POLPLOT    specifies the desired polarization ratio before plotting.
POSTSCRIP  General comments about AIPS use of PostScript incl macros
PRINTER    Verb to set or show the printer(s) used
PROFL      Generates plot file for a profile display.
```

| | |
|---|---|
| PRTAB | prints any table-format extension file |
| PRTIM | prints image intensities from an MA catalog entry |
| PRTPL | Task to send a plot file to the line printer |
| QMSPL | Task to send a plot file to the QMS printer/plotter |
| RAINLEVS | Sets RGBLEVS to fill LEVS with a rainbow color scheme |
| RGBLEVS | colors to be applied to the contour levels |
| RSPEC | Plots and prints spectrum of rms of a cube |
| SCLIM | operates on an image with a choice of mathematical functions |
| SL2PL | Task to convert a Slice File to a Plot File |
| SNPLT | Plots selected contents of SN, TY, PC or CL files |
| STARS | Task to generate an ST ext. file with star positions |
| STEPLEVS | Sets RGBLEVS to fill LEVS with a repeated sequence of colors |
| STFND | Task to find stars in an image and generate an ST table. |
| SYMBOL | General adverb, probably defines a plotting symbol type |
| TAPLT | Plots data from a Table extension file |
| TEKSERVER | Information about the X-11 Tektronix emulation server |
| TEKSRV | Information about the X-11 Tektronix emulation server |
| TKAMODEL | Verb to add slice model display directly on TEK |
| TKARESID | Verb to add slice model residuals directly on TEK |
| TKASLICE | Verb to add a slice display on TEK from slice file |
| TKBOX | Procedure to set a Clean box with the TK cursor |
| TKERASE | Erase the graphics screen or window |
| TKGUESS | Verb to display slice model guess directly on TEK |
| TKMODEL | Verb to display slice model directly on TEK |
| TKNBOXS | Procedure to set Clean boxes 1 - n with the TK cursor |
| TKPL | Task to send a plot file to the TEK |
| TKPOS | Read a position from the graphics screen or window |
| TKRESID | Verb to display slice model residuals directly on TEK |
| TKSLICE | Verb to display slice file directly on TEK |
| TKWIN | Procedure to set BLC and TRC with Graphics cursor |
| TVAGUESS | Verb to re-plot slice model guess directly on TV graphics |
| TVAMODEL | Verb to add slice model display directly on TV graphics |
| TVARESID | Verb to add slice model residuals directly on TV graphics |
| TVASLICE | Verb to add a slice display on TV graphics from slice file |
| TVCOLORS | Sets adverb PLCOLORS to match the TV (DOTV=1) usage |
| TVGUESS | Verb to display slice model guess directly on TV graphics |
| TVMODEL | Verb to display slice model directly on TV graphics |
| TVPL | Display a plot file on the TV |
| TVRESID | Verb to display slice model residuals directly on TV graphics |
| TVSLICE | Verb to display slice file directly on TV |
| TVSTAR | Verb to plot star positions on top of a TV image |
| TXPL | Displays a plot (PL) file on a terminal or line printer |
| UVHGM | Plots statistics of uv data files. |
| UVPLT | plots data from a UV data base |
| UVPRM | measures parameters from a UV data base |
| VLBACRPL | Plots crosscorrelations |
| VLBASNPL | Plots selected contents of SN or CL files |
| VPLOT | plots uv data and model from CC file |
| WETHR | Plots selected contents of WX tables, flags data based on WX |
| WIPER | plots and edits data from a UV data base using the TV |
| XAXIS | Which parameter is plotted on the horizontal axis. |
| XBASL | Fits and subtracts nth-order baselines from cube (x axis) |
| XGAUS | Fits 1-dimensional Gaussians to images |
| XPLOT | Plots image rows one at a time on the graphics or TV screen |

## 13.26 POLARIZA

| | |
|---|---|
| BANDPOL | specifies polarizations of individual IFs |
| BDEPO | computes depolarization due to rotation measure gradients |
| COMB | combines two images by a variety of mathematical methods |
| DOPOL | selects application of any polarization calibration |
| FARAD | add ionospheric Faraday rotation to CL table |
| FARS | Faraday rotation synthesys based on the brightness vs wavelength |
| LPCAL | Determines instrumental polarization for UV data |
| MAPBM | Map VLA beam polarization |
| MEDI | combines four images by a variety of mathematical methods |
| PCAL | Determines instrumental polarization for UV data |
| PCNTR | Generate plot file with contours plus polarization vectors |
| PCUT | Cutoff in polarized intensity |
| PDVER | specifies the version of the spetral polarization table to use |
| PMODEL | Polarization model parameters |
| POLANGLE | Intrinsic polarization angles for up to 30 sources |
| POLCO | Task to correct polarization maps for Ricean bias |
| POLPLOT | specifies the desired polarization ratio before plotting. |
| RLCOR | corrects a data set for R-L phase differences |
| RLDIF | determines Right minus Left phase difference |
| RM | Task to calculate rotation measure and magnetic field |
| SWPOL | Swap polarizations in a UV data base |
| TRUEP | determines true antenna polarization from special data sets |
| VLABP | VLA antenna beam polarization correction for snapshot images |
| VLBACPOL | Procedure to calibrate cross-polarization delays |

## 13.27 POPS

| | |
|---|---|
| ABOUT | displays lists and information on tasks, verbs, adverbs |
| ABS | returns absolute value of argument |
| ACOS | Returns arc cosine of argument (half-circle) |
| APROPOS | displays all help 1-line summaries containing specified words |
| ARRAY1 | General scratch array adverb |
| ARRAY2 | General scratch array adverb |
| ARRAY3 | General scratch array adverb |
| ARRAY | Declares POPS symbol name and dimensions |
| ASIN | Returns arc sine of argument (half-circle) |
| ATAN2 | Returns arc tangent of two arguments (full circle) |
| ATAN | Returns arc tangent of argument (half-circle) |
| BY | gives increment to use in FOR loops in POPS language |
| CATNO | Specifies AIPS catalog slot number range |
| CEIL | returns smallest integer greater than or equal the argument |
| CHAR | converts number to character string |
| CLRTEMP | clears the temporary literal area during a procedure |
| COMPRESS | recovers unused POPS address space and new symbols |
| CORE | displays the used and total space used by parts of POPS table |
| COS | returns cosine of the argument in degrees |
| DEBUG | turns on/off the POPS-language's debug messages |
| DEFAULT | Verb-like sets adverbs for a task or verb to initial values |
| DELAY | Verb to pause AIPS for DETIME seconds |
| DELTAX | Increment or size in X direction |
| DELTAY | Increment or size in Y direction |
| DENUMB | a scalar decimal number |
| DPARM | General numeric array adverb used many places |
| DUMP | displays portions of the POPS symbol table in all formats |
| EDIT | enter edit-a-procedure mode in the POPS language |
| EHEX | converts decimal to extended hex |

```
EHNUMB    an extended hexadecimal "number"
ELSE      starts POPS code done if an IF condition is false (IF-THEN..)
ENDEDIT   terminates procedure edit mode of POPS input
END       marks end of block (FOR, WHILE, IF) of POPS code
ERASE     removes one or more lines from a POPS procedure
ERROR     was there an error
EVLA      puts the list of eVLA antennas in the current file on stack
EXIT      ends an AIPS batch or interactive session
EXP       returns the exponential of the argument
EXPLAIN   displays help + extended information describing a task/symbol
FINISH    terminates the entry and compilation of a procedure
FLOOR     returns largest integer <= argument
FOR       starts an iterative sequence of operations in POPS language
GET       restores previously SAVEd full POPS environment
GETPOPSN  Verb to return the pops number on the stack
GG        spare scalar adverb for use in procedures
GRANDOM   Finds a random number with mean 0 and rms 1
HELP      displays information on tasks, verbs, adverbs
HSA       puts the list of HSA antennas in the current file on stack
IF        causes conditional execution of a set of POPS statements
I         spare scalar adverb for use in procedures
INP       displays adverb values for task, verb, or proc - quick form
INPUTS    displays adverb values for task, verb, or proc - to msg file
ISBATCH   declares current AIPS to be, or not to be, batch-like
J         spare scalar adverb for use in procedures
KLEENEX   ends an AIPS interactive session wiping the slate klean
LENGTH    returns length of string to last non-blank character
LIST      displays the source code text for a POPS procedure
LN        returns the natural logarithm of the argument
LOG       returns the base-10 logarithm of the argument
MAX       returns the maximum of its two arguments
MIN       returns the minimum of its two arguments
MOD       returns remainder after division of 1st argument by 2nd
MODIFY    modifies the text of a line of a procedure and recompiles
MODULUS   returns square root of sum of squares of its two arguments
NOADVERB  Information about the lack of a defined adverb or verb
NUMTELL   selects POPS number of task which is the target of a TELL
NX        General adverb referring to a number of things in the Y direction
NY        General adverb referring to a number of things in the Y direction
OUTPUTS   displays adverb values returned from task, verb, or proc
PARALLEL  Verb to set or show degree of parallelism
PASSWORD  Verb to change the current password for the login user
PCAT      Verb to list entries in the user's catalog (no log file).
POPSDAT   lists all POPS symbols, used to create them in MEmory files
POPSYM    Describes the symbols used in POPS
PRINTER   Verb to set or show the printer(s) used
PRINT     Print the value of an expression
PROCEDUR  Define a POPS procedure using procedure editor
PROC      Define a POPS procedure using procedure editor.
PSEUDO    Description of POPS pseudoverbs - obsolete list file
PSEUDOVB  Declares a name to be a symbol of type pseudoverb
QINP      displays adverb values for task, verb, or proc - restart form
RANDOM    Compute a random number from 0 to 1
READ      Read a value from the users terminal
REHEX     converts extended hex string to decimal
RENAME    Rename a file (UV or Image)
RESTART   Verb to trim the message log file and restart AIPS
RESTORE   Read POPS memory file from a common area.
```

```
RETURN     Exit a procedure allowing a higher level proc to continue.
RUN        Pseudoverb to read an external RUN files into AIPS.
SAVDEST    Verb to destroy all save files of a user.
SAVE       Pseudoverb to save full POPS environment in named file
SCALAR     Declares a variable to be a scalar in a procedure
SCANLENG   an extended hexadecimal "number"
SCRATCH    delete a procedure from the symbol table.
SETDEBUG   Verb to set the debug print and execution level
SG2RUN     Verb copies the K area to a text file suitable for RUN
SGDESTR    Verb-like to destroy named POPS environment save file
SGINDEX    Verb lists SAVE areas by name and time of last SAVE.
SIN        Compute the sine of a value
SLOT       Specifies AIPS catalog slot number
SPY        Verb to determine the execution status of all AIPS tasks
SQRT       Square root function
STORE      Store current POPS environment
STQUEUE    Verb to list pending TELL operations
STRING     Declare a symbol to be a string variable in POPS
SUBMIT     Verb which submits a batch work file to the job queue
SUBSTR     Function verb to specify a portion of a STRING variable
T1VERB     Temporary verb for testing (also T2VERB...T9VERB)
TAN        Tangent function
TAPES      Verb to show the TAPES(s) available
TASK       Name of a task
TGET       Verb-like gets adverbs from last GO of a task
TGINDEX    Verb lists those tasks for which TGET will work.
THEN       Specified the action if an IF test is true
TIMDEST    Verb to destroy all files which are too old
TO         Specifies upper limit of a FOR loop
TPUT       Verb-like puts adverbs from a task in file for TGETs
TYPE       Type the value of an expression
USAVE      Pseudoverb to save full POPS environment in named file
VALUE      Convert a string to a numeric value
VERB       Declares a name to be a symbol of type verb
VERSION    Specify AIPS version or local task area
VGET       Verb-like gets adverbs from version task parameter save area
VGINDEX    Verb lists those tasks for which VGET will work.
VLA        puts the list of VLA antennas in the current file on stack
VLARUN     calibrating amplitude and phase, and imaging VLA data
VLBA       puts the list of VLBA antennas in the current file on stack
VLBAPIPE   applies amplitude and phase calibration procs to VLBA data
VNUMBER    Specifies the task parameter (VGET/VPUT) save area
VPUT       Verb-like puts adverbs from a task in files for VGETs
WAITTASK   halt AIPS until specified task is finished
WHILE      Start a conditional statement
XHELP      Accesses hypertext help system
X          spare scalar adverb for use in procedures
Y          spare scalar adverb for use in procedures
```

## 13.28 PROCEDUR

```
ANTNUM     Returns number of a named antenna
BASFIT     fits antenna locations from SN-table data
BOX2CC     Converts CLBOX in pixels to CCBOX in arc seconds
BREAK      procedure to TELL FILLM to break all current uv files, start new
CIRCLEVS   Sets RGBLEVS to fill LEVS with a circular color scheme
COTVLOD    Proc to load an image into a TV channel about a coordinate
```

```
CROSSPOL   Procedure to make complex poln. images and beam.
CRSFRING   Procedure to calibrate cross pol. delay and phase offsets
CXPOLN     Procedure to make complex poln. images and beam.
FEW        procedure to TELL FILLM to append incoming data to existing uv files
FITDISK    writes images / uv data w extensions to disk in FITS format
FLAMLEVS   Sets RGBLEVS to fill LEVS with a red flame color scheme
FXALIAS    least squares fit aliasing function and remove
FXAVG      Procedure to enable VLBA delay de-correlation corrections
GRANDOM    Finds a random number with mean 0 and rms 1
MANY       procedure to TELL FILLM to start new uv files on each scan
MAPPR      Simplified access to IMAGR
MAXTAB     Returns maximum version number of named table
MERGECAL   Procedure to merge calibration records after concatenation
OFFROAM    Procedure to clear the TV from a Roam condition
PEELR      calibrates interfering sources in multi-facet imges
PFT        The Perley-Feigelson Test; see PFTLOAD.RUN, PFTEXEC.RUN
QUIT       procedure to TELL FILLM to stop at the end of the current scan
RAINLEVS   Sets RGBLEVS to fill LEVS with a rainbow color scheme
READISK    writes images / uv data w extensions to tape in FITS format
REFREQ     Allows changing of reference pixel
RUNWAIT    Runs a task and waits for it to finish
SCANTIME   Returns time range for a given scan number
SETXWIN    Procedure to set BLC and TRC with TV cursor
STEPLEVS   Sets RGBLEVS to fill LEVS with a repeated sequence of colors
STOP       procedure to TELL FILLM to break all current uv files and stop
STUFFR     averages together data sets in hour angle
TELFLM     procedure to TELL real-time FILLM a new APARM(1) value
TKBOX      Procedure to set a Clean box with the TK cursor
TKNBOXS    Procedure to set Clean boxes 1 - n with the TK cursor
TKWIN      Procedure to set BLC and TRC with Graphics cursor
TVALL      Procedure loads image to TV, shows labeled wedge, enhances
TVCOLORS   Sets adverb PLCOLORS to match the TV (DOTV=1) usage
TVFLUX     displays coordinates and values selected with the TV cursor
TVMAXFIT   displays fit pixel positions and intensity at maxima on TV
TVRESET    Reset the TV without erasing the image planes
VLACALIB   Runs CALIB and LISTR for VLA observation
VLACLCAL   Runs CLCAL and prints the results with LISTR
VLALIST    Runs LISTR for VLA observation
VLARESET   Reset calibration tables to a virginal state
VLASUMM    Plots selected contents of SN or CL files
VLATECR    Calculate ionospheric delay and Faraday rotation corrections
VLBACALA   applies a-priori amplitude corrections to VLBA data
VLBACPOL   Procedure to calibrate cross-polarization delays
VLBACRPL   Plots crosscorrelations
VLBAEOPS   Corrects Earth orientation parameters
VLBAFIX    Procedure that fixes VLBA data, if necessary
VLBAFPOL   Checks and corrects polarization labels for VLBA data
VLBAFQS    Copies different FQIDS to separate files
VLBAFRGP   Fringe fit phase referenced data and apply calibration
VLBAFRNG   Fringe fit data and apply calibration
VLBAIT     Procedure to read and process VLBA data (Phil Diamond)
VLBAKRGP   Fringe fit phase referenced data and apply calibration
VLBAKRNG   Fringe fit data and apply calibration
VLBALOAD   Loads VLBA data
VLBAMCAL   Merges redundant calibration data
VLBAMPCL   Calculates and applies manual instrumental phase calibration
VLBAPANG   Corrects for parallactic angle
VLBAPCOR   Calculates and applies instrumental phase calibration
```

```
VLBASNPL   Plots selected contents of SN or CL files
VLBASRT    Sorts VLBA data, if necessary
VLBASUBS   looks for subarrays in VLBA data
VLBASUMM   Prints a summary of a VLBI experiment
VLBATECR   Calculate ionospheric delay and Faraday rotation corrections
WRTDISK    writes images / uv data w extensions to tape in FITS format
```

## 13.29 PSEUDOVE

```
Type:  General type of POPS symbol
Use:   Pseudoverbs are magic symbols which cause FORTRAN routines to
       carry out specific actions.  Unlike verbs, pseudoverbs are
       executed as soon as they are encountered by the compiler even
       in compile mode.  In general, the FORTRAN routines which are
       invoked will parse the remainder of the input line under
       special, non-standard rules.  Any normal code typed on the line
       ahead of the pseudoverb will not be executed.
Grammar:  See the HELP listings for the specific pseudoverb.
Examples:    HELP  HELP
             ARRAY   JUNK(4, -7 TO 9)
             PROC DUMMY (I,J)
             LIST DUMMY
             DEBUG TRUE
             INPUTS MLOAD
****************************************************************

ABORTASK   stops a running task
ARRAY      Declares POPS symbol name and dimensions
COMPRESS   recovers unused POPS address space and new symbols
CORE       displays the used and total space used by parts of POPS table
DEBUG      turns on/off the POPS-language's debug messages
EDIT       enter edit-a-procedure mode in the POPS language
ELSE       starts POPS code done if an IF condition is false (IF-THEN..)
ENDBATCH   terminates input to batch work file
ENDEDIT    terminates procedure edit mode of POPS input
ERASE      removes one or more lines from a POPS procedure
FINISH     terminates the entry and compilation of a procedure
GET        restores previously SAVEd full POPS environment
IF         causes conditional execution of a set of POPS statements
ISBATCH    declares current AIPS to be, or not to be, batch-like
LIST       displays the source code text for a POPS procedure
MODIFY     modifies the text of a line of a procedure and recompiles
MSGKILL    turns on/off the recording of messages in the message file
TELL       Send parameters to tasks that know to read them on the fly
WHILE      Start a conditional statement
```

## 13.30 RUN

```
ANCHECK    Checks By sign in Antenna files
DDT        verifies correctness and performance using standard problems
DDTSAVE    verifies correctness and performance using standard problems
HYB        RUN to set parameters for HYBRID (CALIB/MX) self-cal imaging
VLAC       verifies correctness of continuum calibration software
VLACSAVE   verifies correctness of continuum calibration
VLAL       verifies correctness of spectral line calibration software
VLALSAVE   verifies correctness of continuum calibration
```

| | |
|---|---|
| VLAPROCS | Procedures to simplify the reduction of VLBA data |
| VLARUN | calibrating amplitude and phase, and imaging VLA data |
| VLBAARCH | Procedure to archive VLBA correlator data |
| VLBAPIPE | applies amplitude and phase calibration procs to VLBA data |
| VLBAUTIL | Procedures to simplify the reduction of VLBA data |
| VLBDDT | Verification tests using simulated data |
| WRTPROCS | Procedures to simplify the reduction of VLBA data |
| Y2K | verifies correctness and performance using standard problems |
| Y2KSAVE | verifies correctness and performance using standard problems |

## 13.31 SINGLEDI

| | |
|---|---|
| BSAVG | Task to do an FFT-weighted sum of beam-switched images |
| BSCLN | Hogbom Clean on beam-switched difference image |
| BSCOR | Combines two beam-switched images |
| BSFIX | Corrects the ra/dec offsets recorded by the 12m |
| BSGRD | Task to image beam-switched single-dish data |
| BSMOD | creates single-dish UV beam-switched data with model sources |
| BSROT | modifies SD beam-switch continuum data for error in throw |
| BSTST | Graphical display of solutions to frequency-switched data |
| CSCOR | applies specified corrections to CS tables |
| DATA2IN | specifies name of input FITS disk file |
| DATAIN | specifies name of input FITS disk file |
| DIFUV | Outputs the difference of two matching input uv data sets |
| INDXH | writes index file describing contents of UV data base |
| INDXR | writes index file describing contents of UV data base |
| OTFBS | Translates on-the-fly continuum SDD format to AIPS UV file |
| OTFIN | Lists on-the-fly single-dish SDD format data files |
| OTFUV | Translates on-the-fly single-dish SDD format to AIPS UV file |
| PRTSD | prints contents of AIPS single-dish data sets |
| SDCAL | Task to apply single dish calibration |
| SDGRD | Task to select and image random-position single-dish data |
| SDIMG | Task to select and image random-position single-dish data |
| SDLSF | least squares fit to channels and subtracts from SD uv data |
| SDMOD | modifies single-dish UV data with model sources |
| SDTUV | Task to convert SD table files to UV like data. |
| SDVEL | shifts spectral-line single-dish data to a given velocity |
| VTEST | Measures velocity discrepancy across fields |
| WTSUM | Task to do a a sum of images weighted by other images |

## 13.32 SPECTRAL

Almost all parts of AIPS are general enough to handle mutiple dimensions of data including multiple frequency channels in the uv domain and 3 or more dimensional "cubes" in the image domain.

| | |
|---|---|
| ACFIT | Determine antenna gains from autocorrelations |
| ALTDEF | Sets frequency vs velocity relationship into image header |
| ALTSWTCH | Switches between frequency and velocity in image header |
| AVSPC | Averages uv-data in the frequency domain |
| BASRM | Task to remove a spectral baseline from total power spectra |
| BCHAN | sets the beginning channel number |
| BLOAT | converts line data to greater number channels |
| BLSUM | sums images over irregular sub-images, displays spectra |
| BPASS | computes spectral bandpass correction table |
| BPASSPRM | Control adverb array for bandpass calibration |
| BPERR | Print and plot BPASS closure outputs |

| | |
|---|---|
| BPLOT | Plots bandpass tables in 2 dimensions as function of time |
| BPSMO | Smooths or interpolates bandpass tables to regular times |
| BPVER | specifies the version of the bandpass table to be applied |
| CHANNEL | sets the spectral channel number |
| CHANSEL | Array of start, stop, increment channel numbers to average |
| CHINC | the increment between selected channels |
| CPASS | computes polynomial spectral bandpass correction table |
| CVEL | shifts spectral-line UV data to a given velocity |
| DOAPPLY | Flag to indicate whether an operation is applied to the data |
| ECHAN | define an end for a range of channel numbers |
| FIXAL | least squares fit aliasing function and remove |
| FLGIT | flags data based on the rms of the spectrum |
| FQUBE | collects n-dimensional images into n+1-dimensional FREQID image |
| FRMAP | Task to build a map using fringe rate spectra |
| FRPLT | Task to plot fringe rate spectra |
| FXALIAS | least squares fit aliasing function and remove |
| HLPSPFLG | Interactive time-channel visibility Editor - internal help |
| HLPTVHUI | Interactive intensity-hue-saturation display - on-line help |
| HLPTVRGB | Interactive red-green-blue display - on-line help |
| ICHANSEL | Array of start, stop, increment channel #S + IF to average |
| IMLIN | Fits and removes continuum emission from cube |
| IRING | integrates intensity / flux in rings / ellipses |
| ISPEC | Plots and prints spectrum of region of a cube |
| MCUBE | collects n-dimensional images into n+1-dimensional image |
| NCHAV | Number of channels averaged in an operation |
| ORDER | Adverb used usually to specify the order of polynomial fit |
| PDVER | specifies the version of the spetral polarization table to use |
| PLCUB | Task to plot intensity vs x panels on grid of y,z pixels |
| POLANGLE | Intrinsic polarization angles for up to 30 sources |
| POSSM | Task to plot total and cross-power spectra. |
| RSPEC | Plots and prints spectrum of rms of a cube |
| SDLSF | least squares fit to channels and subtracts from SD uv data |
| SDVEL | shifts spectral-line single-dish data to a given velocity |
| SERCH | Finds line signals in transposed data cube |
| SMOTH | Task to smooth a subimage from upto a 7-dim. image |
| SPECINDX | Spectral index used to correct calibrations |
| SPECPARM | Spectral index per polarization per source |
| SPECTRAL | Flag to indicate whether an operation is spectral or continuum |
| SPECURVE | Spectral index survature used to correct calibrations |
| SPFLG | interactive flagging of UV data in channel-TB using the TV |
| SQASH | Task to collapse several planes in a cube into one plane |
| SYSVEL | Systemic velocity |
| UJOIN | modifies UV data converting IFs to spectral channels |
| UV2TB | Converts UV autocorrelation spectra to tables |
| UVBAS | averages several channels and subtracts from uv data. |
| UVDEC | Decrements the number of spectral channels, keeping every nth |
| UVGLU | Glues UV data frequency blocks back together |
| UVLIN | Fits and removes continuum visibility spectrum, also can flag |
| UVLSD | least squares fit to channels and divides the uv data. |
| UVLSF | least squares fit to channels and subtracts from uv data. |
| UVMLN | edits data based on the rms of the spectrum |
| UVMOD | Modify UV database by adding a model incl spectral index |
| VBGLU | Glues together data from multiple passes thru the VLBA corr. |
| VTEST | Measures velocity discrepancy across fields |
| WTSUM | Task to do a a sum of images weighted by other images |
| XBASL | Fits and subtracts nth-order baselines from cube (x axis) |
| XGAUS | Fits 1-dimensional Gaussians to images |
| XPLOT | Plots image rows one at a time on the graphics or TV screen |

## 13.33 TABLE

| | |
|---|---|
| BSPRT | print BS tables |
| CLCOP | copy CL/SN file calibration between polarizations |
| CLINV | copy CL/SN file inverting the calibration |
| DOTABLE | selects use of table-format for data |
| EXTAB | exports AIPS table data as tab-separated text |
| HF2SV | convert HF tables from FRING/MBDLY to form used by Calc/Solve |
| HFPRT | write HF tables from CL2HF |
| HLPEDICL | Interactive SN/CL table uv-data editor - internal help |
| HLPEDISN | Interactive SN/CL table (not UV) editor - internal help |
| HLPEDISS | Interactive SY table (not UV) editor - internal help |
| HLPEDISY | Interactive SY table uv-data editor - internal help |
| HLPEDITS | Interactive TY table (not UV) editor - internal help |
| HLPEDITY | Interactive TY table uv-data editor - internal help |
| MFPRT | prints MF tables in a format needed by modelling software |
| OBEDT | Task to flag data of orbiting antennas |
| OBTAB | Recalculate orbit parameters and other spacecraft info |
| OFLAG | uses on-line flag table information to write a flag table |
| PRTAB | prints any table-format extension file |
| PRTOF | prints on-line flag table information |
| SNCOP | Task to copy SN table averaging some input IFs |
| TABED | Task to edit tables |
| TACOP | task to copy tables, other extension files |
| TAFLG | Flags data in a Table extension file |
| TAMRG | Task to merge table rows under specified conditions |
| TAPLT | Plots data from a Table extension file |
| TAPPE | Task to append 2 tables and merge to output table |
| TASAV | Task to copy all extension tables to a dummy uv or map file |
| TASRT | Task to sort extension tables. |
| TBDIF | Compare entries in two tables |
| TBIN | Reads a text file AIPS table into AIPS |
| TBOUT | Writes an AIPS table into a text file for user editting. |
| VLBAMCAL | Merges redundant calibration data |

## 13.34 TAPE

| | |
|---|---|
| ATLOD | Reads ATCA data in RPFITS dormat into AIPS |
| AVEOT | Advances tape to end-of-information point |
| AVFILE | Moves tape forward or back to end-of-file marks |
| AVMAP | Advance tape by one image (IBM-CV = obsolete tape file) |
| AVTP | Positions tape to desired file |
| BAKLD | reads all files of a catalog entry from BAKTP tape |
| BAKTP | writes all files of a catalog entry to tape in host format |
| BLOCKING | specifies blocking factor to use on e.g. tape records |
| DENSITY | gives the desired tape density |
| DISMOUNT | disables a magnetic tape and dismounts it from the tape drive |
| DOEOF | selects end-of-file writing or reading until |
| DOEOT | selects tape positioning before operation: present or EOI |
| DONEWTAB | do we make new tables, use a new table format, etc. |
| DOTABLE | selects use of table-format for data |
| DOTWO | do we make two of something |
| FILLM | reads VLA on-line/archive format uv data tapes (post Jan 88) |
| FILLR | reads old VLA on-line-system tapes into AIPS |
| FIT2A | reads the fits input file and records it to the output ascii file |
| FITAB | writes images / uv data w extensions to tape in FITS format |
| FITLD | reads tape to load FITS images or FITS UV files to disk |
| FITTP | writes images / uv data w extensions to tape in FITS format |

```
FORMAT     gives a format code number: e.g. FITS accuracy required
GSCAT      reads Fits Guide star catalog file
IMLOD      reads tape to load images to disk
INTAPE     specifies the input tape drive number
MOUNT      makes a tape drive available to user's AIPS and tasks
NFILES     The number of files to skip, usually on a tape.
NPIECE     The number of pieces to make
OUTTAPE    The output tape drive number.
PRTTP      prints contents of tapes, all supported formats
QUANTIZE   Quantization level to use
REMHOST    gives the name of another computer which will provide service
REMTAPE    gives the number of another computer's tape device
REWIND     Verb to rewind a tape
TAPES      Verb to show the TAPES(s) available
TCOPY      Tape to tape copy with some disk FITS support
TPHEAD     Verb to list image header from FITS or IBM-CV tape
TPMON      Information about the TPMON "Daemon"
UVLOD      Read export or FITS data from a tape or disk
VLAMODE    VLA observing mode
VLAOBS     Observing program or part of observer's name
```

## 13.35 TASK

```
TASKS
Type:  General type of POPS symbol (not in symbol table)
Use:   Tasks are separate programs which may be started by
       AIPS and which receive their input parameters from
       AIPS.  In the interactive AIPS, tasks run
       asynchronously from AIPS.  In the batch AIPS,
       the language processor waits for each task to finish
       before starting another one.
Grammar:    TASK = 'name' ;   GO
       will cause the task whose name is assigned to the
       string adverb TASK to be started.  Note: the name
       should have no leading blanks and should be no longer
       than 5 characters.
Alternative grammar:    GO  name ;
       where name is the name of the task to be run.
Related adverbs:
   TASK       Task name
   DOWAIT     On "GO", wait for task completion before returning
                 to AIPS control
   VERSION    Version of task to be executed.
Related verbs:
   GO         Initiate a shed task
   HELP       List information about a task
   INP        List adverb values for a task
   INPUTS     Same as INP but also written to MSG file
   SPY        Inquire which tasks are active
   WAITTASK   Suspend AIPS operation until a specific task
                 is complete
   ABORTASK   Kill a task immediately
   TGET       Get adverb values from last execution of TASK
   TPUT       Save adverb values without execution of TASK
   TGINDEX    List all TGET/SAVE files
****************************************************************
```

```
ACCOR     Corrects cross amplitudes using auto correlation measurements
ACFIT     Determine antenna gains from autocorrelations
ADDIF     Adds an IF axis to a uv data set
AFILE     sorts and edits MkIII correlator A-file.
AHIST     Task to convert image intensities by adaptive histogram
AIPSB     AIPS main program for executing batch jobs
AIPSC     AIPS main program for testing and queuing batch jobs
AIPS      AIPS main program for interactive use
ANBPL     plots and prints  uv data converted to antenna based values
ANCAL     Places antenna-based Tsys and gain corrections in CL table
ANTAB     Read amplitude calibration information into AIPS
APCAL     Apply TY and GC tables to generate an SN table
APCLN     Deconvolves images with CLEAN algorithm
APGPS     Apply GPS-derived ionospheric corrections
APGS      deconvolves image with Gerchberg-Saxton algorithm
APVC      Deconvolves images with van Cittert algorithm
ATLOD     Reads ATCA data in RPFITS dormat into AIPS
ATMCA     Determines delay/phase gradient from calibrator observations
AVER      Averages over time UV data sets in 'BT' order
AVSPC     Averages uv-data in the frequency domain
AVTP      Positions tape to desired file
BAKLD     reads all files of a catalog entry from BAKTP tape
BAKTP     writes all files of a catalog entry to tape in host format
BASRM     Task to remove a spectral baseline from total power spectra
BATER     stand-alone program to prepare and submit batch jobs
BDEPO     computes depolarization due to rotation measure gradients
BLANK     blanks out selected, e.g. non-signal, portions of an image
BLAPP     applies baseline-based fringe solutions a la BLAPP
BLAVG     Average cross-polarized UV data over baselines.
BLCAL     Compute closure offset corrections
BLCHN     Compute closure offset corrections on a channel-by-channel basis
BLING     find residual rate and delay on individual baselines
BLOAT     converts line data to greater number channels
BLSUM     sums images over irregular sub-images, displays spectra
BLWUP     Blow up an image by any positive integer factor.
BOXES     Adds Clean boxes to BOXFILE around sources from a list
BPASS     computes spectral bandpass correction table
BPCOR     Correct BP table.
BPERR     Print and plot BPASS closure outputs
BPLOT     Plots bandpass tables in 2 dimensions as function of time
BPSMO     Smooths or interpolates bandpass tables to regular times
BSAVG     Task to do an FFT-weighted sum of beam-switched images
BSCLN     Hogbom Clean on beam-switched difference image
BSCOR     Combines two beam-switched images
BSFIX     Corrects the ra/dec offsets recorded by the 12m
BSGEO     Beam-switched Az-El image to RA-Dec image translation
BSGRD     Task to image beam-switched single-dish data
BSMAP     images weak sources with closure phases
BSMOD     creates single-dish UV beam-switched data with model sources
BSPRT     print BS tables
BSROT     modifies SD beam-switch continuum data for error in throw
BSTST     Graphical display of solutions to frequency-switched data
CALIB     determines antenna calibration: complex gain
CALRD     Reads model-image FITS file
CALWR     writes calibrator images w CC files to FITS disk files
CANDY     user-definable (paraform) task to create an AIPS image
CANPL     translates a plot file to a Canon printer/plotter
CAPLT     plots closure amplitude and model from CC file
```

| | |
|---|---|
| CCEDT | Select CC components in BOXes and above mininum flux. |
| CCFND | prints the contents of a Clean Components extension file. |
| CCGAU | Converts point CLEAN components to Gaussians |
| CCMOD | generates clean components to fit specified source model |
| CCMRG | sums all clean components at the same pixel |
| CCNTR | generate a contour plot file from an image |
| CCRES | Removes or restores a CC file to a map with a gaussian beam. |
| CCSEL | Select signifigant CC components |
| CHKFC | makes images of Clean boxes from Boxfile |
| CL2HF | Convert CL table to HF table |
| CLCAL | merges and smooths SN tables, applies them to CL tables |
| CLCOP | copy CL/SN file calibration between polarizations |
| CLCOR | applies user-selected corrections to the calibration CL table |
| CLINV | copy CL/SN file inverting the calibration |
| CLIP | edits data based on amplitudes, phases, and weights out of range |
| CLIPM | |
| CLPLT | plots closure phase and model from CC file |
| CLSMO | smooths a calibration CL table |
| CNTR | generate a contour plot file or TV plot from an image |
| COHER | Baseline Phase coherence measurement |
| COMAP_DO | MX adverbs not changed by COMAP |
| COMAP | Procedure to MAP and Self-Calibrate a UVDATA set |
| COMAP_MX | MX adverbs not changed by COMAP |
| COMAP_NA | Procedure to MAP and Self-Calibrate a UVDATA set |
| COMAP_UV | Procedure to MAP and Self-Calibrate a UVDATA set |
| COMB | combines two images by a variety of mathematical methods |
| CONFI | Optimize array configuration by minimum side lobes |
| CONPL | Plots AIPS gridding convolution functions |
| CONVL | convolves an image with a gaussian or another image |
| CORER | calculates correlator statistics and flags bad ones |
| CORFQ | corrects uvw for incorrect observing frequency |
| CPASS | computes polynomial spectral bandpass correction table |
| CPYRT | replaces history with readme file, inserts copyright |
| CSCOR | applies specified corrections to CS tables |
| CUBIT | Model a galaxy's density and velocity distribution from full cube |
| CVEL | shifts spectral-line UV data to a given velocity |
| CXCLN | Complex Hogbom CLEAN |
| DAYFX | Fixes day number problems left by FILLM |
| DBCON | concatenates two UV data sets |
| DCONV | deconvolves a gaussian from an image |
| DECOR | Measures the decorrelation between channels and IF of uv data |
| DEFLG | edits data based on decorrelation over channels and time |
| DELZN | Determines residual atmosphere depth at zenith and clock errors |
| DESCM | copies a portion of a UV data set |
| DFCOR | applies user-selected corrections to the calibration CL table |
| DFQID | modifies UV data changing the indicated FQIDs |
| DFTPL | plots DFT of a UV data set at arbitrary point versus time |
| DIFRL | divides the RR data by LL data |
| DIFUV | Outputs the difference of two matching input uv data sets |
| DISKU | shows disk use by one or all users |
| DQUAL | Rearranges source list, dropping qualifiers |
| DRCHK | stand-alone program checks system setup files for consistency |
| DSORC | copies a data set elliminating some source numbers |
| DSTOK | Drops the cross-hand polarizations |
| DTCHK | Task to check results of a test using simulated data. |
| DTSIM | Generate fake UV data |
| DTSUM | Task to provide a summary of the contents of a dataset |
| EDITA | Interactive TV task to edit uv data based on TY/SY/SN/CL tables |

```
EDITR     Interactive baseline-oriented visibility editor using the TV
ELINT     Determines and removes gain dependence on elevation
EVASN     Evaluates statistics in SN/CL tables
EVAUV     Subtracts & divides a model Into uv data, does statistics on results
EXTAB     exports AIPS table data as tab-separated text
FACES     makes images of catalog sources for initial calibration
FARAD     add ionospheric Faraday rotation to CL table
FARS      Faraday rotation synthesys based on the brightness vs wavelength
FETCH     Reads an image from an external text file.
FFT       takes Fourier Transform of an image or images
FGPLT     Plots selected contents of FG table
FILIT     Interactive BOXFILE editing with facet images
FILLM     reads VLA on-line/archive format uv data tapes (post Jan 88)
FILLR     reads old VLA on-line-system tapes into AIPS
FINDR     Find normal values for a uv data set
FIT2A     reads the fits input file and records it to the output ascii file
FITAB     writes images / uv data w extensions to tape in FITS format
FITLD     reads tape to load FITS images or FITS UV files to disk
FITTP     writes images / uv data w extensions to tape in FITS format
FIXAL     least squares fit aliasing function and remove
FIXBX     converts a BOXFILE to another for input to IMAGR
FIXWT     Modify weights to reflect amplitude scatter of data
FLAGR     Edit data based on internal RMS, amplitudes, weights
FLATN     Re-grid multiple fields into one image incl sensitivity
FLGIT     flags data based on the rms of the spectrum
FLOPM     reverses the spectral order of UV data, can fix VLA error
FQUBE     collects n-dimensional images into n+1-dimensional FREQID image
FRCAL     Faraday rotation self calibration task
FRING     fringe fit data to determine antenna calibration, delay, rate
FRMAP     Task to build a map using fringe rate spectra
FRPLT     Task to plot fringe rate spectra
FUDGE     modifies UV data with user's algorithm: paraform task
FXPOL     Corrects VLBA polarization assignments
FXTIM     fixes start date so all times are positive
FXVLA     Task to correct VLA data for on-line errors in special cases.
FXVLB     Builds a CQ table to enable VLBA correlator loss corrections
GAL       Determine parameters from a velocity field
GETJY     determines calibrator flux densities
GLENS     models galaxy gravitational lens acting on 3 component source
GPSDL     Calculate ionospheric delay and Faraday rotation corrections
GREYS     plots images as contours over multi-level grey
GRIPR     standalone program to enter suggestions/complaints to AIPS
GSCAT     reads Fits Guide star catalog file
GSTAR     Task to read a Guide Star (UK) table and create an ST table.
HAFIX     Recomputes u,v,w when time is hour angle (UVdata is output of TI2HA)
HF2SV     convert HF tables from FRING/MBDLY to form used by Calc/Solve
HFPRT     write HF tables from CL2HF
HGEOM     interpolates image to different gridding and/or geometry
HISEQ     task to translate image by histogram equalization
HLPCLEAN  Cleaning tasks  - internal help
HLPEDICL  Interactive SN/CL table uv-data editor - internal help
HLPEDISN  Interactive SN/CL table (not UV) editor - internal help
HLPEDISS  Interactive SY table (not UV) editor - internal help
HLPEDISY  Interactive SY table uv-data editor - internal help
HLPEDITS  Interactive TY table (not UV) editor - internal help
HLPEDITY  Interactive TY table uv-data editor - internal help
HLPEDIUV  Interactive uv-data editor - internal help
HLPFILIT  Interactive Clean box file editing with image display
```

| | |
|---|---|
| HLPIBLED | Interactive Baseline based visibility Editor - internal help |
| HLPPLAYR | OOP TV class demonstration task - internal (on-line) help |
| HLPSCIMG | Cleaning tasks - internal help |
| HLPSCMAP | Cleaning tasks - internal help |
| HLPSPFLG | Interactive time-channel visibility Editor - internal help |
| HLPTVFLG | Interactive time-baseline visibility Editor - internal help |
| HLPTVHUI | Interactive intensity-hue-saturation display - on-line help |
| HLPTVRGB | Interactive red-green-blue display - on-line help |
| HLPWIPER | WIPER run-time help file |
| HOLGR | Read & process holography visibility data to telescope images |
| HORUS | makes images from unsorted UV data, applying any calibration |
| IBLED | Interactive BaseLine based visibility EDitor |
| IM2UV | converts an image to a visibility data set |
| IMAGR | Wide-field and/or wide-frequency Cleaning / imaging task. |
| IMCLP | Clip an image to a specified range. |
| IMEAN | displays the mean & extrema and plots histogram of an image |
| IMERG | merges images of different spatial resolutions |
| IMFIT | fits gaussians to portions of an image |
| IMFLT | fits and removes a background intensity plane from an image |
| IMLHS | converts images to luminosity/hue TV display |
| IMLIN | Fits and removes continuum emission from cube |
| IMLOD | reads tape to load images to disk |
| IMMOD | adds images of model objects to an image |
| IMRMS | Plot IMEAN rms answers |
| IMTXT | Write an image to an external text file. |
| IMVIM | plots one image's values against another's |
| INDXH | writes index file describing contents of UV data base |
| INDXR | writes index file describing contents of UV data base |
| IRING | integrates intensity / flux in rings / ellipses |
| ISPEC | Plots and prints spectrum of region of a cube |
| JMFIT | fits gaussians to portions of an image |
| KNTR | make a contour/grey plot file from an image w multiple panels |
| KRING | fringe fit data to determine antenna calibration, delay, rate |
| LAYER | Task to create an RGB image from multiple images |
| LDGPS | load GPS data from an ASCII file |
| LGEOM | regrids images with rotation, shift using interpolation |
| LISTR | prints contents of UV data sets and assoc. calibration tables |
| LOCIT | fits antenna locations from SN-table data |
| LPCAL | Determines instrumental polarization for UV data |
| LTESS | makes mosaic images by linear combination |
| LWPLA | translates plot file(s) to a PostScript printer or file |
| M3TAR | translate Haystack MKIII VLBI format "A" TAR's into AIPS |
| MANDL | creates an image of a subset of the Mandlebrot Set |
| MAPBM | Map VLA beam polarization |
| MATCH | changes antenna, source, FQ numbers to match a data set |
| MATHS | operates on an image with a choice of mathematical functions |
| MBDLY | Fits multiband delays from IF phases, updates SN table |
| MCUBE | collects n-dimensional images into n+1-dimensional image |
| MEDI | combines four images by a variety of mathematical methods |
| MF2ST | Task to generate an ST ext. file from Model Fit ext. file |
| MFPRT | prints MF tables in a format needed by modelling software |
| MK3IN | translate Haystack MKIII VLBI format "A" tapes into AIPS |
| MK3TX | extract text files from a MKIII VLBI archive tape |
| MODVF | task to create a warped velocity field |
| MOMFT | calculates images of moments of a sub-image |
| MOMNT | calculates images of moments along x-axis (vel, freq, ch) |
| MOVE | Task to copy or move data from one user to another |
| MSORT | Sort a UV dataset into a specified order |

```
MULIF     Change number of IFs in output
MULTI     Task to convert single-source to multi-source UV data
MWFLT     applies linear & non-linear filters to images
MX        makes images & deconvolves using UV data directly - replaced
NINER     Applies various 3x3 area operaters to an image.
NNLSQ     Non-Negative-Least-Squares decomposition of spectrum
NOBAT     Task to lock lower priority users out of the AP
NOIFS     makes all IFs into single spectrum
OBEDT     Task to flag data of orbiting antennas
OBPLT     Plot columns of an OB table.
OBTAB     Recalculate orbit parameters and other spacecraft info
OFLAG     uses on-line flag table information to write a flag table
OGEOM     Simple image rotation, scaling, and translation
OHGEO     Geometric interpolation with correction for 3-D effects
OMFIT     Fits sources and, optionally, a self-cal model to uv data
OOSRT     Sort a UV dataset into a specified order
OOSUB     Subtracts/divides a model from/into a uv data base
OTFBS     Translates on-the-fly continuum SDD format to AIPS UV file
OTFIN     Lists on-the-fly single-dish SDD format data files
OTFUV     Translates on-the-fly single-dish SDD format to AIPS UV file
PADIM     Task to increase image size by padding with some value
PASTE     Pastes a selected subimage of one image into another.
PATGN     Task to create a user specified test or primary-beam pattern
PBCOR     Task to apply or correct an image for a primary beam
PBEAM     Fits the analytic function to the measured values of the beam
PCAL      Determines instrumental polarization for UV data
PCCOR     Corrects phases using  PCAL tones data from PC table
PCLOD     Reads ascii file containing pulse-cal info to PC table.
PCNTR     Generate plot file with contours plus polarization vectors
PFPL1     Paraform Task to generate a plot file: (does grey scale)
PFPL2     Paraform Task to generate a plot file: (slice intensity)
PFPL3     Paraform Task to generate a plot file: (does histogram)
PGEOM     Task to transform an image into polar coordinates.
PHASE     Baseline Phase coherence measurement
PHCLN     PHCLN has been removed, use PHAT adverb in APCLN.
PHSRF     Perform phase-referencing within a spectral line database.
PLAYR     Verb to load an image into a TV channel
PLCUB     Task to plot intensity vs x panels on grid of y,z pixels
PLOTR     Basic task to generate a plot file from text input
PLROW     Plot intensity of a series of rows with an offset.
POLCO     Task to correct polarization maps for Ricean bias
POLSN     Make a SN table from cross polarized fringe fit
POSSM     Task to plot total and cross-power spectra.
PROFL     Generates plot file for a profile display.
PRTAB     prints any table-format extension file
PRTAC     prints contents and summaries of the accounting file
PRTAN     prints the contents of the ANtenna extension file
PRTCC     prints the contents of a Clean Components extension file.
PRTIM     prints image intensities from an MA catalog entry
PRTOF     prints on-line flag table information
PRTPL     Task to send a plot file to the line printer
PRTSD     prints contents of AIPS single-dish data sets
PRTTP     prints contents of tapes, all supported formats
PRTUV     prints contents of a visibility (UV) data set
QMSPL     Task to send a plot file to the QMS printer/plotter
QUACK     Flags beginning or end portions of UV-data scans
REAMP     modifies UV data re-scaling the amplitudes
REGRD     Regrids an image from one co-ordinate frame to another
```

```
REMAG     Task to replace magic blanks with a user specified value
RESEQ     Renumber antennas
REWAY     computes weights based in rms in spectra
RFI       Look for RFI in uv data
RGBMP     Task to create an RGB image from the 3rd dim of an image
RLCOR     corrects a data set for R-L phase differences
RLDIF     determines Right minus Left phase difference
RLDLY     fringe fit data to determine antenna R-L delay difference
RM        Task to calculate rotation measure and magnetic field
RMSD      Calculate rms for each pixel using data at the box around the pixel
RSPEC     Plots and prints spectrum of rms of a cube
RSTOR     Restores a CC file to a map with a gaussian beam.
RTIME     Task to test compute times
SABOX     create box file from source islands in facet images
SAD       finds and fits Gaussians to portions of an image
SBCOR     Task to correct VLBA data for phase shift between USB & LSB
SCIMG     Full-featured imaging plus self-calibration loop with editing
SCLIM     operates on an image with a choice of mathematical functions
SCMAP     Imaging plus self-calibration loop with editing
SDCAL     Task to apply single dish calibration
SDCLN     deconvolves image by Clark and then "SDI" cleaning methods
SDGRD     Task to select and image random-position single-dish data
SDIMG     Task to select and image random-position single-dish data
SDLSF     least squares fit to channels and subtracts from SD uv data
SDMOD     modifies single-dish UV data with model sources
SDTUV     Task to convert SD table files to UV like data.
SDVEL     shifts spectral-line single-dish data to a given velocity
SERCH     Finds line signals in transposed data cube
SETAN     Reads an ANtenna file info from a text file
SETFC     makes a BOXFILE for input to IMAGR
SETJY     Task to enter source info into source (SU) table.
SHADO     Calculate the shadowing of antennas at the array
SHADW     Generates the "shadowed" representation of an image
SHOUV     displays uv data in various ways.
SKYVE     Regrids a DSS image from one co-ordinate frame to another
SL2PL     Task to convert a Slice File to a Plot File
SLCOL     Task to collate slice data and models.
SLFIT     Task to fit gaussians to slice data.
SLICE     Task to make a slice file from an image
SMOTH     Task to smooth a subimage from upto a 7-dim. image
SNCOP     Task to copy SN table averaging some input IFs
SNCOR     applies user-selected corrections to the calibration SN table
SNDUP     copies and duplicates SN table from single pol file to dual pol
SNEDT     Interactive SN/CL/TY/SY table editor using the TV
SNFLG     Writes flagging info based on the contents of SN files
SNPLT     Plots selected contents of SN, TY, PC or CL files
SNSMO     smooths and filters a calibration SN table
SOLCL     adjust gains for solar data according to nominal sensitivity
SOUSP     fits source spectral index from SU table or adverbs
SPCAL     Determines instrumental polzn. for spec. line UV data
SPECR     Spectral regridding task for UV data
SPFLG     interactive flagging of UV data in channel-TB using the TV
SPIXR     Fits spectral indexes to each row of an image incl curvature
SPLAT     Applies calibration and splits or assemble selected sources.
SPLIT     converts multi-source to single-source UV files w calibration
SQASH     Task to collapse several planes in a cube into one plane
STARS     Task to generate an ST ext. file with star positions
STEER     Task which deconvolves the David Steer way.
```

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STESS     Task which finds sensitivity in mosaicing
STFND     Task to find stars in an image and generate an ST table.
STFUN     Task to calculate a structure function image
STRAN     Task compares ST tables, find image coordinates (e.g. guide star )
SUBIM     Task to select a subimage from up to a 7-dim. image
SUFIX     modifies source numbers on uv data
SUMIM     Task to sum overlapping, sequentially-numbered images
SUMSQ     Task to sum the squared pixel values of overlapping,
SWAPR     modifies UV data by swapping real and imaginary parts
SWPOL     Swap polarizations in a UV data base
TABED     Task to edit tables
TACOP     task to copy tables, other extension files
TAFFY     User definable task to operate on an image
TAFLG     Flags data in a Table extension file
TAMRG     Task to merge table rows under specified conditions
TAPLT     Plots data from a Table extension file
TAPPE     Task to append 2 tables and merge to output table
TASAV     Task to copy all extension tables to a dummy uv or map file
TASRT     Task to sort extension tables.
TBAVG     Time averages data combining all baselines.
TBDIF     Compare entries in two tables
TBIN      Reads a text file AIPS table into AIPS
TBOUT     Writes an AIPS table into a text file for user editting.
TBSUB     Make a new table from a subset of an old table
TBTSK     Paraform OOP task for tables
TCOPY     Tape to tape copy with some disk FITS support
TECOR     Calculate ionospheric delay and Faraday rotation corrections
TFILE     sorts and edits MkIII correlator UNIX-based A-file.
TI2HA     modifies times in UV data to hour angles
TIORD     checks data for time ordering, displays failures
TKPL      Task to send a plot file to the TEK
TRANS     Task to transpose a subimage of an up to 7-dim. image
TRUEP     determines true antenna polarization from special data sets
TVCPS     Task to copy a TV screen-image to a PostScript file.
TVDIC     Task to copy a TV screen-image to a Dicomed film recorder.
TVFLG     interactive flagging of UV data using the TV
TVHLD     Task to load a map with histogram equalization
TVHUI     make TV image from images of intensity, hue, saturation
TVHXF     Task to calculate transfer function based on histogram
TVPL      Display a plot file on the TV
TVRGB     make TV image from images of true color (RGB) images
TXPL      Displays a plot (PL) file on a terminal or line printer
TYAPL     undoes and re-does nominal sensitivity application
TYSMO     smooths and filters a calibration TY or SY table
UBAVG     Baseline dependent time averaging of uv data
UJOIN     modifies UV data converting IFs to spectral channels
UNCAL     sets up tables for uncalibrating Australia Telescope data
USUBA     Assign subarrays within a uv-data file
UTESS     deconvolves images by maximizing emptiness
UV2MS     Append single-source file to multi-source file.
UV2TB     Converts UV autocorrelation spectra to tables
UVADC     Fourier transforms and corrects a model and adds to uv data.
UVAVG     Average or merge a sorted (BT, TB) uv database
UVBAS     averages several channels and subtracts from uv data.
UVCMP     Convert a UV database to or from compressed format
UVCON     Generate sample UV coverage given a user defined array layout
UVCOP     Task to copy a subset of a UV data file
UVCRS     Finds the crossing points of UV-ellipses.
```

```
UVDEC     Decrements the number of spectral channels, keeping every nth
UVDGP     Copy a UV data file, deleting a portion of it
UVDI1     Subtract UV data(averaged up to one time) from the other UV data
UVDIF     prints differences between two UV data sets
UVFIL     Create, fill a uv database from user supplied information
UVFIT     Fits source models to uv data.
UVFIX     Recomputes u,v,w for a uv database
UVFLG     Flags UV-data
UVFND     prints selected data from UV data set to search for problems
UVGLU     Glues UV data frequency blocks back together
UVHGM     Plots statistics of uv data files.
UVHIM     Images statistics of uv data files.
UVHOL     prints holography data from a UV data base with calibration
UVIMG     Grid UV data into an "image"
UVLIN     Fits and removes continuum visibility spectrum, also can flag
UVLOD     Read export or FITS data from a tape or disk
UVLSD     least squares fit to channels and divides the uv data.
UVLSF     least squares fit to channels and subtracts from uv data.
UVMAP     makes images from calibrated UV data.
UVMLN     edits data based on the rms of the spectrum
UVMOD     Modify UV database by adding a model incl spectral index
UVMTH      Averages one data set and applied it to another.
UVNOU     flags uv samples near the U,V  axes to reduce interference
UVPLT     plots data from a UV data base
UVPOL     modifies UV data to make complex image and beam
UVPRM     measures parameters from a UV data base
UVPRT     prints data from a UV data base with calibration
UVRFI     Mitigate RFI by Fourier transform or fitting the circle
UVSEN     Determine RMS sidelobe level and brightness sensitivity
UVSIM     Generate sample UV coverage given a user defined array layout
UVSRT     Sort a UV dataset into a specified order
UVSUB     Subtracts/divides a model from/into a uv data base
UVWAX     flags uv samples near the U,V  axes to reduce interference
VBCAL     Scale visibility amplitudes by antenna based constants
VBGLU     Glues together data from multiple passes thru the VLBA corr.
VBMRG     Merge VLBI data, eliminate duplicate correlations
VLABP     VLA antenna beam polarization correction for snapshot images
VLANT     applies VLA antenna position corrections from OPs files
VLBIN     Task to read VLBI data from an NRAO/MPI MkII correlator
VLOG      Pre-process external VLBA calibration files
VPFLG     Resets flagging to all correlators whenever 1 is flagged
VPLOT     plots uv data and model from CC file
VTESS     Deconvolves sets of images by the Maximum Entropy Method
VTEST     Measures velocity discrepancy across fields
WARP      Model warps in Galaxies
WETHR     Plots selected contents of WX tables, flags data based on WX
WFCLN     Wide field and/or widefrequency  CLEANing/imaging task.
WIPER     plots and edits data from a UV data base using the TV
WTMOD     modifies weights in a UV data set
WTSUM     Task to do a a sum of images weighted by other images
XBASL     Fits and subtracts nth-order baselines from cube (x axis)
XGAUS     Fits 1-dimensional Gaussians to images
XMOM      Fits one-dimensional moments to each row of an image
XPLOT     Plots image rows one at a time on the graphics or TV screen
XSMTH     Smooth data along the x axis
XSUM      Sum or average images on the x axis
XTRAN     Create an image with transformed coordinates
```

## 13.36 TV

```
BLANK     blanks out selected, e.g. non-signal, portions of an image
CNTR      generate a contour plot file or TV plot from an image
COLORS    specifies the desired TV colors
COSTAR    Verb to plot a symbol at given position on top of a TV image
COTVLOD   Proc to load an image into a TV channel about a coordinate
CURBLINK  switch TV cursor between steady and blinking displays
CURVALUE  displays image intensities selected via the TV cursor
DELBOX    Verb to delet boxes with TV cursor & graphics display.
DELTAX    Increment or size in X direction
DELTAY    Increment or size in Y direction
DFILEBOX  Verb to delete Clean boxes with TV cursor & write to file
DONEWTAB  do we make new tables, use a new table format, etc.
DOTV      selects use of TV display option in operation
DRAWBOX   Verb to draw Clean boxes on the display
FACTOR    scales some display or CLEANing process
FILEBOX   Verb to reset Clean boxes with TV cursor & write to file
FILIT     Interactive BOXFILE editing with facet images
GRBLINK   Verb which blinks 2 TV graphics planes
GRCHAN    specifies the TV graphics channel to be used
GRCLEAR   clears the contents of the specified TV graphics channels
GREAD     reads the colors of the specified TV graphics channel
GROFF     turns off specified TV graphics channelS
GRON      turns on specified TV graphics channelS
GWRITE    reads the colors of the specified TV graphics channel
IM2TV     Verb to convert pixel coordinates to TV pixels
IMERASE   replaces an image portion of the TV screen with zeros
IMLHS     converts images to luminosity/hue TV display
IMPOS     displays celestial coordinates selected by the TV cursor
IMWEDGE   load step wedge of full range of image values to TV
IMXY      returns pixel coordinates selected by the TV cursor
NBOXES    Number of boxes
NCCBOX    Number of clean component boxes
OFFHUINT  Proc which restores TV functions to normal after TVHUE
OFFPSEUD  Verb which deactivates all pseudo-color displays
OFFSCROL  Verb which deactivates scroll of an image
OFFTRAN   Verb which restores transfer function to normal
OFFZOOM   Verb which returns the hardware IIS zoom to normal
OFMFILE   specifies the name of a text file containing OFM values
PCNTR     Generate plot file with contours plus polarization vectors
PIX2XY    Specifies a pixel in an image
PIXAVG    Average image value
PIXRANGE  Range of pixel values to display
PIXSTD    RMS pixel deviation
PIXVAL    Value of a pixel
PROFL     Generates plot file for a profile display.
REBOX     Verb to reset boxes with TV cursor & graphics display.
REMOVIE   Verb to rerun a previously loaded (TVMOVIE) movie
REROAM    Verb to use previous roam image mode, then does roam
RGBCOLOR  specifies the desired TV graphics color
RGBGAMMA  specifies the desired color gamma corrections
RGBMP     Task to create an RGB image from the 3rd dim of an image
ROAM      Roam around an image too large for the display.
ROAMOFF   Verb to recover image from roam display in simple display mode
ROMODE    Specified roam mode
SETMAXAP  Examines/alters system parameter limiting dynamic pseudo-AP
SETROAM   Verb use to set roam image mode, then do roam.  OBSOLETE
SETSLICE  Set slice endpoints on the TV interactively
```

```
SETXWIN    Procedure to set BLC and TRC with TV cursor
TBLC       Gives the bottom left corner of an image to be displayed
TTRC       Specifies the top right corner of a subimage to be displayed
TV1SET     Verb to reset 1D gaussian fitting initial guess on TV plot.
TV3COLOR   Verb to initiate 3-color display using 3 TV channels
TVAGUESS   Verb to re-plot slice model guess directly on TV graphics
TVALL      Procedure loads image to TV, shows labeled wedge, enhances
TVAMODEL   Verb to add slice model display directly on TV graphics
TVANOT     Verb to load anotation to the TV image or graphics
TVARESID   Verb to add slice model residuals directly on TV graphics
TVASLICE   Verb to add a slice display on TV graphics from slice file
TVBLINK    Verb which blinks 2 TV planes, can do enhancement also
TVBOX      Verb to set boxes with TV cursor & graphics display.
TVBUT      Tells which AIPS TV button was pushed
TVCHAN     Specified a TV channel (plane)
TVCLEAR    Verb to clear image from TV channel(s)
TVCOLORS   Sets adverb PLCOLORS to match the TV (DOTV=1) usage
TVCORN     Specified the TV pixel for the bottom left corner of an image
TVCPS      Task to copy a TV screen-image to a PostScript file.
TVCUBE     Verb to load a cube into tv channel(s) & run a movie
TVDIC      Task to copy a TV screen-image to a Dicomed film recorder.
TVDIST     determines spherical distance between two pixels on TV screen
TVFIDDLE   Verb enhances B/W or color TV image with zooms
TVFLUX     displays coordinates and values selected with the TV cursor
TVGUESS    Verb to display slice model guess directly on TV graphics
TVHELIX    Verb to activate a helical hue-intensity TV pseudo-coloring
TVHLD      Task to load a map with histogram equalization
TVHUEINT   Verb to make hue/intensity display from 2 TV channels
TVHUI      make TV image from images of intensity, hue, saturation
TVHXF      Task to calculate transfer function based on histogram
TVILINE    Verb to draw a straight line on an image on the TV
TVINIT     Verb to return TV display to a virgin state
TVLABEL    Verb to label the (map) image on the TV
TVLEVS     Gives the peak intensity to be displayed in levels
TVLINE     Verb to load a straight line to the TV image or graphics
TVLOD      Verb to load an image into a TV channel
TVLUT      Verb which modifies the transfer function of the image
TVMAXFIT   displays fit pixel positions and intensity at maxima on TV
TVMBLINK   Verb which blinks 2 TV planes either auto or manually
TVMLUT     Verb which modifies the transfer function of the image
TVMODEL    Verb to display slice model directly on TV graphics
TVMOVIE    Verb to load a cube into tv channel(s) & run a movie
TVNAME     Verb to fill image name of that under cursor
TVOFF      Verb which turns off TV channel(s).
TVON       Turns on one or all TV image planes
TVPHLAME   Verb to activate "flame-like" pseudo-color displays
TVPL       Display a plot file on the TV
TVPOS      Read a TV screen position using cursor
TVPSEUDO   Verb to activate three types of pseudo-color displays
TVRESET    Reset the TV without erasing the image planes
TVRESID    Verb to display slice model residuals directly on TV graphics
TVRGB      make TV image from images of true color (RGB) images
TVROAM     Load up to 16 TV image planes and roam a subset thereof
TVSCROL    Shift position of image on the TV screen
TVSET      Verb to set 1D gaussian fitting initial guesses from TV plot.
TVSLICE    Verb to display slice file directly on TV
TVSPLIT    Compare two TV image planes, showing halves
TVSTAR     Verb to plot star positions on top of a TV image
```

| | |
|---|---|
| TVSTAT | Find the mean and RMS in a blotch region on the TV |
| TVTRANSF | Interactively alters the TV image plane transfer function |
| TVWEDGE | Show a linear wedge on the TV |
| TVWINDOW | Set a window on the TV with the cursor |
| TVWLABEL | Put a label on the wedge that you just put on the TV |
| TVXY | Pixel position on the TV screen |
| TVZOOM | Activate the TV zoom |
| TXINC | TV X coordinate increment |
| TYINC | TV Y coordinate increment |
| TZINC | TV Z coordinate increment |
| WEDERASE | Load a wedge portion of the TV with zeros |
| XAS | Information about TV-Servers |
| XVSS | Information about older Sun OpenWindows-specific TV-Server |

## 13.37 TV-APPL

| | |
|---|---|
| BLSUM | sums images over irregular sub-images, displays spectra |
| EDITA | Interactive TV task to edit uv data based on TY/SY/SN/CL tables |
| EDITR | Interactive baseline-oriented visibility editor using the TV |
| GAMMASET | changes the gamma-correction exponent used in the TV OFM |
| HLPCLEAN | Cleaning tasks - internal help |
| HLPEDICL | Interactive SN/CL table uv-data editor - internal help |
| HLPEDISN | Interactive SN/CL table (not UV) editor - internal help |
| HLPEDISS | Interactive SY table (not UV) editor - internal help |
| HLPEDISY | Interactive SY table uv-data editor - internal help |
| HLPEDITS | Interactive TY table (not UV) editor - internal help |
| HLPEDITY | Interactive TY table uv-data editor - internal help |
| HLPEDIUV | Interactive uv-data editor - internal help |
| HLPFILIT | Interactive Clean box file editing with image display |
| HLPIBLED | Interactive Baseline based visibility Editor - internal help |
| HLPPLAYR | OOP TV class demonstration task - internal (on-line) help |
| HLPSCIMG | Cleaning tasks - internal help |
| HLPSCMAP | Cleaning tasks - internal help |
| HLPSPFLG | Interactive time-channel visibility Editor - internal help |
| HLPTVFLG | Interactive time-baseline visibility Editor - internal help |
| HLPTVHUI | Interactive intensity-hue-saturation display - on-line help |
| HLPTVRGB | Interactive red-green-blue display - on-line help |
| HLPWIPER | WIPER run-time help file |
| IBLED | Interactive BaseLine based visibility EDitor |
| IMAGR | Wide-field and/or wide-frequency Cleaning / imaging task. |
| OFMADJUS | interactive linear adjustment of current TV OFM lookup tables |
| OFMCONT | creates/modifies TV color OFMs with level or wedged contours |
| OFMDIR | lists names of the user's and system's OFM files from OFMFIL |
| OFMGET | loads TV OFMS from an OFM save file |
| OFMLIST | lists the current TV OFM table(s) on the terminal or printer |
| OFMSAVE | saves the TV's current OFM lookup table in a text file |
| OFMTWEAK | interactive modification of current TV OFM lookup tables |
| OFMZAP | deletes an OFM lookup table save file |
| PLAYR | Verb to load an image into a TV channel |
| SNEDT | Interactive SN/CL/TY/SY table editor using the TV |
| SPFLG | interactive flagging of UV data in channel-TB using the TV |
| TVFLG | interactive flagging of UV data using the TV |
| WIPER | plots and edits data from a UV data base using the TV |
| XBASL | Fits and subtracts nth-order baselines from cube (x axis) |
| XGAUS | Fits 1-dimensional Gaussians to images |
| XPLOT | Plots image rows one at a time on the graphics or TV screen |

## 13.38 UTILITY

| | |
|---|---|
| ANTNUM | Returns number of a named antenna |
| CCEDT | Select CC components in BOXes and above mininum flux. |
| CCSEL | Select signifigant CC components |
| CL2HF | Convert CL table to HF table |
| EPOCONV | Convert between J2000 and B1950 coordinates |
| MAXTAB | Returns maximum version number of named table |
| MBDLY | Fits multiband delays from IF phases, updates SN table |
| MK3TX | extract text files from a MKIII VLBI archive tape |
| MOVE | Task to copy or move data from one user to another |
| OPCODE | General adverb, defines an operation |
| OPTELL | The operation to be passed to a task by TELL |
| PRNUMBER | POPS number of messages |
| PRTIME | Time limit |
| RUNWAIT | Runs a task and waits for it to finish |
| SCANTIME | Returns time range for a given scan number |
| SHOW | Verblike to display the TELL adverbs of a task. |
| SORT | Specified desired sort order |
| SQASH | Task to collapse several planes in a cube into one plane |
| STRAN | Task compares ST tables, find image coordinates (e.g. guide star ) |
| SWAPR | modifies UV data by swapping real and imaginary parts |
| TBDIF | Compare entries in two tables |
| TBIN | Reads a text file AIPS table into AIPS |
| TBOUT | Writes an AIPS table into a text file for user editting. |
| TBSUB | Make a new table from a subset of an old table |
| TBTSK | Paraform OOP task for tables |
| TCOPY | Tape to tape copy with some disk FITS support |
| UVAVG | Average or merge a sorted (BT, TB) uv database |
| UVCMP | Convert a UV database to or from compressed format |
| UVDI1 | Subtract UV data(averaged up to one time) from the other UV data |
| UVNOU | flags uv samples near the U,V axes to reduce interference |
| UVRFI | Mitigate RFI by Fourier transform or fitting the circle |
| UVWAX | flags uv samples near the U,V axes to reduce interference |
| VLAPROCS | Procedures to simplify the reduction of VLBA data |
| VLARUN | calibrating amplitude and phase, and imaging VLA data |
| VLASUMM | Plots selected contents of SN or CL files |
| VLBAARCH | Procedure to archive VLBA correlator data |
| VLBACALA | applies a-priori amplitude corrections to VLBA data |
| VLBACPOL | Procedure to calibrate cross-polarization delays |
| VLBACRPL | Plots crosscorrelations |
| VLBAEOPS | Corrects Earth orientation parameters |
| VLBAFIX | Procedure that fixes VLBA data, if necessary |
| VLBAFPOL | Checks and corrects polarization labels for VLBA data |
| VLBAFQS | Copies different FQIDS to separate files |
| VLBAFRGP | Fringe fit phase referenced data and apply calibration |
| VLBAFRNG | Fringe fit data and apply calibration |
| VLBAKRGP | Fringe fit phase referenced data and apply calibration |
| VLBAKRNG | Fringe fit data and apply calibration |
| VLBALOAD | Loads VLBA data |
| VLBAMCAL | Merges redundant calibration data |
| VLBAMPCL | Calculates and applies manual instrumental phase calibration |
| VLBAPANG | Corrects for parallactic angle |
| VLBAPCOR | Calculates and applies instrumental phase calibration |
| VLBAPIPE | applies amplitude and phase calibration procs to VLBA data |
| VLBASNPL | Plots selected contents of SN or CL files |
| VLBASRT | Sorts VLBA data, if necessary |
| VLBASUBS | looks for subarrays in VLBA data |
| VLBASUMM | Prints a summary of a VLBI experiment |

```
VLBATECR   Calculate ionospheric delay and Faraday rotation corrections
VLBAUTIL   Procedures to simplify the reduction of VLBA data
```

## 13.39 UV

```
ACCOR      Corrects cross amplitudes using auto correlation measurements
ADDIF      Adds an IF axis to a uv data set
AFILE      sorts and edits MkIII correlator A-file.
ALIAS      adverb to alias antenna numbers to one another
ANBPL      plots and prints  uv data converted to antenna based values
ATLOD      Reads ATCA data in RPFITS dormat into AIPS
AVER       Averages over time UV data sets in 'BT' order
AVOPTION   Controls type or range of averaging done by a task
AVSPC      Averages uv-data in the frequency domain
BAND       specifies the approximate frequency of UV data to be selected
BASFIT     fits antenna locations from SN-table data
BASRM      Task to remove a spectral baseline from total power spectra
BDF2AIPS   script access to obit task BDFIn to translate EVLA data to AIPS
BDFLIST    script access to obit task ASDMList to list contents of ASDM data
BIF        gives first IF to be included
BLAVG      Average cross-polarized UV data over baselines.
BLOAT      converts line data to greater number channels
BPASSPRM   Control adverb array for bandpass calibration
BPLOT      Plots bandpass tables in 2 dimensions as function of time
BPSMO      Smooths or interpolates bandpass tables to regular times
BREAK      procedure to TELL FILLM to break all current uv files, start new
BSMOD      creates single-dish UV beam-switched data with model sources
BSROT      modifies SD beam-switch continuum data for error in throw
CALIB      determines antenna calibration: complex gain
CAPLT      plots closure amplitude and model from CC file
CLIP       edits data based on amplitudes, phases, and weights out of range
CLPLT      plots closure phase and model from CC file
CMETHOD    specifies the method by which the uv model is computed
CMODEL     specifies the method by which the uv model is computed
COHER      Baseline Phase coherence measurement
CORER      calculates correlator statistics and flags bad ones
CORFQ      corrects uvw for incorrect observing frequency
CVEL       shifts spectral-line UV data to a given velocity
DAYFX      Fixes day number problems left by FILLM
DBCON      concatenates two UV data sets
DECOR      Measures the decorrelation between channels and IF of uv data
DEFER      Controls when file creation takes place
DEFLG      edits data based on decorrelation over channels and time
DESCM      copies a portion of a UV data set
DFQID      modifies UV data changing the indicated FQIDs
DFTPL      plots DFT of a UV data set at arbitrary point versus time
DIFRL      divides the RR data by LL data
DIFUV      Outputs the difference of two matching input uv data sets
DOACOR     specifies whether autocorrelation data are included
DOARRAY    spcifies if subarrays are ignored or the information used
DOBTWEEN   Controls smoothing between sources in calibration tables
DOCONCAT   selects concatenated or indivudual output files
DOEBAR     Controls display of estimates of the uncertainty in the data
DOIFS      controls functions done across IFs
DOSTOKES   selects options related to polarizations
DOUVCOMP   selects use of compression in writing UV data to disk
DQUAL      Rearranges source list, dropping qualifiers
```

```
DSORC      copies a data set elliminating some source numbers
DSTOK      Drops the cross-hand polarizations
DTCHK      Task to check results of a test using simulated data.
DTSUM      Task to provide a summary of the contents of a dataset
EDITA      Interactive TV task to edit uv data based on TY/SY/SN/CL tables
EDITR      Interactive baseline-oriented visibility editor using the TV
EIF        last IF number to be included in operation
EVASN      Evaluates statistics in SN/CL tables
EVAUV      Subtracts & divides a model Into uv data, does statistics on results
EVLA       puts the list of eVLA antennas in the current file on stack
FEW        procedure to TELL FILLM to append incoming data to existing uv files
FGPLT      Plots selected contents of FG table
FILLM      reads VLA on-line/archive format uv data tapes (post Jan 88)
FILLR      reads old VLA on-line-system tapes into AIPS
FINDR      Find normal values for a uv data set
FITAB      writes images / uv data w extensions to tape in FITS format
FITDISK    writes images / uv data w extensions to disk in FITS format
FITTP      writes images / uv data w extensions to tape in FITS format
FIXAL      least squares fit aliasing function and remove
FIXWT      Modify weights to reflect amplitude scatter of data
FLAGR      Edit data based on internal RMS, amplitudes, weights
FLGIT      flags data based on the rms of the spectrum
FLOPM      reverses the spectral order of UV data, can fix VLA error
FRMAP      Task to build a map using fringe rate spectra
FRPLT      Task to plot fringe rate spectra
FUDGE      modifies UV data with user's algorithm: paraform task
FXALIAS    least squares fit aliasing function and remove
FXPOL      Corrects VLBA polarization assignments
FXTIM      fixes start date so all times are positive
FXVLA      Task to correct VLA data for on-line errors in special cases.
FXVLB      Builds a CQ table to enable VLBA correlator loss corrections
HAFIX      Recomputes u,v,w when time is hour angle (UVdata is output of TI2HA)
HLPEDICL   Interactive SN/CL table uv-data editor - internal help
HLPEDISN   Interactive SN/CL table (not UV) editor - internal help
HLPEDISS   Interactive SY table (not UV) editor - internal help
HLPEDISY   Interactive SY table uv-data editor - internal help
HLPEDITS   Interactive TY table (not UV) editor - internal help
HLPEDITY   Interactive TY table uv-data editor - internal help
HLPEDIUV   Interactive uv-data editor - internal help
HLPIBLED   Interactive Baseline based visibility Editor - internal help
HLPSPFLG   Interactive time-channel visibility Editor - internal help
HLPTVFLG   Interactive time-baseline visibility Editor - internal help
HLPWIPER   WIPER run-time help file
HOLGR      Read & process holography visibility data to telescope images
HSA        puts the list of HSA antennas in the current file on stack
IBLED      Interactive BaseLine based visibility EDitor
IM2UV      converts an image to a visibility data set
LISTR      prints contents of UV data sets and assoc. calibration tables
LOCIT      fits antenna locations from SN-table data
LPCAL      Determines instrumental polarization for UV data
M3TAR      translate Haystack MKIII VLBI format "A" TAR's into AIPS
MANY       procedure to TELL FILLM to start new uv files on each scan
MAPBM      Map VLA beam polarization
MATCH      changes antenna, source, FQ numbers to match a data set
MK3IN      translate Haystack MKIII VLBI format "A" tapes into AIPS
MSORT      Sort a UV dataset into a specified order
MULIF      Change number of IFs in output
MULTI      Task to convert single-source to multi-source UV data
```

```
NOIFS      makes all IFs into single spectrum
NPIECE     The number of pieces to make
OBJECT     The name of an object
OBPLT      Plot columns of an OB table.
OMFIT      Fits sources and, optionally, a self-cal model to uv data
OOSRT      Sort a UV dataset into a specified order
OOSUB      Subtracts/divides a model from/into a uv data base
PCAL       Determines instrumental polarization for UV data
PCCOR      Corrects phases using  PCAL tones data from PC table
PEELR      calibrates interfering sources in multi-facet imges
PHASE      Baseline Phase coherence measurement
PHSLIMIT   gives a phase value in degrees
PHSRF      Perform phase-referencing within a spectral line database.
POSSM      Task to plot total and cross-power spectra.
PRTAN      prints the contents of the ANtenna extension file
PRTUV      prints contents of a visibility (UV) data set
QUACK      Flags beginning or end portions of UV-data scans
QUAL       Source qualifier
QUIT       procedure to TELL FILLM to stop at the end of the current scan
READISK    writes images / uv data w extensions to tape in FITS format
REAMP      modifies UV data re-scaling the amplitudes
REFDATE    To specify the initial or reference date of a data set
REFREQ     Allows changing of reference pixel
RESEQ      Renumber antennas
REWAY      computes weights based in rms in spectra
REWEIGHT   Reweighting factors for UV data weights.
RLCOR      corrects a data set for R-L phase differences
RLDIF      determines Right minus Left phase difference
ROBUST     Uniform weighting "robustness" parameter
SBCOR      Task to correct VLBA data for phase shift between USB & LSB
SDLSF      least squares fit to channels and subtracts from SD uv data
SDMOD      modifies single-dish UV data with model sources
SDVEL      shifts spectral-line single-dish data to a given velocity
SETAN      Reads an ANtenna file info from a text file
SHADO      Calculate the shadowing of antennas at the array
SHOUV      displays uv data in various ways.
SMOOTH     Specifies spectral smoothing
SNEDT      Interactive SN/CL/TY/SY table editor using the TV
SNFLG      Writes flagging info based on the contents of SN files
SNPLT      Plots selected contents of SN, TY, PC or CL files
SORT       Specified desired sort order
SOUSP      fits source spectral index from SU table or adverbs
SPCAL      Determines instrumental polzn. for spec. line UV data
SPECR      Spectral regridding task for UV data
SPFLG      interactive flagging of UV data in channel-TB using the TV
SPLAT      Applies calibration and splits or assemble selected sources.
SPLIT      converts multi-source to single-source UV files w calibration
STOKES     Stokes parameter
STOP       procedure to TELL FILLM to break all current uv files and stop
STUFFR     averages together data sets in hour angle
SUFIX      modifies source numbers on uv data
SWAPR      modifies UV data by swapping real and imaginary parts
SWPOL      Swap polarizations in a UV data base
TBAVG      Time averages data combining all baselines.
TELFLM     procedure to TELL real-time FILLM a new APARM(1) value
TFILE      sorts and edits MkIII correlator UNIX-based A-file.
TI2HA      modifies times in UV data to hour angles
TIORD      checks data for time ordering, displays failures
```

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TRUEP      determines true antenna polarization from special data sets
TVFLG      interactive flagging of UV data using the TV
UBAVG      Baseline dependent time averaging of uv data
UCAT       list a user's UV and scratch files on one or more data areas
UJOIN      modifies UV data converting IFs to spectral channels
USUBA      Assign subarrays within a uv-data file
UV1TYPE    Convolving function type 1, pillbox or square wave
UV2MS      Append single-source file to multi-source file.
UV2TB      Converts UV autocorrelation spectra to tables
UV2TYPE    Convolving function type 2, exponential function
UV3TYPE    Convolving function type 3, sinc function
UV4TYPE    Convolving function type 4, exponent times sinc function
UV5TYPE    Convolving function type 5, spheroidal function
UV6TYPE    Convolving function type 6, exponent times BessJ1(x) / x
UVADC      Fourier transforms and corrects a model and adds to uv data.
UVAVG      Average or merge a sorted (BT, TB) uv database
UVBAS      averages several channels and subtracts from uv data.
UVBOX      radius of the smoothing box used for uniform weighting
UVBXFN     type of function used when counting for uniform weighting
UVCMP      Convert a UV database to or from compressed format
UVCON      Generate sample UV coverage given a user defined array layout
UVCOP      Task to copy a subset of a UV data file
UVCOPPRM   Parameter adverb array for task UVCOP
UVCRS      Finds the crossing points of UV-ellipses.
UVDEC      Decrements the number of spectral channels, keeping every nth
UVDGP      Copy a UV data file, deleting a portion of it
UVDI1      Subtract UV data(averaged up to one time) from the other UV data
UVDIF      prints differences between two UV data sets
UVFIL      Create, fill a uv database from user supplied information
UVFIT      Fits source models to uv data.
UVFIX      Recomputes u,v,w for a uv database
UVFIXPRM   Parameter adverb array for task UVFIX
UVFLG      Flags UV-data
UVFND      prints selected data from UV data set to search for problems
UVGLU      Glues UV data frequency blocks back together
UVHGM      Plots statistics of uv data files.
UVHIM      Images statistics of uv data files.
UVHOL      prints holography data from a UV data base with calibration
UVIMG      Grid UV data into an "image"
UVLIN      Fits and removes continuum visibility spectrum, also can flag
UVLOD      Read export or FITS data from a tape or disk
UVLSD      least squares fit to channels and divides the uv data.
UVLSF      least squares fit to channels and subtracts from uv data.
UVMLN      edits data based on the rms of the spectrum
UVMOD      Modify UV database by adding a model incl spectral index
UVMTH       Averages one data set and applied it to another.
UVNOU      flags uv samples near the U,V  axes to reduce interference
UVPLT      plots data from a UV data base
UVPOL      modifies UV data to make complex image and beam
UVPRM      measures parameters from a UV data base
UVPRT      prints data from a UV data base with calibration
UVRANGE    Specify range of projected baselines
UVRFI      Mitigate RFI by Fourier transform or fitting the circle
UVSEN      Determine RMS sidelobe level and brightness sensitivity
UVSIM      Generate sample UV coverage given a user defined array layout
UVSIZE     specifies number of pixels on X and Y axes of a UV image
UVSRT      Sort a UV dataset into a specified order
UVSUB      Subtracts/divides a model from/into a uv data base
```

```
UVTAPER    Widths in U and V of gaussian weighting taper function
UVWAX      flags uv samples near the U,V  axes to reduce interference
UVWTFN     Specify weighting function, Uniform or Natural
VBGLU      Glues together data from multiple passes thru the VLBA corr.
VECTOR     selects method of averaging UV data
VLA        puts the list of VLA antennas in the current file on stack
VLBA       puts the list of VLBA antennas in the current file on stack
VLBIN      Task to read VLBI data from an NRAO/MPI MkII correlator
VPFLG      Resets flagging to all correlators whenever 1 is flagged
VPLOT      plots uv data and model from CC file
VTEST      Measures velocity discrepancy across fields
WEIGHTIT   Controls modification of weights before gain/fringe solutions
WETHR      Plots selected contents of WX tables, flags data based on WX
WIPER      plots and edits data from a UV data base using the TV
WRTDISK    writes images / uv data w extensions to tape in FITS format
WRTPROCS   Procedures to simplify the reduction of VLBA data
WTMOD      modifies weights in a UV data set
WTUV       Specifies the weight to use for UV data outside UVRANGE
ZEROSP     Specify how to include zero spacing fluxes in FT of UV data
```

## 13.40 VERB

```
VERB
Type:  General type of POPS symbol
Use:   Verbs are the magic words which cause FORTRAN code to
       execute some function.  They are compiled into AIPS
       by the programmers and their meaning remains fixed
       at least until the programmers change their minds.
Grammar:   Verbs may be given either in compile mode or in
       regular execute mode.  In the former, their pointers
       are stored with the procedure and they are executed
       when the procedure is invoked.  In the latter, they
       are compiled with the other statements and parameters
       on the input line and then executed before a new
       input line is read.
Execution:  Verbs are executed when the line in which they
       appear is executed and are simply referenced by their
       name.  The syntax "GO verb_name" is converted by AIPS to
       "TPUT verb_name ; verb_name" which saves the adverbs of
       "verb_name" for a later TGET and then executes
       "verb_name".  The syntax "TASK = 'verb_name' ; GO" will
       not work.
****************************************************************

ABOUT      displays lists and information on tasks, verbs, adverbs
ABS        returns absolute value of argument
ACOS       Returns arc cosine of argument (half-circle)
ACTNOISE   puts estimate of actual image uncertainty and zero in header
ADDBEAM    Inserts clean beam parameters in image header
ADDDISK    makes a computer's disks available to the current AIPS session
ALLDEST    Delete a group or all of a users data files
ALTDEF     Sets frequency vs velocity relationship into image header
ALTSWTCH   Switches between frequency and velocity in image header
APROPOS    displays all help 1-line summaries containing specified words
ASIN       Returns arc sine of argument (half-circle)
ATAN2      Returns arc tangent of two arguments (full circle)
ATAN       Returns arc tangent of argument (half-circle)
```

```
AVEOT      Advances tape to end-of-information point
AVFILE     Moves tape forward or back to end-of-file marks
AVMAP      Advance tape by one image (IBM-CV = obsolete tape file)
AXDEFINE   Define or modify an image axis description
BAMODIFY   edits characters in a line of a batch work file
BATCH      starts entry of commands into batch-job work file
BATCLEAR   removes all text from a batch work file
BATEDIT    starts an edit (replace, insert) session on a batch work file
BATLIST    lists the contents of a batch work file
BY         gives increment to use in FOR loops in POPS language
CALDIR     lists calibrator models available as AIPS FITS files
CATALOG    list one or more entries in the user's data directory
CEIL       returns smallest integer greater than or equal the argument
CELGAL     switches header between celestial and galactic coordinates
CHAR       converts number to character string
CHKNAME    Checks for existence of the specified image name
CLR2NAME   clears adverbs specifying the second input image
CLR3NAME   clears adverbs specifying the third input image
CLR4NAME   clears adverbs specifying the fourth input image
CLRMSG     deletes messages from the user's message file
CLRNAME    clears adverbs specifying the first input image
CLRONAME   clears adverbs specifying the first output image
CLRSTAT    remove any read or write status flags on a directory entry
CLRTEMP    clears the temporary literal area during a procedure
COODEFIN   Define or modify an image axis coordinate description
COPIXEL    Convert between physical and pixel coordinate values
COS        returns cosine of the argument in degrees
COSTAR     Verb to plot a symbol at given position on top of a TV image
COWINDOW   Set a window based on coordinates
CPUTIME    displays curren tcpu and real time usage of the AIPS task
CURBLINK   switch TV cursor between steady and blinking displays
CURVALUE   displays image intensities selected via the TV cursor
DEFAULT    Verb-like sets adverbs for a task or verb to initial values
DELAY      Verb to pause AIPS for DETIME seconds
DELBOX     Verb to delet boxes with TV cursor & graphics display.
DFILEBOX   Verb to delete Clean boxes with TV cursor & write to file
DISMOUNT   disables a magnetic tape and dismounts it from the tape drive
DRAWBOX    Verb to draw Clean boxes on the display
DUMP       displays portions of the POPS symbol table in all formats
EGETHEAD   returns parameter value from image header and error code
EGETNAME   fills in input name adverbs by catalog slot number, w error
EHEX       converts decimal to extended hex
END        marks end of block (FOR, WHILE, IF) of POPS code
EPOCONV    Convert between J2000 and B1950 coordinates
EPOSWTCH   Switches between B1950 and J2000 coordinates in header
EVLA       puts the list of eVLA antennas in the current file on stack
EXIT       ends an AIPS batch or interactive session
EXP        returns the exponential of the argument
EXPLAIN    displays help + extended information describing a task/symbol
EXTDEST    deletes one or more extension files
EXTLIST    lists detailed information about contents of extension files
FILEBOX    Verb to reset Clean boxes with TV cursor & write to file
FILEZAP    Delete an external file
FLOOR      returns largest integer <= argument
FOR        starts an iterative sequence of operations in POPS language
FREESPAC   displays available disk space for AIPS in local system
GAMMASET   changes the gamma-correction exponent used in the TV OFM
GET2NAME   fills 2nd input image name parameters by catalog slot number
```

```
GET3NAME   fills 3rd input image name parameters by catalog slot number
GET4NAME   fills 4th input image name parameters by catalog slot number
GETHEAD    returns parameter value from image header
GETNAME    fills 1st input image name parameters by catalog slot number
GETONAME   fills 1st output image name parameters by catalog slot number
GETPOPSN   Verb to return the pops number on the stack
GETTHEAD   returns keyword and other values value from a table header
GO         starts a task, detaching it from AIPS or AIPSB
GRBLINK    Verb which blinks 2 TV graphics planes
GRCLEAR    clears the contents of the specified TV graphics channels
GRDROP     deletes the specified gripe entry
GREAD      reads the colors of the specified TV graphics channel
GRINDEX    lists users and time of all gripe entries
GRIPE      enter a suggestion or bug report for the AIPS programmers
GRLIST     lists contents of specified gripe entry
GROFF      turns off specified TV graphics channelS
GRON       turns on specified TV graphics channelS
GWRITE     reads the colors of the specified TV graphics channel
HELP       displays information on tasks, verbs, adverbs
HINOTE     adds user-generated lines to the history extension file
HITEXT     writes lines from history extension file to text file
HSA        puts the list of HSA antennas in the current file on stack
IM2TV      Verb to convert pixel coordinates to TV pixels
IMCENTER   returns pixel position of sub-image centroid
IMDIST     determines spherical distance between two pixels
IMERASE    replaces an image portion of the TV screen with zeros
IMHEADER   displays the image header contents to terminal, message file
IMPOS      displays celestial coordinates selected by the TV cursor
IMSTAT     returns statistics of a sub-image
IMVAL      returns image intensity and coordinate at specified pixel
IMWEDGE    load step wedge of full range of image values to TV
IMXY       returns pixel coordinates selected by the TV cursor
INP        displays adverb values for task, verb, or proc - quick form
INPUTS     displays adverb values for task, verb, or proc - to msg file
JOBLIST    lists contents of a submitted and pending batch job
KLEENEX    ends an AIPS interactive session wiping the slate klean
LENGTH     returns length of string to last non-blank character
LN         returns the natural logarithm of the argument
LOG        returns the base-10 logarithm of the argument
MAXFIT     returns pixel position and image intensity at a maximum
MAX        returns the maximum of its two arguments
MCAT       displays images in the user's catalog directory
MIN        returns the minimum of its two arguments
MOD        returns remainder after division of 1st argument by 2nd
MODULUS    returns square root of sum of squares of its two arguments
MOUNT      makes a tape drive available to user's AIPS and tasks
OFFHUINT   Proc which restores TV functions to normal after TVHUE
OFFPSEUD   Verb which deactivates all pseudo-color displays
OFFSCROL   Verb which deactivates scroll of an image
OFFTRAN    Verb which restores transfer function to normal
OFFZOOM    Verb which returns the hardware IIS zoom to normal
OFMADJUS   interactive linear adjustment of current TV OFM lookup tables
OFMCONT    creates/modifies TV color OFMs with level or wedged contours
OFMDIR     lists names of the user's and system's OFM files from OFMFIL
OFMGET     loads TV OFMS from an OFM save file
OFMLIST    lists the current TV OFM table(s) on the terminal or printer
OFMSAVE    saves the TV's current OFM lookup table in a text file
OFMTWEAK   interactive modification of current TV OFM lookup tables
```

```
OFMZAP     deletes an OFM lookup table save file
OUTPUTS    displays adverb values returned from task, verb, or proc
PARALLEL   Verb to set or show degree of parallelism
PASSWORD   Verb to change the current password for the login user
PCAT       Verb to list entries in the user's catalog (no log file).
PLGET      gets the adverbs used to make a particular plot file
PRINTER    Verb to set or show the printer(s) used
PRINT      Print the value of an expression
PROCEDUR   Define a POPS procedure using procedure editor
PROC       Define a POPS procedure using procedure editor.
PRTHI      prints selected contents of the history extension file
PRTMSG     prints selected contents of the user's message file
PSEUDOVB   Declares a name to be a symbol of type pseudoverb
PUTHEAD    Verb to modify image header parameters.
PUTTHEAD   inserts a given value into a table keyword/value pair
PUTVALUE   Verb to store a pixel value at specified position
QHEADER    Verb to summarize the image header: positions at center
QIMVAL     Determines pixel value and coordinate at specified position
QINP       displays adverb values for task, verb, or proc - restart form
QUEUES     Verb to list all submitted jobs in the job queue
RANDOM     Compute a random number from 0 to 1
READ       Read a value from the users terminal
REBOX      Verb to reset boxes with TV cursor & graphics display.
RECAT      Verb to compress the entries in a catalog file
REHEX      converts extended hex string to decimal
REMDISK    removes a computer's disks from the current AIPS session
REMOVIE    Verb to rerun a previously loaded (TVMOVIE) movie
RENAME     Rename a file (UV or Image)
RENUMBER   Verb to change the catalog number of an image.
REROAM     Verb to use previous roam image mode, then does roam
RESCALE    Verb to modify image scale factor and offset
RESTART    Verb to trim the message log file and restart AIPS
RESTORE    Read POPS memory file from a common area.
RETURN     Exit a procedure allowing a higher level proc to continue.
REWIND     Verb to rewind a tape
ROAM       Roam around an image too large for the display.
ROAMOFF    Verb to recover image from roam display in simple display mode
RUN        Pseudoverb to read an external RUN files into AIPS.
SAVDEST    Verb to destroy all save files of a user.
SAVE       Pseudoverb to save full POPS environment in named file
SCALAR     Declares a variable to be a scalar in a procedure
SCRATCH    delete a procedure from the symbol table.
SCRDEST    Verb to destroy scratch files left by bombed tasks.
SET1DG     Verb to set 1D gaussian fitting initial guesses.
SETDEBUG   Verb to set the debug print and execution level
SETMAXAP   Examines/alters system parameter limiting dynamic pseudo-AP
SETROAM    Verb use to set roam image mode, then do roam.  OBSOLETE
SETSLICE   Set slice endpoints on the TV interactively
SG2RUN     Verb copies the K area to a text file suitable for RUN
SGDESTR    Verb-like to destroy named POPS environment save file
SGINDEX    Verb lists SAVE areas by name and time of last SAVE.
SHOW       Verblike to display the TELL adverbs of a task.
SIN        Compute the sine of a value
SIZEFILE   return file size plus estimate of IMAGR work file size
SPY        Verb to determine the execution status of all AIPS tasks
SQRT       Square root function
STALIN     revises history by deleting lines from history extension file
STQUEUE    Verb to list pending TELL operations
```

```
STRING     Declare a symbol to be a string variable in POPS
SUBMIT     Verb which submits a batch work file to the job queue
SUBSTR     Function verb to specify a portion of a STRING variable
SYSTEM     Verb to send a command to the operating system
T1VERB     Temporary verb for testing (also T2VERB...T9VERB)
TABGET     returns table entry for specified row, column and subscript.
TABPUT     replaces table entry for specified row, column and subscript.
TAN        Tangent function
TAPES      Verb to show the TAPES(s) available
TGET       Verb-like gets adverbs from last GO of a task
TGINDEX    Verb lists those tasks for which TGET will work.
THEN       Specified the action if an IF test is true
TIMDEST    Verb to destroy all files which are too old
TK1SET     Verb to reset 1D gaussian fitting initial guess.
TKAGUESS   Verb to re-plot slice model guess directly on TEK
TKAMODEL   Verb to add slice model display directly on TEK
TKARESID   Verb to add slice model residuals directly on TEK
TKASLICE   Verb to add a slice display on TEK from slice file
TKERASE    Erase the graphics screen or window
TKGUESS    Verb to display slice model guess directly on TEK
TKMODEL    Verb to display slice model directly on TEK
TKPOS      Read a position from the graphics screen or window
TKRESID    Verb to display slice model residuals directly on TEK
TKSET      Verb to set 1D gaussian fitting initial guesses.
TKSLICE    Verb to display slice file directly on TEK
TKVAL      Verb to obtain value under cursor from a slice
TKXY       Verb to obtain pixel value under cursor
TO         Specifies upper limit of a FOR loop
TPHEAD     Verb to list image header from FITS or IBM-CV tape
TPUT       Verb-like puts adverbs from a task in file for TGETs
TV1SET     Verb to reset 1D gaussian fitting initial guess on TV plot.
TV3COLOR   Verb to initiate 3-color display using 3 TV channels
TVAGUESS   Verb to re-plot slice model guess directly on TV graphics
TVAMODEL   Verb to add slice model display directly on TV graphics
TVANOT     Verb to load anotation to the TV image or graphics
TVARESID   Verb to add slice model residuals directly on TV graphics
TVASLICE   Verb to add a slice display on TV graphics from slice file
TVBLINK    Verb which blinks 2 TV planes, can do enhancement also
TVBOX      Verb to set boxes with TV cursor & graphics display.
TVCLEAR    Verb to clear image from TV channel(s)
TVCUBE     Verb to load a cube into tv channel(s) & run a movie
TVDIST     determines spherical distance between two pixels on TV screen
TVFIDDLE   Verb enhances B/W or color TV image with zooms
TVGUESS    Verb to display slice model guess directly on TV graphics
TVHELIX    Verb to activate a helical hue-intensity TV pseudo-coloring
TVHUEINT   Verb to make hue/intensity display from 2 TV channels
TVILINE    Verb to draw a straight line on an image on the TV
TVINIT     Verb to return TV display to a virgin state
TVLABEL    Verb to label the (map) image on the TV
TVLINE     Verb to load a straight line to the TV image or graphics
TVLOD      Verb to load an image into a TV channel
TVLUT      Verb which modifies the transfer function of the image
TVMBLINK   Verb which blinks 2 TV planes either auto or manually
TVMLUT     Verb which modifies the transfer function of the image
TVMODEL    Verb to display slice model directly on TV graphics
TVMOVIE    Verb to load a cube into tv channel(s) & run a movie
TVNAME     Verb to fill image name of that under cursor
TVOFF      Verb which turns off TV channel(s).
```

| | |
|---|---|
| TVON | Turns on one or all TV image planes |
| TVPHLAME | Verb to activate "flame-like" pseudo-color displays |
| TVPOS | Read a TV screen position using cursor |
| TVPSEUDO | Verb to activate three types of pseudo-color displays |
| TVRESID | Verb to display slice model residuals directly on TV graphics |
| TVROAM | Load up to 16 TV image planes and roam a subset thereof |
| TVSCROL | Shift position of image on the TV screen |
| TVSET | Verb to set 1D gaussian fitting initial guesses from TV plot. |
| TVSLICE | Verb to display slice file directly on TV |
| TVSPLIT | Compare two TV image planes, showing halves |
| TVSTAR | Verb to plot star positions on top of a TV image |
| TVSTAT | Find the mean and RMS in a blotch region on the TV |
| TVTRANSF | Interactively alters the TV image plane transfer function |
| TVWEDGE | Show a linear wedge on the TV |
| TVWINDOW | Set a window on the TV with the cursor |
| TVWLABEL | Put a label on the wedge that you just put on the TV |
| TVZOOM | Activate the TV zoom |
| TYPE | Type the value of an expression |
| UCAT | list a user's UV and scratch files on one or more data areas |
| UNQUE | remove a given job from the job queue |
| USAVE | Pseudoverb to save full POPS environment in named file |
| VALUE | Convert a string to a numeric value |
| VERB | Declares a name to be a symbol of type verb |
| VGET | Verb-like gets adverbs from version task parameter save area |
| VGINDEX | Verb lists those tasks for which VGET will work. |
| VLA | puts the list of VLA antennas in the current file on stack |
| VLBA | puts the list of VLBA antennas in the current file on stack |
| VPUT | Verb-like puts adverbs from a task in files for VGETs |
| WAITTASK | halt AIPS until specified task is finished |
| WEDERASE | Load a wedge portion of the TV with zeros |
| XHELP | Accesses hypertext help system |
| ZAP | Delete a catalog entry and its extension files |

## 13.41 VLA

| | |
|---|---|
| APGPS | Apply GPS-derived ionospheric corrections |
| BDF2AIPS | script access to obit task BDFIn to translate EVLA data to AIPS |
| BDFLIST | script access to obit task ASDMList to list contents of ASDM data |
| BREAK | procedure to TELL FILLM to break all current uv files, start new |
| CALDIR | lists calibrator models available as AIPS FITS files |
| CALIN | specifies name of input disk file usually with calibration data |
| CLCOR | applies user-selected corrections to the calibration CL table |
| CVEL | shifts spectral-line UV data to a given velocity |
| DAYFX | Fixes day number problems left by FILLM |
| DFCOR | applies user-selected corrections to the calibration CL table |
| FARAD | add ionospheric Faraday rotation to CL table |
| FEW | procedure to TELL FILLM to append incoming data to existing uv files |
| FILLM | reads VLA on-line/archive format uv data tapes (post Jan 88) |
| FIXAL | least squares fit aliasing function and remove |
| FLOPM | reverses the spectral order of UV data, can fix VLA error |
| FRMAP | Task to build a map using fringe rate spectra |
| FXALIAS | least squares fit aliasing function and remove |
| GPSDL | Calculate ionospheric delay and Faraday rotation corrections |
| LDGPS | load GPS data from an ASCII file |
| MANY | procedure to TELL FILLM to start new uv files on each scan |
| MAPBM | Map VLA beam polarization |
| QUIT | procedure to TELL FILLM to stop at the end of the current scan |

| | |
|---|---|
| REWAY | computes weights based in rms in spectra |
| STOP | procedure to TELL FILLM to break all current uv files and stop |
| TECOR | Calculate ionospheric delay and Faraday rotation corrections |
| TELFLM | procedure to TELL real-time FILLM a new APARM(1) value |
| TYAPL | undoes and re-does nominal sensitivity application |
| TYSMO | smooths and filters a calibration TY or SY table |
| USERLIST | Alphabetic and numeric list of VLA users, points to real list |
| VLABP | VLA antenna beam polarization correction for snapshot images |
| VLANT | applies VLA antenna position corrections from OPs files |
| VLAPROCS | Procedures to simplify the reduction of VLBA data |
| VLARUN | calibrating amplitude and phase, and imaging VLA data |
| VLATECR | Calculate ionospheric delay and Faraday rotation corrections |

## 13.42 VLBI

| | |
|---|---|
| ACCOR | Corrects cross amplitudes using auto correlation measurements |
| ACFIT | Determine antenna gains from autocorrelations |
| AFILE | sorts and edits MkIII correlator A-file. |
| ALIAS | adverb to alias antenna numbers to one another |
| ANBPL | plots and prints uv data converted to antenna based values |
| ANCAL | Places antenna-based Tsys and gain corrections in CL table |
| ANTAB | Read amplitude calibration information into AIPS |
| ANTNAME | A list of antenna (station) names |
| APCAL | Apply TY and GC tables to generate an SN table |
| ASTROMET | Describes the process of astrometric/geodetic reduction in AIPS |
| BANDPOL | specifies polarizations of individual IFs |
| BLING | find residual rate and delay on individual baselines |
| BSPRT | print BS tables |
| CALIN | specifies name of input disk file usually with calibration data |
| CAPLT | plots closure amplitude and model from CC file |
| CL2HF | Convert CL table to HF table |
| CLCOR | applies user-selected corrections to the calibration CL table |
| CLPLT | plots closure phase and model from CC file |
| CROSSPOL | Procedure to make complex poln. images and beam. |
| CRSFRING | Procedure to calibrate cross pol. delay and phase offsets |
| CVEL | shifts spectral-line UV data to a given velocity |
| CXPOLN | Procedure to make complex poln. images and beam. |
| DFCOR | applies user-selected corrections to the calibration CL table |
| DTSIM | Generate fake UV data |
| EDITR | Interactive baseline-oriented visibility editor using the TV |
| FRING | fringe fit data to determine antenna calibration, delay, rate |
| FRMAP | Task to build a map using fringe rate spectra |
| FRPLT | Task to plot fringe rate spectra |
| FXAVG | Procedure to enable VLBA delay de-correlation corrections |
| FXPOL | Corrects VLBA polarization assignments |
| HF2SV | convert HF tables from FRING/MBDLY to form used by Calc/Solve |
| HFPRT | write HF tables from CL2HF |
| HLPIBLED | Interactive Baseline based visibility Editor - internal help |
| HLPSCIMG | Cleaning tasks - internal help |
| HLPSCMAP | Cleaning tasks - internal help |
| HYB | RUN to set parameters for HYBRID (CALIB/MX) self-cal imaging |
| IBLED | Interactive BaseLine based visibility EDitor |
| KRING | fringe fit data to determine antenna calibration, delay, rate |
| M3TAR | translate Haystack MKIII VLBI format "A" TAR's into AIPS |
| MATCH | changes antenna, source, FQ numbers to match a data set |
| MBDLY | Fits multiband delays from IF phases, updates SN table |
| MERGECAL | Procedure to merge calibration records after concatenation |

```
MK3IN      translate Haystack MKIII VLBI format "A" tapes into AIPS
MK3TX      extract text files from a MKIII VLBI archive tape
OBPLT      Plot columns of an OB table.
PCCOR      Corrects phases using  PCAL tones data from PC table
PCLOD      Reads ascii file containing pulse-cal info to PC table.
PHSLIMIT   gives a phase value in degrees
POLSN      Make a SN table from cross polarized fringe fit
RESEQ      Renumber antennas
RLDLY      fringe fit data to determine antenna R-L delay difference
SEARCH     Ordered list of antennas for fring searches
SNEDT      Interactive SN/CL/TY/SY table editor using the TV
TAU0       Opacities by antenna number
TECOR      Calculate ionospheric delay and Faraday rotation corrections
TFILE      sorts and edits MkIII correlator UNIX-based A-file.
TRECVR     Receiver temperatures by polarization and antenna
UVPOL      modifies UV data to make complex image and beam
VBCAL      Scale visibility amplitudes by antenna based constants
VBGLU      Glues together data from multiple passes thru the VLBA corr.
VBMRG      Merge VLBI data, eliminate duplicate correlations
VLASUMM    Plots selected contents of SN or CL files
VLBAARCH   Procedure to archive VLBA correlator data
VLBACALA   applies a-priori amplitude corrections to VLBA data
VLBACPOL   Procedure to calibrate cross-polarization delays
VLBACRPL   Plots crosscorrelations
VLBAEOPS   Corrects Earth orientation parameters
VLBAFIX    Procedure that fixes VLBA data, if necessary
VLBAFPOL   Checks and corrects polarization labels for VLBA data
VLBAFQS    Copies different FQIDS to separate files
VLBAFRGP   Fringe fit phase referenced data and apply calibration
VLBAFRNG   Fringe fit data and apply calibration
VLBAIT     Procedure to read and process VLBA data (Phil Diamond)
VLBAKRGP   Fringe fit phase referenced data and apply calibration
VLBAKRNG   Fringe fit data and apply calibration
VLBALOAD   Loads VLBA data
VLBAMCAL   Merges redundant calibration data
VLBAMPCL   Calculates and applies manual instrumental phase calibration
VLBAPANG   Corrects for parallactic angle
VLBAPCOR   Calculates and applies instrumental phase calibration
VLBAPIPE   applies amplitude and phase calibration procs to VLBA data
VLBASNPL   Plots selected contents of SN or CL files
VLBASRT    Sorts VLBA data, if necessary
VLBASUBS   looks for subarrays in VLBA data
VLBASUMM   Prints a summary of a VLBI experiment
VLBATECR   Calculate ionospheric delay and Faraday rotation corrections
VLBAUTIL   Procedures to simplify the reduction of VLBA data
VLBIN      Task to read VLBI data from an NRAO/MPI MkII correlator
VLBINPRM   Control parameters to read data from NRAO/MPI MkII correlators
VLOG       Pre-process external VLBA calibration files
VPLOT      plots uv data and model from CC file
WEIGHTIT   Controls modification of weights before gain/fringe solutions
```

# A EASY CONTINUUM UV-DATA CALIBRATION AND IMAGING

This appendix contains a step-by-step guide to calibrating simple continuum data from interferometers using *AIPS*. This older guide is now preceded with information about a new "pipeline" of *AIPS* procedures which can *automagically* calibrate, image, and even self-calibrate many multi-source continuum (and line) data sets. Although this pipeline is unlikely to produce immediately publishable results in most cases, it does produce a data set with preliminary calibration and editing which can then be edited further "by hand." Following the additional editing, the pipeline may be re-run to produce improved images. When good single-source data sets are produced, self-calibration can also be performed using the methods described in § 5.4.

## A.1 VLARUN

The user should read *AIPS* Memo 112, "Capabilities of the VLA pipeline in AIPS," by Lorant O. Sjouwerman dated March 19, 2007. This memo goes into details and advice that are beyond the scope of this appendix. The memo may be obtained from the *AIPS* web set `http://www.aips.nrao.edu/`.

To use the pipeline, you must first load the VLA Archive or other multi-source visibility data into *AIPS*; see § 4.1.1. To acquire the pipeline, including all procedures and special adverbs, enter

| | |
|---|---|
| > RUN VLARUN C_R | to define the procedures and adverbs |

Do this only once. The procedures will be remembered in your `LASTEXIT` `SAVE`/`GET` file.

The pipeline has three stages: (1) calibration and editing, (2) basic imaging, and (3) self-calibration. Study the recommendations and other advice in `EXPLAIN VLARUN` C_R. Note that `VLARUN` can also handle spectral-line data. Then, the inputs for the calibration stage include

| | |
|---|---|
| > TASK 'VLARUN' ; INP C_R | to review the inputs needed. |
| > WORKDISK *n* C_R | to specify the disk containing the *uv* data. |
| > CATNUM *catn* C_R | to specify the catalog number of the *uv* data; `INNAME` et al. may also be used. |
| > FASTSW 1 C_R | to correct source name peculiarities induced by fast-switching observations. |
| > AUTOFLAG 2 C_R | to use `FLAGR` on all data and `QUACK` on all but high frequency data sets |
| > PHAINT 1 ; AMPINT 5 C_R | to set the phase calibration interval to 1 minute and the amplitude calibration interval to 5 minutes. |
| > DOMODEL 1 C_R | to use standard flux calibrator models where available. |
| > NOPAUSE -1 C_R | to have the pipeline pause after `GETJY` to allow you to evaluate whether it is okay to proceed. |
| > AUTOPLOT -1 C_R | to make no diagnostic plot files. |
| > DOIMAGES -1 C_R | to do calibration and editing only. |
| > INP ; TPUT C_R | to double check the inputs and save them. |
| > VLARUN C_R | to calibrate and edit your data. |

The pipeline can do imaging and even self-calibration, although the latter is not for the faint at heart. To include this in your pipeline run, enter

| | |
|---|---|
| > DOIMAGES 1 C_R | to request imaging. |
| > ARRYSIZE 0 C_R | to let the procedure find the array dimensions. |
| > IMSIZE -1 C_R | to image the target source over the full primary beam, with smaller areas for calibrators. |
| > NITER *nit* ; CUTOFF *f* C_R | to set the number of iterations *nit* and Clean flux limit *f*. NITER must be > 0 for the image to be Cleaned. Use conservative values to begin with and higher limits in subsequent runs. |
| > ALLIMG 1 C_R | to make images of calibrators as well as target sources. |
| > SLFCAL 0 C_R | to avoid self-calibration initially. |
| > INP ; TPUT C_R | to double check the inputs and save them. |
| > VLARUN C_R | to calibrate, edit, and image your data. |

In the first run of VLARUN, it is recommended to avoid self-calibration although the making of images will help you evaluate the quality of the auto-editing. If your data are not "perfect" (*i.e.*, good enough), then consider one or more of the interactive editing tasks such as TVFLG (§ 4.4.3), SPFLG (§ 10.2.2), EDITA (§ 4.4.2), and EDITR (§ 5.5.2) along with the advice given on editing in § 4.3.1, § 4.4, § 4.4.1, and § 5.5. Then

| | |
|---|---|
| > TGET VLARUN C_R | to restore the inputs. |
| > AUTOFLAG -1 C_R | to do no more automatic flagging. |

Consider raising NITER and/or lowering CUTOFF in this second pass, plus

| | |
|---|---|
| > SLFCAL *snit* C_R | to also do self-calibration with interactivity on the TV (*snit* > 0) or in a batch-like process (*snit* < 0) for \|*snit*\| self-cal iterations. |
| > INP ; TPUT C_R | to double check the inputs and save them. |
| > VLARUN C_R | to calibrate, edit, and image your data. |

Repeat as needed. Note that VLARUN has been used on many of the data sets in the VLA archive, with the results archived at `http://archive.nrao.edu/`. These results include both images and calibrated *uv* data sets.

## A.2 Basic calibration

*From VLA Archive Tape to a UV FITS Tape*
*AIPS Memo No. 76 Updated*
Glen Langston

The Gentle User enters the Computer room with a VLA archive tape containing a scientific breakthrough. The user's sources are named SOURCE1 and SOURCE2. The interferometer phase is calibrated by observations of CAL1 and CAL2. The flux density scale is calibrated by observing 3C48 (=0137+331) and polarization is calibrated with observations of 3C286 and/or 3C138. Mount the tape on drive number *n*, log in and start *AIPS*. Example input: AIPS NEW. Mount the tape: INTAPE=*n*; DENS=6250; MOUNT.

**PRTTP** Find out what is on the tape, get project number and bands. TASK='PRTTP'; PRTLEV=-2; NFILES=0; INP; GO; WAIT; REWIND.

**FILLM** Load your data from tape. Select only one band at a time to process. TASK='FILLM'; VLAOBS='?'; BAND=' '; NFILES=?; DOWEIGHT 1; INP; GO (Replace all ?'s with appropriate values.) FILLM will load your visibilities (*uv*-data) with weights suitable for calibration into a large file for each band. It also creates 6 *AIPS* tables each; these tables have two letter names which are:

HI Human readable history of things done to your data. Use PRTHI to read it.

AN Antenna location and polarization tables. Antenna polarization calibration is placed here.

NX Index into visibility file based source name and observation time. Not modified by calibration.

SU Source table contains the list of sources observed and indexes into the frequency table. The flux densities of the calibration sources are entered into this table.

FQ Frequencies of observation and bandwidth with index into visibility data. Not modified.

CL Calibration table describing the antenna based gains. Version 1 should never be modified. The CL table contains entries at regular time intervals (*i.e.*, 2 minutes) for each antenna. **The ultimate goal of calibration is to create a good CL version 2.** Use PRTAB to read tables.

**PRTAN** Print out the antenna locations. TASK='PRTAN'; PRTLEV=0; INP; GO. Choose a good *Reference* antenna (called *R*) near the center of the array (REFANT=R). Check the VLA operator log to make sure the antenna was OK during the entire observation.

**QUACK** Flag the bad points at the beginning of each scan, even the ones with good amplitudes could have bad phases. Creates a Flag Table (FG). You want to use FG table version 1 for all tasks. TASK='QUACK'; FLAGV=1; OPCOD=' '; APARM=0; SOUR=' '; INP; GO deletes the first six seconds of each scan, which may not be enough.

FG A flag table marks bad data. FG tables contain an index into the UV data based on time range, antenna number, frequency and IF number.

**LISTR** Lists your UV data in a variety of ways. Make a list of your observations. TASK='LISTR'; OPTYP='SCAN'; DOCRT=-1; SOUR=' '; CALC='*'; TIMER=0; INP; GO. NOTE: IF you have observed in a way as to create more than one FREQID, you must run through the entire calibration once for EACH FREQID. For new users, it is better to use UVCOP to copy each FREQID into separate files and calibrate each file separately. This is required if you are doing polarization calibration.

**UVCOP** Skip this step if your data consists of only one FREQID. Copy different FREQIDs into separate files. TASK='UVCOP'; FREQID=?; CLRON; OUTDI=INDI; INP; GO. The result will be a ??.UVCOP file.

**SETJY** Sets the flux of your flux calibration source in the SU table. TASK='SETJY'; SOUR='3C48',' '; OPTYP='CALC'; FREQID=1; INP; GO. Adjust flux density for partial resolution following the rules in the VLA Calibration Source Manual or the *AIPS CookBook*.

**TASAV** As insurance, make a copy of all your tables. TASK='TASAV'; CLRON; OUTDI=INDI; INP; GO.

**CALIB** CALIB is the heart of the *AIPS* calibration package. RUN VLAPROCS, an *AIPS runfile*, to create procedures VLACALIB, VLACLCAL and VLARESET. The procedure VLACALIB runs CALIB. Set UVRANGE and ANTENNA to zero to allow use of models for 3C48. For L, C and X band 5% and 5 degree errors are OK; for other bands the limits are higher. CALIB places antenna amplitude and phase corrections into an SN table for the time of observation of phase calibration sources.

SN Solution table contains antenna based amplitude and phase corrections for the time of observations of the calibration sources. These SN table results are latter interpolated for all times of observation and placed in a CL table. Only the CL table corrections will be applied to the program sources.

TASK='VLACAL'; CALS='3C48',' '; CALCODE='*'; REFANT=*R*; UVRA=0; SNVER=1; DOCALIB=-1; DOPRINT=1; MINAMP=10; MINPH=10; INP; VLACAL. VLACALIB will load and use a source model for 3C48, making UVRANGE unnecessary. The task CALIB lists antenna pairs which deviate significantly from the solution. If you have lots of errors, then carefully examine your data using TVFLG or LISTR. (See *AIPS CookBook* for a lengthy discussion

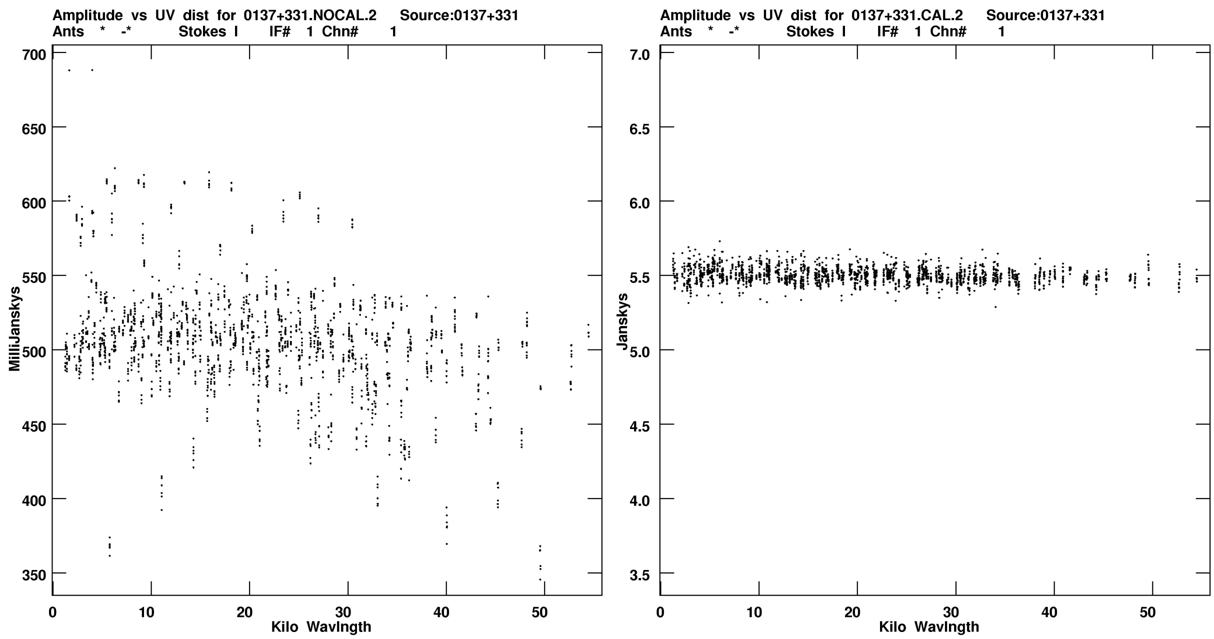


Figure A.1: *(left)* Un-calibrated *uv*-data and *(right)* calibrated *uv*-data from a C-band snapshot of 3C48. Default VLA gains are a tenth of the actual gains and can show significant scatter. Only wild *uv* points ∼50% greater than the average can be detected before calibration.

on flagging.) If one antenna is bad over a limited time range, use UVFLG to flag that antenna for the time from just after the previous good CAL observation to before the next good CAL observation.

**UVFLG** Flag bad UV-data. TASK='UVFLG'; ANTEN=?,0; BASELI=?,0; TIMER=?; OUTFGVER=1; SOUR=' '; OPCOD=' '; INP; GO. If in doubt about any data, FLAG THEM! If you have flagged the primary calibrator, return to CALIB above and try again.

**CALIB** Now calibrate the antenna gain based on the rest of the cal sources. Look in the Calibrator manual for UV limits; if there are limits, VLACAL must be run separately for these sources. TGET VLACAL; CALS='CAL1','CAL2',' '; ANTEN=0; BASELI=0; UVRANGE=?,?; INP; VLACAL. Flag bad antennas listed. Each execution of CALIB replaces previous corrections in the SN table or appends new corrections. If unsatisfied with a VLACAL execution, all effects of it are removed by running VLACAL again for the same sources (but different ADVERBS or after flagging bad data).

**GETJY** Sets the flux of phase calibration sources in the SU table. TASK 'GETJY'; SOUR='CAL1,'CAL2',' '; CALS='3C48',' '; BIF=0; EIF=0; INP; GO. GETJY over-writes existing SU table entries, and is not affected by previous executions.

**TASAV** Good time to save your tables. TGET TASAV; INP; GO.

**CLCAL** Read the antenna amplitude and phase corrections from the SN table and interpolate the corrections into a new CL table. CLCAL applies calibration source corrections to the program sources. Each execution of CLCAL adds to output CL table version 2. CLCAL is run using the procedure VLACLCAL. TASK='VLACLC'; SOUR='SOURCE1','CAL1',' '; CALS='CAL1',' '; OPCODE='CALI'; TIMER=0; INTERP='2PT'; INP; VLACLC. Run CLCAL for the second source using the second calibrator. TGET VLACLC; SOUR='SOURCE2','CAL2',' '; CALS='CAL2',' '; INP; VLACLC. Move the SN table corrections for 3C48 into the CL table. TGET VLACLC; SOUR='3C48',' ';CALS='3C48',' '; INP; VLACLC. (3C48 could also be calibrated with CAL1 or CAL2.)

**LISTR** Make a matrix listing of the Amplitude and RMS of calibration sources with calibration applied. Look for wild points. TASK='LISTR'; OPTYP='MATX'; SOUR='CAL1','CAL2',' '; DOCAL=2; DOCRT=-1; DPARM=3,1,0; UVRA=0; ANTEN=0; BASELI=0; BIF=1; INP; GO. If only a few points are bad, flag them and continue. If too many are bad, delete CL table 2 and the SN tables using VLARESET. Then return to the first CALIB step. If the data look good, run LISTR again for IF two. TGET LISTR; BIF=2; INP; GO

**UVPLT** Plot the *uv*-data in a variety of ways. Make a Flux versus Time plot first. Choose XINC so the plot will have no more than 1000 points. TASK='UVPLT'; SOUR='SOURCE1',' '; XINC=10; BPARM(1)=11; DOCAL=2; BIF=1; INP; GO. Look at the plot with LWPLA, TKPL, TVPL or TXPL. Plot other IF . Flag wild points. Plot Flux versus baseline. TGET UVPLT; BPARM=0; INP; GO.

Calibration is now complete for continuum, un-polarized observations. Write the calibrated data to tape with FITTP if you don't want to calibrate the polarization. To create images from the *uv*-data use SPLIT to calibrate the multi-source data and create a single source *uv*-data set. (FITTP and SPLIT are described at the end of the polarization calibration process.)

## A.3 Polarization calibration

For polarization observations, the following steps are required. For 21cm or longer wavelength observations, ionospheric Faraday rotation corrections may be needed. See FARAD in the *AIPS CookBook*, but don't expect much help anymore.

**TASAV** As added insurance, save your tables again. TGET TASAV; INP; GO.

**LISTR** Print the parallactic angles of the calibration sources. TGET LISTR; SOUR=' '; CALC='*'; OPTYP='GAIN'; DPARM=9,0; INP; GO

**PCAL** Intrinsic antenna polarization calculation. PCAL will be successful only if cal. sources are observed at several parallactic angles. PCAL will modify the AN and SU tables. TASK='PCAL'; CALS='CAL1','CAL2',' '; BIF=1; EIF=2; DOCAL=2; REFANT=*R*; INP; GO

**RLDIF** Now determine the absolute linear polarization angle. Make a matrix listing of the angle of 3C286. TASK 'RLDIF'; SOUR='3C286',' '; DOCAL=2; BIF=1; EIF=0; DOPOL=1; GAINUSE=2; DOCRT=-1; INP; GO. The observed angles are different for each frequency and IF . This task returns the average angles for all IFs in CLCORPRM.

**CLCOR** Now apply the angle corrections to CL table 2. The relative phase of Left and Right circular polarization produces the linear polarization angle and the phase correction is applied to L. The phase difference (twice the angle of linear polarization) for 3C286 is $66^o$ and for 3C138, $\phi = -18^o$ at L band, perhaps $-24^o$ at higher frequencies. Change RLDIF's results to this form with FOR I = 1:20; CLCORP(I)=66-CLCORP(I); END. Then TASK='CLCOR'; STOKES='L'; SOUR=' '; OPCOD='POLR'; BIF=1; EIF=2; GAINVER=2; GAINUSE=0; INP; GO. Run RLDIF again to check the phases. TGET RLDIF; INP; GO. Note that CLCOR copies the CL table version 2 to 3 while applying the phase correction. If the phases are wrong, delete version 3, return to PCAL and RLDIF and then do another CLCOR.

## A.4 Backup and imaging

**FITTP** Writes the output *uv*-data to tape. DISMOUNT your archive; MOUNT your output tape. TASK='FITTP'; DOEOT=1; OUTTAP=INTAP; INP; GO. Use DOEOT=-1 when at the beginning of a new tape.

**SPLIT** The *AIPS* calibration process only modifies the tables associated with the multi-source *uv*-data set. SPLIT selects individual sources, reads the CL table and multiplies the visibilities by the corrections to produce a calibrated single-source *uv*-data set. TASK='SPLIT'; SOUR=' '; CALC=' '; UVRA=0; TIMER=0; DOCAL=2; FLAGVER=1; GAINUSE=3; DOPOL=1; DOBAN=-1; BIF=0; EIF=0; STOKES=' '; BLVER=-1; APARM=0; DOUVCOM=1; ICHANSEL=0; INP; GO

**Mapping** Use your favorite Fourier Transform task (*e.g.*, IMAGR) to produce images from the calibrated data. Procedure MAPPR provides a simplified interface to IMAGR.

## A.5 Additional recipes

### A.5.1 Banana colada

1. Peel and slice 1 ripe **banana**.
2. Place sliced banana in blender along with 6 ounces **pineapple juice** (or crushed tinned pineapple in its own juice) and 1 ounce **rum** plus 1 ounce **coconut rum** *or* 2 ounce **rum** plus 1 teaspoon **Coco Lopez**.
3. Optionally add 1 ounce **banana liqueur**.
4. Blend until smooth.
5. Add crushed ice, if so desired.
6. If the mixture is too thick, add more juice (or more rum if you prefer!); if too thin, add more banana. This is a really easy recipe to adjust to one's taste.

### A.5.2 Breaded chicken and bananas

1. In food processor, blend 1 can **condensed milk**, 1/3 cup **milk**, 1/2 cup flaked **coconut**, and 1/4 cup **lemon juice** until smooth. Pour into a bowl.
2. Prepare 3 cups **corn flake crumbs** in another bowl or plate.
3. Cut 6 very firm **bananas** lengthwise, dip in milk mixture, roll in corn flakes, and set aside.
4. Cut 2 **chickens** into pieces, dip in milk mixture, roll in corn flakes, and place in greased baking pans (2 13x9 pans may be required).
5. Sprinkle chicken with 1/2 cup melted **butter** and bake as 350° F for one hour.
6. Arrange bananas over the chicken. Sprinkle with 1/4 cup melted **butter**. Bake 15 minutes longer or until chicken juices run clear.
7. Garnish with sliced star and/or kiwi fruits if desired.

Thanks to Turbana Corporation (`www.turbana.com`).

# B A STEP-BY-STEP GUIDE TO SPECTRAL-LINE DATA ANALYSIS IN *AIPS*

Initially contributed by Andrea L. Cox and Daniel Puche

In this guide, we assume that the reader is familiar with the basic tools of *AIPS*; *e.g.*, `MCAT` (§ 3.3), `GETN` (§ 3.3.1), `IMHEAD` (§ 3.3.4) and other *AIPS* tools involving the manipulation of the data catalog are not mentioned. This guide contains three main sections covering editing and calibration of spectral-line data, making and Cleaning of map cubes, and moment analysis and rotation curves of galaxies. *It is assumed through these sections that all sources in the data set were observed at the same frequency; the final section of this guide describes what you should do before beginning data reduction if this is not the case.*

This is an outline of a typical reduction procedure for spectral-line data from the VLA; different users may use slightly different approaches. This guide is a supplement to the *AIPS* `EXPLAIN` and `ABOUT` verbs (§ 3.8) and the *AIPS CookBook*. Some of the less obvious or more important parameters for each task will be mentioned, but the user should *always* check to ensure that the rest of the parameters are specified correctly. When in doubt, the defaults are usually fairly safe. Words in boldface or typewriter fonts represent *AIPS* tasks and their inputs. When you see a phrase enclosed in brackets, replace the phrase and the brackets with the correct input. For example, to specify the source 0134+329

`SOURCE` '< *source_name* >' would be typed as

`SOURCE` '0134+329' The text below is in a three-column format, showing a step number on the left, a descriptive paragraph in the center, the name of the *AIPS* task or verb on the right.

## B.1 Editing and calibrating spectral-line data

### B.1.1 Loading the data

(1) Go to the VLA archive web page at

`http://archive.cv.nrao.edu/`

and locate the desired data set using the basic retrieval tool. Use the observing date, program code, or observer's name to locate the data. Give the retrieval code provided to the PI to unlock data within the proprietary period (usually 6 months). Select the data file(s) desired and ask for them with *AIPS*-friendly names. Wait for the e-mail notification that the files are ready and then follow the supplied advice to copy the data files to your computer.

(2) Before starting `AIPS`, create an environment variable pointing at the disk directory containing the data files. Use `cd` < *data_area* > followed by `setenv MYDATA ‘pwd‘` if you use C-shell or its variants or `export MYDATA=‘pwd‘` if you use the bash shell. (Note the back tick marks surrounding the `pwd`.) Then start `AIPS`.

(3) Load the data from the archive file(s) to *AIPS* data areas. Use the defaults to load the data without further averaging. The $m$ disk files will be named $<$ *program_name* $>$ _*i* for $i = n+1, \ldots, n+m$. **FILLM**

```
VLAOBS '< program_name >' ; DOWEIGHT 1
NFILES n ; NCOUNT m
DATAIN 'MYDATA:< program_name > _'
```

The data loaded to disk will normally be in two parts: One will have the class "CH0" and the other will have the class "LINE." The names of the files are thus

```
DATE.CH0
DATE.LINE
```

where "DATE" is the date the observations began. Each file is a multi-source file, containing observations for all your sources: flux calibrators, phase calibrators, and target sources. Your spectral-line data are contained in the LINE file, while the CH0 file is a "pseudo-continuum" file; it is the average of the inner 75% of the bandpass and will be used for gain and phase calibration.

(4) List the "scan summaries" from the CH0 data. *Keep the output for future reference.* Note that the frequency in the header of a multi-source file is always the sky frequency in the center of the band of the first scan of the observation (see § B.4). **LISTR**

```
OPTYPE 'SCAN' ; DOCRT -1 ; OUTPRINT ' '
```

to print on the line printer. To make a text file instead

```
OUTPRINT 'MYDATA:< filename_in_all_caps >'
```

(5) Print the antenna configuration file. *Keep the output for future reference.* **PRTAN**

### B.1.2 Inspecting and editing the data

There are a number of different ways to isolate and edit bad *uv* points from your data set. The method described below is typical. Other tasks of interest can be found by typing ABOUT EDITING and ABOUT UV and by consulting § 4.3.1, § 4.4.3, § 4.4.2, § 5.5.2, and § 10.2.2 in the *AIPS CookBook*.

(6) Plot amplitude versus baseline length for your flux and phase calibrators. Inspect each source, Stokes, and IF separately. Set XINC so there are only a few thousand visibilities on the output plot (the total number of visibilities is listed on the scan summary sheets from Step 4). Use the TV to save trees. **UVPLT**

```
BPARM 0 ; DOTV 1
```

If there are anomalous amplitude points, continue to the next step. If your data points have a small scatter, you may not need to edit and can skip to calibration (Step 10).

(7) Determine if the anomalous data points are from a particular baseline, antenna, Stokes, or IF, inspecting each Stokes and IF separately. The output of this task will be all points that have anomalous amplitudes, based on your selection criteria. **UVFND**

```
OPCODE 'CLIP' ; APARM(1) < max_flux >
APARM(3) < min_flux >
```

(8) Once you have determined which data points to flag with UVFND, flag them with UVFLG. You can flag by time-range, baseline, or antenna and you can flag any or all of the Stokes parameters or IFs. To assist in undoing flags, set a REASON. **UVFLG**

```
OPCODE 'FLAG' ; OUTFGVER 1
```

(9) Examine the *uv* data for your calibrators on the TV to check for any obvious problems which you might have missed; see § 4.4.3. Check each IF and each Stokes separately and edit the data more carefully, if necessary, before continuing. **TVFLG**

`DOCAL -1 ; CALCODE '*' ; FLAGVER 1`

### B.1.3 Calibrating the data

Steps 10–15 should be applied to the `CH0` data alone, not to the `LINE` data. To ensure that all inputs are set to their defaults before continuing, type

`RESTORE 0`

Then, when you are satisfied with your editing, type

`RUN VLAPROCS`

to set up VLA-specific parameters and procedures for calibration. You may turn all adverbs for a specific < *task* > to their default values with

`DEFAULT` < *task* >

*If you have multi-frequency data, each frequency must be calibrated separately; this can be done by specifying the* `FREQID` *parameter in each task (see § B.4).* More information on calibrating your data can be found by typing `ABOUT CALIBRAT` and `HELP CALIBRAT` and consulting Chapter 4.

(10) Calculate the flux of the primary flux calibrator for the channel zero (`CH0`) data. **SETJY**

`SOURCE` '< *flux_calibrator* >' , ' ' ; `OPTYPE 'CALC`

(11) Calculate gain and phase solutions for *all* of the calibrators. In this case, you must run this procedure once for each source. Check for the presence of an appropriate model with `CALDIR`. For those sources having a model **VLACALIB**

`DOCALIB 1 ; UVRANGE 0 ; ANTENNAS 0`

`CALSOUR` '< *flux$_c$alibrator_1* >' , ' '

For sources without a model, choose a `UVRANGE` according to the tables in the *VLA Calibration Manual*. You may do more than one source at a time, if they have the same `UVRANGE`. The output of this procedure is a solution (`SN`) extension table, which is printed automatically. Select a reference antenna (`REFANT`) which did not have any problems during the observing run and which is located near the center of the array.

`DOCALIB 1 ; UVRANGE` < *uv_min* > , < *uv_max* >

`CALSOUR` '< *calibrator_1* >' , . . . , '< *calibrator_n* >'

`DOPRINT 1; OUTPRINT` '< *filename_in_all_caps* >'

The output from `VLACALIB` will include a list of closure errors. If there are too many large errors, edit your data carefully using `UVFND`, `TVFLG`, or `LISTR` as described above. *Destroy old SN tables with* `EXTDEST` and then re-run `VLACALIB` until the solutions are satisfactory. The output will include amplitudes and phases for each baseline; for each calibrator, the amplitudes should be approximately constant and the phases should vary smoothly over time.

(12) Calculate the flux densities of the secondary (phase) calibrators from the primary (flux) calibrator, based upon the flux densities in the source (`SU`) table and the antenna gain solutions in the solution (`SN`) table. *Destroy bad or redundant versions of the* `SN` *tables before using this task.* Compare the computed fluxes with those listed in the *VLA Calibration Manual*. **GETJY**

`SOURCES` '< *phase_cal_1* >' , . . . , '< *phase_cal_n* >'

`CALSOUR` '< *flux_cal* >' , ' '

(13) This procedure interpolates the solutions derived from the calibrators into the calibration (CL) table for *all* sources. Run this procedure once for each phase calibrator (which may be used to calibrate multiple sources). **VLACLCAL**

SOURCES '< *phase_cal* >' ,'< *source_1* >' , . . . , '< *source_n* >'

CALSOUR '< *phase_cal* >' , ' '

OPCODE 'CALI' ; INTERPOL '2PT'

OUTPRINT '< *filename_in_all_caps* >'

Note: if you are observing at low frequencies or there are gaps in your observations of phase calibrators, you may want to use SAMPTYPE 'BOX' and review the other inputs carefully. They have changed.

(14) Apply the calibration to the phase calibrators and examine the amplitudes, which should be nearly constant, and the phases, which should be nearly zero. **LISTR**

SOURCES ' ' ; CALCODE '*' ⇐ *print results for all calibrators*

OPTYPE 'MATX' ; DOCALIB 2 ; GAINUSE 2; DPARM 5, 1, 0

UVRANGE 0 ; DOCRT -1 ; OUTPRINT '< *filename_in_all_caps* >'

(15) Examine the *uv* data for your *sources* on the TV to check for any obvious problems which you may have missed. Re-edit the data (Steps 6–9) if necessary. **TVFLG**

DOCAL 2 ; GAINUSE 2 ; CALCOD '-CAL'

If you have too many visibilities to fit on the TV screen, you may want to set TIMERANGE, SOURCES or DPARM(6) (the input averaging time) to limit the amount of data displayed. There are also interactive options to set the on-screen averaging time and the time range currently displayed.

(16) To calibrate the spectral-line data, simply copy the calibration (CL) table from the CH0 to the LINE data. **TACOP**

INEXT 'CL' ; NCOUNT 1 ; INVERS 2

Also be sure to copy the flagging (FG) table

INEXT 'FG' ; INVERS 1

Steps 17 and 18 should be applied to the LINE data alone, not to the CH0 data

(17) Calibrate the bandpass for the LINE data using the primary (flux) calibrator. The output from this task is a table (BP) of the bandpass spectrum. **BPASS**

GET3NAME < *CH0data* >

CALSOUR '< *flux_cal* >' , ' '; CALCODE '*'

DOCALIB -1 ; FLAGVER 1

(18) Examine the bandpass for each of the antennas on the TV. **POSSM**

APARM(8) 2 ; DOTV 1 ; STOKES 'RR'

ANTENNAS 0 ; NCOUNT 4 ⇐*plot 4 antennas at a time*

Then do the LL Stokes. After this, generate a plot (PL) file of the total bandpass for each Stokes.

NCOUNT 0 ; DOTV -1

Plot the bandpass on the laser printer; specify PLVER for each Stokes. **LWPLA**

(19) Now that the calibration is completed, write the calibrated CH0 and LINE data to tape. **FITTP**

Print the contents of the tape(s) for your data. **PRTTP**

(20) Apply the calibration and editing tables, writing single-source *uv* files for imaging. **SPLIT**

CALCODE '-CAL' ⇐*write uv for all non-calibrator sources*

DOCALIB 2; GAINVER 2 ; DOBAND 1; BPVER 1

## B.2 Making and Cleaning image cubes

(21) Determine the imaging parameters needed for a full-field image of the continuum. Set the BPARMs to cover the full single-dish beam area (or more at 21-cm wavelength). **SETFC**

IMSIZE 0 ; CELLSIZE 0

BOXFILE 'MYDATA:< $source_name$ >.BOX'

Delete the output BOXFILE and re-run the task with your chosen (more congenial or exact) CELLSIZE.

(22) Make a CH0 image with a large field (set by IMSIZE and CELLSIZE returned by SETFC) to look for strong continuum sources. Use uniform weighting (UVWTFN ' ') with ROBUST of 0 or −1 if resolution is more important than detecting significantly extended sources; set ROBUST to 2 or more if the converse is true. **IMAGR**

STOKES 'I' ; NITER 0

Then make a dirty image cube of your LINE data in the center field only (unless more are needed for the line source).

NFIELD 1 ; BCHAN 1 ; ECHAN 0

(23) Examine the cube on the TV to determine which channels are free of line emission. **TVMOVIE**

(24) Calculate the noise in a few of the line-free channels.

Display a channel on the TV **TVALL**

TBLC = 0 , 0 , < *channel_number* > ; TTRC 0

Select a large window that contains no continuum sources. **TVWIN**

Calculate the RMS noise inside the window. The verb TVSTAT is helpful if there are no large rectangular windows free of continuum emission. **IMSTAT**

Having an initial guess of the signal-free RMS, you may attempt to refine that estimate (see message generated) and also produce a histogram plot. **IMEAN**

BLC 0 ; TRC 0; DOTV 1; DOHIST 1; NBOXES 256

(25) Remove the continuum emission by fitting a baseline in the *uv* plane to the line-free channels; see EXPLAIN UVLSF and § 8.3. If you don't want this task for flagging, but only for continuum subtraction, the important parameters are **UVLSF**

ORDER 1 ; DOOUT 1 ; FLUX 0 ; CUTOFF 0

Choose your line-free channels, normally avoiding the channels at the edges of your bandpass since they are usually quite noisy.

ICHANSEL < $begin_1$ >,< $end_1$ >,, 0, 0, < $begin_2$ >,< $end_2$ >

This task will also write a new continuum data set which is a better estimate of the continuum than the CH0 file which contains contributions from the line signals. If there is a bright continuum source far away from the phase center, you *will* want to use SHIFT to center it while running UVLSF. Multiple interfering sources might even require UVSUB with a good continuum model rather than UVLSF.

(26) Make a dirty cube containing only the line emission. Use the same parameters as in Step 22, including usually only one field — but consider multi-scale Clean. **IMAGR**

(27) Calculate the noise in the line-free channels as in Step 24.

(28) Make a contour plot of the beam.

Display a channel on the TV. **TVALL**

`TBLC = 0, 0,` < *channel_number* > `; TTRC 0`

Select a window containing the source (or beam) you want to plot. **TVWIN**

Display the contour plot on the TV. For a beam plot, good parameters are **KNTR**

`PLEV 10 ; LEVS -3,-1,1,3,5,7,9 DOTV 1`

When you are happy with the plot, generate a plot (`PL`) extension file.

`DOTV -1`

Send the plot file to the default printer. **LWPLA**

Measure the beam diameter at half-power (FWHP) to get beam parameters (`BMAJ`, `BMIN`, `BPA`) for the Cleaning process. If you do not specify these, `IMAGR` will choose them automatically by fitting a Gaussian beam with an elliptical cross-section. This is usually fine for uniformly-weighted images (`ROBUST` around 0), but may not be desirable for naturally-weighted images for which the beam is often rather non-Gaussian.

(29) Select boxes containing all of the line emission in the cube. Use as many boxes as necessary (up to 50). The better that you constrain the locations of real emission, the faster the Cleaning process will go. Note that `IMAGR` allows you to set the boxes interactively when you run with `DOTV 1`, which is important when Cleaning reveals emission initially lost in the sidelobes of the stronger objects. **TVBOX**

(30) Make a Clean cube of the line emission. Start by Cleaning just one or two channels (set with `BCHAN` and `ECHAN`) to ensure that your inputs are set correctly. If you don't want to waste time, it is a good idea to Clean only those channels with emission that is $\geq 4$ times the RMS noise (Step 20). Use `SUBIM` and `MCUBE` to construct a full cube of the images later. Use the same parameters as in previous runs of `IMAGR`, but specify the beam parameters (`BMAJ`, `BMIN`, `BPA`) and control the Cleaning depth with `FLUX` and `NITER`. **IMAGR**

(31) Examine the Cleaned cube and do progressively deeper cleaning with `IMAGR` until you are satisfied with the result. The `DOTV 1` option in `IMAGR` will help you reach this state more quickly. You can examine the Clean components with `PRTCC`. You should Clean until the total Cleaned flux converges. **TVMOVIE**

(32) Correct for attenuation away from the center of the primary beam. Use your Cleaned cube as the input, the default parameters should be adequate, and the output is a corrected cube. **PBCOR**

(33) Back up the Cleaned cubes and the cubes after `PBCOR` to tape. **FITTP**

Print the contents of the tapes for your records. **PRTTP**

## B.3 Moment analysis and rotation curve of galaxies

After correcting for primary beam attenuation with `PBCOR`, the noise in the images will depend upon position. Because of this, you should use the uncorrected line cube for moment analysis.

(34) The frequency axis can be labeled in either frequency or velocity units. Make sure that the desired units are chosen; use IMHEAD to check. Velocity is recommended for moment analysis. **ALTSW**

(35) Transpose the axes to VEL-RA-DEC (or FREQ-RA-DEC) order. **TRANS**

TRANSCOD '312'

(36) Generate images of the total emission (MOM0), the velocity field (MOM1), and the line width (MOM2) using the transposed cube as input. Be sure to exclude the end channels as they generally are very noisy. Try various values for the flux cutoff FLUX and the width of the smoothing functions (set by CELLSIZE) until you are satisfied with the results. **MOMNT**

(37) Correct for the attenuation away from the center of the primary beam in the MOM0 image, as in Step 28. If you computed the moment images with a velocity axis, use ALTSW to change to a frequency axis before running PBCOR. **PBCOR**

(38) Make contour plots of the MOM0 and MOM1 images; see Step 24. Note that KNTR can superpose contour and grey-scale plots as in Figure 8.4. **KNTR**

(39) The task GAL allows you to generate a "tilted-ring" model rotation curve of two types from a galaxy's velocity field or to fit single-parameter rotation curves to annuli of a specified width. The EXPLAIN file for this task describes all of the parameters in detail and contains general advice on how to obtain an optimum fit. **GAL**

The task CUBIT, written by Judith Irwin, allows you to fit a rotating galaxy model to the full Cleaned image cube. The EXPLAIN file for this task describes all of the parameters in detail and contains general advice on how to obtain an optimum fit. **CUBIT**

## B.4 Multi-frequency observations

### B.4.1 General frequency information

For any *uv* data file, the frequency listed in the header information is the sky frequency of the center of the band (LINE or CH0) during the first scan of the observation. This is true regardless of whether you observed at a single frequency or multiple frequencies. After you SPLIT a multi-source file into single-source files, the frequency in the header refers to the sky frequency at the center of the band during the first scan *on that source*.

Corrections for the Doppler shift due to the rotation of the Earth can be taken into account within AIPS, if the data were observed at fixed frequency. Task CVEL may be used, but it requires that the spectra be well sampled in frequency.

### B.4.2 Multi-frequency *uv* files

**A simple rule of thumb:** If you want to calibrate sources together, load the data with the same value of FREQID in FILLM. If you want to calibrate sources separately, give them different FREQIDs. For multi-frequency files, you should be sure to assign a different qualifier (QUAL) to each observing frequency (or velocity) with the OBSERVE program *before taking the observations*. There are essentially two types of multi-frequency observations:

1. Standard multi-frequency observations in which you want to do the entire calibration process separately for each frequency. When reading in such data with FILLM, set CPARM(7) = 0. This sets a different value of FREQID to data that differ by more than the maximum Doppler shift in a source in a day. During calibration, you can control which data you process by choosing the appropriate values for FREQID and QUAL. After calibration of each source/frequency, you may destroy the SN table to avoid using it to calibrate sources with different FREQIDs. For each source/frequency, you should create a new version of the calibration (CL) and bandpass (BP) tables (*e.g.*, for the second source/frequency, you will create version 3 of the CL table and version 2 of the BP table). (It principle, FREQIDs may co-exist in single tables without interference, but if they are in carefully specified separate tables they cannot interfere with each other.)

2. Observations of, or affected by, Galactic emission or absorption, in which you want to combine data at different frequencies to do the calibration. Normally, these are observations in which the calibrator sources themselves are absorbed by Galactic HI around 0 velocity. It is *extremely important* that you assign a different qualifier to each frequency with the OBSERVE program. Then load the data with FILLM forcing a single value of FREQID by setting CPARM(7) = -1. In this case, the information that two observations with the same FREQID have different frequencies will be contained only in the qualifiers. Whatever data are loaded with the same value of FREQID will have the same reference frequency; it should be possible to average over the observing frequencies using the appropriate programs in AIPS (CLCAL and BPASS).

## B.5 Additional recipes

### B.5.1 Banana breeze pie

1. In a small saucepan, melt 1/3 cup **butter** or **margarine**. Add 1/4 cup **sugar** and 1/2 teaspoon **cinnamon**. Stir constantly over low heat until bubbles form around the edges of pan.
2. Remove from heat, add 1 cup **cornflake cereal** crumbs and mix well. Press mixture evenly into a 9-inch pie pan to form crust. Chill.
3. Beat 8 ounces softened **cream cheese** until light and fluffy. Add 1 15-ounce can **condensed milk** and blend thoroughly. Add 1/3 cup **lemon juice** and 1 teaspoon **vanilla**. Stir until thickened.
4. Slice 3 ripe **bananas** and line crust. Pour filling into crust and refrigerate for 2–3 hours or until firm. Do not freeze.
5. Slice 2 ripe **bananas**, dip in lemon juice and arrange on top of pie. Note. for a change of pace, use lime juice.

### B.5.2 Banana cutlets

1. Peel 6 medium-ripe **bananas** and halve them crosswise.
2. Dip them in 1/3 cup **lemon juice** and then roll in 1 cup crushed **cornflake crumbs**.
3. Saute them in 3 tablespoons **butter** until a golden brown.
4. Serve on lettuce.

# C A Step-by-Step Recipe for VLBA Data Calibration in $\mathcal{AIPS}$

This appendix provides a step-by-step guide to calibrating many types of VLBA and HSA (High Sensitivity Array or Effelsberg, Arecibo, GBT, and phased VLA) experiments. Continuum strong-source or phase-referencing observations are included, as are simple spectral-line observations. This appendix applies specifically to data sets with full calibration transfer. There is an addendum (§ C.8) describing issues with flagging for non-VLBA data sets and other matters for cases in which not all calibration data are loaded by FITLD. It may often be used (with some modifications in loading amplitude data) for data sets containing other antennas. Simple VLBA utilities that go all the way up to and including fringe-fitting are described.

## C.1 Table Philosophy

$\mathcal{AIPS}$ follows an incremental calibration process on multi-source data sets. Calibration solutions are written to SN ("Solution") tables, which can be inspected in various ways. CLCAL is used to apply an SN table and write a new CL ("Calibration") table, which stores the cumulative calibrations. The actual visibilities are not altered until the final calibration is applied using SPLIT (or SPLAT), which produces single-source (or multi-source) data sets that can be imaged. With this philosophy, it is easy to back up a step or two if errors are made in processing. Users should keep track of which tables contain which solutions and calibrations as they go through the calibration process.

A key verb to be aware of is EXTDEST, which can delete any unwanted table. For example, to delete SN version 3 from the data set cataloged as data set 1 on disk 1, type INDISK 1; GETNAME 1; INEXT 'SN'; INVER 3; INP EXTDEST; EXTDEST. *Beware of the fact that once a table is deleted, there is no 'undelete' function.*

## C.2 Data set assumed in this Appendix

This appendix assumes a VLBA-only data set observed at several frequency bands (*e.g.*, 1.6, 2.3, and 5.0 GHz). To include data from the VLA see § C.8. It is also assumed that phase-referencing programs have been observed according to the philosophy discussed in detail in VLBA Scientific Memo No. 24. The hypothetical observation considered here contains the following sources:

- 'CAL-BAND' — fringe-search and bandpass calibrator
- 'CAL-AMP' — amplitude-check source
- 'CAL-POL' — polarization position angle calibrator
- 'STRONG' — strong target source
- 'CAL-PHASE' — phase-reference source
- 'WEAK' — weak target source, to be calibrated with CAL-PHASE

In the text below, table versions, such as SN version 1, are referred to as SN 1.

## C.3 VLBA Utilities

Note that there are simple VLBA procedures ("front ends" to standard tasks) that will take the user all the way from data loading up to and including fringe-fitting. (The description below applies to the 31DEC02 and later releases, but VLBATECR and VLBAEOPS are only available in the 31DEC05 release.) These are tremendous labor-savers for those working with reasonably straightforward data sets. For spectral line, use the procedures to calibrate a lower spectral resolution version of the spectral line data and copy the final calibration to the line set. To access the utilities, type RUN VLBAUTIL from inside AIPS. The currently available procedures that simplify data reduction are

- VLBALOAD: loads VLBA data with simplified inputs
- VLBAFIX: Fixes VLBA data
- VLBASUBS: finds subarrays in VLBA data. Made redundant by VLBAFIX
- VLBAMCAL: removes redundant calibration data from tables. Made redundant by VLBALOAD
- VLBAFQS: copies different frequency IDs to separate files. Made redundant by VLBAFIX
- VLBAFPOL: fixes polarization labeling for common cases. Made redundant by VLBAFIX
- VLBATECR: automatically downloads and applies ionospheric corrections
- VLBAEOPS: automatically downloads and applies corrections to the Earth Orientation Parameters used by the correlator
- VLBASUMM: makes summary listings of your data set
- VLBACALA: determines *a-priori* amplitude calibrations
- VLBAPANG: determines phase corrections for parallactic angles
- VLBAPCOR: determines instrumental phase corrections using pulse cals
- VLBAMPCL: determines instrumental phase corrections using FRING
- VLBACPOL: calibrates cross polarization delays
- VLBAFRNG: does global fringe fit using FRING
- VLBAKRNG: does global fringe fit using KRING
- VLBAFRGP: does global fringe fit for phase referenced experiments using FRING
- VLBAKRGP: does global fringe fit for phase referenced experiments using KRING
- VLBASNPL: plots the SN or CL tables versus time
- VLBACRPL: plots the cross-correlation spectrum

There are two additional procedures that can make life easier, called ANTNUM and SCANTIME. ANTNUM will return the antenna number of the antenna corresponding to a certain character string. For example, in many data sets, typing REFANT = ANTNUM ('BR') will be the equivalent of typing REFANT = 1. SCANTIME will return the time range of a given scan number, for use in various programs. Typing TIMERANG = SCANTIME(4) will fill the eight-element array TIMERANG with the start and stop times of the $4^{\text{th}}$ scan of a given data set. (There must be an NX (index) table, within which scan number is row number, for this to work.)

Note that all of the VLBAUTIL procedures have HELP files with good discussions about when to use the simple procedures and when to use the tasks directly. Also, note that the procedures do not include data editing, which should be performed at appropriate points in the calibration process. You only need to RUN VLBAUTIL once to access all of the procedures. If you run it again for any reason, it is a good idea to type COMPRESS immediately afterward to avoid overflowing AIPS' symbol memory.

## C.4 Data Loading and Inspection

1. Load the data using VLBALOAD (which is a very simplified FITLD). Typically, the user will set DOUVCOMP=1 to write compressed data. CLINT should be set so that there are several CL table entries for each self-calibration or fringe-fitting interval anticipated; this will minimize interpolation error during the calibration process. However, setting CLINT too short will result in a needlessly large table. Somewhere between CLINT = 0.25 and CLINT = 1.0 is about right. A FITLD parameter that is set automatically in VLBALOAD is WTTHRESH = 0.7, which results in irrevocable discarding of all data with playback weight less than 0.7. The only way around this is to use FITLD explicitly. After March 7, 2002, VLBALOAD will merge redundant entries in the calibration tables, making VLBAMCAL unnecessary.

2. *If you used a version of* VLBALOAD *later than March 7 2002, then this step has already been performed.* Merge redundant VLBA gain curve (GC), pulse cal (PC) and system temperature tables (TY) using VLBAMCAL. Multiple VLBA correlator jobs create multiple entries in the GC, PC and TY tables; these must be merged before continuing with data reduction. Another, slightly more general procedure which can be used is MERGECAL (which is loaded by typing RUN MERGECAL). Both these procedures use TAMRG, which is a very general, therefore complicated task.

3. After March 7, 2002, correct data with VLBAFIX. *If necessary*, VLBAFIX sorts (with MSORT), splits into different frequencies (with UVCOP), fixes the polarization structure (with FXPOL), and indexes (with INDXR) the data. VLBAFIX will also correct for subarrays (with USUBA), but you must tell it to do so. There are only 2 inputs of interest in VLBAFIX, CLINT, the CL table interval, and SUBARRAY which should be set to 1 if there are subarrays and 0 if not. The steps in these procedures are very similar to VLBASUBS, VLBAFQS and VLBAFPOL, which can be run individually instead of VLBAFIX. This is a very benign procedure, it can be run on every data set read into AIPS and will only perform the necessary fixes. Note that, if the data are split into different frequencies, the flag table is applied and deleted. *If you run* VLBAFIX *there is no need to run* VLBASUBS, VLBAFQS *or* VLBAFPOL.

4. *If you ran* VLBAFIX *this step in not necessary.* Deal with subarrays, if needed, using VLBASUBS. Note that this should *only* be done if you know there are real subarrays. FITLD will err on the side of caution and print messages saying that the data may contain subarrays. When a true subarray condition is found, FITLD will print a detailed message listing the source numbers and antennas causing the subarray condition. If needed, VLBASUBS will sort the data (with MSORT), correct the subarray nomenclature (with USUBA), and/or have the index (NX) table and calibration (CL) version 1 table rebuilt (with INDXR). The only user-controllable input for VLBASUBS is the CL table interval; therefore for more options run MSORT, USUBA, and INDXR separately.

5. *If you ran* VLBAFIX *this step in not necessary.* For multi-frequency data sets, separate frequencies into single-frequency data sets using VLBAFQS. The procedure VLBAFQS will run UVCOP to separate the different FREQIDs, deleting the data flagged by the correlator with FLAGVER=1, and then re-index the data set to generate new CL and NX tables. The only user-controlled input is CLINT, the CL table interval. Again, for more control, you may use UVCOP separately; INDXR should not be required. To determine which frequency ID corresponds to which band, run LISTR with OPTYP = 'SCAN', or just run IMHEAD on each output file. Note that, if the data are split into different frequencies, the flag table is applied and deleted.

6. *If you ran* VLBAFIX *this step in not necessary.* Fix polarization labeling, if needed, with VLBAFPOL. The VLBA correlator does not preserve polarization information unless it is operating in full polarization mode. This results in polarizations not being labeled correctly when both R and L polarizations are observed but RL and LR are not correlated, either within the same band or in different bands. Each VLBA correlator band is loaded into *AIPS* as a separate IF and is assigned the same polarization. For the simplest cases of VLBA-only data, the procedure VLBAFPOL attempts to determine which polarization case applies and creates a new data set with correct IF and polarization assignments using FXPOL. VLBAFPOL assumes that all of your FREQIDs have similar polarization setups. For this reason, you should normally run VLBAFPOL after copying each frequency ID to a separate file

using VLBAFQS. This strategy also reduces the amount of disk space needed for VLBAFPOL. VLBAFPOL also will recommend a course of action for more complicated situations. If you want to run FXPOL on your own, below are examples of 2 common cases.

(a) If dual polarization (RR and LL, no cross-hands) was used, run FXPOL with BANDPOL = '*RL' for normal VLBA setups. For Mark IV setups (probably not used for a VLBA-only data set) you may need to run FXPOL with BANDPOL = '*LR'.

(b) If multiple bands were used, standard setup files probably caused 2.3 and 8.4 GHz to be observed in RCP, while others were observed in LCP. Therefore, when RCP and LCP observations occur in the same program, the polarizations are almost certainly mislabeled. Identify the polarization that you know was used for a given frequency band (*e.g.*, from the schedule file). Then, run FXPOL with BANDPOL = '*L' to change to LCP, or BANDPOL = '*R' to change to RCP. The result can be checked using IMHEAD to show the data-set header, which will contain STOKES = -1 for RCP and STOKES = -2 for LCP.

7. At this point it is a good idea to get a listing of the antennas and scans in your data by running VLBASUMM. VLBASUMM runs PRTAN over all antenna tables and LISTR with OPTYPE='SCAN' and gives a choice of writing a text file to disk or sending the listing to a printer.

8. Apply ionospheric corrections, if desired, with TECOR or VLBATECR. This task uses Global Positioning System (GPS) models of the electron content in the ionosphere to correct the dispersive delays caused by the ionosphere. It is particularly important for phase referencing experiments at low frequency. We recommend TECOR for all experiments at 8 GHz or lower. *After November 2005* there is a procedure, called VLBATECR, which automatically downloads the needed GPS files and runs TECOR with a minimum of intervention. However, to use TECOR, you must ftp the GPS files; see EXPLAIN TECOR. Run TECOR with GAINVER=1, GAINUSE=2, APARM=1,0, if you have only one CL table. Note that TECOR had a problem with experiments which approached or crossed midnight, which has been fixed in the 31DEC01 version of AIPS. See EXPLAIN TECOR for instructions on what files to download. TECOR is only as good as the ionospheric model, so it is a very good idea to compare the corrected and uncorrected phases using VPLOT. To inspect the phases using VPLOT, use options BPARM = 0, 2; APARM=0; DOCAL=1; GAINUSE=*highest* CL *table*. The phases should not wind as much (although they will probably not be completely flattened), when the corrected CL table is applied. To see the corrections themselves, use SNPLT on the new CL table setting OPTYPE = 'DDLY'.

9. Apply corrections to the Earth Orientation Parameters (EOPs). VLBI correlators must use measurements of the Earth Orientation Parameters (EOPs) to take them out of the observations. These change slowly with time and therefore the EOPs used by the correlator must be continually updated. From 5-May-2003 to 9-Aug-2005 the VLBA correlator used old predicted EOPs which could be significantly wrong and will effect all phase referencing experiments. Even outside these dates the EOPs could be significantly off so it is now recommended that all phase-referencing experiments be corrected for this possible error. CLCOR (OPCODE='EOPS') and VLBAEOPS will do this correction. The procedure VLBAEOPS automatically downloads a file with correct EOPs and runs CLCOR. To run CLCOR independently you must download a file with correct EOPs by hand, see EXPLAIN CLCOR for instructions, and run CLCOR setting OPCODE='EOPS'.

10. For a simple spectral-line data set, or any data set with high spectral resolution (*i.e.*, more than 16 or 32 channels per IF), it is a very good idea to average the data set to 16 or 32 channels before deriving the calibration parameters. Otherwise, the calibration tasks may take forever to run. It is recommended that you quickly inspect the channels of interest for your line data (*e.g.*, with UVPLT) for high points. Remove obviously high amplitudes with CLIP (or *e.g.*, UVMLN) before averaging. Inspect the full resolution data also for high delays and fringe rates. Spectral averaging in such cases may not be acceptable. Continue calibration on the averaged data set as if it were a continuum set. There is a better method to calibrate spectral line data described in § 9.4.7 and § 9.4.8.12, but the one used here is simpler and will usually give acceptable results. To reduce the data-set size, run the task AVSPC with

AVOPTION = 'SUBS'. For example, to average IFs with $N_{\rm chan}$ down to 16 channels, set the adverb CHANNEL = $N_{\rm chan}/16$ (*e.g.*, to average from 1024 to 16 channels, use CHANNEL = 64).

## C.5 Amplitude Calibration

Amplitude calibration uses measured antenna gains and system temperatures ($T_{\rm sys}$), as well as finding a correction for voltage offsets in the samplers.

1. Before amplitude calibration is done there must be information for all antennas in the gain curve (GC), system temperature (TY), and weather (WX) tables. There may be missing data; this will be the case for VLBA data before April 1999, or data from non-VLBA antennas. Beginning during November 2003, these tables will normally include information for the VLA and GBT telescopes when they are used. § C.8 has details on how to incorporate the VLA $T_{\rm sys}$ and gain curves for earlier observations or if they are omitted. A similar procedure may be followed for other non-VLBA antennas. Otherwise consult § 9.4.2.5.

2. Correct sampler offsets and apply amplitude calibration by running VLBACALA. The procedure VLBACALA runs several tasks, ACCOR, SNSMO, CLCAL, APCAL and CLCAL. ACCOR (run with SOLINT=2) uses the autocorrelation to correct the sampler voltage offsets. This should always be run for data from the VLBA correlator, since it is significant for 2-bit data and may be important for 1-bit data. After ACCOR creates an SN table, SNSMO smooths the table in order to remove any outlying points. Then the SN table is applied to the highest CL table using CLCAL (using INTERPOL='2PT'), and a new CL table is created. To apply the amplitude calibration, APCAL is run on the highest TY and GC tables, and a new SN table is created. Adverb DOFIT controls whether APCAL also uses the weather tables to fit and correct for opacity. It may be desirable to perform an atmospheric opacity correction at high frequencies, particularly if very accurate source fluxes are needed. See § 9.4.4.2 for a more detailed discussion of APCAL. Lastly, VLBACALA runs CLCAL to apply the amplitude calibration SN table to the CL created by the last run on CLCAL. After running this procedure you will have two new SN tables and two new CL tables. The highest numbered CL table contains all the calibration up to this point. VLBACALA will print messages telling you about the new tables it has created. To keep track of your tables, it is important to copy these messages.

3. At this point it is a *very* good idea to examine your data.

   (a) Run the task SNPLT or procedure VLBASNPL (which is a very simplified SNPLT) to examine the tables created by ACCOR. Use INEXT='CL'; OPTYPE= 'AMP'; INVERS=CL-*table-with-sampler-offsets*; DOTV=1 (to display to the TV; for a hardcopy use DOTV=-1 and LWPLA to print the plot files). The solutions that SNPLT plots should be close to 1000 milligain or 1 gain. Some IFs may be ∼ 5% lower than other IFs due to the VLBA system design; application of the ACCOR solutions will (among other things) give proper relative calibration among the IFs.

   (b) Run SNPLT or VLBASNPL to examine the amplitude calibration. This time look at the SN table that APCAL created. Use INEXT='SN'; OPTYPE= 'AMP'; INVERS=*highest* SN *table*; DOTV=1 for VLBASNPL; or to inspect IF $m$, use SNPLT and BIF = $m$; EIF = $m$; OPTYP = 'AMP'; INVER = 1; INEXT = 'SN'; OPCODE = ' '; NPLOT = 10; DOTV = 1; GO SNPLT. For a hardcopy, use DOTV = -1; GO SNPLT; GO LWPLA. Plotted amplitudes are the square-roots of the system-equivalent flux densities (SEFDs), in Jansky, where the SEFD is the flux density of a source that would double the system temperature. (Low numbers are good!) At centimeter wavelengths, VLBA antennas have SEFDs near 300 Jy, so gains above 30° elevation should be near 17–18 and should vary slowly and smoothly with time (*i.e.*, change in elevation) for an individual source. To look at the input system temperatures, run SNPLT with OPTYP = 'TSYS'; INEXT = 'TY'; INVER = 0. On rare occasions, you might find clearly discrepant points that have leaked in from a different frequency band. In that case, you can use task SNEDT, or the clipping option of SNSMO, to get rid of the bad points. You may notice that at low elevations the gains on individual antennas are high. All data below a given elevation can be flagged by running UVFLG; *e.g.*, to flag all data below 10°, run UVFLG with APARM(4)=0 and APARM(5) = 10. Elevation *vs.* time can be listed with LISTR, using OPTYP = 'GAIN'; INEXT = 'SN'; INVER = 1; DOCRT = 1; DPARM(1) = 11. Note that FG tables are not applied to other tables, so flagged data still may have points plotted by SNPLT. The $T_{\mathrm{sys}}$ measurements are also a very good diagnostic of bad data from poor weather, equipment failures, *etc.*. If there are time ranges of unusually high or low $T_{\mathrm{sys}}$ you may consider flagging those time ranges using UVFLG. Be particularly suspicious of patches of unusual gains at only one IF or STOKES of an antenna. Remember, one of the best things you can do for your final result is to get rid of bad data.

(c) At this point, you may wish to use your favorite method of inspecting data for flagging (*e.g.*, EDITR, TVFLG, IBLED). On-line flags are already included in FG 1 unless they were applied as the data were split into separate frequencies. Use OUTFGVER = 2 initially to copy FG 1 to FG 2, then work with FG 2, so the data do not have to be loaded again if mistakes are made. (But be careful to use the proper FLAGVER and OUTFGVER in various programs.) For example, run EDITR with inputs SOURCES= 'CAL-BAND','' (do each source separately); DOCAL=1; GAINUSE=*highest* CL *table*; FLAGVER=2; OUTFGVER=2; DOTWO=1; ANTUSE=1,2,3,4,5,6,7,8,9,10. Once you gain experience you might want to set CROWDED=1 which allows plots of all polarizations and IFs in one plot; this can speed up editing significantly. At this point be concerned about anomalously high or low amplitudes, remember there can be a slow change in amplitude with time due to source structure. Some people do no additional flagging at this stage, but later use the results of fringe-fitting and visibility plots of calibrated data to point the way to bad data, or they do their flagging in the Caltech program DIFMAP.

(d) Run POSSM or VLBACRPL (a simplified version of POSSM) on a calibrator to check that the CL table with the gain corrections has appropriate values. Plot cross-correlation amplitude and phase for a short time period, and examine calibrator flux and phase coherence within each IF. The phase will show a slope *vs.* frequency, indicating an uncalibrated (so far) residual delay. Sample inputs for VLBACRPL are SOURCE = 'CAL-BAND'; REFANT = $n$; GAINUSE = 2; SOLINT = -1; DOTV = 1. Use STOKES = 'RR' or 'LL' as appropriate. For a weak phase-referencing calibrator, the flux density may look too high due to scalar averaging of the amplitudes, which are dominated by noise. If the data are coherent over the desired time range, using POSSM with APARM(1) = 1 (a vector average), will provide a more realistic estimate of the source flux density. At this point, you may want to note a time with good fringes on all antennas, to use when instrumental phase corrections are made. The only important input to VLBACRPL is the reference antenna REFANT, which it plots. A good choice for the reference antenna is one in the center of the array (PT, LA, FD, or KP for the VLBA) that performed well according to the log, the PI letter, and the initial amplitude calibration and was around for most of the experiment. Hereafter, this is denoted as antenna $n$.

4. For spectral-line experiments needing velocity accuracy better than 1 km/s, a Doppler correction should be performed. Use CVEL; see § 9.4.5 and § 9.4.6 for details.

5. This is a useful time to run TASAV to save all your ancillary tables to another file. If you foul up the calibration, the relevant tables can be copied back using TACOP.

## C.6 Delay, Rate, and Phase Calibration

Now that the data have calibrated amplitudes, the next step is to do the calibration of the antenna delays, rates, and phases. This section describes that process.

1. Correct the antenna parallactic angles, if desired, using VLBAPANG. The RCP and LCP feeds on alt-az antennas will rotate in position angle with respect to the source during the course of the observation

(all VLBA and VLA antennas are alt-az). Since this rotation is a simple geometric effect, it can be corrected by adjusting the phases without looking at the data. You *must* do this correction for polarization experiments. This correction is also important in phase referencing experiments, because the parallactic angle difference between calibrator and target is different at different stations which leads to an extra phase error which can be corrected. VLBAPANG copies the highest numbered CL table with TACOP and then runs CLCOR (OPCODE = 'PANG'; CLCORPRM = 1,0). VLBAPANG has no inputs that require discussion. Be sure to correct the parallactic angles before any of the following steps. Again keep track of which CL tables add which correction.

2. Next, the instrumental delay residuals must be removed. These offsets or "instrumental single-band delays" are caused by the passage of the signal through the electronics of the VLBA baseband converters or MkIII/MkIV video converter units. There are two different methods to remove these instrumental delays, one for the case where you have pulse-cal information for some, but not necessarily all, of your antennas; and one for the case where you have no pulse-cal information at all. Note that the preferred method for continuum experiments is to use the pulse-cals, since they correct the instrumental delay over the whole experiment, rather than on a short scan which is "pretty good" for the rest of the experiment. Spectral-line observers would have switched off the pulse-cals as they interfere with line observations, so they are forced to use the second (strong source) method. For VLBA continuum experiments before April 1999, you can load the pulse-cal data using PCLOD; consult the § 9.4.2.

   (a) For the case where you have some pulse-cal information, run VLBAPCOR. VLBAPCOR is another procedure which runs quite a few tasks, PCCOR, CLCAL, FRING (sometimes) and CLCAL again (sometimes). PCCOR extracts pulse-cal information from the PC table and creates an SN table. Then CLCAL is run to apply that SN table to the highest CL table, creating a new CL table. If there are antennas that do not have information in the PC table, or their PC entries are wrong, then VLBAPCOR runs FRING on a short calibrator scan (input TIMERANGE). The SN table from FRING contains corrections for the antennas left out of the PC table, and is applied to CL table without corrections from PCCOR, and added to the CL table with the PC corrections. For the simplest case of all VLBA antennas, the inputs for VLBAPCOR should be TIMER=*time range on* CAL-BAND *with good fringes for all baselines*; REFANT=$n$; SUBARRAY=0; CALSOUR='CAL-BAND''; GAINUSE=0; OPCODE=''; ANTENNAS=0. For the case where you have the VLA (in this example antenna 11), which does not have pulse-cals, your inputs should be the same as above except OPCODE='CALP'; ANTENNAS=11,0. For the second case it is important that there are no "Failed" solutions from the run for FRING; if there are failed solutions, then you should delete the tables that were created and find another TIMERANG with good fringes to the REFANT, particularly on the antenna(s) in the ANTENNAS list. Also see EXPLAIN VLBAPCOR for a detailed description of the steps involved with using pulse-cals and FRING without using VLBAPCOR.

   (b) The alternate method is to use solve for the phase cals manually with VLBAMPCL. This method uses the fringes on a strong source to compute the delay and phase residuals for each antenna and IF. VLBAMPCL runs FRING to find the corrections and then CLCAL to apply them. If there is no calibrator scan that includes all antennas then there is an option to run FRING and CLCAL again on another source in order to correct the antenna(s) not corrected by the first scan. For the simplest case where all antennas have strong fringes to CAL-BAND, set TIMERANG = *time range of scan on calibrator with strong fringes to all antennas*; REFANT = $n$; CALSOUR = 'CAL-BAND'; GAINUSE = *highest* CL *table*; OPCODE = ''. If there are no scans that have fringes to all antennas, then you should select a second scan with good fringes to the antennas missing from the first scan (in this example antennas 1 and 9), *plus the reference antenna*. In this case set OPCODE = 'CALP'; TIME2 = *time range of second scan*; SOURCES = *second calibrator*; ANTENNAS = 1, 9.

3. Now you *must* check the results of correcting your instrumental delays using VLBACRPL or POSSM. Set GAINUSE=*highest* CL *table*, and plot cross-correlations (VLBACRPL will do this for you). The plotted cross-correlations should show the phase slope removed from each IF and there should no longer be a phase jump between IFs, although the phase will not usually be at 0°. If you do a "manual" instrumental delay correction (*i.e.*, you used FRING, not PCCOR); then the phases far in time from the

scan on which FRING was performed may have a small slope and a small phase jump between the IFs. Also non-zero phase slopes still may be seen at low elevations, where the atmosphere causes additional delay residuals, or for low-frequency observations where the ionospheric delay varies. If POSSM or VLBACRPL is run on a scan of the phase-reference source, CAL-PHASE, there may be more phase noise than for CAL-BAND, because the source is likely to be much weaker. Try APARM(1) = 1 (vector averaging) to get a true measure of the source flux density. If you see significant phase slopes, or phase jumps between IFs on *any* baseline, then the instrumental phase corrections have not worked and you need to figure out why and start again. You can also inspect your new CL table with SNPLT or VLBASNPL. Choose OPTYP = 'DELA' or OPTYP = 'PHAS' and for a given antenna and IF, SNPLT should show a single value of delay repeated for the entire length of the data set, while phase will vary slightly due to the parallactic angle correction and/or the pulse-cal application. If only a portion of the observation appears, there may have been a problem, such as specifying only a certain time range or source in CLCAL. If some antenna was not operating at the beginning (typically MK or BR) or end (typically SC or HN) of the observation, some CL entries will be missing; this is okay. If there appears to be a problem, use SNPLT to look at the previous CL tables to see where things went wrong, delete any erroneous tables, back up to the appropriate stage of the calibration, and move forward from there.

4. Now you must remove global frequency- and time-dependent phase errors using either FRING or KRING or one of the procedures which use these programs, VLBAFRNG, VLBAKRNG, VLBAFRGP and VLBAKRGP. This cannot be done simply for spectral-line sources, so the practice here is to determine delay and rate solutions from the (continuum) phase-reference sources and interpolate them over the spectral line observations. The procedures run either FRING or KRING along with CLCAL. VLBAFRNG and VLBAFRGP use FRING, with VLBAFRGP specifically for phase referencing. Similarly, VLBAKRNG and VLBAKRGP use KRING, with VLBAKRGP specifically for phase referencing. For all these procedures, if the SOURCES adverb is set, then CLCAL is run once for each source in SOURCES. For the phase-referencing procedures (VLBAFRGP and VLBAKRGP), any source that is in the SOURCES list that is *not* in the CALSOUR list will be phase referenced to the *first* source in the CALSOUR list. These procedures will produce new (highest numbered) SN and CL tables. Since it is probably best to run CLCAL on each source separately, SOURCES should always be set. To use VLBAFRGP for a simple phase referencing experiment (remember that CAL-PHASE is the phase reference calibrator), set CALSOUR='CAL-PHASE','CAL-BAND','CAL-AMP','CAL-POL','STRONG'; GAINUSE=*highest* CL *table*; REFANT=*n*; SEARCH 9 4 1 3 5 6 7 8 10; SOLINT=*coherence time*; DPARM(7)=1 *(if a polarization experiment)*; SOURCES='CAL-PHASE'; 'CAL-BAND'; 'CAL-AMP'; 'CAL-POL'; 'STRONG','WEAK'; INTERPOL='SIMP'. For this example, FRING will be run on the sources in CALSOUR and then CLCAL will be run 6 times, with all of the sources except WEAK referenced to themselves and WEAK referenced to CAL-PHASE, using interpolation method SIMP. For a non-phase-referencing experiment you would use VLBAFRNG with inputs the same as above except for SOURCES, which would not contain WEAK. The results will be the highest SN and CL tables. The INTERPOL to use is a personal preference, AMBG is usually recommended but can cause spurious phase wraps if the rates are very low, which is common with VLBA antennas; SIMP is a simpler interpolation method and therefore more robust. You might want to restrict the channel range slightly using BCHAN and ECHAN, since the channels at the high end of each IF will have lower SNR, due to the cutoffs in the bandpass filters. For a data set with 16 channels per IF, numbered from 1 to 16, setting ECHAN to 14 or 15 may be worth trying. Note that some people like to run CALIB rather than FRING or KRING for this stage of phase-referencing observations, but fringe fitting is recommended, as it solves for rates, which CALIB doesn't do.

   (a) The above fringe fit may take a bit of time, depending on the computer and the spectral resolution. Then, use SNPLT or VLBASNPL to inspect the solutions in the SN table. It's not totally out of the question that some data will be found that need flagging, which can be done with UVFLG. In that case, it's a good idea to delete the last SN and CL table and re-run VLBAFRGP or VLBAFRNG.

   (b) This fringe-fitting stage is the most likely place where things can go wrong, for reasons that are not immediately apparent to the observer. Below, a few common examples are listed.

      - **Many solutions failed.** The source may be too weak, or the coherence time too short. Try increasing or decreasing SOLINT. Or narrow the search window. For most VLBA data, DPARM(2) = 400 and DPARM(3) = 60 should be a good first step, though the rate window specified in DPARM(3) is proportional to the observing frequency, and may need to be larger at 22 GHz and above. Try setting ECHAN so that the top one or two spectral channels in each IF are not used. For more options you could try running FRING and reduce the SNR threshold with APARM(7). Also, if the phase-reference source was too weak, you might try restricting solutions to the shorter baselines with UVRANGE, but it also might be that you're out of luck!

- **Some antenna has low SNR, and may cause an entire set of solutions to go bad.** This typically happens because an antenna should have been flagged. A common cause is when OV is looking at the White Mountains, and neither the on-line system nor the astronomer has flagged the data. Then, you need to run UVFLG and re-run VLBAFRGP or VLBAFRNG.
- **The task fails with some message related to memory allocation.** This may happen if there are lots of spectral channels, or a long SOLINT. Possible solutions are to run AVSPC, to reduce the size of the search window with DPARM(2) and DPARM(3), or to reduce SOLINT. This is much less likely to occur in 31DEC00 and should never occur beginning with 31DEC07.
- **There are discrepant delay/rate solutions.** Look at the solutions you believe, and try VLBAFRGP or VLBAFRNG again with DPARM(2) and DPARM(3) specified appropriately. Full widths are specified, so if the good solutions fall between +15 mHz and −15 mHz, use DPARM(3) = 30. (Actually, you should use a value somewhat larger to allow some margin.) It may be that an antenna is suffering from radio-frequency interference, so some channels and/or IFs will need to be flagged.
- **Some solutions are outside the specified delay/rate range.** This can happen because the initial coarse fringe search uses the range specified by DPARM(2) and DPARM(3), but the least-squares solution can take off from there and go elsewhere.
- **Delays and rates for some station change rapidly near the beginning or end of the observation.** This may be caused by low elevation at the relevant station. Depending on how desperate you are to include low-SNR data, you may wish to flag some time range, or flag all data at elevations below 5° or 10° (particularly at high frequencies).
- **Phases wrap rapidly, particularly on the phase-reference source, CAL-PHASE.** There may not be a lot you can do about this initially, because it's possible that the tropospheric delay just changed too fast for the cycle time used in the observation, especially at low elevation. However, you may wish to note the times and antennas when the phase connection is best (typically the southwestern antennas near transit). Later, when imaging the program source, it can be helpful to image with a subset of antennas and time ranges, then use that initial image to self-calibrate the rest of the data.

5. Use SNPLT or VLBASNPL to inspect the interpolation of the phases in the CL. When you inspect the CL table notice any phase wraps that seem out of place. The human eye is better at pattern matching than a computer and these phases may be in error. If so you might want to run CLCAL independently and try another interpolation method or you might want to edit the CL table. Remember that this is your last calibration table; you want to get rid of any bad calibration now before applying it to the data. Getting rid of spurious wraps in the final CL table using SNEDT will improve your final image more consistently than anything else, *particularly* for phase referencing.

## C.7 Final Calibration Steps

1. If you used AVSPC to reduce the size of the data set used in determining calibration, you must copy your final calibration tables back to the full-size data set. This can be done with task TACOP. For bookkeeping purposes, it may be best to copy over all the CL tables with the same table numbers in both the averaged and un-averaged data sets. Copy the FG table as well, since any data which are bad in the averaged dataset will be bad in the full resolution dataset. After inspecting the data with UVPLT

or VPLOT, run EDITR, TVFLG, CLIP, SPFLG, or other data editor to edit the bad data from the calibrated spectral-line dataset.

2. In some cases (spectral-line observations and continuum experiments seeking dynamic ranges of a few thousand or more, or large fields of view), it is important to calibrate the bandpass shapes. To do this, run BPASS on the bandpass calibrator, CAL-BAND. Make sure that the spectral line data for the bandpass calibrator is clean and devoid of high points, using UVPLT or SPFLG. Inputs for BPASS are CALSOUR = 'CAL-BAND'; DOCALIB = 1; GAINUSE = *highest* CL *table*; SOLINT = 0; BPVER = -1; BPASSPRM(5)=1; BPASSPRM(9) = 1; BPASSPRM(10) = 1; REFANT = *n*. If the phases vary rapidly duiring the bandpass calibrator scan, then the results using these adverbs will not be satisfactory. Try BPASSPRM(5)=0; BPASSPRM(10)=4 instead. It is a good idea to do a vector averaged POSSM and to look at the bandpass calibrator with DOCAL=1; GAINUSE=*highest* CL *table* before and after making the bandpass (first with DOBAND=-1, then with DOBAND=1) to check the result. You can also examine the BP table using POSSM by setting APARM(8)=2.

3. After you have made the BP table for spectral line, you may want to correct for the change in frequency by the motion of the antennas with respect to the Sun *etc.*. This is done with CVEL, after the source velocities are entered in the SU table with SETJY. For a detailed description see § 9.4.6.

4. Polarization calibration still remains, if desired, and if all the appropriate calibration sources were observed. This can be done in a variety of ways; see § 9.4.8 for details.

5. Finally, apply the calibration to the visibility data and make single-source data sets using SPLIT. (Some people might wish to use SPLAT to average over time as well as spectral channel.) Inputs for a continuum observation are SOURCES = ' '; BIF = 0; EIF = 0; DOPOL = -1 (or 1 if polarization calibration was attempted); DOBAND = -1 (or 1 if bandpass calibration was done); DOUVCOMP = 1; NCHAV = 0; APARM = 1,0; DOCALIB = 1; GAINUSE = *highest* CL *table*. For a spectral-line observation, set APARM = 0, because you don't want to average over frequency. Use OUTDISK and OUTCLASS as appropriate for your computer and record-keeping purposes.

The single-source data sets are now ready for imaging and possible self-calibration. At this point, it is a good idea to look at the amplitude check source 'CAL-AMP' using tasks such as UVPLT or VPLOT in order to see if there are any antenna gain calibrations that must be adjusted. Doing a UVPLT for each target source is a good idea also, because there may be discrepant amplitude points due to interference or poor fringe fits (among other things). UVFLG and CLIP are useful tasks to deal with these bad points.

## C.8 Incorporating non-VLBA antennas

Beginning in November 2003, calibration data from the VLA and the GBT are incorporated in the tables loaded by FITLD *except for flag tables*. See the next section on dealing with flagging. More recently, calibration data from Arecibo and Effelsberg are also incorporated. We retain the following sections for observations made before these dates and for observations made with other telescopes. Note that for other "foreign" (non-VLBA and non-HSA) antennas, a procedure similar to that in § C.8.2 can be followed.

The observation being calibrated may have incorporated either a single VLA antenna or the phased VLA, but the amplitude calibration parameters for the VLA were not transferred automatically. (See VLBA Operations Memo No. 34 for some details.) You will need to create an input text file for the VLA, then run ANTAB before APCAL. The gains and system temperatures for this file, in an appropriate format, are supplied in a file called *xxxxx*cal.y.gz', where '*xxxxx*' is the observation code (*e.g.*, 'bm120'), located at http://www.vlba.nrao.edu/astro/VOBS/astronomy/mmmyy/xxxxx/. That file contains instructions on editing the file to get correct inputs. For a phased array or a 1.3-cm observation in which 3 antennas are used, follow the instructions in § C.8.3; for a single antenna, use § C.8.2.

### C.8.1 Pointing Flags

The VLA, GBT and AR on-line systems produce only recorder-related flags, not pointing flags. Thus, for example, there are no flags for when the telescope is not on-source. This can lead to a large amount of bad data especially if you are changing source frequently. However, the VLBI scheduling program SCHED creates a *.flag file which contains estimates of how long it takes these antennas to get on source. The *.flag file will also contain flags for all antennas in the experiment, so it is best to remove the flags that pertain to the VLBA antennas. The flag file is in a format that can be read in with UVFLG using the INTEXT adverb.

### C.8.2 Single VLA Antenna

Beginning in June 2003, the INDEX, GAIN, and TSYS information in this table are reformatted to be directly acceptable to *AIPS*. You should check the times in the text file to make sure that your observation has been properly described. Only a few special cases will require editing of the file; in most cases you are able to invoke ANTAB with no editing.

In the input text file, add an INDEX entry within the TSYS card (**Do not separate the INDEX entry from the TSYS entry by a "/" !!!**), uncomment the GAIN line for your particular observing frequency, and uncomment the TSYS line. There are examples of INDEX entries in the comments at the head of the file. Then, place this text file in an appropriate directory to read it in with ANTAB. The most straightforward step is to place it in directory $FITS with filename VLA.ANTAB. At the AOC in Socorro, the $FITS directory for a given computer, *e.g.*, 'laguna', is located at /DATA/LAGUNA_1/FITS.

1. After merging the calibration tables for the VLBA antennas, prevent confusion and any chance of having to re-run FITLD by first copying the VLBA TY and GC tables. If you used VLBAMCAL, the VLBA parameters will be in TY 1 and GC 1, and they should be copied to TY 2 and GC 2. If you used MERGECAL, the VLBA parameters will be in TY 2 and GC 2, which should be copied to TY 3 and GC 3. For the example used here, then run ANTAB with CALIN = 'FITS:VLA.ANTAB', setting TYVER and GCVER to their highest numbered values (either 2 or 3). If ANTAB fails, it is most likely caused by having an incorrect format for the input file. Perhaps you forgot to add the INDEX entry within the TSYS card, or gave it the wrong format, or failed to uncomment the GAIN or TSYS lines.

2. Now, run VLBACALA as described in § C.5 to combine the gain and system temperature information for all antennas into the appropriate SN table. Therefore, the APCAL inputs should include TYVER = 0; GCVER = 0; ANTENNAS = 0. If VLBACALA fails while running APCAL, it is possible that your input file was not properly set up for ANTAB. Perhaps the INDEX line gives polarizations that are inconsistent with those specified in the headers of the VLBI data set, which could mean you forgot to run FXPOL. Then, use SNPLT or VLBASNPL as described in § C.5 to make sure that the resulting SN now contains amplitude calibration for all VLBA antennas and the VLA. At most frequencies, the VLBA antennas should perform slightly better than a VLA antenna, so the amplitude gains plotted for the VLA antenna will be slightly higher. **Make sure that all antennas and IFs are included!**

### C.8.3 Phased VLA

The VLA may be phased on a program source ('STRONG'), or may be phased on a phase-reference source ('CAL-PHASE'), with the resulting solutions applied to the program source ('WEAK'). Rather than recording a system temperature, the VLA system will record a ratio of antenna temperature to system temperature, which will vary as the array phases up. In order to convert the ratio of antenna and system temperatures to a usable gain, the flux density of some source will be needed.

1. Load and calibrate the VLA data by standard means (see Chapter 4). Determine the flux density of a relevant strong source, usually either 'STRONG' or 'CAL-PHASE'. Then, on the VLBI data

set, insert the flux density of this source into the SU table using SETJY. For example, if the source is 'CAL-PHASE' and its flux density is 0.432 Jy, run SETJY with SOURCES = 'CAL-PHASE'; BIF = 0; EIF = 0; ZEROSP = 0.432,0; OPTYPE = ' '.

2. Edit the input file as indicated above for a single VLA antenna. Again, an INDEX line, a GAIN line, and a TSYS line must be checked (after June 2003) or be created or uncommented. The GAIN line is independent of observing band (the source flux is used to determine the gain), and the TSYS line should include the parameter 'SRC/SYS', indicating that the ratio of antenna temperature to system temperature is being supplied.

3. Run ANTAB to read in the input file of amplitude calibration parameters. Then run VLBACALA to put this in an SN table. Both steps are essentially the same as for a single VLA antenna (see § C.8.2). The most likely problem is that APCAL in VLBACALA will fail because you forgot to enter a source flux density using SETJY, although the error message may not always make this obvious.

4. Run VLBASNPL or SNPLT to inspect the resulting SN table, as for the single VLA antenna. In this instance, you should see that the phased VLA is very sensitive. If the phasing worked well at centimeter wavelengths, the amplitude should be near 4 or 5 instead of the value of 17 or 18 seen for a single VLBA antenna. At the start of scans where the VLA is being phased, you may see a rapid change in the amplitude gain (toward smaller numbers) as the antenna phases are brought into alignment. The SN table should be inspected very carefully, because there may be data that should be flagged when the VLA phasing did not work well. Three possible reasons for poor phasing are (1) the source is too weak; (2) the troposphere is misbehaving; or (3) there was radio-frequency interference at the VLA.

### C.8.4 Summary

Following the insertion of the amplitude solutions for the VLA, you can return to follow the standard path for calibration of VLBA data. Although the procedures from here on are identical to the VLBA-only case, the observer may wish to pay attention to several issues.

1. The phased VLA is far more sensitive than a single VLBA antenna, so it is often a good idea to use the phased VLA as the reference antenna for fringe-fitting.

2. The phased VLA has a large delay offset which should have been taken into account by use of a GPS file during correlation. Still, the user should pay close attention to the fringe fits, and be aware of the possibility that the VLA may have larger residual delays and rates than a VLBA antenna.

3. The VLA does not slew as rapidly as the VLBA. The FG table supplied by calibration transfer includes back-end flags only, and does not incorporate information about the pointing of the VLA antennas, and when they arrive on source. Therefore, some judicious flagging by the user may be necessary. It is very likely you will have low amplitudes on VLA baselines for the first 10 or so seconds of each scan; the AIPS task QUACK can be used to flag these low amplitudes. For example, if the VLA is antenna 11, use inputs ANTENNAS=11,0; FLAGVER=1; OPCODE='BEG'; REASON='QUACK:VLA'; APARM=0, 0.2 in QUACK.

4. The VLA elevation limit is 8°, while the VLBA antennas can go much lower. This means that a source may set at the VLA well before it sets at Pie Town or Los Alamos, for example.

5. The VLA observing time is allocated in Local Sidereal Time rather than UTC. Therefore, it may start or finish observing as much as 15 or 20 minutes before/after the VLBA, even if the same amount of time is allocated.

## C.9 Some Useful References

1. Chatterjee, S., "Recipes for Low Frequency VLBI Phase-referencing and GPS Ionospheric Correction," VLBA Scientific Memo No. 22, May 1999.
`http://www.vlba.nrao.edu/memos/sci/`

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3. Ulvestad, Jim, "A Step-By-Step Recipe for VLBA Data Calibration in AIPS, Version 1.3" VLBA Scientific Memo No. 25 (the basis of this appendix), January 2, 2001.
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## C.10 Additional recipes

### C.10.1 Chewy banana split dessert

1. Prepare and bake one package (19.8 0z) chewy fudge (or other favorite) **brownie mix**. Allow to cool thoroughly, four hours or more.
2. Peel 2 large ripe **bananas** and place very thin slices on top of brownie.
3. Cover bananas evenly with one 12-oz. container of **whipped topping** (thawed) and drizzle 1/2 cup **chocolate syrup** over that.
4. Refrigerate to chill completely. Cut into squares to serve.

### C.10.2 Orange baked bananas

1. Mix in a saucepan 1/2 cup firmly packed **brown sugar**, 1 tablespoon **cornstarch**, 1/8 teaspoon **cinnamon**, and a few grains **salt**.
2. Add gradually, blending in 3/4 cup boiling water.
3. Bring rapidly to boiling and cook about 5 minutes or until sauce is thickened, stirring constantly.
4. Remove from heat and blend in $1\frac{1}{2}$ teaspoons grated **orange peel**, 1/4 cup **orange juice**, 1 teaspoon **lemon juice**, and 2 tablespoons **butter**.
5. Peel and cut into halves lengthwise 6 **bananas** with all-yellow or green-tipped peel.
6. Arrange halves cut side down in baking dish and brush with about 2 tablespoons melted **butter**.
7. Sprinkle 1/2 teaspoon **salt** over bananas and then pour the orange sauce over bananas.
8. Bake at 375° F for 10 to 20 minutes.

### C.10.3 Little banana cream tarts

1. Preheat oven to 325° F.
2. Combine 6 tablespoons **margarine** or butter (softened), 1/4 cup packed **brown sugar**, 1/4 cup **powdered sugar**, and 1/2 teaspoon **vanilla extract**.
3. Stir in 2/3 cups crushed **cereal** (2 cups un-crushed Multi-Bran Chex suggested), 1/2 cup all-purpose **flour**, and 1/3 cup finely chopped **nuts** (optional).
4. Divide dough evenly into 12 balls. Place each ball in 2.5-inch muffin cup; press into sides. Bake 8 to 10 minutes.
5. Let stand in pan 15 minutes. Use knife to remove each tart carefully from pan. Tarts will be very soft. Let cool completely.
6. Melt 2 tablespoons **margarine** in skillet over low heat.
7. Stir in 2 tablespoons **heavy cream**, 4 tablespoons packed **brown sugar**, and 1/8 teaspoon **allspice**. Cook until sugar is dissolved, stirring occasionally.
8. Stir in 3 medium **bananas**, sliced. Divide filling evenly among the cooled tarts and garnish with whipped cream.

Thanks to Ralston Purina Company.

### C.10.4 Banana mandarin cheese pie

1. In large mixer bowl, beat 8 ounces softened **cream cheese** until fluffy.
2. Gradually beat in 8 ounces **sweetened condensed milk** until smooth.
3. Stir in 1 teaspoon **lemon juice** and 1 teaspoon **vanilla extract**.
4. Slice 2 medium **bananas**, dip in lemon juice, and drain.
5. Line 8(?)-inch **graham cracker pie crust** with bananas and about 2/3 of an 11-ounce can (drained) **mandarin oranges**.
6. Pour filling over fruit and chill for 3 hours or until set.
7. Garnish top with remaining orange segments and 1 medium **banana** sliced and dipped in lemon juice.

### C.10.5 Banana Dream Pizza

1. Preheat oven to 400° F. In a large bowl, combine 2 1/2 cups **all-purpose flour**, 2 tsp **baking powder**, and a pinch of **salt**. Add 4 Tsp softened **sweet cream butter** and blend. Add 3/4 cup warm **milk** and mix well. If the dough is still sticky, add a small amount of flour.
2. Form the dough into a ball. Knead it on a floured surface until it is smooth. Roll out the dough and place it in an oiled, 16-inch pizza pan. Bake for 15-20 minutes, or until the crust is light brown.
3. In a nonmetallic bowl, mash 4 **bananans**. Add 1 teaspoon **lime or lemon juice** and 6 tablespoons **honey**; mix well.
4. Slice 2 **bananas** horizontally and place the slices in water to cover. Add 1 teaspoon **lime or lemon juice** to prevent discoloration.
5. Spread the banana mixture on the crust.
6. Drain the sliced bananas and blot them with paper towels. Place them in a circular pattern on the banana mixture. Baste the banana slices with 3 tablespoons **melted butter**.
7. Bake for 20–30 minutes at 400° F until the crust is golden brown.
8. Remove from the oven and top with 1 quart **vanilla ice cream** and 1/2 cup chopped **macadamia nuts** while still hot. Serve immediately.

# D HINTS FOR REDUCING HIGH-FREQUENCY VLA DATA IN *AIPS*

High-frequency data (22 or 43 GHz) from the VLA may be reduced occasionally with the standard centimeter-wavelength recipe given in this *CookBook*, particularly in the smaller arrays. However, quire frequently,, the standard recipe will be inadequate for such data, particularly in the larger (A and B) array configurations. Nevertheless, VLA data taken at these high-frequencies in the largest array configurations can be calibrated in almost all cases with only a few minor adjustments to the centimeter wavelength recipe.

One reason for more complicated calibration is the high resolution, which resolves the standard flux density calibrators, particularly 3C48. However, most of the problems are caused by the atmosphere, where the troposphere introduces rapid phase fluctuations between the antenna elements of the interferometer. Both effects scale with baseline length expressed in units of wavelength, but the latter also heavily depends on the current weather; phases are sometimes observed to wind on time scales of less than a minute. This causes decorrelation during your calibrator and target source scans, and requires you to determine phase-only calibration, before the flux density (*i.e.*, gain) calibration should be attempted.

In this appendix, an approach to reducing high-frequency VLA data in *AIPS* is described which should help to overcome the most common problems. It is assumed that the reader has some experience with reducing data in *AIPS*, and is familiar with the "standard recipe" (*e.g.*, Appendix A), tools to examine the data, to apply self-cal, and if appropriate, to deal with spectral-line and polarization calibration issues. If not, you should read the *AIPS CookBook* first (in particular Chapter 4).

High-frequency calibration begins when loading the data, requiring specific parameters in `FILLM` to be set (ideally one should use these `FILLM` inputs for all frequencies).

Run `FILLM` with:

| | |
|---|---|
| > DOWEIGHT 1 C_R | to apply $T_{sys}$ weights for each individual `IF` and polarization. |
| > DOUVCOMP −1 C_R | to store the data without compression, which discards individual IF weights. |
| > CPARM 0 ; CPARM(8) 0.05 C_R | to use a short time interval in the `CL` table entries (in min); 0.05min = 3s. |
| > BPARM 0 ; BPARM(10) 0.75 C_R | to apply opacity and gain curve corrections with zenith opacited weighted 75% by the measured weather and 25% by seasonal averages. |

This creates a `CL` table that can be interpolated over very short intervals, hopefully short enough to cover the atmospheric phase fluctuations accurately. The default `CL` table interval is 5 minutes, which may be fine for centimeter wavelengths, but is much too long for proper interpolation of high-frequency phases. Also, you have "nominal sensitivity" weights for individual `IF`/Pol entries, which reflect sensitivity differences between the receivers, IFs, etc. To retain this "nominal sensitivity" weighting you are required to set `DOCALIB=1` (actually $0 <$ `DOCALIB` $\leq 99$ and a non-negative value for `GAINUSE`) in all the calibration tasks during the remainder of the data calibration.

The importance of the `CL` table interval is illustrated in Figure D.1 and Figure D.2. On the large scale, the phases look beyond redemption. But, on a relatively short time scale, the phases are relatively well behaved and may be calibrated easily.

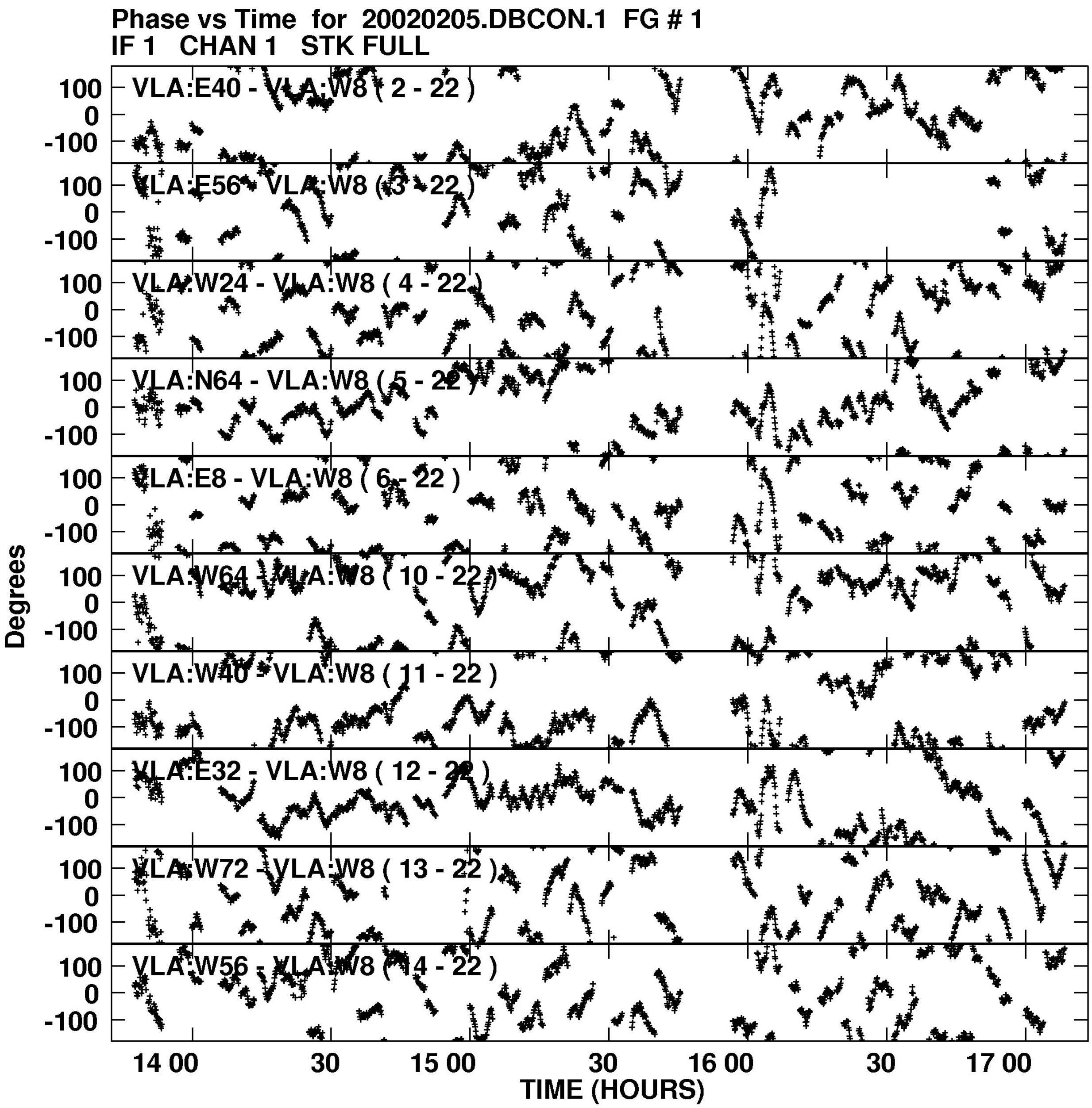


Figure D.1: Uncalibrated VLA A-array 43 GHz phases to the reference antenna in the center of the array (22) over 3 hours on a strong source (frequency switched every 6 minutes) as a function of time plotted by VPLOT look very volatile. Around 16:00 hours they even wrap 360 degrees within one minute. They cannot be calibrated using the default CL table interval of 5 minutes.

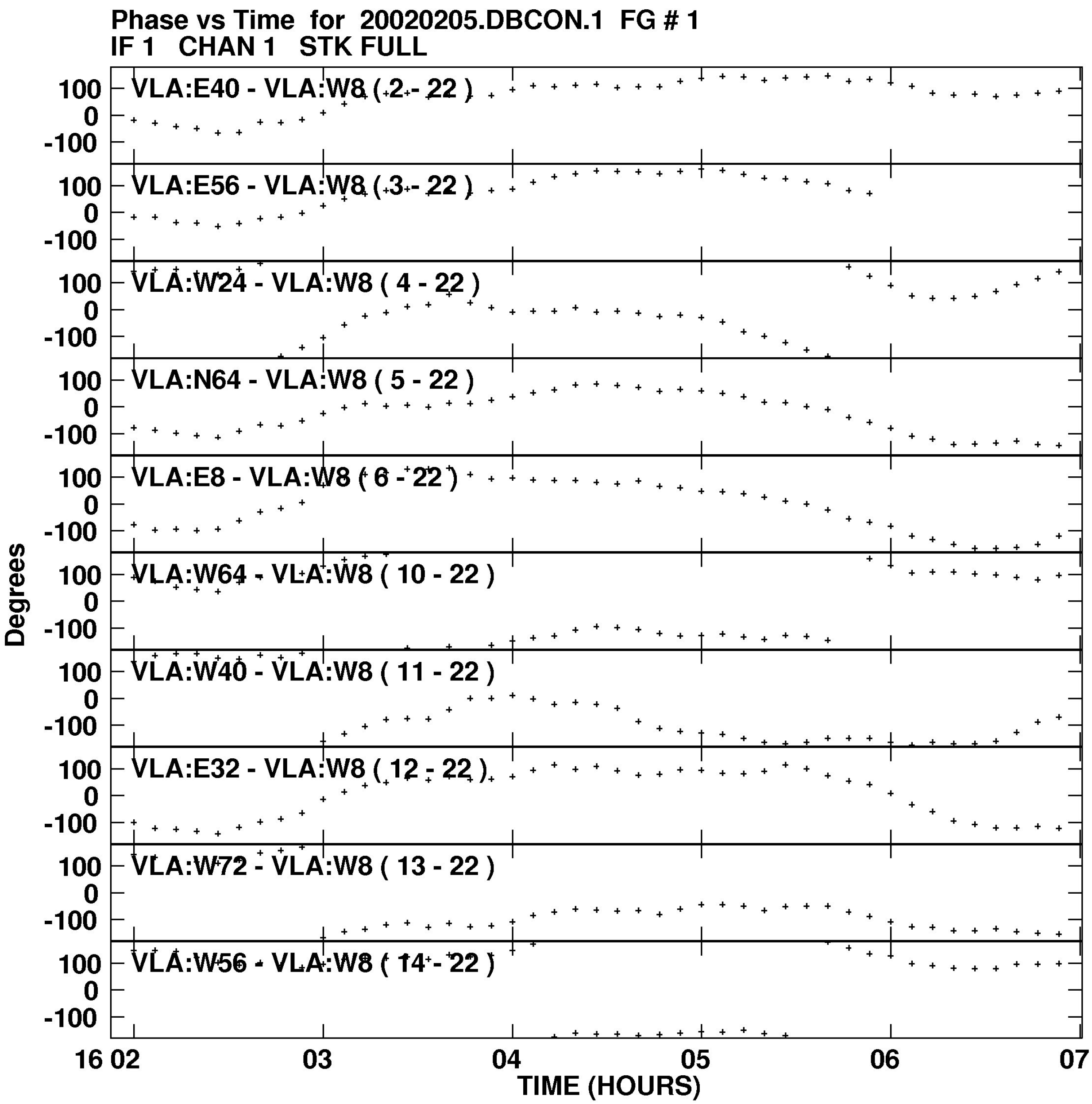


Figure D.2: A blow up from VPLOT of the time range 16:02 to 16:07 from Figure D.1. The uncalibrated visibility phases are seen to be well behaved, albeit on a short time scale. They can be calibrated if the SN table solutions are found on these typical short time scales and are interpolated with a CL table that has sufficiently short spacing between entries to allow for interpolation of the rapid phase fluctuations. An interval of 20 seconds would be okay here.

After loading your data, check your CL table entries, *e.g.*, LISTR with OPTYPE 'GAIN', PRTAB with DOHMS 1, or SNPLT on a short (few minutes) time range with OPTYPE 'AMP'. Make sure the entries are at the interval you expect (much less than a minute) and that the opacity and gain curve corrections have been applied (gains deviating from one by a few percent). Inspect your continuum or "channel 0" data (gains, system temperatures), and flag bad data. For example, you also may wish to flag antenna 1, which is known to have bad optics at 43 GHz, and the antennas without a 43 GHz receiver (currently in December 2002, antennas 9 and 15, but for earlier observations you may want to check the receiver status page (http://www.vla.nrao.edu/astro/guides/highfreq/), or your observation log — these antennas may have been left present in your data when you first do a pointing scan in X-band). Standard tools for data inspection and flagging are described in Chapter 4 of the *AIPS CookBook* (LISTR, UVPRT, VPLOT, SNPLT, UVFLG, TVFLG, EDITR, EDITA, and many more). Make sure that at least your calibrators are "clean." Run VPLOT on your calibrators with a reference antenna close to the center of the array (determined by using PRTAN) to get an indication how rapidly your phases fluctuate; use ANTENNA *reference_antenna* 0; SOLINT 0; BPARM 0 2 0 (for phase only). If your program source is too weak to allow self-calibration and the phase change from one scan on your calibrator to the next is of the order of 180°, you probably want to flag the source data in between the calibrator scans. Task SNFLG may be useful for doing this flagging.

Note that fast-switching, when used, will have changed the source names you used in making the observe schedule file. Your sources will have been renamed to their J2000 positions, making it difficult to recognize the calibrator and target scans when you run LISTR (OPTYPE 'SCAN').

Run SETJY on your absolute flux density calibrator: 3C286 = J1331+305 = B1328+307, or 3C48 = J0137+331 = B0134+329. And maybe it is a good idea to make a copy of your correct CL table number one (actually all tables) with TASAV before continuing, so in case of accidents, you have CL table one with the opacity/gain corrections applied. (INDXR may be used to re-create a CL table, including the opacity and gain corrections made by FILLM.

If you have 31DEC07 or later, run VLANT to correct phases for improved estimates of the antenna positions. Note that this task requires your computer to be connected to the Internet if your data are recent (within past 18 months or so). Otherwise, apply baseline corrections following advice at www.vla.nrao.edu/astro/archive/baselines/.

Run CALIB, at this stage to correct for phase only, with a small solution interval (depending on your signal to noise, *e.g.*, 20 seconds) on all your calibrator sources. You should use the Clean-components models for 3C286 or 3C48 provided with *AIPS*. See § 4.3.3.1 for information on CALDIR and CALRD. Then run CALIB on these sources separately using the appropriate model. There are also models for 3C147 and 3C138.

Inputs to the first pass of CALIB:

| | |
|---|---|
| > CALSOUR '*cal1*', '*cal2*', . . . C<sub>R</sub> | to define your calibrators; **all but those for which you plan to use a model, *e.g.*, 3C48**. |
| > DOCALIB 1 CR | to apply nominal sensitivities, essential that $0 <$ DOCALIB $\leq 99$. |
| > GAINUSE 0 CR | apply latest CL table (is version 2 after VLANT. |
| > REFANT *reference_antenna* CR | to pick a well behaved antenna in the array center. |
| > SOLINT 20/60 CR | to solve every 20 seconds; may have to try some values. |
| > SOLMODE 'P' CR | to do phase calibration only at this stage. |
| > SNVER 1 CR | to collect all solutions in SN table one. |

And, if you have 3C48, 3C138, 3C147, and/or 3C286 as absolute flux density calibrator(s), you should re-run CALIB, one calibrator source at a time, with the previous/above values plus:

| | |
|---|---|
| > CALSOUR '*ssss*', ' ' CR | to specify the name you have used for the calibrator source. |
| > IN2DISK *d2* CR | to specify the disk with the source model. |
| > GET2NAME *ctn2* CR | to specify the CC model to be used by its catalog number. |

| | |
|---|---|
| > INVERS 0 C_R | to use the model's latest CC-version (*i.e.*, one). |
| > NCOMP 0 C_R | to use all the CC-components of the model. |

This may work, but there is no guarantee. Some tricks to apply, in no particular order, in your data set or CALIB to obtain a larger relative portion of good versus bad solutions would be:

- Flag some more bad data points on your calibrator sources.
- Discard antennas with uncertain baseline positions (see observing log file).
- Choose a different reference antenna (the one you have might be misbehaving).
- Decrease the UVRANGE to weight short baselines (centrally located antennas) more in the solution.
- Use SOLTYPE 'L1' to be less sensitive to outlying points.
- Use FRING instead of CALIB with a larger SOLINT to solve for the phase rates, switching off the delay search with DPARM(2) = -1.
- Increase or decrease SOLINT; increase for weak, decrease for strong sources.
- Decrease the SNR cutoff APARM(7) (default 5) to include more noisy but possibly valid solutions.
- Decrease the number of antennas required for a solution (APARM(1), default 6) to require fewer antennas
- Recreate 'CH 0' from 'LINE' to get up to 25% more bandwidth on calibrators.

Note that at 43 GHz in A-array the unprojected *uv*-distance between the outer two antennas on one arm is 0.5 Mega-wavelengths, and the outer 6 antennas — the default for APARM(1) — require good solutions out to 2 Mega-wavelengths for CALIB to accept the solution for your outermost antenna. Hence, it is a good idea to set APARM(1) to *e.g.*, four (or three, if you're willing to check the output SN table carefully).

Check the resulting SN table number one with LISTR (OPTYPE 'GAIN', DPARM 1 0) or SNPLT (INEXT 'SN', OPTYPE 'PHAS'), and judge whether you have enough solutions and whether you believe the phases shown are likely to reflect the variation caused by the troposphere. If not, fiddle around with your data and/or parameters in CALIB as suggested above and try again. In case the majority of solutions are fine, you may want to edit spurious points in your SN table with *e.g.*, SNEDT, SNCOR, or SNSMO.

Once you are satisfied with the phases in your SN table, you want to apply phase corrections to minimize decorrelation in your calibrator scans before you determine the absolute flux density scale. To insert the corrections, run CLCAL with:

| | |
|---|---|
| > SOURCES ' ' C_R | to correct phases for all sources. |
| > CALSOUR '*cal1*', '*cal2*', ... C_R | to include **all** your calibrators. |
| > INTERPOL '2PT' C_R | to interpolate between solutions ('SIMP' will average phases over a scan). |
| > SNVER 1; GAINVER 1;GAINUSE 2 C_R | to apply SN#1 to CL#1, creating CL#2. |
| > REFANT *reference_antenna* C_R | to select the same antenna as used in CALIB. |

In less straightforward observations you may not be able to run CLCAL only once, *e.g.*, when you are switching frequencies. If in doubt, consult Chapter 4 of the *AIPS CookBook*. It is however very simple to run CLCAL multiple times. Inspect your new CL table two (three after VLANT) for unexpected dubious interpolations and extrapolations (LISTR with OPTYPE 'GAIN', DPARM 1 0, or SNPLT with INEXT 'CL', OPTYPE 'PHAS') and backtrack possible problems.

Now re-run CALIB with the corrected phases to obtain the flux density scale. Begin with those sources not requiring models:

| | |
|---|---|
| > CALSOUR '*cal1*', '*cal2*', . . . CR | to identify your calibrators; all, except 3C48 and 3C286. |
| > DOCALIB 1 CR | to apply antenna gain/opacity and antenna location corrections to the data and theirweights. |
| > GAINUSE 0 CR | to apply latest CL table (is 3 here). |
| > REFANT *reference_antenna* CR | to pick the same antenna as used before. |
| > SOLINT 0 CR | to average over the full scan; remember that phase variations are corrected by DOCALIB. |
| > SOLMODE 'A&P' CR | to do full calibration to get flux densities and residual phases. |
| > SNVER 2 CR | to collect solutions in a new SN table (two). |

Then run CALIB again for the absolute flux density calibrator 3C286, or 3C48, using a model and the previous/above values plus:

| | |
|---|---|
| > CALSOUR '*sssss*', ' ' CR | to specify the name you have for the source. |
| > UVRANGE 0 CR | to use the full uv range without restrictions. |
| > IN2DISK *d2* CR | to specify the disk with the source model. |
| > GET2NAME *ctn2* CR | to specify the model to be used by its catalog number. |
| > INVERS 0 CR | to use the model's latest CC-version (*i.e.*, one). |
| > NCOMP 0 CR | to use all the CC-components of the model. |

The same tricks may be used as for phase-only to improve the ratio of good to bad solutions. Check your SN table 2 thoroughly; the phases **must** be zero or very close to zero (therefore INTERPOL '2PT' is preferred over INTERPOL 'SIMP' in CLCAL), and you want to make sure the gains of your reference antenna do not scatter too much for individual sources. Before GETJY the flux density scale is not fixed so the average gain will depend on source. GETJY corrects this so that the gains for each antenna should be similar for all sources. If you can identify misbehaving antennas, flag them, delete SN table 2 (as it does not overwrite values for which data have been deleted), and re-run CALIB as many times as needed to re-create SN table two. Cautious users will start from the beginning.

Run GETJY to obtain the secondary calibrator flux densities:

| | |
|---|---|
| > SOURCES '*cal1*', '*cal2*', . . . CR | to specify the unknown sources; *not* the primary calibrator(s). |
| > CALSOUR '3C48', ' ' CR | to specify the source name(s) you have used in SETJY. |
| > SNVER 2 CR | to point to the flux density/gain solution table. |

If you used a model for the flux density calibrator, your flux scale is tied to the flux density of that calibrator in the SU table. The model Clean components are scaled to match that flux.

Carefully note the flux densities reported by GETJY and do not trust these values blindly. LISTR or SNPLT may point out problematic antenna solutions, requiring you to flag some more data and start over. If you flag data, it is best to delete SN table #2. Solutions at the times of deleted data will not be overwritten. It is helpful to know what flux you expect for your secondary calibrators. See the full source list at `aips2.nrao.edu/vla/calflux.html`. It is particularly helpful to use one or more of the sources regularly monitored by NRAO staff; see `html://www.aoc.nrao.edu/∼smyers/calibration/` for total flux as well as polarization information. You want to check the values, because sometimes the flux densities deviate considerably from the expected values and make no sense. This could be the case if the pointing solutions that were determined prior to your primary calibrator scan are inappropriate for this particular primary calibrator scan *e.g.*, when it is windy or when the cloud cover on your single primary calibrator scan differs from the cloud cover on the secondary calibrators, or, even worse, when these combine. In some cases you may be forced to approximate the flux density scale by entering a (recent) flux density for one of your secondary calibrators, ignoring the primary calibrator scan and accepting an introduced flux density uncertainty. If you decide you have to restart, do not forget to delete your SN and CL tables (except for CL table 1 and 2 if you used VLANT) and to reset the flux densities of all your calibrators with SETJY (OPTYPE 'REJY'), before entering a ZEROSP for a new flux density calibrator source (also with SETJY). Re-iterate until you are happy with the flux-density scale.

The final flux density calibration table is obtained by running CLCAL again:

| | |
|---|---|
| > SOURCES ' ' C_R | to calibrate flux densities for all sources. |
| > CALSOUR '*cal1*', '*cal2*', . . . C_R | to include calibrators to use for your targets. |
| > INTERPOL '2PT', or 'SIMP' C_R | (to specify the interpolation method: no real difference for per-scan solutions). |
| > SNVER 2; GAINVER 2; GAINUSE 3 C_R | to apply SN#2 to CL#2, creating CL#3. |
| > REFANT *reference_antenna* C_R | to select the same antenna as used in CALIB. |

From here you are almost ready to follow the usual "standard recipe," *i.e.*, polarization and bandpass calibration if appropriate, and splitting into single-source data sets. However, remember to set DOCALIB = 1 in all these tasks as long as you are working on the multi-source data set and haven't applied initial phase, flux density (including polarization, bandpass) and "nominal sensitivity" calibration with SPLIT. After SPLIT, the individual weights will have been entered in the data, properly scaled by the latest CL table you've made. Using your single source calibrated data, set DOCALIB = -1 in your subsequent imaging and analysis tasks, unless you do self-calibration.

If you anticipated checking your fast-switching calibration by including a "check source" (a moderately strong source observed a few times with the same fast-switching parameters at about the same distance from your fast-switching source as your target source, but not necessarily in the same direction), you can now assess a snapshot of your calibration by imaging this source. If the fast-switching has worked perfectly, your check source has the expected morphology, flux density, and position. Any position error on the check source should indicate the accuracy of the astrometry on your target source. If you did not include a check source, all but the astrometry and spatial dependence of the calibration can be inferred from your fast-switching source by imaging a scan (use a modified SN/CL table by skipping the calibration on this scan) with the calibration derived from the two neighboring scans.

## D.1 Additional recipes

### D.1.1 Banana-pineapple rum bread

1. Place 1/2 cup **white rum** and 1/2 cup diced **dried pineapple** in a bowl, cover, and let sit for at least one hour.
2. In a mixing bowl, beat together 4 tablespoon **butter** or margarine and 3/4 cup **sugar**. Add 1 extra large **egg** and continue beating until light and fluffy.
3. Add 2 large mashed ripe **bananas** and mix well. Beat in 1/3 cup plain **yogurt** — curdling of the mixture is normal.
4. In another mixing bowl, combine 2 cups **all-purpose flour**, 1/2 tablespoon **baking soda**, 1 teaspoon ground **cinnamon**, 1 teaspoon ground **nutmeg**, 1 teaspoon ground **allspice**, and 1/2 teaspoon **salt**.
5. Add the wet ingredients and mix until well blended. Drain the pineapple and add. Fold in 1/2 cup coarsely chopped **pecans**.
6. Pour into liberally greased 9-inch loaf pan. Bake at 350° F for 45 to 55 minutes or until the bread passes the toothpick test. Remove the pan from the oven and let it sit for 10 minutes, before turning out on a rack to cool.

Thanks to Tim D. Culey, Baton Rouge, La. (tsculey@bigfoot.com).

### D.1.2 Dulce Zacatecaño

1. Peel 3 large not-too-ripe **bananas** and slice lengthwise. Saute in 5 tablespoons **butter** until golden brown. Drain on paper, place in a shallow baking dish, and sprinkle with a little **sugar**.
2. Whip 1/2 cup **heavy sweet cream**. Add 1/4 cup **sugar**, 1/4 cup **dry sherry wine**, and 1 teaspoon **vanilla**. Pour over bananas covering them completely. Chill and serve very cold.

Thanks to Ruth Mulvey and Luisa Alvarez *Good Food from Mexico*.

### D.1.3 Virginia's instant banana pie

1. Mix 1 cup **sour cream**, 1 cup **milk**, and 1 small package **instant vanilla pudding** until mixture thickens.
2. Slice 3 medium **bananas** into the bottom of a 9-inch **graham cracker pie crust**.
3. Pour the pudding over the bananas and refrigerate at least 2 hours.

### D.1.4 Chocolate chip banana bread

1. Blend 2 cups mashed **bananas**, 1 tablespoon grated **orange peel**, and 1/3 cup **orange juice** in a bowl. Beat in 3 **eggs**. Stir in 1 cup packed **brown sugar** and 1/3 cup **vegetable oil**.
2. Combine 2-1/2 cups **all-purpose flour**, 1 cup **chocolate chips** 2 teaspoons **baking powder**, 1/2 teaspoon **baking soda**, 1/2 teaspoon **salt**, and 1/2 teaspoon **nutmeg**.
3. Stir dry ingredients into banana mixture just until blended. Pour into 4 greased 5-3/4 x 3-1/4-inch loaf pans.
4. Bake in 350° F oven for 45 to 55 minutes or until tester inserted comes out clean. Let cool in pans on rack for 10 minutes. Remove from pan and let cool completely on rack.

Thanks to Tim D. Culey, Baton Rouge, La. (`tsculey@bigfoot.com`).

### D.1.5 Banana bran muffins

1. Preheat oven to 400° F.
2. Grease 12 2.75-inch muffin cups.
3. In bowl, combine 1/2 cup crushed **cereal** (1.5 cups un-crushed Multi-Bran Chex recommended), 1.5 cups all-purpose **flour**, 1/2 cup **sugar**, 1/3 cup chopped **nuts** (optional), 2.5 teaspoons **baking powder**, and 1/2 teaspoon **baking soda**.
4. In a separate bowl, combine 3 large mashed **bananas** (1.5 cups), 1 **egg** slightly beaten, 1/4 cup vegetable **oil**, 2 tablespoons **water**, and 1 teaspoon **vanilla extract**.
5. Add to cereal mixture and stir just until moistened. Do not over-mix.
6. Divide evenly among muffin cups.
7. Bake 18–20 minutes, or until tester inserted in center comes out clean.

Thanks to Ralston Purina Company.

# E Special Considerations for EVLA data calibration and imaging in $\mathcal{AIPS}$

The old VLA with its once state of the art, but now dated, correlator and electronics has been turned off. The new electronics and correlator of the EVLA have been turned on and made available to users. For the time being, this availability will be "Shared Risk Observing" of two basic forms: "Open" (OSRO) with limited capabilities and "Resident" (RSRO) with potentially unlimited capabilities. OSRO data was initially limited to two spectral windows, but may now be up to 2 GHz in total bandwidth with 64 2-MHz channels in each of 16 spectral windows in each of 4 polarization products. Other arrangements are also available for spectral-line and continuum observing. RSRO data may have many thousands of spectral channels and, in time, up to 8 GHz of bandwidth per polarization. $\mathcal{AIPS}$ software will be important to both programs, although RSRO data are expected, by management, to be processed primarily in CASA.

At this writing, the EVLA has already produced amazing scientific results, but with considerable difficulties which are expected to be corrected over time. Delays are sometimes not set accurately, causing the data analysis to begin with the "VLBI" task `FRING` needed to correct large slopes in phase across the bandpass. The flagging information known to the on-line system (telescope off source and the like) is now available in the data format and so can reach $\mathcal{AIPS}$ either as an initial flag table or as already flagged data. Other useful flagging data, such as the antenna has no receiver, is not yet present in the data. Substantial flagging effort may therefore still be required. System temperatures and gains are now transferred, but should be applied with caution to scale the visibilities and to compute data weights. The data weights without this adjustment reflect only integration time. The weather table is available with the data so that reasonable opacities may be determined. However, the "over-the-top", table which is used in determining antenna positions, the frequency offset table, used in managing Doppler tracking, and the `CQ` table, used to correct amplitudes for spectral averaging in the presence of non-zero delays, are not available if the data come to $\mathcal{AIPS}$ via CASA. The `OT` table is now provides when the data are read using the `OBIT` package, but astrometric data used to compute accurate projected spacings are not yet available.

Although these issues should be corrected, quite possibly during 2011, the following guide will not assume that they have been completed. Steps that can be omitted or simplified when they are will be described. This appendix is written with the assumption that the reader is moderately familiar with $\mathcal{AIPS}$ as described in the preceding chapters. It is also written with the assumption that you are using current versions of the `31DEC11` or later releases of the software.

## E.1 Getting your data into $\mathcal{AIPS}$

Your EVLA data are stored as an "ALMA Science Data Model" (ASDM) format file in "SDMBDF" (Science Data Model Binary Data Format) in the NRAO archive. They may be read out of the archive in that format, a CASA measurement set format, or in an $\mathcal{AIPS}$-friendly uvfits format. This last is produced by the CASA uvfits writing software. Go the the web page

`http://archive.cv.nrao.edu/`

and select the Advanced Query Tool. Fill out enough of the form to describe your data and submit the query. If the data are not yet public, you will need the Locked Project Access Key which may be obtained from the NRAO data analysts. To avoid the need for this key, you may log in to `my.nrao.edu` after which it will know if you are entitled to access particular locked projects. The query will return a list of the data sets which meet your specifications. *(Users logged in to an NRAO Socorro computer should use a variant of these instructions; see below.)* On this form, enter your e-mail address, choose AIPS Friendly names (almost certainly does not work), AIPS FITS under the EVLA-WIDAR section and choose the desired time averaging. If the delays are not accurately known, spectral averaging can be damaging to the data amplitudes. However, the data are often recorded at one-second intervals which is rather short, making the data voluminous. Judicious averaging can help with data set size and processing times without compromising the science. Choose the data set(s) you wish to receive and submit the request. You will be told an estimate of the output data set sizes and the amount of time you will need to wait for the format translation to occur. A 19 Gbyte SDMBDF file run as a test with no averaging was estimated to produce a UVFITS file of 30.26 Gbytes and to take 103 minutes to prepare for download. That time assumes that your download job is the only one being performed. If your download fails, you will probably be told erroneously by e-mail that it worked. The output file will however be missing or incomplete. Try again before contacting NRAO for help.

If you are logged into an NRAO Socorro computer — and perhaps if you are not, — you may find a better route to acquire your data with useful additional information not available via CASA. Try requesting your data in SDMBDF format instead of uvfits and also uncheck the "Create tar file" box *only if you are on a Socorro computer*. (Remote users will need to have the archive load the SDMBDF file into "tar" form in the public ftp area for copying to their home machine.) If you have enough disk space, direct the data to a directory on your machine, *after you have made that directory world writable* (`chmod 777`*directory-name*). The downloading of the SDMBDF file is quite efficient compared to having the archive computer do all the file translation. When you are told that the SDMBDF file is ready, you may run `AIPS` and load the data via the verbs `BDFLIST` and `BDF2AIPS`. These verbs run programs in the `OBIT` software package to load your data directly into *AIPS* including flag (`FG`), index (`NX`), calibration (`CL`), over-the-top (`OT`), SysPower (`SY`), and CalDevice (`CD`) tables which you will not get from CASA. If you use this approach, you may skip the `UVLOD` and `INDXR` steps described below. Note that these verbs require that `OBIT` be installed on your computer — as it is in Socorro — and that `ObitTalk` be in your `$PATH`. `OBIT` is relatively easy to install and may be obtained from `bcotton@nrao.edu`.

Unlocked files will be downloaded to the NRAO public ftp site

`ftp://ftp.aoc.nrao.edu/e2earchive/`

by default and you may then use ftp to copy the file to your computer. Locked files will go to a protected ftp site and you must use ftp to download those, even within NRAO. The instructions for downloading will be e-mailed to you. Be sure to specify *binary* for the copy. If you are located in the AOC in Socorro, you may set an environment variable to the archive location, *e.g.*,

| | |
|---|---|
| export E2E=/home/ftp/pub/e2earchive C_R | for bash shells |
| setenv E2E /home/ftp/pub/e2earchive C_R | for C shells such as tcsh |

and simply read unlocked data files directly from the public download area. Note that the file will be deleted automatically after 48 hours in both public and protected data areas.

SDMBDF files may be read into *AIPS* using `BDFLIST` to learn what is in your data set and then `BDF2AIPS` to translate the data. Thus

| | |
|---|---|
| > DEFAULT 'BDF2AIPS'; INP C_R | to initialize all relevant adverbs. |
| > DOWAIT 1 ; DOCRT 1 C_R | to wait for the verbs to finish and to display the log file on the terminal as it is generated. Be sure to set `DOWAIT -1` after using `BDF2AIPS`. |
| > ASDMF(1) = '*path_to_asdm_dir* C_R | to set the full path name into the adverb. Note the lack of close quote so that case is preserved. If the name is too long (> 64 characters), put part of the name in `ASDMF(1)` and the rest in `ASDMF(2)`. Trailing blanks in `ASDMF(1)` will be ignored. |
| > BDFLIST C_R | to list the contents of the SDMBDF. Note particularly the "configuration" numbers. |
| > DOUVCOMP FALSE C_R | to write visibilities in uncompressed format. There are no weights at present, so there is no loss of information in compressed format, but the conversion from compressed format costs more than reading the larger data files. |
| > OUTNA '*myname*' C_R | to set the *AIPS* name. |

| | |
|---|---|
| > OUTCL ' ' C_R | to take default (UVEVLA) class. |
| > OUTDI 3 C_R | to write the data to disk 3 (one with enough space). |
| > FOR CONFIG = 0:100 ; BDF2AIPS; END C_R | to load all of the configurations in your data, terminating with error messages on the first configuration number not present in your data. |

There are other adverbs — NCHAN, NIF, BAND, and CALCODE — available if needed to limit which data are read. At present, CONFIG is all that is needed to select data, but these others may be needed when more complicated modes become available.

The uvfits data file may be read from disk into *AIPS* using UVLOD or FITLD, using:

| | |
|---|---|
| > DEFAULT 'UVLOD' ; INP C_R | to initialize and review the inputs needed. |
| > DATAIN 'E2E:*filename*' C_R | where *filename* is the disk file name in logical area E2E; (see § 3.10.3). |
| > OUTNA '*myname*' C_R | to set the *AIPS* name. |
| > OUTCL ' ' C_R | to take default (UVDATA) class. |
| > OUTSEQ 0 C_R | to take next higher sequence #. |
| > OUTDI 3 C_R | to write the data to disk 3 (one with enough space). |
| > DOUVCOMP FALSE C_R | to write visibilities in uncompressed format. There are no weights at present, so there is no loss of information in compressed format, but the conversion from compressed format costs more than reading the larger data files. |
| > INP C_R | to review the inputs. |
| > GO C_R | to run the program when you're satisfied with inputs. |

Watch the messages from UVLOD to see where your data set goes and whether the task ran properly. When it is finished, check the output header:

| | |
|---|---|
| > INDI $n$; GETN $m$ C_R | to select the data set on disk $n$ and catalog number $m$. |
| > IMHEAD C_R | to examine the header. |

Note that the header does not show the usual complement of *AIPS* extension files. CASA translates the on-line data into its internal format and then writes the uvfits file read by *AIPS*. Since CASA does not have files comparable to *AIPS* index and CL tables, it does not provide them. To build index and calibration tables, use;

| | |
|---|---|
| > TASK 'INDXR' ; INP C_R | to select the task and review its inputs. |
| > INFILE ' ' ; PRTLEV = 0 C_R | to be sure not to use an input text file and to avoid excess messages. |
| > CPARM = 0 , 0 , 1/2 C_R | to make a CL table 1 with a 30-second interval. |
| > BPARM $\tau$ , 0 C_R | to take default VLA gains and a zenith opacity of $\tau$. Set $\tau = -1$ for no opacity correction. You may set $\tau = 0$, which is now recommended, to get *new* default opacities. These are based on a detailed model predicting the opacity at any frequency from that at 22 GHz. The combination of weather and seasonal model long used by FILLM and INDXR is now used solely to estimate the 22 GHz opacity. |
| > GO C_R | to run the task after checking the inputs. |

It is a good idea to list the structure of your data set and your antenna locations on the printer and to keep those listings next to your work station for reference:

| | |
|---|---|
| > DEFAULT LISTR ; INP C_R | to initialize the LISTR inputs and review them. |
| > INDI $n$; GETN $m$ C_R | to select the data set on disk $n$ and catalog number $m$. |
| > OPTYPE 'SCAN' ; DOCRT -1 C_R | to choose a scan listing on the printer. |

> GO ; GO PRTAN C_R — to print the scan listing and the antenna file contents.

Read these with care. There have sometimes been problems with antenna identifications, with the order of the IF frequencies, and even with identification of sources by scan. Task SUFIX may be used to correct the last problem and, if desired, FLOPM may be used to reverse the frequency order. Oddly ordered IFs may require UVCOP to split them apart followed by VBGLU to paste them back together. You may have to use SETJY or TABPUT to change the CALCODE of some sources if your calibration sources have a blank calibrator code or your target sources have a non-blank calibrator code.

## E.2 Initial calibration — VLANT, FRING

As with the VLA, NRAO maintains text files describing any changes which are made to our estimate of the antenna locations. Users may wish to apply these changes if their data were taken between the time when antennas were moved to their current stations and the time that the corrections were entered into the on-line control data base. Task VLANT works for both VLA and EVLA data, reading these text files and performing the needed changes to the CL table, writing a new one. Thus

> DEFAULT VLANT ; INP C_R — to initialize the VLANT inputs and review them.

> INDI *n*; GETN *m* C_R — to select the data set on disk *n* and catalog number *m*.

> GO C_R — to run the task, writing CL table 2.

We have had difficulty setting all of the delays in the EVLA to values which are sufficiently accurate. If the delay is not set correctly, the interferometer phase will vary linearly with frequency, potentially wrapping through several turns of phase within a single spectral window ("IF band"). We hope that bad delays will not arise in future, allowing you to skip this section, but use POSSM to check for phase slopes. This is a problem familiar to VLBI users and AIPS has a well-tested method to correct the problem. Using your LISTR output, select a time range of about one minute *toward the end of a scan* on a strong point-source calibrator, usually your bandpass calibrator. Then

> DEFAULT FRING ; INP C_R — to initialize the FRING inputs and review them.

> INDI *n*; GETN *m* C_R — to select the data set on disk *n* and catalog number *m*.

> SOLINT 1.05 * *x* C_R — to set the averaging interval in minutes slightly longer than the data interval (*x*) selected.

> TIMERANG *db* , *hb* , *mb* , *sb* , *de*, *he* , *me* , *se* C_R — to specify the beginning day, hour, minute, and second and ending day, hour, minute, and second (wrt REFDATE) of the data to be included. Too much data will cause trouble.

> DPARM(9) = 1 C_R — to fit only delay, not rate. *This is very important.*

> DPARM(4) = *t* C_R — to help the task out by telling it the integration time *t* in seconds. Oddities in data sample times may cause FRING to get a very wrong integration time otherwise.

> INP C_R — to check the voluminous inputs.

> GO — to run the task, writing SN table 1 with delays for each antenna, IF, and polarization.

The different IFs in current EVLA data sets may come from different basebands and therefore have different residual delays. The option APARM(5) = 3 to force the first $N_{if}/2$ IFs to have one delay solution while the second half of the IFs has another is strongly recommended, but only when the first half all come from one of the "AC" or "BD" basebands (hardware IFs) and the second half come from the other. This SN table will need to be applied to the main CL table created by INDXR or OBIT.

> TASK 'CLCAL' ; INP C_R — to look at the necessary inputs.

> TIMERANG 0 C_R — to reset the time range.

| | |
|---|---|
| > GAINUSE 0 ; GAINVER 0 C_R | to select the highest CL table as input and write one higher as output (version 2 and 3, resp. in this case). |
| > SNVER 1 ; INVER 1 C_R | to use only the SN table just created. |
| > INP C_R | to review the inputs. |
| > GO C_R | to make an updated calibration table. |

Be sure to apply this (or higher) CL table with DOCALIB 1 in all later steps.

## E.3 Initial editing

You should use the tools below to flag out obviously bad data. The tasks which automatically flag data for you, however, depend on meaningful amplitudes and flat spectral shapes. Therefore, flagging and calibration are an iterative process. Do the obvious flagging without spending a lot of time on it. Then do an initial calibration of bandpass, amplitude, and phase. Use that calibration to run RFLAG and/or other auto-flagging tasks. Then throw away all CL tables following VLANT and begin again with FRING, BPASS, CALIB, etc.

There will be data validity information prepared both by the on-line control software and by the WIDAR correlator and some of this information is already available as an initial flag table. The tasks above will have applied this table for you by default since FLAGVER 0. On-line flags may already have caused data to be flagged within your data set (but *not* deleted) by CASA. Unfortunately, a flag table is present only via the OBIT route and it does not include all obvious matters as yet. UVFLG will be needed to add flags for shadowing (APARM(5)=25 or so) to a flag table. We still need to look at the data to flag out whatever remains of the time off source not flagged using on-line flagging information. There have also been drop outs in which the visibility is pure zero, typically for all channels and IFs and a single integration. The drop outs should now be handled by OBIT, UVLOD, and FITLD. Note, however, that CASA and FITLD pass along all data samples, including those that are fully flagged. This makes the data set rather larger than one might wish. Use UVCOP (or TYAPL — see § E.6) to remove all fully flagged data samples. Before doing this, use TVFLG (§ 4.4.3) to look for any more data samples that might need to be flagged fully. Check especially samples at the beginnings and ends of scans. Try

| | |
|---|---|
| > DEFAULT TVFLG ; INP | to reset all adverbs and choose the task. |
| > INDI *n*; GETN *m* C_R | to select the data set on disk *n* and catalog number *m*. |
| > DOCAL 1 ; DOBAND -1 C_R | to apply the delay calibration. If a bandpass has been determined, use DOBAND 3 or 1 to apply it. |
| > BCHAN *c*1 ; ECHAN *c*2 C_R | to average across a range of channels — not as flexible as ICHANSEL but probably okay here. |
| > NCHAV ECHAN-BCHAN+1 C_R | to average all the channels into one number. |
| > BIF *j* ; EIF BIF C_R | to edit one IF only, which will suffice for problems that are not IF dependent, such as drop outs, antenna not on source, etc. Choose an IF that is reasonably free of RFI. |
| > CALCODE '*' C_R | to do just calibrators for the moment. |
| > DPARM(6) $\Delta$ *t* C_R | to do no time averaging in the work file set $\Delta$ *t* to the data interval in seconds. |
| > GO C_R | to start the task. |

The default smoothing time shown in the display will probably be some multiple of $\Delta$ *t*. Select sub-windows and change the smoothing time to one times the basic interval in order to edit in detail. Remember to change the initial setup so that the flags apply to all channels and all IFs. See § 4.4.3 for more information. The EVLA has shown a tendency to produce periods of data which are too low in amplitude to be normal noise, but which are not zero. Use TVFIDDLE or TVTRANSF functions to enhance the brightness of the amplitudes to make sure that apparently black regions really are black (flagged already).

We note here that some users feel that the data need to be inspected more carefully than with just an average of most of the channels. POSSM (below) may be of use to find RFI. Avoiding the worst of that, you may still wish to run TVFLG to look at the average of a few channels at a time. Use NCHAV and CHINC appropriately. Task SPFLG (§ 10.2.2) is the ultimate weapon when looking for channel-dependent difficulties, but is onerous when there are many baselines. These more onerous tools should probably not be used at this preliminary stage; use them after some of the auto-flagging tasks have been run.

## E.4 Basic calibration

For *both* continuum and line observations, we must begin by determining which spectral channels are reliable and which are affected by the inevitable loss of signal-to-noise at band edges or are degraded by radio-frequency interference (RFI). Use POSSM to display spectra from the shorter baselines on the TV:

| | |
|---|---|
| > DEFAULT POSSM ; INP | to set the task name and clear the adverbs. |
| > INDI *n*; GETN *m* C_R | to select the data set on disk *n* and catalog number *m*. |
| > SOURCE '*bandpass_cal*' C_R | to select the strong bandpass calibrator. |
| > DOTV 1 ; NPLOTS 1 C_R | to plot only on the TV, one baseline at a time. |
| > ANTEN *n1* , *n2* , *n3* , *n4* C_R | to select the antennas nearest the center of the array or the maintenance areas. |
| > BASELINE ANTEN C_R | and only them. |
| > DOCAL 1 ; APARM 0 C_R | to apply the FRING solutions and display vector averaged spectra. Scalar averaged spectra will turn up at the edges reflecting the decreased signal to noise in the outer channels. |
| > APARM(9)=1 C_R | to plot all IFs in a single plot. |
| > GO C_R | to run the task. Make notes of the desirable channels IF by IF. |

If there is no RFI, then you may be able to use the same channel range for all IFs. If the RFI is particularly pernicious, you may have to edit it out of your data before continuing; see § E.5. The first time through this section, you should accept but perhaps try to avoid the worst of the RFI. After the detailed editing, that RFI should be gone.

POSSM may reveal extensive ringing in your spectra due to narrow RFI signals. Try SMOOTH=1,0 to apply Hanning smoothing. If this proves beneficial, you should apply this SMOOTH, plus the initial flag table and calibration to the data once and for all with SPLAT. Using SMOOTH in all operations can produce errors in bandpass functions (if you forget it once in a while) and will produce especially strange results when you use the channel-dependent auto-flagging routines such as RFLAG..

For polarization calibration, it is assumed that the phase difference between the right and left polarizations of your calibration is stable with time. Thus, if polarization is important, it is *critical* to find a reference antenna with a stable right minus left phase. Use CALIB with SOLMODE 'P' and as short a time interval as possible on your strongest calibration sources. Use SNPLT with STOKES 'DIFF' and OPTYPE 'PHAS' to look at the right minus left phases in the SN table produced by CALIB. Find the one that is the most stable and use that as REFANT henceforth. To avoid later confusion, delete the SN used for this determination with EXTDEST.

The basic EVLA calibration is much like that described in detail in Chapter 4 except that bandpass calibration is now *required* rather than merely *recommended*. Having chosen those channels which may be reliably used to normalize the bandpass functions,

| | |
|---|---|
| > DEFAULT BPASS ; INP | to reset all adverbs and choose the task. |
| > INDI *n*; GETN *m* C_R | to select the data set on disk *n* and catalog number *m*. |
| > DOCAL 1 C_R | to apply the delay calibration — *very important*. |

| | |
|---|---|
| > CALSOUR '*bandpass_cal*' C_R | to select the strong bandpass calibrator. |
| > SOLINT 0 C_R | to find a bandpass solution for each scan on the BP calibrator. |
| > ICHANSEL $c11, c12, 1, if1, c21, c22, 1, if2, c31, c32, 1, if3, \ldots$ C_R | to select the range(s) of channels which are reliable for averaging in each IF. Use the central 30% of the channels if your calibrators are all very strong or more like 90% if they are not. Remember these values — you will use them again. |
| > BPASSPRM(5) 1 ; BPASSPRM(10) 3 C_R | to normalize the results only after the solution is found using the channels selected by ICHANSEL. Use BPASSP(5)=-1 if your phases are not stable within each scan. |
| > GO C_R | to make a bandpass (BP) table. |

Do not use spectral smoothing at this point unless you want to use the same smoothing forever after. Apply the flag table. A model for the calibrator may be used; see § 4.3.3.1.

BPASS now contains the adverbs SPECINDX and SPECURVE through which the spectral index and its curvature (to higher order than is known for any source) may be entered. For the standard amplitude calibrators 3C286, 3C48, 3C147, and 3C138, these parameters are known and will be provided for you by BPASS. For other sources, you must provide these parameters. If you do not, the spectral index of the calibration source will be frozen into the target source. Bandwidths on the EVLA are wide enough that this is a serious problem. If you do not know the spectral index of your calibration source, the new task SOUSP may be used to determine the spectral indices from the SU table. Of course, that means that GETJY must already have been run. Since BPASS must usually be run before CALIB and hence GETJY, this suggests that one may have to iterate this whole process at least once.

Note that the bandpass parameters shown above assume that the phases are essentially constant through each scan of the bandpass calibrator. This may not be true, particularly at higher frequencies. In this case, you have two choices. One is to set BPASSPRM(5) to 0 which will determine the vector average of the channels selected by ICHANSEL at every integration and divide that into the data of that integration. This will remove all continuum phase fluctuations, but runs a risk of introducing a bias in the amplitudes since they do not have Gaussian statistics. BPASSPRM(5) = -1 now applies a phase-only correction on a record-by-record basis. A better procedure, which is rather more complicated, is as follows. Use SPLIT to separate the bandpass calibrator scans into a separate single-source file applying any flags and delay calibration and the like. Then run CALIB on this data set with a short SOLINT to determine and apply a phase-only self-calibration. On the *uv* data set written out by CALIB, run BPASS using the parameters described in the previous paragraph. Finally, use TACOP to copy the BP table back to the initial data set.

You now need to run SETJY with OPTYPE 'CALC' and SOURCES set to point at your primary flux calibration sources. You should load the models for these sources that apply to your data with CALRD; see § 4.3.3.1. Then run CALIB with the model once for each primary flux calibrator:

| | |
|---|---|
| > DEFAULT CALIB ; INP | to reset all adverbs and choose the task. |
| > INDI $n$; GETN $m$ C_R | to select the data set on disk $n$ and catalog number $m$. |
| > IN2DI $n2$; GET2N $m2$ C_R | to select the model image on disk $n2$ and catalog number $m2$. |
| > DOCAL 1 ; DOBAND 3 C_R | to apply the delay and bandpass calibration — very important. |
| > SOLINT 0 ; NMAPS 1 C_R | to compute a solution for each calibration scan and use the source model. |
| > CALSOUR '*flux_cal*' C_R | to select the primary flux calibrator by whatever form of its name appears in your LISTR output. |
| > ICHANSEL $c11, c12, 1, if1, c21, c22, 1, if2, c31, c32, 1, if3, \ldots$ C_R | to select the range(s) of channels which are reliable for averaging in each IF. These *must* be the same values that you used in BPASS. |

| | |
|---|---|
| > SNVER 2 C_R | to put all CALIB solutions in solution table 2. |
| > GO C_R | to find the complex gains for the flux calibrator. |

Read the output closely. If solutions fail, examine your data closely for bad things. The primary flux calibrator should work without failure. After you have done each primary flux calibrator for which you have models, run CALIB on the remaining calibration sources:

| | |
|---|---|
| > CALSOUR '*other_cal1*', '*other_cal2*' C_R | to select the secondary calibrators by whatever names appear in your LISTR output. |
| > CLR2NAME ; NMAPS 0 C_R | to do no models. |
| > GO C_R | to find the remaining complex gains. |

Again, examine the output messages closely. There may be a few failures but there should not be many in a good data set. The RUN file procedure VLACALIB (see § 4.3.3.1) may be used but it does not offer the ICHANSEL option which may be required by your data. It also does a scalar averaging for the amplitudes. In 31DEC10, this averaging was changed to be a vector average of the spectral channels followed by a scalar average over time. Scalar averaging suffers from Ricean bias in the amplitudes and so should be used only when the calibration source is very strong or when the atmospheric phases are very unstable.

At this point it is necessary to calibrate the fluxes of the secondary calibration sources using your SN table:

| | |
|---|---|
| > TASK 'GETJY' ; INP C_R | to set the task name without changing other adverbs. |
| > SOURCE CALSOUR C_R | to select the secondary sources by the list of name you just used. |
| > CALSOUR '*flux_cal*' C_R | to select the primary flux calibrator by whatever form of its name appears in your LISTR output. |
| > INP C_R | to check the inputs closely; remember to do all times, IFs, etc. with SNVER 2. |
| > GO C_R | to adjust the gains in the SN table and the fluxes in the SU (source) table. |

Look at the messages with care — the fluxes in the various IFs should be consistent and the error bars should be reasonably small ($<$ 10% at high frequencies, smaller at low frequencies). If not, look at your SN table with SNPLT to see if there are bad solutions. If there are, delete SN table 2, do more flagging with TVFLG or SPFLG, and repeat the process.

Use the interactive TV task EDITA to examine the values in your SN table. There may be bad solutions which will require additional flagging of your calibration data. If there is a significant amount of flagging, you should repeat the calibration process to avoid the influence of bad data on the gains and GETJY results.

You may wish to iterate at this point, determining the spectral indices of your bandpass calibrators with SOUSP and re-doing BPASS, CALIB, and GETJY. If the result is a seriously changed spectral index for your secondary sources you may have to iterate further.

Finally, apply the gain solutions to your calibration table:

| | |
|---|---|
| > DEFAULT CLCAL ; INP C_R | to clear the adverbs. |
| > INDI *n*; GETN *m* C_R | to select the data set on disk *n* and catalog number *m*. |
| > CALCODE '*' C_R | to select all calibration sources. |
| > SNVER 2; INVERS SNVER C_R | to select your solution table from CALIB. Do *not* include the SN table from FRING a second time! |
| > GO C_R | to apply SN table 2 to CL table 3, creating CL table 4. |

Check the result using POSSM and/or VPLOT.

## E.5 Detailed flagging

The calibration you have done to this point has been degraded by RFI which has not yet been flagged. However, you need to do the above in order to bring all spectral channels and all antennas and sources into the same flux scale. Now automatic tasks may be used — and they are needed for the large volumes of data produced by the EVLA.

A very promising new tool flags RFI on the assumption that it is either quite variable in time or in frequency. This task, called RFLAG, computes the rms over short time intervals in each spectral channel and IF individually and flags the interval whenever the rms exceeds a user-controlled threshold. Optionally, it will also fit a mean and rms over the spectral channels to the real and imaginary parts of the visibility separately. It does this by robust methods in each IF independently. Any channel deviating from the mean in either part by more than a user-specified amount will also be flagged. If `DOPLOT`$> 0$, `RFLAG` will make plots of normal and cumulative histograms and of the mean and rms of the time and spectral computations as a function of channel. It will also make a flag table only if requested (`DOFLAG`$> 0$). These plots will suggest threshold parameters and allow you to choose values to use. A flag table is made for any value of `DOFLAG` if no plots are requested (`DOPLOT`$\leq 0$).

In detail, `RFLAG` is run using

| | |
|---|---|
| > DEFAULT RFLAG ; INP C_R | to clear and review the adverbs. |
| > INDI $n$; GETN $m$ C_R | to select the data set on disk $n$ and catalog number $m$. |
| > SOURCES '*source_1*', '*source_2*', . . . C_R | to select sources of similar flux level. |
| > DOCALIB 1 ; DOBAND 1 C_R | to apply continuum and bandpass calibration. |
| > STOKES 'FULL' C_R | to examine all polarizations. |
| > DOPLOT 15 ; DOTV 1 C_R | to examine all kinds of plots on the TV. |
| > FPARM 3 , $x$ , -1, -1 C_R | to examine spectral rms over 3 time intervals each a bit longer than $x$ seconds. The $-1$'s cause the program to use other adverbs for the cutoffs and to do a spectral solution as well as the time one. |
| > FPARM(9) = 4.0 ; FPARM(10) = 4. C_R | to set the cutoff values as 4 times the median rms plus deviation found in the spectral plots as a function of IF. The default is 5. |
| > FUNCTYPE 'LG' C_R | to plot the histograms on a log scale. |
| > NBOXES 1000 C_R | to use 1000 boxes in the histograms. |
| > INP C_R | to re-examine the inputs. `VPARM` will let you control aspects of the plotting. |
| > GO | to run the program. |

This will produce plots and set cutoff levels in adverbs `NOISE` and `SCUTOFF`. Another run, with `DOPLOT = 0` will apply these cutoffs and create a new flag table. Note that the flux cutoff levels may depend on the source flux, calling for different levels for strong calibrators, weak calibrators, and very weak target sources. Different cutoff levels for `STOKES='RRLL'` and `STOKES = 'RLLR'` may also be needed. This is a new task, so experiment a bit. Note that, if you set `DOFLAG=1`, the creation of a new flag table will happen after the plots in the same execution of `RFLAG`. If a channel is found bad at a time in any one polarization, all polarizations are flagged. If you have a significant spectral line signal in your data, use `DCHANSEL` to have the affected channels ignored throughout `RFLAG`.

There are a lot of adverbs to `RFLAG`. `FPARM(5)` and 6 will allow the flagging of whole spectra if the rms is too low to be believable (amplitudes way low but not 0) or so high as to suggest that these data should be avoided. `FPARM(7)`, 8, 11, and 12 control the extending of flags to additional channels, baselines, or antennas if too large a fraction of channels, baselines, or baselines to an antenna are flagged in the basic time and spectral operations. Similar adverbs also occur in the new task `REFLG` whose job it is to compress the enormous flag tables generated by auto-flagging tasks like RFLAG, CLIP, and even TVFLG and SPFLG when you clip or flag areas. REFLG can also extend a flag to all times if too large a fraction of time is flagged for a given channel, baseline, etc. REFLG may not reduce your flag table enough, although it is inexpensive to run and so worth the effort. The application of 10 million flag entries to a data set repetitively is rather expensive. Copying the data, applying the flags once and for all, is the best solution. UVCOP has been the traditional method to do this. However, TYAPL which needs to be run next and must make a new copy of the data has been given the option of applying a flag table to avoid having to copy the data set twice.

A new tool which may help identify bad data at this early stage is the task REWAY described in § E.8. It basically does the functions of FPARM(5) and 6 in RFLAG and must copy the selected data to a new file, so it is not particularly recommended. Run it with no flagging of the output for bad values of the spectral rms. Then plot the weights with VPLOT or ANBPL to look for weights that are seriously abnormal (high or low). Those data may need to be flagged. High weights mean that the data are of abnormally low amplitude, whilst low weights mean that the data are very noisy. REWAY uses robust methods to find the rms and so a few channels of RFI may not cause very low weights, but lots of RFI or receiver failures will make the weights abnormally low.

POSSM may be used again to see if serious RFI remains after RFLAG and it may be appropriate to run TVFLG to look at groups of a small number of spectral channels (or even every channel) on your calibration source. Task FLGIT (§ 8.1) is an older task that attempts to flag RFI that is both channel- and time-dependent in a non-interactive fashion. SPFLG (§ 10.2.2) is labor and time intensive but would be the most reliable method to deal with the problem. CLIP will flag particularly high amplitudes, but RFLAG should get them in most realistic cases.

The auto-editing task FLAGR is also of some use here. It averages the spectral channels to get an estimate of the mean and rms and uses those numbers evaluated over time and baseline in a variety of algorithms to further flag the data. RFI which is rather wide spectrally and long lived may be found in this way.

## E.6 Calibration with the SysPower table

Having done a more careful job with your editing, it is now time to discard with EXTDEST the bandpass (BP) tables and all CL tables after the one written by VLANT. Discard all SN tables, but keep the highest numbered flag (FG) table.

The EVLA uses switched noise tubes and records the total power when the noise tube is on and when it is off. These data, taken in synchronism with the visibilities, are recorded in the SysPower table of the ASDM. The OBIT program BDFIn, available to AIPS users in the new verb BDF2AIPS, reads this table and creates an AIPS SY table. The columns of this table contain POWER DIF ($Gain \times (P_{on} - P_{off})$, POWER SUM ($Gain \times (P_{on} + P_{off})$, and POST GAIN ($Gain$) columns for right and left polarizations with values for each IF.

This table is accessible to AIPS users with a number of tasks. To examine its contents in various ways, use SNPLT with OPTYPEs 'PDIF', 'PSUM', PGN, 'PON', POFF, and 'PSYS'. This last one is especially interesting since $P_{sum}/P_{dif}/2 * T_{cal} = T_{sys}$, the system temperature. It should reflect changes in elevation and strength of the observed source, but should be immune to adjustments to the gain of the telescope. You may use EDITA (§ 4.4.2) to edit your *uv* data on the basis of the contents of the SY table. Editing may be based on Psum, Pdif, Tsys, and on the differences between these parameters and a running median of these parameters. One may also edit the SY table itself with SNEDT; the same parameters are available.

More importantly, the SY table can be used to do an initial calibration of the visibility data. Use the display programs to decide if your SY table is fine as is or needs editing. The tasks TYSMO and TYAPL (§ 4.1.1.1) may be used with EVLA data having an SY table. TYSMO flags SY samples on the basis of Pdif, Psum, and Tsys and then smooths Psum and Pdif to replace the flagged samples and/or reduce the noise. You may want to do this to remove outlying bad points and to reduce the jitter in these measurements. In 31DEC11, TYSMO even applies a flag table to the SY before its clipping and smoothing operations. (Use SNEDT in 31DEC10 to do the same operation before running TYSMO.) Be sure to plot the results to make sure that the task did what you wanted. Then use TYAPL to remove a previously applied SY table (if any) and to apply the SY table you have prepared. The result should be data scaled nearly correctly in Jy and weights in $1/\mathrm{Jy}^2$ in all IFs. Note that TYSMO and TYAPL also require a table of the Tcal values which OBIT provides in an *AIPS* CD table. Amplitude calibrations are not applied to EVLA data weights until they have been made meaningful by TYAPL or REWAY. Set FLAGVER in TYAPL if you want to apply your flag table once and for all.

Now return to § E.4 to repeat the bandpass and continuum calibrations with correctly scaled data with most of the RFI removed.

## E.7 Polarization calibration — RLDLY, PCAL, and RLDIF

You may skip this section unless you have cross-hand polarization data and wish to make use of them. Although there have been major improvements in *AIPS* polarization routines, they still do not correct parallel hand visibilities for polarization leakage. Thus you need to calibrate polarization only if you wish to make images of target source Q and U Stokes parameters. Polarization calibration is discussed extensively in § 4.6; we will discuss changes made because of the wide bandwidths and other aspects of the EVLA.

Frequently, the delay difference between right- and left-hand polarizations must be determined even if FRING was not required for the parallel-hand data. Use POSSM to plot the RL and LR spectra to see of there are significant slopes in phase. If so, use a calibration source with significant polarization, although the EVLA D terms are often large enough to provide a usable signal in the absence of a real polarized signal. Note that 3C286 is significantly polarized and is likely to be the best source to use for this purpose. Then

> TASK 'RLDLY' ; INP C_R — to look at the necessary inputs.

> TIMERANG *db* , *hb* , *mb* , *sb* , *de*, *he* , *me* , *se* C_R — to specify the beginning day, hour, minute, and second and ending day, hour, minute, and second (wrt REFDATE) of the data to be included. Use an interval not unlike the one you used in FRING.

> REFANT $n_r$ C_R — to select a reference antenna - only baselines to this antenna are used so select carefully.

> BCHAN $c_1$ ; ECHAN $c_2$ C_R — to select channels free of edge effects.

> DOCAL 1 ; GAINUSE 0 C_R — to apply the FRING results and all other current calibrations.

> DOIFS *j* C_R — to set the adverb to the value of APARM(5) used in FRING (§ E.2. The IFs are done independently ($\leq 0$), all together ($= 1$), or in halves ($\geq 2$).

> INP C_R — to check the inputs.

> GO C_R — to produce a new SN table with a suitable left polarization delay.

RLDLY will copy the CL table which was applied to the input data through GAINUSE to a new CL table applying the correction to the L polarization delay.

You may skip the next two paragraphs if you have sufficient signal-to-noise and plan to solve for the calibrator Q and U on a channel basis. Otherwise, you need to determine the apparent Q and U of the calibration source(s) on an IF-by-IF basis first. Then

> DEFAULT PCAL ; INP — to reset all adverbs and choose the task.

> INDI $n$; GETN $m$ C_R — to select the data set on disk $n$ and catalog number $m$.
> DOCAL 1 ; DOBAND 3 C_R — to apply the delay, complex gain, and bandpass calibration.
> CALSOUR '*pol_cal1*', '*pol_cal2*' C_R — to select the polarization calibrator(s) by whatever form of their names appears in your LISTR output. These sources must have I polarization fluxes in the source table.
> ICHANSEL $c11, c12, 1, if1, c21, c22, 1, if2, c31, c32, 1, if3, \ldots$ C_R — to select the range(s) of channels which are reliable for averaging in each IF. These probably should be the same values that you used in BPASS.
> DOMODEL -1; SPECTRAL -1 C_R — to solve for source polarization in a continuum manner.
> PRTLEV 1 C_R — to see the answers and uncertainties on an antenna and IF basis.
> CPARM 0,1 C_R — to update the source table with the calibrator source Q and U found.
> INP C_R — to review the inputs.
> GO C_R — to find the antenna leakage terms and the source Q and U values on an IF-dependent basis.

PCAL will write the antenna leakage terms in the antenna file and the source Q and U terms in the source table (if CPARM(2) $> 0$).

Having prepared a continuum solution for Q and U, you must also correct it for the difference in phase between R and L polarizations which normally varies considerably between IFs. The task RLDIF will correct the antenna, source, and calibration tables for this difference using observations of a source with known ratio of Q to U. 3C286 is by far the best calibrator for this purpose.

> DEFAULT RLDIF ; INP — to reset all adverbs and choose the task.
> INDI $n$; GETN $m$ C_R — to select the data set on disk $n$ and catalog number $m$.
> DOCAL 1 ; DOBAND 3 C_R — to apply the delay, complex gain, and bandpass calibration.
> DOPOL 1 C_R — to apply the polarization calibration.
> BCHAN $c_1$; ECHAN $c_2$ C_R — to average data from channels $c_1$ through $c_2$ only.
> SOURC '*pol_cal1*', '*pol_cal2*' C_R — to select the polarization calibrator(s) by whatever form of their names appears in your LISTR output. These sources must have known polarization angles.
> SPECTRAL 0 C_R — to do the correction in continuum mode.
> DOAPPLY 1 C_R — to apply the solutions to a CL table (making a new modified one) and to the AN and SU tables, updating them in place.
> DOCRT 0 C_R — to omit all the possible printing.
> INP C_R — to review the inputs.
> GO C_R — to determine and apply the corrections.

The EVLA polarizers appear to be very stable in time, but to have significant variation with frequency. See Figure E.1. Serious polarimetry with the EVLA will *require* solving for the antenna polarization leakage as a function of frequency. To compute a spectral solution, assuming you already did the process in the preceding paragraph:

> TGET PCAL C_R — to retrieve the PCAL adverbs.
> SPECTRAL 1 C_R — to do the channel-dependent mode.
> DOMODEL 0 C_R — to solve for Q and U as a function of frequency. Because PCAL does not solve for a right-left phase difference and that difference is a function of spectral channel, you must solve for a source polarization.

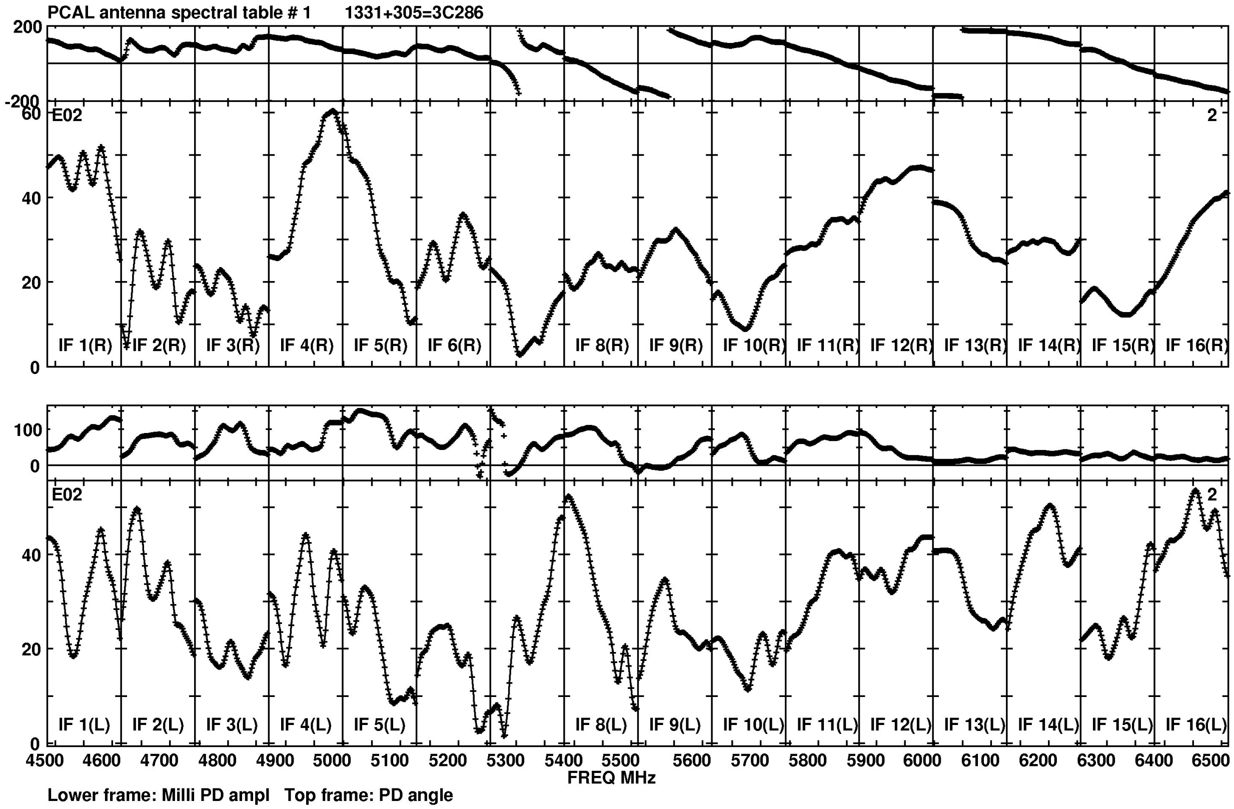


Figure E.1: Example spectrum showing D term solutions for one antenna in right and left polarizations covering about 2 GHz at C band

> INTPARM $p_1, p_2, p_3$ C_R — to smooth the data after all calibration has been done while honoring ICHANSEL.

> SPECPARM 0 C_R — to determine the calibration source I, Q, and U spectral indices from fluxes in the source table. If you use PMODEL you must provide spectral indices for the model that apply in the frequency range of the data (curvature cannot be specified).

> INP C_R — to review the inputs, the task will take a while to run.

> GO C_R — to run the task writing a PD table of spectral leakages ("D terms") and, if DOMODEL $\leq 0$, a CP table of source Q and U spectra.

If the combination of flagging, ICHANSEL, and INTPARM results in no solutions for some channels, the solutions from nearby channels will be interpolated or extrapolated so that all channels get solutions.

After running PCAL in spectral mode, you may examine the resulting PD (polarization D terms) table with POSSM using APARM(8)=6 and BPLOT using INEXT = 'PD'. If a CP table (calibrator polarization) was written, you may also use POSSM with APARM(8) = 7 or 8 and BPLOT with INEXT = 'CP' to examine the results.

You are almost, but not quite done. The combination of CALIB and BPASS has produced a good calibration for everything except the phase difference between right and left polarizations. This is now a function of spectral channel and needs to be corrected. The task RLDIF has been modified to determine a continuum or spectral right minus left phase difference and to modify the CL or BP table, respectively, to apply a phase change to the left polarization on an IF or channel, respectively, basis. Thus

| | |
|---|---|
| > DEFAULT RLDIF ; INP | to reset all adverbs and choose the task. |
| > INDI $n$; GETN $m$ CR | to select the data set on disk $n$ and catalog number $m$. |
| > DOCAL 1 ; DOBAND 3 CR | to apply the delay, complex gain, and bandpass calibration. |
| > DOPOL 1 CR | to apply the polarization calibration, spectral if present. |
| > BCHAN $c_1$; ECHAN $c_2$ CR | to use solutions from channels $c_1$ through $c_2$ only, extrapolating solutions to channels outside this range. |
| > INTPARM $p_1, p_2, p_3$ CR | to smooth the data after all calibration has been done. |
| > SOURC '*pol_cal1*', '*pol_cal2*' CR | to select the polarization calibrator(s) by whatever form of their names appears in your LISTR output. These sources must have known polarization angles. |
| > POLANGLE $p_1, p_2$ CR | to provide the task with the source polarization angle(s) in degrees in source number order. The phase correction will be twice this value minus the observed RL phase. Do not provide values for 3C286, 3C147, 3C48, and 3C138. These are known to RLDIF including rotation measures and other spectral dependence. |
| > SPECTRAL 1 CR | to do the correction in spectral mode. |
| > DOAPPLY 1 CR | to apply the solutions to a BP table (making a new modified one) and to the PD and CP tables. |
| > DOCRT -1 ; OUTPRI '*file_name*' CR | to write the phase corrections applied to a text file suitable for plotting by PLOTR. |
| > INP CR | to review the inputs. |
| > GO CR | to determine and apply the corrections. |

Use UVPLT, LISTR or POSSM to check that the expected RL and LR phases now appear with all calibrations turned on. Following these steps, you apply the polarization calibration in any task offering DOPOL. A value of 1 will apply the spectral solution if present or the continuum one is there is no PD table. A value of 6 for DOPOL requests the continuum solution despite the presence of a spectral solution. Use POSSM to plot the calibration sources in RL, LR, Q, and U polarization to make sure that all has functioned correctly (these are newly revised tasks).

## E.8 Target source data — edit and SPLIT

At this point, your calibration should be finished. You should now do an initial editing on the target sources, much like that done above for the calibration sources:

| | |
|---|---|
| > DEFAULT TVFLG ; INP | to reset all adverbs and choose the task. |
| > INDI $n$; GETN $m$ CR | to select the data set on disk $n$ and catalog number $m$. |
| > DOCAL 1 ; DOBAND 3 CR | to apply the delay, complex gain, and bandpass calibration. |
| > BCHAN $c1$ ; ECHAN $c2$ CR | to average across a range of channels — not as flexible as ICHANSEL but probably okay here. |
| > BIF $j$ ; EIF BIF CR | to edit one IF only, which will suffice for problems that are not IF dependent, such as drop outs, antenna not on source, etc. Choose an IF that is reasonably free of RFI. |
| > NCHAV ECHAN-BCHAN+1 CR | to average all the channels into one number. |
| > CALCODE '-CAL' CR | to do just target sources now. |
| > DPARM(6) $\Delta\ t$ CR | to do no time averaging in the work file set $\Delta\ t$ to the data interval in seconds. |

| | |
|---|---|
| > GO C_R | to start the task. |

Again, remember to set it to flag all channels and IFs. You may have to select sub-windows and force the averaging to one times $\Delta\ t$ to edit in detail, or perhaps the default time averaging will be beneficial. In general, the `DISPLAY AMP V DIFF` is a powerful way to catch bad amplitudes and phases. It will catch drop outs either as bright lines for strong sources or dark grey ones for weak sources.

Since EVLA data sets tend to be large and unwieldy, it is recommended that you separate the data into the separate target sources, applying the current calibration and flagging once and for all. The imaging task `IMAGR` can do this on the fly, but, especially for observations of spectral-line sources, this is excessively expensive.

| | |
|---|---|
| > DEFAULT SPLIT ; INP | to reset all adverbs and choose the task. |
| > INDI *n*; GETN *m* C_R | to select the data set on disk *n* and catalog number *m*. |
| > DOCAL 1 ; DOBAND 3 C_R | to apply the delay, complex gain, and bandpass calibration. |
| > CALCODE '-CAL' C_R | to do just target sources now. |
| > GO C_R | to write out separate calibrated data sets for each target source. |

Unless `TYAPL` has been used, EVLA data sets have weights which only reflect the integration time in seconds. Calibration routines do not change these weights when changing the data amplitudes. There is a new task called `REWAY` which computes a robust rms over spectral channels within each IF and polarization. It can simply base the weights on these on a record-by-record, baseline-by-baseline basis. Alternatively, it can use a scrolling buffer in time so that the robust rms includes data for a user-specified number of records surrounding the current one. A third choice is to average the single-time rmses over a time range and then convert them to antenna-based rmses. In all three modes, the task can then smooth the rmses over time applying clipping based on user adverbs and the mean and variance found in the rmses. A flag table (extension file) may be written to the input data file removing those data found to have rmses that are either too high or too low. For these weights to be meaningful, the bandpass and spectral polarization calibration must be applied and any RFI or other real spectral-line signal channels must be omitted from the rms computation. For the weights to be correctly calibrated, all amplitude calibration must also be applied. For these reasons, `REWAY` might well be used instead of `SPLIT`, running it one source at a time. Thus,

| | |
|---|---|
| > DEFAULT REWAY ; INP | to reset all adverbs and choose the task. |
| > INDI *n*; GETN *m* C_R | to select the data set on disk *n* and catalog number *m*. |
| > DOCAL 1 ; DOBAND 3 C_R | to apply the delay, complex gain, and bandpass calibration. |
| > SOURCE '$target_1$' , ' ' C_R | to do one target source. |
| > APARM 11, 30, 12, 0, 10, 4 C_R | to use a rolling buffer of 11 times separated by no more than 30 seconds and then smoothed further with a Gaussian 12 seconds in FWHM. Data are flagged if the rms is more than 4 times the variance away from the mean averaged over all baselines, IFs, and polarizations. Flagging on the variance of the rms from the mean on a baseline basis is essentially turned off by the 10. |
| > GO C_R | to write out a calibrated, weighted data set for the first target source. |

Then, when that finishes

| | |
|---|---|
| > SOURCE '$target_2$' , ' ' ; GO C_R | to do another target source. |

It is not clear that this algorithm is optimal, but it certainly should be better than using all weights 1.0 throughout. It will be interesting to compare data weights found with `TYAPL` to those found with `REWAY`.

## E.9 Spectral-line imaging hints

At present, the EVLA observing setup allows you to select the initial frequency of observation based on a desired LSRK velocity in the central channel. From there, however, the observations are conducted at a fixed frequency. The task CVEL may be used to shift the visibility data to correct for the rotation of the Earth about its axis as well as the motion of the Earth about the Solar System barycenter and the motion of the barycenter with respect to the Local kinetic Standard of Rest. CVEL works on multi-source as well as single-source data sets. It applies any flagging and bandpass calibration to the data before shifting the velocity (which it does by a carefully correct Fourier transform method). Note, the use of Fourier-transforms means that one *must not* use CVEL on data with channel separations comparable to the widths of some of the spectral features. The velocity information used by CVEL must be correct. For multi-source data, this information is kept in the source table and should be checked. For single-source data, this information will be provided by SPLIT and may be changed by verb ALTDEF or the adverbs of CVEL.

In many spectral-line observations you will now want to separate the continuum signal from the channel-dependent signals. This is discussed in some detail in § 8.3. The larger number of channels from the EVLA does mean that continuum may be estimated with greater accuracy than when there were rather few channels which were both free of edge effects and spectral-line signal. The wider total bandwidth may, however, invalidate the assumption that the continuum signal at each visibility point can be represented by a polynomial of zero or first order. If there is a single dominant continuum source offset from the phase center, the assumption may be rendered valid by shifting the data with UVLSF to center the continuum source temporarily in order to subtract it. To examine this assumption and to determine which channels appear safe to use as "continuum" channels, use POSSM.

| | |
|---|---|
| > DEFAULT POSSM ; INP | to set the task name and clear the adverbs. |
| > INDI *Tn*; GETN *Tm* C_R | to select the calibrated line data set on disk *Tn* and catalog number *Tm*. |
| > DOTV 1 ; NPLOTS 1 C_R | to plot only on the TV, one baseline at a time. |
| > ANTEN *n1* , *n2* , *n3* , *n4* C_R | to select the antennas nearest the center of the array |
| > BASELINE ANTEN C_R | and only them. |
| > APARM 0 C_R | to display vector averaged spectra. Scalar averaged spectra will turn up at the edges reflecting the decreased signal to noise in the outer channels which will assist in determining channels that should be omitted. |
| > BIF *j* ; EIF BIF C_R | to plot one IF at a time. |
| > GO C_R | to run the task. Make notes of the desirable channels IF by IF. |

Note also whether the continuum appears to be a linear function of channel. If so, then use UVLSF to fit the continuum signal, writing a continuum only and a spectral-line only data set:

| | |
|---|---|
| > DEFAULT UVLSF ; INP | to set the task name and clear the adverbs. |
| > INDI *Tn*; GETN *Tm* C_R | to select the calibrated line data set on disk *Tn* and catalog number *Tm*. |
| > ICHANSEL $c11, c12, 1, if1, c21, c22, 1, if2, c31, c32, 1, if3, \ldots$ C_R | to select the range(s) of channels which are reliable for fitting the continuum. For a multi-IF data set, you will need to select the channel ranges carefully by IF. |
| > ORDER 1 C_R | to select fitting the continuum in real and imaginary parts with a first order polynomial in channel number. UVLSF offers orders up to four, but they are not for the faint at heart and will give bad results if there are large ranges of channels left out of the fit due to line signals. |

| | |
|---|---|
| > DOOUTPUT 1 CR | to have the continuum which was fit written as a separate data set. This may be used to image the continuum. |
| > SHIFT $\Delta x, \Delta y$ CR | to shift the phase center to the dominant continuum source temporarily for the fitting. |
| > GO CR | to run the task. |

Imaging the continuum output may, in addition to any scientific value of the continuum image, provide additional flagging and even self-calibration information which may be applied to the line data.

If UVLSF cannot be used, flag the channels at the edges and those with spectral signals using UVFLG. Construct a continuum image with IMAGR on this flagged, spectral-line data set. Note that you might want to reduce the size of the data set with time averaging (UVAVG) and/or channel averaging (SPLIT or AVSPC) before beginning the imaging. Imaging is discussed in detail in § 5.2 through § 5.3.6 and will not be discussed here. You may find that additional editing is needed and that iterative self-calibration is of use. Be sure to copy those flags (but not the edge and spectral-signal flags) and final SN table back to the line data set. Apply them with SPLIT and then subtract the final continuum model with UVSUB. It you have had to use the spectral index options of IMAGR, you may do the proper subtraction including these options with OOSUB rather than UVSUB.

Spectral-line imaging of EVLA data will resemble that for the old VLA except for the increased number of spectral channels and the consequent increase in the data set size. Since IMAGR must read the full data set to select the data for the next channel to be imaged, it is important that the data set be small enough to fit in computer memory if at all possible. OSRO data sets may not need this operation and skipping it may simplify any continuum imaging that you wish to do. However, separating the IFs into separate files will not interfere with spectral imaging and will help with the data set size problem:

| | |
|---|---|
| > DEFAULT UVCOP ; INP | to reset all adverbs and choose the task. |
| > INDI $Tn$; GETN $Tm$ CR | to select the calibrated target data set on disk $Tn$ and catalog number $Tm$. |
| > DOWAIT 1 CR | to have the task resume AIPS only after it has finished. |
| > OUTSEQ 0 ; OUTDISK INDISK CR | to avoid file name issues and select the output disk. |
| > FOR BIF = 1 TO $N$; EIF = BIF ; GO; END CR | to make separate files of each of the $N$ IFs. |
| > DOWAIT -1 CR | to turn off waiting. |

Doing this UVCOP step on large RSRO data sets will be worth any extra trouble it may cause. Note that you could perform the separation into separate IFs before UVLSF which will speed up POSSM and UVLSF. However, the continuum output would then have to be assembled using VBGLU, which is why the steps above were shown in the present order.

Spectral-line imaging is discussed in § 8.4 as well as throughout Chapter 5. With large numbers of spectral channels, you may wish to have IMAGR find appropriate Clean boxes for you. Set IM2PARM(1) through IM2PARM(6) cautiously. IM2PARM(7) controls whether the boxes of channel $n$ are passed on to channel $n+1$. The default does not pass the boxes along when auto-boxing which is probably the correct decision. The end result of the imaging will be one image "cube" for each IF since each IF has to be imaged separately even with a multi-IF input data set. (If you set BIF = 1; EIF = 0 and try to image channel 103, you will actually image the average of channel 103 from each of the IFs.) To put the individual cubes together into one large cube, use MCUBE (§ 8.5.1).

The wide bandwidths of the EVLA have revealed an error in the old code. IMAGR and MCUBE now control the units of data cubes carefully, making sure that each plane is in units of Jy per *header* beam. The actual restoring beamwidths used are now maintained in a CG table. This allows the best resolution to be used in each plane and the approximate match between the units of the residual image and the restored components to be maintained, while still returning correct fluxes when integrating brightness over area. CONVL with OPCODE = 'GAUS' will now use the CG table to find the exact Gaussian needed to produce a constant resolution in each plane. Use of BMAJ = 0 in IMAGR followed by CONVL is now the best way to insure a constant resolution with correct image units throughout.

## E.10 Continuum imaging hints

The first problem that continuum observers will notice with their EVLA data is that the spectral and time resolution of the data, by default anyway, will be rather more than their science requires. It will be possible to instruct the software which extracts data from the archive to do some averaging in both frequency and time. However, detailed editing for RFI and other issues may require excellent resolution in both these domains. After the data have been edited, you can average data in both domains so long as you are careful not to average so much that you produce radial (bandwidth) and/or transverse (time) smearing within the image area. Note that the increased sensitivity of the EVLA will increase the area over which non-negligible astronomical objects may be found while the wide bandwidth will mean that lowest frequency part of your band will be sensitive, because of its larger primary beam, to a much larger area on the sky than the highest frequency part. The spectral averaging can be done with `SPLIT`; use `APARM(1)=1` and set `NCHAV`, `CHINC`, and perhaps `SMOOTH` appropriately. Similarly, `AVSPC` can be used with `AVOPTION='SUBS'`, setting `CHANNEL` and `SMOOTH` suitably. You will almost certainly wish to retain some spectral separation, so do not use the "channel 0" option.

Time averaging should be done with `UVAVG`:

| | |
|---|---|
| > DEFAULT UVAVG ; INP | to reset all adverbs and choose the task. |
| > INDI *Sn*; GETN *Sm* C_R | to select the calibrated target data set on disk *Sn* and catalog number *Sm*. |
| > YINC $\Delta t$ C_R | to average to $\Delta t$ seconds. |
| > OPCODE 'TIME' C_R | to have all samples in a given interval written with the same time; this helps with self-cal. Other options are available. |
| > GO C_R | to produce the averaged data set. |

`UBAVG` will do a more aggressive averaging, using baseline-dependent time intervals appropriate for the desired field of view. Do not use `UBAVG` if you are planning to use self-calibration since it destroys the time regularity in the data on which `CALIB` depends. `IMAGR` may now do this extra averaging for you on the fly to reduce the size of the work file it uses. Set `IM2PARM(11)` and `(12)`.

Imaging of the continuum is discussed at great length in Chapter 5 and those details will not be repeated here. Bandwidth-synthesis imaging, which will be the only form of continuum imaging with the EVLA, will make certain adverbs more important. Set `BCHAN` and `ECHAN` to avoid the noisier edge channels. Set `NCHAV = ECHAN - BCHAN + 1` and `CHINC = NCHAV`. This will then image all of your IFs and spectral channels into a single image, positioning each channel correctly in the *uv* plane. With the EVLA, you will be imaging a wider field of view than you did with the VLA. Use `SETFC` with `IMSIZE 0 ; CELLSIZE 0` to see if you should image with a single facet or with multiple facets. If using multiple facets and trying for significant dynamic range, start imaging with `OVERLAP 2 ; ONEBEAM -1`, but consider `OVRSWTCH = -0.05` or so to switch into faster methods of Cleaning when the dynamic range in the residual is small enough.

`31DEC09` and later versions of `IMAGR` allow you to request automatic finding of the Clean boxes (`IM2PARM` of 1 through 6). In cases with low sidelobes, this works rather well, but you should probably keep an eye on what it does with `DOTV 1` in any case. `IM2PARM(12)` controls the baseline-dependent time averaging while specifying the maximum field of view you expect. This allows you to reduce the size of the work file considerably which will at least reduce the time required for many of the steps in the imaging proportionally. It may be rather better than that if the work file is very large otherwise, requiring actual reading of the disk every time the data are accessed. Note, however, that the uniform weighting of your data will be affected. This averaging reduces the number of samples at short spacings disproportionally and so appears to reduce their weight in the imaging. Some `UVTAPER` could be used to compensate for this.

By default, bandwidth synthesis imaging assumes that the primary beam and all continuum sources are the same at every frequency. In fact, the primary beam size varies linearly with frequency (to first order anyway) and sources have spectral index. `IMAGR` will allow you to compensate for the average spectral index at almost no cost with IMAGRPRM(2). A far more accurate and expensive correction for spectral index may be made if you do the following. First image each spectral channel (or group of closely-spaced channels) separately. Combine them into a cube with FQUBE, transpose the cube with TRANS, and solve for spectral index images with SPIXR. To use these images, set IMAGRPRM(17) to a radius ($> 0$) in pixels of a smoothing area and put the image name parameters in the 3rd and 4th input image names. Note that this algorithm is expensive, but that it can be sped up with judicious use of the FQTOL parameter. The change of primary beam with frequency may be corrected by setting IMAGRPRM(1) = 25 for the diameter of the EVLA dishes. Note that this algorithm is expensive, but that it can be sped up with judicious use of the FQTOL parameter. These two corrections work together, so that doing both costs very little more than doing just one of them.

If you are observing a strong source and trying for very high dynamic range, you will probably have to correct for errors that are baseline- rather than antenna-dependent. One source of these errors is the antenna polarization leakage which affects the parallel-hand visibilities in a non-closing fashion. Task BLCAL can be used after you have as good an image as you can get without it. This task will divide the data by the model and average over a user-specified time to find baseline-dependent corrections which may then be applied to the data by setting adverb BLVER. We recommend that you average the divided data over all of the times in your data to get a single correction for each baseline (and IF and polarization). If you use shorter intervals, you run the risk of forcing your data to look too much like your model. Since the polarization leakage is probably a function of frequency, an experimental version of BLCAL called BLCHN has been released. It determines the same correction but does not average over channels. The correction is saved in a table which POSSM and BPLOT are able to display. However, the calibration routines do not know how to apply this table, so BLCHN writes out the corrected data as well as the table.

## E.11 Concluding remarks, early science

AIPS itself, and particularly this appendix, do not begin to cover all of the issues that will arise with EVLA data. The increased sensitivity of the EVLA will mean that imaging will no longer be able to ignore effects that are difficult to correct such as pointing errors, beam squint, variable antenna polarization across the field, leakage of polarized signal into the parallel-hand visibilities, etc., etc. These are research topics which may have solutions in AIPS or other software packages such as OBIT and CASA eventually.

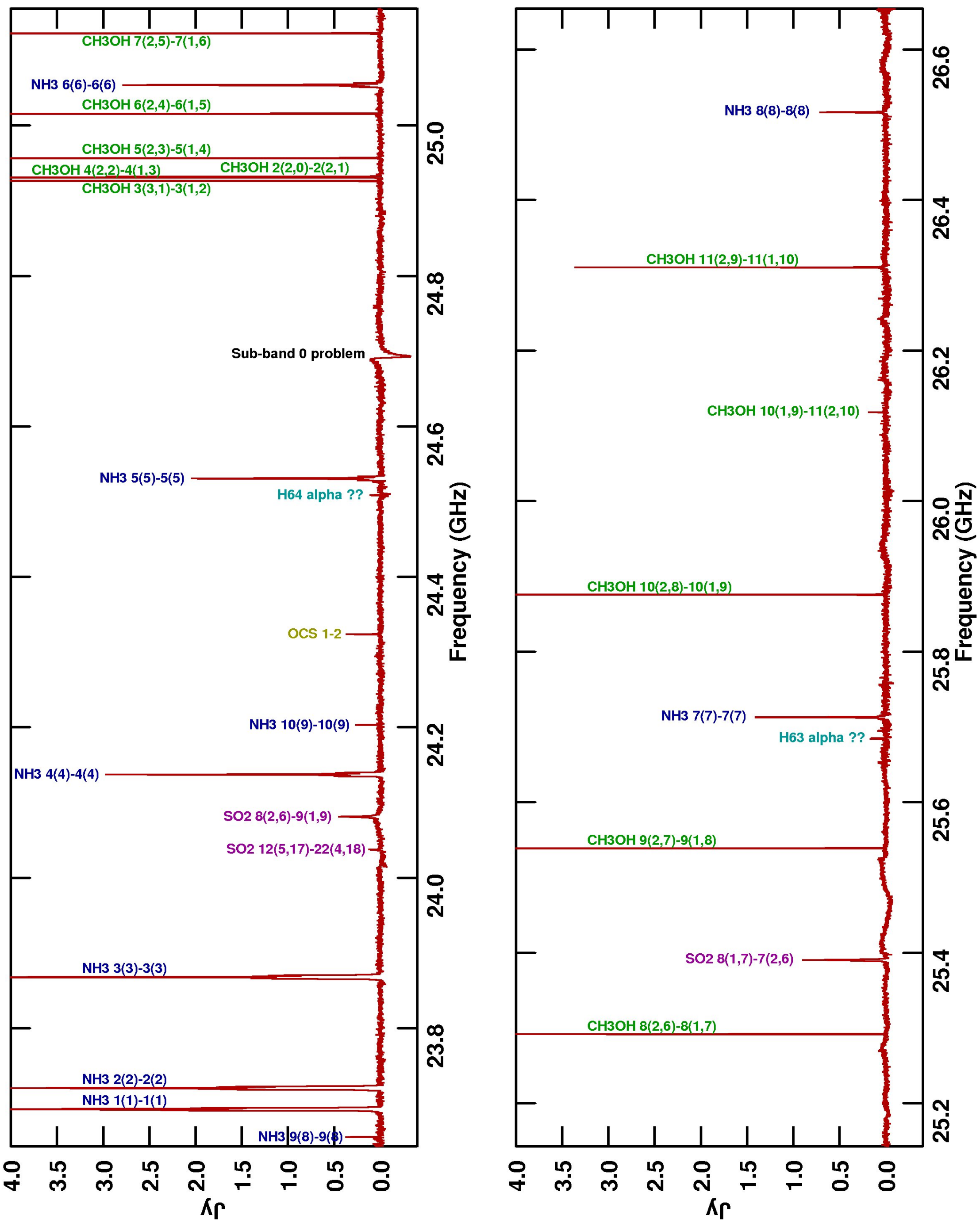


Figure E.2: The spectrum of the hot core of Orion A at K band. Three separate observations of 8192 channels each 0.125 MHz wide were made using 12 antennas in the D array. Two hours total telescope time went into each of the two lower thirds of the spectrum and 1 hour was used for the highest third. The plot was made using ISPEC over a 54 by 60 arc second area. Line identifications provided by Karl Menten.

# F FILE SIZES

Your data reduction strategy will be more effective if you have an idea of how big the data and map file sizes will be on disk. Also, it will help you estimate just how many files you can backup to tape. In this appendix, we will discuss file sizes in bytes, which are 8 bits in size, rather than "blocks," which can vary in size between different computers. Inside $\mathcal{AIPS}$, the definition of "byte" is perverted, but all systems now use a 1024-byte (8192 bit) "block."

## F.1 Visibility ($uv$) data sets

$uv$ data files contain information about the coherence function of a wavefront at random locations and random times. Consequently, the way this information is stored on disk is different from that for images where the pixels are on a regular grid. AIPS $uv$ data are stored on disk in a manner similar to the way that it would be organized on a FITS "random group" tape. The data are stored as logical records; each record (a "visibility") contains **all** the data taken on one baseline at a given time. Consequently, a record may contain information for several IFs, several frequencies at each of those IFs and more than one polarization combination for each frequency/IF. The first part of each logical record contains what are known as "random parameters" *e.g.*, spatial frequency coordinates and time. After the random parameters, there is a small, regular array of data.

For a multi-source data set such as might be created by FILLM, the random parameter group will include the following. `UU-L-SIN`, `VV-L-SIN`, and `WW-L-SIN` give the spatial frequency coordinates, computed with a sine projection in units of wavelengths at the reference frequency. `TIME1` is the label for the time in days. `BASELINE` is the baseline number ($256ant_1 + ant_2 + subarray/100.$) and `SOURCE` is the source number corresponding to an entry in the source table. If you have frequency table identifiers (which is usually the case these days), then there will be an additional random parameter, `FREQSEL`. For a compressed database, two additional random parameters will be required — `WEIGHT` to give a single data weight for all samples in the record and `SCALE` to give the gain used to compress that record.

The regular data array is similar to an image array in that the order of axes is arbitrary. However, the convention is for the first axis to be of type `COMPLEX`, having a dimension of 3 for uncompressed data (real, imaginary, weight) and a dimension of 1 for compressed data. The other axes of the regular array are `IF`, `RA`, `DEC`, `FREQ` and `STOKES`.

### F.1.1 $uv$ database sizes

The number of words in each "visibility" is given by

$$(\#\ random\ parameters) + [(dimension\ of\ \texttt{COMPLEX}\ axis) \times (\#\ polns) \times (\#\ freqs) \times (\#\ IFs)]$$

The size of the database to be loaded to disk with FILLM is given by

$$(word\ per\ record) \times (\#\ vis) \times 4\,\text{bytes}$$

The number of visibilities is given (approximately) by

$$\frac{length\ of\ observation}{integration\ time} \times number\ of\ baselines$$

where the number of baselines is the usual $\frac{1}{2}n(n-1)$. This is equal to 351 for the VLA for the usual 27-antenna array.

For example, a 12-hour observation with 30 second integrations, one frequency and 2 IFs with RR, RL, LR and LL written in compressed format (`DOUVCOMP = TRUE` in `FILLM`) will occupy about 34 Mbytes on disk. In practice, the *uv* file will usually be a little larger due to the way the system allocates space on the disks. You must also remember to allow room for the extension tables — see § F.3. If this database had been written in uncompressed format, the *uv* data would have occupied around 62 Mbyte, but would have carried information about different data weights for different IFs.

Consider another example illustrated by the `IMHEAD` listing below:

```
Image=MULTI     (UV)         Filename=20/07/90    .L BAND.   1
Telescope=VLA                Receiver=VLA
Observer=AFTST               User #= 1364
Observ. date=20-JUL-1990     Map date=23-JUL-1990
# visibilities    105198     Sort order  TB
Rand axes: UU-L-SIN  VV-L-SIN  WW-L-SIN  BASELINE  TIME1
           SOURCE  FREQSEL  WEIGHT  SCALE
--------------------------------------------------------------
Type    Pixels   Coord value  at Pixel    Coord incr   Rotat
COMPLEX      1    1.0000000E+00    1.00 1.0000000E+00    0.00
STOKES       4   -1.0000000E+00    1.00-1.0000000E+00    0.00
IF           2    1.0000000E+00    1.00 1.0000000E+00    0.00
FREQ         1    1.4524000E+09    1.00 2.5000000E+07    0.00
RA           1     00 00 00.000    1.00      3600.000    0.00
DEC          1     00 00 00.000    1.00      3600.000    0.00
--------------------------------------------------------------
Maximum version number of extension files of type HI is   1
Maximum version number of extension files of type AN is   1
Maximum version number of extension files of type NX is   1
Maximum version number of extension files of type SU is   1
Maximum version number of extension files of type FQ is   1
Maximum version number of extension files of type CL is   1
Maximum version number of extension files of type SN is   2
```

This compressed (`COMPLEX Pixels = 1`) *uv* database contains 9 random parameters, 4 polarizations, 1 frequency, and 2 IFs. for *each* of 105198 visibilities. The size of the database file itself is, therefore,

$$\Big[\{9 + [1 \times 4 \times 1 \times 2]\} \times 105198 \times 4\Big] \text{ bytes} = 7.153\,\text{Mbytes}.$$

Note that this data set is 17/33 the size of an uncompressed data set.

### F.1.2 Compressed format for *uv* data

The use of "compressed" data can make substantial savings in the amount of disk space that you require, particularly for spectral-line databases. All tasks should now be able to handle either the compressed or the uncompressed formats. Compressed data files can be identified by the dimension of 1 for the `COMPLEX` axis in the database header. (Uncompressed data will have a dimension of 3.) The savings can be close to a factor of three for spectral line observations.

This is achieved by converting all data weights into a single `WEIGHT` random parameter, by finding a single `SCALE` random parameter with which to scale all real and imaginary parts of the visibilities into 16-bit integers, and by packing the real and imaginary terms into one 32-bit location using magic-value blanking for flagged data. This is to be compared with the uncompressed format in which each of the real, imaginary and weight terms are each stored in a 32-bit floating-point location. The use of a single weight value masks *real* differences in system temperatures between polarizations and IFs, which one should retain for the lowest possible noise in imaging.

In general, data compression is a good thing and should be used, but with a little caution. With a single frequency, single IF, and single polarization, you will not save any disk space. In all other cases, there are respectable savings to be made. However, the use of a packed data word for the real and imaginary parts of the visibility function along with magic value blanking imposes a restriction on the "spectral dynamic range" of the data set of around 32000:1. Consequently, there are some situations where compressed data should *not* be used. For example, if the spectral dynamic range in the *uv* database is likely to be greater than, say, 1000:1, you must use *uncompressed* data format to avoid loss of accuracy. This situation can arise in maser spectra, for example, in which there are maser lines of 1 Jy and $> 32000$ Jy; in this case, you should never use compressed data. Bandpass calibration can cause large correction factors to be applied to the edge channels of a database. In the presence of noise or interference, bad channels can become very much greater in amplitude than good channels. In such cases you must either use uncompressed format or be very careful to flag bad channels or to drop them with the BCHAN and ECHAN adverbs *as* you apply the bandpass calibration. In general, continuum data sets can be loaded with data compression since these dynamic range considerations will not normally apply. The loss of weight information may not be worth the savings in disk space, however. Compressed data takes less time ro read/write due to the small number of bytes, but casts in cpu time some due to the extra computation.

If there has been on-line or later flagging that depends on polarization, IF, or spectral channel (*i.e.*, RFI excision) or differences in the intrinsic weights between polarizations, IFs, or spectral channels (*i.e.*, different system temperatures for different IFs), then data compression causes a serious loss of information related to the data weight.

## F.2 Image files

Since images are regular arrays, the sizes of image files are easier to calculate. The images are stored as floating-point numbers, *i.e.*, 32 bits per pixel, so the image file size in bytes is given by

$$4 \times \prod_i length(i)$$

where $length(i)$ is the number of pixels on the $i^{th}$ axis. For example, a 128-channel cube with each plane a $256 \times 256$ image will require around 34 Mbytes of disk storage space. This may be increased a little due to the way in which the system allocates space for files.

## F.3 Extension files

Subsidiary data about *uv* database and image files are written in "extension files." These include, for example, history records (HI files), plot instructions (PL files), calibration solutions (SN files), ad nauseum. Some extension files can become large. A history file uses 1024 bytes for every 14 history records, a small amount under most circumstances. A plot file is normally small, but the output from GREYS can be as large as one plane of the image and the output of KNTR is larger by a factor of the number of panes in the plot.

The CL (calibration) table contains the total model of the interferometer at each interval. Many of these logical records are blank in the case of most interferometers but, for the VLBA, these records will contain essential information. The CL table contains a logical record for each antenna in the array at each CL time stamp. The CL time stamps are set by the user when loading the data. The default for VLA data is every 5 minutes. For VLBI data, it is every 1 minute. Each CL logical record requires

$$\{15 + [14 \times (\#\ IFs) \times (\#\ pols)]\} \times 4\,\text{bytes}$$

For a 12-hour observation with the VLA with 2 IFs and 4 polarization pairs, with entries every 5 minutes, the CL table will occupy about

$$\left[\{15 + [14 \times 2 \times 2]\} \times 4 \times \frac{(12 \times 60)}{5} \times 27\right] \text{bytes} = 1.05\,\text{Mbytes}$$

Since most other files are considerably smaller, their sizes can be ignored. That they exist and may require some disk, should not be forgotten. To look at the full AIPS disk usage on your computer in summary form:

| | |
|---|---|
| > TASK 'DISKU' ; INP C_R | to review the inputs. |
| > INDISK 0 ; DETIME 0 C_R | to look at all disks and all data sets |
| > USERID 32000 C_R | to look at all user numbers. |
| > DOALL FALSE ; GO C_R | to run the task in a summary mode. |

Then to look at file sizes in detail:

| | |
|---|---|
| > INDISK $n$ ; USERID 0 C_R | to restrict the display to your data sets and one disk. |
| > DOALL TRUE ; GO C_R | to run the task to list all files on disk $n$. |

## F.4 Storing data on tape

Images and *uv* databases are written to magnetic tape by FITTP for archival purposes and for transfer to other computers and sites. Three FITS-standard formats are available, controlled through the adverb FORMAT. The preferred format is 32-bit floating point (IEEE standard) format. There are no dynamic range limitations in this format and, on many modern computers, no bit manipulation is required since they use IEEE floating internally.

Of the two integer formats, there is little reason to use the 32-bit integer since it poses dynamic range, rescaling, and other problems with no saving in space. The 16-bit integer format uses 16-bit signed 2's complement integers to represent the data. Such numbers are limited to the range -32768 to 32767. FITTP has to find the maximum and minimum in the image and then scale the data to fit in this numeric range. For images of limited dynamic range, this format is perfectly adequate. In fact, FITAB offers the option to reduce the dynamic range even further with the QUANTIZE adverb. For images written to FITS disk files, this allows for better compression before the files are transmitted over the Internet. For high-dynamic range images, the 16-bit format may not be adequate. (The integer formats are no longer allowed for *uv* data. More than one user has reduced all his "good" spectral channels to pure 0 by scaling all the *uv* data to include one really horrendously bad sample.) A less important benefit of the floating point format is that the numbers representing your data are recorded exactly on tape as they are stored on disk; there are no "quantization errors". This may be important for software development.

The preceding paragraphs do not tell the full story, however. The portion of the FITS standard used by FITTP does not allow for *uv* data on tape in a compressed format. Instead, FITTP expands the data into the uncompressed form and then writes the data on tape. In the conversion, the real and imaginary values that were stored in one packed number are expanded into three real values — one each for real, imaginary and weight terms — and the weight and scale random parameters are removed since they are no longer required. Consequently, the compressed data are expanded to

$$\frac{\{(\#\ random\ parameters - 2) + [(\#\ pol) \times (\#\ IFs) \times (\#\ frequencies) \times 3]\}}{\{(\#\ random\ parameters) + [(\#\ pol) \times (\#\ IFs) \times (\#\ frequencies)]\}}$$

the original size (where # *random parameters* is the original number in the compressed database).

As an example, let us consider a multi-source spectral-line database stored on disk in compressed format. The data set has seven channels each at 2 IFs with 2 polarizations. There are nine random parameters and 834031 visibilities. From § F.1, we can calculate the size of the *uv* file to be 123 Mbytes. (Remember, this doesn't include any of the extension files, some of which might be several Mbytes in size.) Before the file is written to tape in 32-bit floating format, it is first expanded by a factor of

$$\frac{\{(9-2)+[2\times 2\times 7\times 3]\}}{\{9+[2\times 2\times 7]\}} = 2.333\,.$$

Consequently, the data will occupy

$$123 \times 2.333\,\mathrm{Mbytes} = 287\,\mathrm{Mbytes}$$

on tape. In other words, this database and all the associated extension files will not fit on a standard, 6250 bpi tape even using `BLOCKING = 10`, but modern tape technology solves this problem.

Note that `FITTP` writes history file data into the FITS header and writes table extension files as extensions after the main image or data set within the same tape file. Plot (`PL`) and slice (`SL`) files are not saved to tape.

Task `FITAB` uses "binary tables" to represent visibility data rather than the old, mildly deprecated "random groups" form of the FITS format. This has several advantages for *uv* data. It allows compressed data to be recorded in that form exactly (except for byte-order questions which should not concern the reader). It also allows the data and attached tables to be divided into pieces which will reduce the size of files to be copied over the Internet, making copying and tape storage somewhat more reliable. The principal disadvantage of `FITAB` *uv* data output is that only two packages can read it so far. Even 𝒜ℐ𝒫𝒮 cannot read the `31DEC07` `FITAB` output except with `31DEC07` and later versions of `UVLOD` and `FITLD`. The one "outside" package that reads the format is `obit` available from Bill Cotton at NRAO Charlottesville.

### F.4.1 DAT and Exabyte tapes

The arrival of modern tape technologies has hastened the demise of 9-track tapes. First Exabyte (8mm) and then DAT (4mm) have provided much higher storage capacities than the 9-track tapes and have also provided faster seeks between file marks and greater data reliability. The new technologies are very much cheaper as well, in part because they have been adopted by the PC market. They are both technically quite complex internally. The DAT tape has a "system log" area at the beginning which allows for the fast seeks. It is a bit fragile, however, since it is updated when the tape is unloaded and hence can be incorrect if there is an unfortunate power failure. Both technologies are still evolving and both now offer various data encoding/compression options. Unfortunately, the data compression techniques vary considerably with tape model and manufacturer and hence should not be used to archive or transport data. The data are blocked on the tapes by means known only to the manufacturers and are not significantly under user control. It is still probably good to use a large `BLOCKING`, but only for I/O transfer reasons. The EOF marks can be expensive on these tape devices.

Exabytes at low density have a capacity of about 2.2 Gbytes on a 112m tape and use about 1 Mbyte (or maybe even 4 Mbytes) for each EOF mark. The large size of the EOF limits the number of files you can write rather significantly. The EOFs are also slow to process mechanically. Exabytes at high density have a capacity of 4.5 Gbytes on a 112m tape and use 48 Kbytes per EOF mark. DATs have a capacity of 2.0 Gbytes on a 90m tape, but also come in 60m and 120m sizes. The EOF mark size is not readily available, but is probably no more than 48 Kbytes. The early warning of the end-of-medium is 40 Mbytes before the actual end of tape.

## F.5 Very large data sets

FITTP and FITAB cannot write multi-volume tapes. Some spectral-line and VLBA databases (and perhaps some continuum databases) may be so large that the file cannot fit on one modern tape even with BLOCKING = 10. What can you do to backup your data? The simplest solution is to use FITAB. This task can write *uv* data in compressed form and can break up a data set into "pieces." You write as many pieces as will fit on the first tape, noting what the piece number is when the end-of-tape is reached. You can then tell FITAB to begin with that piece number on the next tape (BDROP = $n$-1 where $n$ is the number of the piece that encountered the end-of-tape). Unfortunately, the FITS format used by FITAB, while perfectly legitimate, is only understood by *AIPS* versions beginning with 15APR99. Furthermore, the 31DEC07 version of FITAB is only understood by 31DEC07 and later versions of *AIPS*. If the data set is so large that it will not fit on the required tape device using FITTP or the data must be taken to a system that does not understand FITAB's format, there are several approaches that you can adopt.

First, you could SPLIT out the database into *single-source* databases and back each of these up individually. Alternatively, you could subdivide the large database in several smaller databases with UVCOP by specifying a different time range for each of the smaller databases and then back these up individually. Another way to solve the problem is to realize that the calibration and flagging information that you have carefully generated during the calibration is contained in the extension tables — the raw data that you loaded is not modified until you finally SPLIT out the individual sources. Consequently, you can write create a dummy *uv* database to which all the extension tables are attached with the task TASAV, then save this "database" on tape with FITTP. The raw visibilities can be saved in the form of copies of the archive tapes.

## F.6 Additional recipes

### F.6.1 Banana stuffing

1. Pare and rub 4 **bananas** through a sieve into bowl.
2. Add 1/2 grated **onion**, 1 **green pepper** chopped fine, 3 tablespoons finely chopped **parsley**, 4 slices cooked **bacon** chopped fine, 1 1/4 cups **bread crumbs**, pinch of **thyme**, 1 teaspoon **salt**, and 1 **egg**.
3. Mix thoroughly, fill 1 **chicken**, and roast in the usual manner.

### F.6.2 Banana nut bread

1. Cream 1 cup **sugar** and 1/2 cup **margarine** together.
2. Add 2 **eggs**, 2 cups **flour**, 1/2 teaspoon **salt**, and 1 teaspoon **baking soda** and mix thoroughly.
3. Add 1 cup chopped **nuts** (walnuts or pecans), 3/4 cup mashed **bananas**, and, lastly, 4 teaspoons **sour milk** and mix well.
4. Put in greased loaf pan.
5. Bake in 350° F oven for 1 hour.

# Z SYSTEM-DEPENDENT AIPS TIPS

*This appendix has not been kept up to date. The information contained herein is indicative of modern practise but not correct in detail.*

Although AIPS attempts to be system independent, some aspects of its use depend inevitably on the specific site. These vary from procedural matters (*e.g.*, assignment of workstations and location of sign-up sheets, tape drives, and workstations or other terminals) to the hardware (*e.g.*, names and numbers of workstations and tape and disk drives, the parameters of television and array processor devices) to the peculiar (*e.g.*, the response of the computer to specific keys on the terminal, the presence of useful job control procedures). This appendix contains information specific to the NRAO's individual AIPS installations. It is intended that non-NRAO installations replace this appendix with one describing their own procedures, perhaps using this version as a template. The general description of using AIPS on workstations was given in Chapter 2 and will not be repeated here.

Within the NRAO, AIPS is installed on two main architectures — Linux PCs and Mac workstations. All our old SUN, IBM RS/6000, CONVEX C–1 and DEC VAX 11/750 and 11/780 systems have been decommissioned. Currently the fastest AIPS machines in the Observatory are the whichever PC was bought last.

## Z.1 NRAO workstations — general information

All NRAO workstations run some version of the Unix operating system, Linux on PCs and SunOS (Solaris) on Suns. Unix systems are intrinsically sensitive to the difference between upper and lower case. Be sure to use the case indicated in the comments and advice given in the following notes. AIPS itself is case-insensitive, however; conversion of lower-case characters to upper-case occurs automatically. (Unix systems have a variety of characters for the prompt at monitor (job-control) level, and allow users to set their own as well. We will use `$` as the prompt in the text below.)

### Z.1.1 The "midnight" jobs

The versions of AIPS on all NRAO Sun, SGI, DEC, and PC systems are kept up to date continually with the master versions on the Charlottesville Sun called `kochab`. This is achieved by automated jobs that start running at very antisocial hours of the early morning. Any changes formally made to the `TST` version of AIPS are copied to the relevant computers and recompiled/relinked. Midnight jobs run in Charlottesville, Socorro, Green Bank, Tucson, and at several other sites around the world.

### Z.1.2 Generating color hard copy

#### Z.1.2.1 Color printers

Color printers are, these days, simply printers that understand the color extensions to the PostScript language used to describe plots. The NRAO owns two Tektronix Phaser 560 color printers, one in Charlottesville and one at the AOC in Socorro. You may display your PostScript file on the printer in Charlottesville simply by typing

$ lpr -Pps1tek560 *filename* C_R where *filename* is the name of your file.
$ lp -d ps1tek560 *filename* C_R for Solaris systems on Suns

The paper size is 8.5 × 11 inches, which is the default for *AIPS* tasks TVCPS and LWPLA. To have the file printed on transparency paper use queue ps1tektran rather than ps1tek560. Full control over this complex printer is available with the multiprint command; type multiprint --help C_R for information. At the AOC, the queue names are pscolor and psoverhd. If you do not wish to save the plot as a disk file, you may also print it directly from within *AIPS*. The color printer is one of the printer choices when you start up AIPS, but you probably want to select a regular PostScript printer as your default printer. You can change your printer selection with the verb PRINTER; use PRINTER 999 C_R to see what your choices are and the PRINTER *n* C_R to choose the printer numbered *n*. *AIPS* print routines will re-direct PostScript files that actually contain color commands to the first PS-CMYK printer in the list, but will not re-direct ordinary print jobs to some other printer than a color printer. There are some special instructions for the color printer at the AOC in § Z.3.7.

#### Z.1.2.2 Software to copy your screen

To obtain a color hardcopy of what is on your screen, there are three software options you can choose. These are TVCPS, xv, and xgrab. Having created a PostScript file, you can print it on color printers at the NRAO or copy the file via e-mail or scp, rcp, or ftp to some other site for printing.

The TVCPS task in *AIPS* will create a color Encapsulated PostScript file from whatever is displayed on the *AIPS* TV server (XAS). If you use the OUTFILE adverb, this file is saved with whatever name you specify (see § 3.10.1). If you specify a black-and-white output to TVCPS, then the output can be sent to any PostScript printer. Color PostScript must be sent to pscolor or the Solitaire. You can, of course, edit the save file (if you are a PostScript wizard) and can insert the file (since it is encapsulated) in another document. See the Charlottesville Workstation Guide for a short chapter on PostScript

The xv program is a Unix utility program available on most systems at the NRAO. It is mainly intended for image display of GIF, JPG, TIFF, and other format files. When you start xv, click the right button mouse anywhere in the xv window to bring up the control window. One of its features is a screen grab which is controlled by the "Grab" button in the lower right corner of the control window. *Before* you press this, arrange your windows and icons so that you can see exactly what it is you want to grab (*e.g.*, the XAS server). Now press the "grab" button. The bell will ring and the cursor will change to a white cross symbol; move it to the top left of the area you want to grab. Then press and hold down the left mouse button, and drag the mouse cursor until it is at the bottom right of the area you want to grab. As you do this, you will see a box pattern on the screen outlining the area selected. Once you are done selecting the area, release the mouse cursor. When xv has finished grabbing the screen, it will beep twice, and whatever you grabbed appears in the main xv window. You can now use the "save" button of the control window to save this as any format you want. Once nice feature of this is the "save as Postscript" option. It allows you to scale, rotate, and position the image in relation to the page. Its user interface is better than most image utilities.

Finally, the xgrab program provides similar functionality to the "grab" feature of xv, with fewer output formats but much more control over how the grabbing is done. By default it allows three seconds in between starting the grab and when it actually starts to read the screen; this can be useful for setting things up. Also, it un-maps itself from the window when grabbing so you don't have to worry about getting it out of the way. Unfortunately, there appears to be some problems with its encapsulated PostScript output.

### Z.1.3 Color film recorders

The NRAO used to own two Solitaire film recorders, one in Charlottesville and one at the AOC in Socorro. Both have now been decommissioned. You are likely to find commercial services in any good-sized town to take PostScript files on floppy or zip disk to convert into slides.

### Z.1.4 Gripe, gripe, gripe, ...

Each week, one of the (few) members of the AIPS group is the so-called "designated AIP." It is this person's job to assist local and remote users with their AIPS problems. Often this person will provide advice or simple fixes to bugs, while more complex problems may be passed off to the person in the group who understands that area best. Contact the designated AIP (and all members of the group) at the e-mail address `daip@nrao.edu`.

Suggestions and complaints entered on all computers with the GRIPE verb (see § 11.1) are sent immediately by e-mail to several addresses in the AIPS programming group, including `daip`. The most urgent are addressed and, sometimes, answered. All gripes were entered into a database which resides on `zia.aoc.nrao.edu`. Users may read the contents of this database in as much detail as they can stand. To do so, login to the account called `gripe` on `zia`. This is a "captive" account, requiring no password, and allowing you only to execute an especially prepared version of the text editor `emacs`. When you tire and exit the special `emacs`, you will be logged out of `zia`. Note that this system has not been maintained in recent years due to the decreases in manpower and increases in the use of e-mail and direct computer connections.

After you log in, you will be presented with a selection/options menu. Fill in and/or alter some of the selection criteria to limit which gripes you will view. Then, select display option `index`, and, `only` when you are fully ready, hit a $C_R$. You will be shown a descriptive list of the selected gripes. If you wish to read one of them in detail, move the cursor to it and hit $C_R$. The space bar gets you the text of the next gripe and typing the letter `q` returns you to the index. Another `q` returns you to the selection/option form. Typing a `?` in any of the displays will provide you with information on all the options available at that level of the system.

AIPS Memo No. 88 describes the system in some detail. This memo may be available on your AIPS system as file `$AIPSPUBL/AIPSMEMO88.PS` in PostScript form. It is also available to the "World-Wide Web" (start with "URL" `http://www.cv.nrao.edu/aips/aipsdoc.html`) so that it may be examined and retrieved over the Internet. The file used is also available via anonymous `ftp` on host `kochab.cv.nrao.edu` as a PostScript file named `/pub/aips/TEXT/PUBL/AIPSMEMO88.PS`.

### Z.1.5 Solving problems at the NRAO

Below are details specific to the Charlottesville and Socorro systems for handling some of the problems which may arise in AIPS.

#### Z.1.5.1 Booting the workstations

Modern workstations, especially the powerful Suns and PCs, are complex Unix systems which may have remote users within the NRAO and guests from elsewhere on the Internet. Users should *never* attempt to boot the system on their own. If the machine appears to be dead, find or call one of the people listed on the bulletin boards in the AIPS Caige for this purpose.

#### Z.1.5.2 Printout fails to appear

Check the *AIPS* output messages that appeared shortly after you submitted your print job, whether it be from `PRTMSG` or `LWPLA`, or some other task. You should see the output of the Unix command to show the printer queue status. If anything went wrong with the print submission, an error message should be obvious. If not, check the output of the `lpq` (or `lpstat` for Solaris 2.$x$) command, see what print queue was involved, and check it again from the Unix command level (not from inside `AIPS`).

`AIPS` will delete spooled files about 5 minutes after they are submitted. If the print queue is stalled (due, say, to a jammed printer) or backed up with a lot of jobs, it is possible that the file was deleted before it was gobbled up by the print spooler. This time delay has been made a locally-controlled parameter, so it is possible to set it to values higher than 5 minutes. At this writing, the Charlottesville systems are using a 20-minute delay time.

Finally, check to see if the printout was (a) diverted to the "big" printer (`psnet` in room 213 at the AOC or `ps3dup` in the Charlottesville library) because it was too long for the smaller printers, (b) you forgot which printer you had selected on `aips` startup, or, at the AOC, (c) someone has taken the output and filed it in the "today" file bin (at the AOC this is on the left side of the post directly behind the `psnet` printer).

#### Z.1.5.3 Stopping excess printout

To find out what jobs are in the spooling queue for the relevant printer, type, at the monitor level:

| | |
|---|---|
| $ lpq C_R | to list default print queue |
| $ lpstat C_R | to list default print queue under Solaris |

or to display a specific queue

| | |
|---|---|
| $ lpq -P*ppp* C_R | to show printer *ppp* |
| $ lpstat *ppp* C_R | to show printer *ppp* under Solaris |

where *ppp might* be `psnet` at the AOC or `ps3dup` in Charlottesville. If the file is still in the queue as job number *nn*, you can type simply

| | |
|---|---|
| $ lprm -P*ppp* *nn* C_R | to remove the job |
| $ cancel *nn* C_R | to remove the job under Solaris |

`lprm` and `cancel` will announce the names of any files that they remove and are silent if there are no jobs in the queue which match the request.

Unfortunately, it is now very difficult to stop long print jobs. The large memories of modern printers mean that more than one print job can already be resident in the printer while your long unwanted job is being printed. Therefore, turning off the printer is not an option. Try to be more careful and not generate excess printout in the first place (save a tree).

A nice option available for most *AIPS* print tasks or verbs is adverb `OUTPRINT` which allows you to divert the output to a text file. Then you can use an editor like `emacs` to examine the file in detail before printing. The Unix command `wc -l file` will count the number of lines in a text file called `file` for you; note that `-l` is the letter ell, not the number one. *AIPS* provides a "filter" program to convert plain (or Fortran) text files to PostScript for printing on PostScript printers. The command

$ F2PS -*nn* < *file* | lpr -P*ppp*

will print text file *file* on PostScript printer *ppp*. The parameter *nn* is the number of lines per page used inside *AIPS*; it is likely to be 97 if direct printing comes out in "portrait" form or 61 if the direct print outs come out in "landscape" form.

It is not unusual for *AIPS* jobs to be in the 1 Mbyte or more in length, which will take 5–10 minutes to print. For large text files, it is quite likely that the `ZLPCL2` shell script will divert the job to a "big" printer (in Socorro, `lp27` in room 213). However, graphics files are not subject to such restrictions.

If you plan on generating large or very complex plot files which you intend to print, please select the `psnet` printer at the AOC or the `ps3dup` printer in Charlottesville. Since they are, effectively, on the ethernet, the bandwidth to it is usually an order of magnitude faster than any serial line. You — and others — will have to spend less time waiting for jobs to come out of the printer. If you are submitting jobs which you know are several Mbyte in size, we ask that you wait until after local business hours to avoid tying up the printer.

#### Z.1.5.4 `CTRL Z` problems

The last process placed in the background via `CTRL Z` can be brought back to the foreground by typing fg $C_R$ in response to the monitor level `%` or `$` (or whatever) prompt Alternatively, the user can type jobs $C_R$, which displays all background processes associated with the current login and can bring a specific process to the foreground by typing fg *% m* $C_R$, where *m* is the job number as displayed by the `jobs` command as `[`*m*`]`. For example, if a user initiated his `AIPS`*n* by typing aips new pr=4 $C_R$ and:

| | |
|---|---|
| `^Z` | `CTRL Z` typed by accident (or intentionally). |
| `Stopped` | `aips new` is put in the background as "stopped" and user is returned to the Unix level. |
| `$` jobs $C_R$ | to display status of background jobs. |
| `[1] + Stopped    aips new` | info from Unix, where `[1]` means job 1, "Stopped" is job 1's state and "aips new" is the command used to start up job 1. |
| `$` fg *m* $C_R$ | to return job *m* to the foreground. |
| `aips new` | appears on the screen just to tell the user to which job he is talking (*i.e.*, it does *not* re-execute `aips new`). You should now be talking to your `AIPS`*n* again. |
| $C_R$ | to get `AIPS`*n* `>` prompt. |

#### Z.1.5.5 "File system is full" message

The message `write failed, file system is full` will appear when the search for scratch space encounters a disk or disks without enough space. This is only a problem when none of the disks available for scratch files has enough space, at which point the task will shut down. Use the `BADDISK` adverb to avoid disks with little available space.

#### Z.1.5.6 Tapes won't mount

Occasionally, both local and remote tape mounts may not work successfully. The source of the problem is often your failure to load the tape physically into the device or to wait until the device is ready to read the tape. DATs and Exabytes, in particular, go through lots of clicking and whirring before they are really ready. An error message like

```
AIPS 1:  ZMOUN2:  Couldn't open tape device /dev/nrst0
```

(or some other tape-device name gibberish) is to be expected in this case.

If you attempt to mount a remote tape and get the messages:

```
AIPS 1:  ZMOUNR: UNABLE TO MOUNT REMOTE TAPE DEVICE, ERROR 96
```

```
AIPS 1:  AMOUNT: TAPE IS ALREADY MOUNTED BY TPMON
```

it means that your AIPS and the tape dæmon that you are using disagree on whether the tape is already mounted in software. The most probable reason for this is that you are attempting to mount someone else's tape (check your inputs and the labels on the device closely) — or that the previous user of the device dismounted the tape from the hardware but neglected to do it from software. In this case, you have two choices: (1) find the culprit and have him do a software dismount, or (2) find an *AIPS* Manager to kill the confused dæmon and restart it. (If you are using tape device $n$ on computer *host_name*, then you need to stop the process called TPMON$m$, where $m = n+1$ on computer *host_name* and then start it again by running /AIPS/START_TPSERVERS on that computer. This should be done by an *AIPS* Manager.)

If you attempt to mount a remote tape and see, instead, the messages:

```
ZVTPO2 connect (INET): Connection refused
AIPS 1:  ZMOUNR: UNABLE TO OPEN SOCKET TO REMOTE MACHINE, ERROR 1
AIPS 1:  ZMOUNT: ERROR 1 RETURNED BY ZMOUN2/ZMOUNR
```

then the tape dæmons are not running on the remote machine. Log into the remote machine as user aips and type:

```
/AIPS/START_TPSERVERS
```

After a minute or two, you should see some messages from STARTPMON about starting TPMON dæmons. Alternatively, you could exit from AIPS and start back up again, including tp=*host_name* on the aips command line; see § 2.2.3. If the tape still doesn't mount after doing this, see the *AIPS* Manager.

#### Z.1.5.7 I can't use my data disk!

If at some point during your work you find you are prevented from reading or writing files on a data disk, it could be that your *AIPS* number does not have access to that area. If you encounter the message:

```
AIPS 2:  CATOPN: ACCESS DENIED TO DISK 8 FOR USER 1783
```

it means that user 1783 has not been given access to write (or read) on disk 8. This can be seen, in the AIPS session, by typing FREESPAC to list the mounted disks. If you see a data disk listed with an access of Not you, it means your *AIPS* number has not been enabled for that disk. If you feel that you should have access to that particular disk, see the data analysts (at the AOC) or an *AIPS* Manager about enabling your user number.

## Z.2 *AIPS* at the NRAO in Charlottesville

The Charlottesville *AIPS* Caige is located in Room 111 on the first floor of the Edgemont Road Office Building. There are four public workstations available there: "vulcan'' a Dell PC, "valen" a Gateway PC, "hominid" a DEC alpha workstation and "lemur" a Sun 2-headed workstation. For normal plots and print jobs there is an HP LaserJet printer called ps1 down the corridor in Room 106. This printer is a network printer and will print in duplex mode in queue ps1dup. Large graphics plots from LWPLA can be sent to the network HP printer in the library (called ps3), while long print jobs should be (and will automatically be) sent to this printer in duplex mode (called ps3dup). There is a Tektronix Phase 560 color printer known as ps1tek560 in the *AIPS* Caige for special plotting and color displays (*e.g.*, from TVCPS) on either paper or transparencies (queue ps1tektran.

The PCs run under relatively current releases of Linux, the free version of the Unix operating system, while the Suns run under versions of SunOS, now called Solaris. They are equipped with color display screens, $1280\times1024$ ($1270\times924$ used by XAS). All are able to display in 24-bit TrueColor. Each system has substantial amounts of disk space. At this writing, vulcan has the most with 4 *AIPS* "disks" (55 Gbytes), valen has

4 (27 Gbytes), hominid has 5 (22 Gbytes),and lemur has 7 (20 Gbytes). All systems have at least one 4mm DAT. There is an 8mm Exabyte on vulcan and lemur and there is a DLT and an AME Mammoth drive on lemur.

### Z.2.1 Using the Charlottesville workstations

#### Z.2.1.1 Signing up for AIPS time in Charlottesville

The sign-up sheets for AIPS on these computers are found on the notice board just to the left of the entrance to the AIPS Caige, Room 111. If you wish to be certain of the availability of a computer, it is advisable to sign up for your AIPS time in advance. To promote fair and efficient use of the system, users are asked to restrict the amount of time that they reserve. Formal rules are not now in effect, but may be imposed should the need arise.

AIPS on the large systems supports up to eight simultaneous interactive users, plus two batch queues. Any user who has signed up has priority for the use of the cpu, console (display), and local tape drives, but is expected to be reasonable about sharing these resources, particularly the tape drives. Visitors to Charlottesville should call Jim Condon, in advance of their arrival, to avoid conflicts with other visitors and to arrange for sign-up time.

#### Z.2.1.2 Managing workstation windows in Charlottesville

After you have logged on to any Sun or IBM as user-id aips, the X-Window system should appear. Unlike the AOC where there are different window managers for IBMs and Suns, at Charlottesville the aips account always uses the fvwm window manager. AIPS may also be run from your own account — we prefer that you do that — but your account must be included in the aipsuser group and your startup procedures must start some X-Windows window manager, preferably fvwm.

The window manager allows you to create, destroy, modify, and select an active window on the screen. When you first start up (in the aips account, there will be at least two xterm terminal emulator windows on the screen, one green and one blue. The green one is for console messages and is usually quite small. The blue one is intended to be the main work area and it is in this window that you probably will start up AIPS itself. There may be additional windows like a clock, a load meter, and other tools.

The default behavior of the window manager is "focus follows pointer." What this means is that in order to use one of the windows, you merely move the cursor with the mouse so that it is within the main part of the window and start typing. Most windows will have a title bar on the top; you can "grab" this title bar by moving the mouse cursor onto it and holding and keeping down the left mouse button; then moving the mouse will also move the window. There is a small square symbol on the right of the title bar (with a dot in the center) that, if pressed with the left mouse button, will iconify the window (you can grab and drag icons too). Clicking once with the left mouse button on any icon will de-iconify, or open it.

The icon panel on the right offers window options (resize, move, quit, kill) and useful tools such as a desk calculator, the emacs editor, xv, Netscape and more. The mouse buttons bring up a series of menus when they are pressed on the background, or root window. The right mouse button shows various window operations such as "raise" and "move." The middle mouse button shows a list of current windows. The left mouse button shows a menu of options; the most useful item on this is a "pull-right" option "Xterm" which, when you press it and "pull right" by dragging the mouse a little to the right, shows another menu with different foreground/background colors. Choose one of these and you will get an xterm terminal emulator with those color combinations. There is also a pull-right menu for remote login to various other useful machines in Charlottesville and other NRAO sites. A wide variety of useful and/or fun programs are also available through other pull-right options.

To start AIPS, choose the xterm window that you want to work with (or create a new one), and type, *e.g.*, from vulcan

```
aips tst pr=3 da=valen tp=lemur
```

This example command selects the TST version of AIPS (the default anyway), chooses printer number 3 (on the ground floor) as the default printer for text and graphics output, makes the data areas from valen accessible (via NFS) in addition to local data areas on vulcan, and makes sure that the TPMON dæmons for remote tape access are running on remote host lemur. These options are explained in some detail in § 2.2.3 and may be viewed in even greater detail by typing HELP AIPS C_R inside AIPS or by typing man aips C_R from the Unix command line.

#### Z.2.1.3 Data disk management in Charlottesville

It is possible to configure *AIPS* so that disk one is some data area common to all local computers. If this is done, your message and SAVE/GET files, which are kept on disk 1, will be the same no matter what computer you are using. There are two problems with this. The PCs and DEC alphas have one computer architecture and the Suns have another; the two architectures cannot share *AIPS* files. But, even if the architectures are the same, the problem is that the Network File System has to wait while disk reads and writes are completed, while reads and writes on local disks may be done asynchronously using large memory buffers in the Unix operating system. Thus, the writing of messages, in particular, is virtually instantaneous on local disks, but costs about one second per message over NFS. Therefore, all NRAO *AIPS* systems use data areas local to the systems for disk one and the other manin data disks.

The same consideration applies to disks used for image and *uv* data files. It is not too expensive to read such files over NFS, but you should only write data to disks on the computer you are using. You should also restrict all scratch files to be on local disks, using the adverb BADDISK to inhibit all NFS disks. Note, that the computer you are using does not have to be the one which you are sitting in front of. You may do an slogin, rlogin, or telnet from an xterm window on, say, the Sun on your desk to, for example, vulcan. Then, when you run AIPS in that window, the local disks will be the ones attached to vulcan. Under many circumstances, the aips procedure will be able to figure out which Sun you are actually typing on and use it for the *AIPS* TV, message, and graphics servers (all both executing and displaying on your Sun).

### Z.2.2 Using the tape drives in Charlottesville

For a general discussion of magnetic tapes, including the *required* software mount, see § 3.9. The following describes how to deal with the physical tape drives themselves.

#### Z.2.2.1 Mounting and removing tapes on 9-track drives

If the front door of the tape unit is not open, it may be in use. Ask around before doing anything. When you're certain that it's okay, press the "offline" button, then press the "Unload/Open" button. The door should drop open for you.

Once the door is open, get ready to put your 9-track tape in. Put a write ring in the tape only if you intend to write on the tape during this *AIPS* session. These drives do not support auto-load rims, so all rims must be removed from the tape before loading. Slide the tape spool in sideways with the label facing up until it sits on the central hub (it will feel like it's balanced). Then close the door. After the display indicates that the drive is ready, you can perform the software mount from AIPS.

#### Z.2.2.2 Mounting tapes on Exabyte and DAT drives

Exabyte (8mm) and DAT (4mm) drives have a window or opening through which a mounted tape may be seen. Before touching anything, look in the window or opening to see if there is already a tape in the drive. If there is, ask around to make sure that the tape is no longer in use. Remember that the user of the drive may be in an office as much as two floors away and that Unix does not provide much protection. If you dismount a remote user's tape and mount your own, that user may well write on it, thinking that he is writing on his own tape, without knowing that he is destroying all your data.

On most drives, there will be a single button on the front panel of the device somewhere. When the device becomes available, press this button to open the door. If there was already a tape in the drive, it will be ejected after some whirring and clanking and a few seconds. If a tape is ejected, remove it. Now put your tape in the drive, label facing upwards. On Exabytes, push the door closed gently. For DAT drives, lightly push the tape into the drive until the device "grabs" the tape and pulls it in the rest of the way. Exabyte and DAT tapes have a small slide in the edge of the tape which faces out which takes the place of the write ring of 9-track tapes. For 8mm (Exabyte) tapes push the slide to the right (color black shows) for writing and to the left (red or white shows) for reading. With 4mm DAT tapes, the slide also goes to the right for writing (but white or red shows) and to the left for reading (black shows).

It is necessary to wait until the mechanism in the drive has "settled down", *i.e.*, when the noises and flashing lights have stopped, before you can access the drive. The first access is, of course, the software `MOUNT` command from inside `AIPS`.

### Z.2.3 Color hard copy in Charlottesville

Having created a PostScript file containing color commands or pictures (see § Z.1.2.), you can print it either on a Tektronix Phaser 560 color printer known as `ps1tek560` in the *AIPS* Caige for plain paper or `ps1tektran` for transparency "paper." Special Tektronix paper is loaded into trays, one of which is used for plain paper and the other for transparency paper. Do *not* use the wrong type of paper for the tray you are filling. Additional boxes of paper may be found inside the cabinet to the left of the printer. When the little green light on the right hand side of the printer is blinking, the printer is either receiving data or computing on data already received. The computer inside the printer is actually rather fast, but a color picture is usually a large data file which takes a while to transmit and display. When the printer is done, it will eject the paper fully.

## Z.3 *AIPS* at the NRAO AOC in Socorro

Most workstations at the AOC are Linux computers, many being dual quad-core machines with 16 Gbyte of RAM and a lot of disk. One old Solaris machine remains available if required. A complete list of the public-use workstations can be found on the web at `http://www.aoc.nrao.edu/`; select "Official Visitors" and then "public workstations." All are equipped with appropriate tape (DAT) devices.

While there are several printers available to users at the AOC, most *AIPS* users will want to use the high-volume PostScript printer `psnet` and the Tektronix Phaser 560 color printer `ps213c`, both of which are located in Room 213.

### Z.3.1 Reserving public-use workstations at the AOC

If you are visiting the AOC for observing or to reduce data then you should fill out a visitor reservation form at least two weeks before you expect to arrive. These forms can be found on the web at `http://www.aoc.nrao.edu/`, select "Official Visitors" and follow instructions from there.. If you check "OBSERVING AND/OR DATA REDUCTION" as your purpose of visit at the end of Section A of the reservation form then you will automatically be assigned a workstation. If you have any special data reduction needs then you should make a note of them in the comments section of the form.

If you are unable to fill out this form using the web or if you have any questions about reservations, you should contact AOC reservations at 575–835–7357 or `nmreserv nrao.edu`. Note that reservations for VLBA projects will not be accepted unless the observer has been notified that correlation is complete and that the data have been scrutinized. If you have any special data reduction needs then you should make a note of them in the Section C of the form.

If you are an AOC staff member and wish to sign up for a public-use workstation then you should contact `helpdesk@nrao.edu` or visit real people in Room 262. In general, visitor's reservations take priority over reservations for AOC staff.

### Z.3.2 Using AOC workstations — introduction

In order to start *AIPS* you need to log in to your assigned workstation and open a terminal window. At the AOC, we generally use the windowing environments supplied by the operating system vendors rather than imposing a lowest-common-denominator "standard" environment. This means that the procedures for logging on and manipulating windows depend on the type of system that you are using. The following sections will provide you with enough information to log in and open a terminal window on the different systems. Linux systems are not covered at this time.

Starting *AIPS* once you have a terminal emulator window is much the same on all workstations and will be covered in a later section.

### Z.3.3 Using SPARCstations at the AOC

There are two windowing environments available to you on the SPARCstations at the AOC. The Common Desktop Environment (CDE) is Sun's preferred environment while the older and less capable OpenWindows environment is still available. The CDE resembles MicroSoft Windows in several respects (both are derived from a set of user interface recommendations developed by IBM) and is probably the easier environment to use if you are not already familiar with OpenWindows.

#### Z.3.3.1 Logging on and choosing your environment

On sitting down at a Solaris workstation you will be presented with a log-in window that has a space for you to type your user name. Enter your username and press return and then, when prompted, enter your password and press return again. The screen will blank and you will then enter the windowing environment that was last used for this account. If you are using a shared account like `aips`, this may not be the environment that you want.

To choose a specific environment, use the mouse to move the pointer to the "Options" button on the log-in screen. Press the left-most button on the mouse and hold it down. A menu will appear. Move the pointer to the "Session" item while keeping the button pressed. This will cause a submenu to pop-up. Still keeping the button pressed, move the pointer to the "Common Desktop Environment (CDE)" item or the "OpenWindows" item, depending on which you prefer, and release the mouse button. You may then log in as before and should enter your preferred environment.

**Hint** When you enter your user name, the graphic to the right of the log-in area will change to indicate the current environment for that account. If you don't like this choice, you can change it using the "Options" menu before you enter the password.

#### Z.3.3.2 Using CDE

CDE will present you with a control panel at the bottom of the screen. The central part of the panel contains a set of buttons that you can use to swap between different "workspaces". You can use these workspaces to organize the windows that you open. Click on the small padlock item near these buttons to lock the screen or click on the button marked "EXIT" to log out. The remaining part of the control panel contains a set of icons that start various applications. If you have not used CDE before, you will probably want to click on the icon that shows a question mark superimposed on a row of books; this will open a help window that contains a short introduction to CDE.

There are small tabs above the icons on the control panel, some of which are marked with a small triangle. Clicking on a tab that is marked with a triangle will pop up a menu that allows you to start more programs. These menus will disappear when you select an item from them or click on the arrow a second time.

If you log in to the `aips` account using CDE you should find that a file manager window and at least one terminal emulator window have been opened for you. You can open more terminal windows in one of two ways[1]. The first is to click on the "Terminal" item in the pop-up menu above the pencil-and-paper icon in the left-hand segment of the control panel. The second is to click on the "Open Terminal" item in the "File" menu belonging to the file manager. If you open the terminal the first way, your initial working directory will be the home directory for the account you are using; if you open it the second way, your initial working directory will be the directory shown in the file manager window.

There are two features of the CDE terminal emulator that you should be aware of. The first is that you can quickly switch the terminal to an 80 or 132-character wide mode using the "Window Size" submenu of the "Options" menu. The second is that the "Options" menu contains a "Reset" submenu with options for hard and soft resets; the hard reset option will usually get your terminal back into a sensible state if you have accidentally set it into a state where it is displaying wierd characters (which often happens if you mistakenly try to display the contents of a binary file).

You can resize windows under CDE by dragging the edges or corners of their frames using the mouse or move them by dragging the title area. The small button with a horizontal bar to the left of the title activates a pop-up menu for window management operations. Double click this button to close the window. The two small buttons to the right of the title shrink the window to an icon (dot) or expand it to maximum size (square).

Iconized windows may be placed on the workspace or in a special icon box, depending on the environment settings. Double click on an icon to restore the corresponding window.

**Caution** The Common Desktop Environment is highly customizable. Please refrain from making significant changes while using a shared account such as `aips` to avoid annoying the other users of this account.

[1] There are actually more than two ways to open a terminal emulator but we only cover the simplest options here.

**Hints** Pressing the "Alt" key in combination with the function keys provides short cuts for many window-system operations. The most common combinations are `Alt-F4` to close the active window and `Alt-F3` to push the active window behind all the others.

**Changes for Solaris 7 and later** Sun added several new tools to the CDE desktop in Solaris 7 and rearranged the control panel. If you are using Solaris 7 and later you open a terminal window by selecting "This Host" from the pop-up menu above the CPU and disk activity meter (a pair of red and blue bars) in the right-hand segment of the control panel.

#### Z.3.3.3 Using OpenWindows

If you log in to the `aips` account using OpenWindows, you will usually be presented with one or more open terminal windows in which you can run AIPS. You can create more terminal windows by moving the pointer to an empty section of the screen, pressing the right-hand mouse button to bring up the workspace button, and then selecting "shell tool", "xterm", or "command tool". The first two of these options will open submenus that allow you to choose from a variety of color schemes (most of them lurid).

Log out by pressing the right-hand mouse button while the pointer is over an empty section of the screen and then selct the "Exit" option from the menu that appears.

**Caution** The OpenWindows environment can be customized to a certain degree. Please refrain from making significant changes to the OpenWindows environment while using shared accounts such as `aips` to avoid annoying the other users of these accounts.

### Z.3.4 Using the SGI workstations at the AOC

If you are using one of the "satellite" SGI workstations, you will be presented with a login window with a space in which to type your user name. Type your username and press return at which point a second space will appear for you to enter your password. After you enter your password and press return, you will be taken into the SGI windowing environment.

You should see a vertical stack of buttons on the screen with the label "Toolchest" above them. To start a terminal window, move the pointer to the button marked "Tools" and hold down the left-hand mouse button and then select "Shell" from the menu that appears and release the button.

You can resize windows by dragging the edges or corners of their frames using the mouse or move them by dragging the title area. The small button with a horizontal bar to the left of the title activates a pop-up menu for window management operations. Double click this button to close the window. The two small buttons to the right of the title shrink the window to an icon (dot) or expand it to maximum size (square).

Iconized windows are placed on the workspace. Double-click on an icon to restore the corresponding window.

When you are ready to log out, press either the left or right-hand mouse button while the pointer is over an empty region of the screen and select "Log Out" from the menu that appears.

### Z.3.5 Starting *AIPS*

Once you have logged in to your workstation and have a terminal emulator window open, you may start *AIPS*İf you wish to run *AIPS* on the machine at which you are sitting we recommend that you start *AIPS* with the following command.

```
aips tst pr=4
```

This will bypass the printer menu and select the high-volume PostScript printer `psnet` in Room 213 as the default AIPS printer.

Note that *AIPS* is configured not to start a separate message window at the AOC. We have found that most users find the message window to be annoying rather than useful. If really want the separate message window to appear, issue one of the following commands before starting *AIPS*.

```
export AIPS_MSG_EMULATOR=xterm
```

If you are using the KornShell or bash.

```
setenv AIPS_MSG_EMULATOR xterm
```

If you are using csh or tcsh

You may replace `xterm` with the name of another terminal emulator (e.g. `dtterm`) if you wish and you can also turn off the Tektronix emulator using one of the following commands.

```
export AIPS_TEK_EMULATOR=none
```

If you are using the KornShell or bash.

```
setenv AIPS_TEK_EMULATOR none
```

If you are using csh or tcsh

If the *AIPS* TV is already running, you may use the following to avoid the messages that are produced as *AIPS* figures out whether the TV is already running.

```
aips tst pr=4 tvok
```

#### Z.3.5.1 Starting *AIPS* on another machine

If you are going to run *AIPS* on a remote machine and use your local workstation as a display, we recommend that you start *AIPS* on your local workstation first and allow it to start the TV. You can then iconize the terminal that you are using to run *AIPS* and open a new terminal window. You should then use the `slogin` or `rlogin` command (`slogin` is preferred) to log in to the remote machine. You should then start *AIPS* using the following command.

```
aips tst pr=4 tv=mydisplay tvok
```

You should replace `mydisplay` with the name of the workstation that you are sitting at.

The SGI workstations are a special case in that they can not run *AIPS*İf you are using an SGI workstation, you should not try to start *AIPS* on the local machine but go directly to the remote machine and start *AIPS* there, omitting the `tvok` argument unless the TV is already running on your workstation.

### Z.3.6 Using the tape drives at the AOC

For a general discussion of magnetic tapes, including the *required* software mount, see § 3.9. The following describes how to deal with the individual tape drives at the AOC.

#### Z.3.6.1 Mounting tapes on Exabyte and DAT drives

Exabyte (8mm) and DAT (4mm) drives have a window or opening through which a mounted tape may be seen. Before touching anything, look in the window or opening to see if there is already a tape in the drive. If there is, ask around to make sure that the tape is no longer in use. Remember that the user of the drive may be in an office as much as two floors away and that Unix does not provide much protection. If you dismount a remote user's tape and mount your own, that user may well write on it, thinking that he is writing on his own tape, without knowing that he is destroying all your data.

On most drives, there will be a single button on the front panel of the device somewhere. When the device becomes available, press this button to open the door. If there was already a tape in the drive, it will be ejected after some whirring and clanking and a few seconds. If a tape is ejected, remove it. Now put your tape in the drive, label facing upwards. On Exabytes, push the door closed gently. For DAT drives, lightly push the tape into the drive until the device "grabs" the tape and pulls it in the rest of the way. Exabyte and DAT tapes have a small slide in the edge of the tape which faces out which takes the place of the write ring of 9-track tapes. For 8mm (Exabyte) tapes push the slide to the right (color black shows) for writing and to the left (red or white shows) for reading. With 4mm DAT tapes, the slide also goes to the right for writing (but white or red shows) and to the left for reading (black shows).

It is necessary to wait until the mechanism in the drive has "settled down", *i.e.*, when the noises and flashing lights have stopped, before you can access the drive. The first access is, of course, the software `MOUNT` command from inside `AIPS`.

The tape drives for `ohsumi`, the Origin 200, are located in the two system units. These are two indigo tower units underneath the bench in Room 259. The Exabyte is in the left-hand tower while the two DATs are in the right-hand tower; somewhat confusingly the upper DAT is *AIPS* drive 3 while the lower one is drive 2. You must open the door at the front of each tower to gain access to the drives. The door hinges are fragile so please open the doors carefully and shut them after you have inserted or extracted the tape so that they do not get kicked accidentally.

#### Z.3.6.2 On-line `FILLM`

On-line `FILLM` can be used both inside the AOC and at the VLA site. If you are planning to use on-line `FILLM` you should contact Eric Greisen (575–835–7236) or Gustaaf van Moorsel (575–835–7396) for instructions.

### Z.3.7 Color hard copy at the AOC

Having created a PostScript file containing color commands or pictures (see § Z.1.2.), you can print it on the color printer in Room 213 or the one in Room 352. The plot may be printed directly from `AIPS`; use `PRINTER 999` C<sub>R</sub> to see the printer choice and `PRINTER` $n$ C<sub>R</sub> to select choice $n$.

The `lp` or `lpr` commands may be used to print a file to queue `aoc352c` (single-sided), `aoc352c/dup` (double sided), or `aoc352c/trans` (transparency). Substitute 213 for 352 is you want the printer on the ground floor.

## Z.4 *AIPS* at the NRAO Very Large Array site

*AIPS* is installed on a SPARCstation called `miranda` with a single Exabyte drive in the control room at the VLA site. This is not intended for large-scale data reduction but can be used for a quick first-look at your data. There is no reservations system for this workstation: feel free to use it if it is not in use. If there is more than one observing team at the site, priority should be given to the current observer.

This machine is essentially identical to the SPARCstations at the AOC and the same operating procedures can be used except that you should not specify the `pr=4` argument when you start *AIPS*: there is only one printer available at the VLA. This printer is on the left-hand side of the control room as you look towards the window.

## Z.5 Additional recipes

### Z.5.1 Sautéd sole tobago with bananas, pecans and lime

1. Preheat 1/2 cup **vegetable oil** in a heavy sauce pan over medium-high heat.
2. Dredge 8 filets of **sole** or **flounder** lightly in **flour**.
3. Sautée until golden brown, about 3 minutes each side. Remove to warm platter.
4. Pour off excess oil and wipe down sauce pan. Place pan back on stove over high head; add 1/4 cup **butter**.
5. When foamy and just starting to brown, add 2 cups diagonally sliced **bananas** (1/2" slices) and 1 cup **pecan** halves. Toss and cook for 1 minute.
6. Add 1/2 cup fresh **lime juice** and 1 cup dry white **wine** (or light stock) . Cook for another 2 minutes.
7. Add 1/4 cup **fresh herbs** (mint, parsley, coriander, basil or tarragon).
8. Pour sauce and bananas over fish. Garnish with additional banana slices and lime wedges.

Thanks to Turbana Corporation (`www.turbana.com`).

### Z.5.2 Cranberry Banana Bread

1. In a large saucepan, bring 2 cups **sugar** and 1 cup **water** to a boil, stirring to dissolve the sugar. Add 4 cups fresh **cranberries** and simmer over low heat for 10 minutes or until berries pop open. Cool. Drain the berries, reserving the juice and measuring 1 cup of berries for use in the bread.
2. Sift together 1 3/4 cup **flour**, 1/2 teaspoon **salt**, 2 teaspoon **baking powder** and 1/4 teaspoon **baking soda**.
3. In a large bowl, combine 2/3 cup **sugar**, 1/3 cup melted **butter**, 2 beaten **eggs**, 1/2 cup chopped **walnuts**, 1 cup mashed **banana**, and 1 cup cooked berries.
4. Add the flour mixture to the berry mixture, stirring until blended. Pour the mixture into a greased and lightly floured 9 x 5 x 3-inch loaf pan. Bake in a preheated, 350° F oven for 1 hour or until a toothpick inserted in the center comes out clean.
5. For a topping (optional), combine 1/4 cup **cranberry juice** from cooked berries, 2 tablespoons **sugar** and 2 tablespoons **Grand Marnier** in a small saucepan and stir over low heat until heated through. Poke a few holes in the baked loaf and pour on the topping.
6. Cool 10 minutes in the pan. Turn the loaf out on a rack and cool completely. Wrap in foil and store one day before slicing.

Thanks to Tim D. Culey, Baton Rouge, La. (`tsculey@bigfoot.com`).

### Z.5.3 Mexican chicken vegetable soup with bananas

1. In large, covered kettle, over medium-low heat, simmer 4 pounds cut up **stewing chicken**, 1/c cup coarsely chopped **onion**, 1 teaspoon **salt**, and 4 cups of hot **water** for 2 hours or until chicken is tender.
2. Remove chicken to cutting board; cut meat from bones into chunks; discard bones. Skim any fat from surface of broth.
3. Add chicken, 1/2 cup chopped **celery**, 1 12-ounce can whole-kernel **corn** and 1 16-ounce can **tomatoes** to soup. Continue simmering, covered for 10 minutes. Season to taste.
4. Five minutes before serving, peel 4 firm (green-tipped) **bananas**, slice diagonally into 1-inch slices.
5. Add sliced bananas to soup, continue cooking just until bananas are tender. Serve immediately.

Thanks to Turbana Corporation (`www.turbana.com`).

### Z.5.4 Curried bananas

1. Melt 2 tablespoons **butter** in saucepan and cook 2 tablespoons minced **onion** in it for 2–3 minutes.
2. Mix 1 tablespoon **curry powder**, 1 teaspoon **salt**, 1/4 cup **flour**, and a dash of **cayenne pepper** with a little **milk** to make a paste.
3. Add paste to onion, cooking gently for 10 minutes. Add balance of 2 cups **milk** slowly, stirring until it boils.
4. Slice 7 small green **bananas**, and cook gently in the sauce until tender.
5. Serve as a vegetable in a ring of hot cooked rice.

From *Everyday BANANA Recipes*, Banana Distributing Co., New Orleans, published by Bauerlein, Inc. New Orleans, 1927.

# G GLOSSARY

**adverb** — See *POPS symbols.*

**AIPS monitor** — a computer terminal (perhaps lacking a keyboard) whose CRT screen is used in AIPS solely for the display of information related to the progress of the execution of the AIPS tasks. (Except, at those AIPS sites without a terminal dedicated to this use, the AIPS user's interactive terminal is used for dual purposes—i.e., to serve as the AIPS monitor as well.) Many of the messages which the AIPS tasks write to the monitor also are recorded in the *message file* (*q.v.*).

**aliased response** — in a radio interferometer map, a spurious feature due to a source—or to a sidelobe—that lies outside of the field of view. Consider the sampling of a visibility function $V$ at the lattice points of a rectangular grid as multiplication of $V$ by the comb-like distribution $R(u,v) = \sum_k \sum_l \delta(u - k\Delta u, v - l\Delta v)$. The Fourier transform $\widehat{RV}$ of $RV$ is given by the convolution $\hat{R} * \hat{V}$. Since $\hat{R}$ is again a comb-like distribution, with peaks, or teeth, separated by $\frac{1}{\Delta u}$ in one direction and by $\frac{1}{\Delta v}$ in the perpendicular direction, $\widehat{RV}$ is periodic, and, about the position of each tooth in the comb, it looks like an infinite summation of rectangular pieces of $\hat{V}$, each of size $\frac{1}{\Delta u} \times \frac{1}{\Delta v}$, taken from all over the plane. Aliased responses can be suppressed very effectively, by judicious choice of the *gridding convolution function* (*q.v.*).

For a more complete discussion, see Dick Sramek and Fred Schwab's Lecture No. 6 in the *Third NRAO Synthesis Imaging Summer School*. Also see VLA Scientific Memoranda Nos. 129 and 131.

**aliasing** — in spectral analysis, error which is due to undersampling: one may wish to sample a signal that is known to be bandlimited, but whose bandwidth may not be known a priori. The Fourier transform of *Shannon's series* is periodic; aliasing error is of the form of an overlapping, or superposition, of these "replicated" spectra. See *Nyquist sampling rate* and *aliased response*.

**ALU** — (Arithmetic Logic Unit) an (optional) microcomputer CPU unit within the $I^2S$ TV display device which allows simple arithmetic operations, such as sums, products, and convolutions, to be performed on the data recorded in the $I^2S$ image planes. At present, AIPS makes little use of the ALU, since many of its features are unique to the $I^2S$ display unit. See *$I^2S$*.

**antenna file** — in AIPS, an *extension file*, associated with a *u-v data file*, in which a list of the interferometer antenna positions is stored.

**antenna/i.f. gain** — Many of the systematic errors affecting radio interferometer measurements are multiplicative in the visibility amplitude and additive in the visibility phase, and are ascribable to individual antenna elements and their associated i.f./l.o. chains. For each antenna/i.f. these sources of error may be lumped together into a complex-valued function of time, $g(t)$, called the *antenna/i.f. gain.* Then, the visibility measurement obtained on the $i$–$j$ baseline at time $t$ is given by $\tilde{V}(u_{ij}(t), v_{ij}(t)) = g_i(t)\overline{g}_j(t)V(u_{ij}(t), v_{ij}(t)) + \epsilon_{ij}(t)$, where $V$ is the true source visibility and where the spatial frequency coordinates $(u,v)$ have been parametrized by time. $g_i\overline{g}_j$ is the systematic "calibration error", and $\epsilon_{ij}$, an additive error component, is assumed to be random and well-behaved. (Another type of systematic error, the *instrumental polarization* (*q.v.*), is not included in the $g_k$, and always must be corrected, by proper calibration, in order to interpret polarization data.)

Some of the most serious sources of error—including atmospheric attenuation, error arising from variations in the atmospheric path length, clock error, and error in the baseline determination—conform fairly well to this multiplicative model. This model relation is exploited heavily by the *self-calibration algorithm* (*q.v.*). Compare *antenna/i.f. phase*, and see *isoplanaticity assumption* and *correlator offset*.

**antenna/i.f. phase** — The *antenna/i.f. phase* for antenna $k$ of an interferometer array is given by the argument (or phase) of the *antenna/i.f. gain* $g_k$: $\psi_k(t) = \arg g_k(t)$. Often in *self-calibration* one assumes that no amplitude errors are present and solves only for the $\psi_k$.

**antenna residual delay** — See *residual delay* and *global fringe fitting algorithm.*

**antenna residual fringe rate** — See *residual fringe rate* and *global fringe fitting algorithm.*

**AP** — See *array processor.*

**AP–120B array processor** — an *array processor* manufactured by Floating Point Systems, Inc., and used at a number of AIPS sites. Its floating-point word length is 38-bits. Typically it is equipped with a main data memory of 32–64 kilowords and a program source memory of 2048 words. With both a pipeline multiplier and a pipeline adder, and a memory cycle time of 167 ns., when programmed at top efficiency it can perform at an arithmetic rate of 12 million floating-point operations per second.

The AP–120B is no longer in production; this product has been superseded by the 5000 series product line. Though the AP–5000's are used at some AIPS sites, their advanced features are not used by AIPS—only those features which are shared by the older model are fully exploited by AIPS tasks.

**array processor** — a computer peripheral attachment which is capable of performing certain floating-point computations, especially vector and matrix operations, at high speed, and independently of the *host computer* central processing unit. Usually the high-speed performance is achieved by a technique known as pipelining. The basic arithmetic operations of addition and multiplication are performed in stages, by a so-called pipeline adder and a pipeline multiplier. These units operate just like an assembly line in a manufacturing plant. Some array processors (AP's) are constructed with multiple pipelines. Address computations are performed concurrently with the arithmetic operations, by a unit which is separate from the pipelines. The algorithms best-suited to an array processor implementation are those which can be structured so as to keep the pipelines filled a fair fraction of the time. Most AP's have their own high-speed data memory, but some are parasitic on the memory of the host computer. Portions of many AIPS tasks have been programmed for the Floating Systems, Inc. model *AP-120B array processor*, (*q.v.*). Also see *array processor microcode*, *Q-routine*, and *pseudo-array processor*.

**array processor microcode** — program source code written in the assembly language of an *array processor*, (*q.v.*). Array processor (AP) manufacturers usually provide an extensive library of utility subroutines that may be called from a high-level programming language, such as Fortran; however, some computationally-intensive algorithms cannot be easily or efficiently implemented using only these libraries. Portions of these algorithms must be written in microcode—a painstaking process. The assembly languages of different models of AP's differ considerably (as do the subroutine libraries, too, in fact) because of differences in the hardware architectures. Thus the AIPS programming group tries to avoid writing microcode. But portions of the AIPS *tasks* for mapmaking, deconvolution, and self-calibration are written in AP microcode. Also see *Q-routine*.

**associated file** — In AIPS, any two or more files among a collection consisting of a *primary data file* and all of its *extension files* are termed *associated*.

**auto re-boot** — a boot initiated by the computer itself, of its own volition. See *boot*.

**back-up** — The act of copying the contents of a computer file to some permanent storage medium such as magnetic tape or punched cards, for the purpose of protecting against accidental loss or in order to liberate storage space (e.g., disk space), is termed *backing-up*. The new copy of the file is termed a *back-up* copy, or simply a *back-up*. See *scratch*.

**bandwidth smearing** — in a radio interferometer map, space-variance of the *point spread function* which is attributable to non-monochromaticity, or finite bandwidth. The point spread function—at a particular point in a map—taking into account bandwidth smearing, but ignoring other instrumental effects, is termed a *delay beam*. Bandwidth smearing is a radial effect: the delay beams become more elongated, in the radial direction from the interferometer *phase tracking center*, as their distance from the phase tracking center increases. The delay beams are easily calculable when all of the receivers in an array have identical, and known, i.f. passbands. E.g., with rectangular passbands of width $\Delta\nu$, and observations centered at a frequency $\nu_0$, the measured visibility amplitude of a point source is proportional to $\frac{\sin\gamma}{\gamma}$ —where $\gamma \equiv \pi(ux + vy + wz)\frac{\Delta\nu}{\nu_0}$, $(u, v, w)$ denotes the spatial frequency coordinates, measured in wavelengths at $\nu_0$, and $(x, y, z)$ denotes the direction cosines of the location of the point source, with respect to the phase tracking center. For more details, see Alan Bridle and Fred Schwab's Lecture No. 13 and Bill Cotton's Lecture No. 12 in the *Third NRAO Synthesis Imaging Summer School* and see VLA Scientific Memo. No. 137.

Bandwidth smearing can, in principle, be eliminated (assuming that the bandpasses are known) by applying an image reconstruction algorithm which has a knowledge of the smearing mechanism; that is, by an algorithm which is more general than the usual deconvolution algorithms—see *image reconstruction*. The most common method for reducing bandwidth smearing is the technique of *bandwidth synthesis*, (*q.v.*).

**bandwidth synthesis** — a technique of radio interferometry which is intended to diminish the effect of *bandwidth smearing*. Bandwidth synthesis observing is very similar to spectral-line mode observing: the i.f. bandpasses are split up into a number of pieces, or channels, and the data in each channel are treated separately up until the mapping/ deconvolution stage of processing. At that stage, the problem can be formulated as a system of simultaneous convolution equations: one has the system $g_1 = b_1 * f + \epsilon_1, \ldots, g_n = b_n * f + \epsilon_n$, where $n$ is the number of frequency channels, $g_k$ is the *dirty map* for channel $k$, $b_k$ the *dirty beam* for that channel, $f$ the unknown radio source brightness distribution (here assuming that $f$ is not a function of frequency), and $\epsilon_k$ is noise (were it not for the noise, and for the fact that each deconvolution problem is ill-posed—in its own right—, there would be no reason to treat the equations simultaneously, or even to consider more than a single one of them). (For a description of a refinement to the bandwidth synthesis technique, for sources with spatially-varying spectral indices, see *broadband mapping technique*.) Note that all the $b_k$ are identical, apart from a dilation factor; i.e., as the *u-v coverage* "shrinks", toward the low end of the observing band, the $b_k$ dilate by the reciprocal of the *u-v* shrinkage factor.

The present state of software development does not allow solving the problem in quite the way it is formulated above. Rather, some mapping/deconvolution algorithm is applied separately to each of the channels, and the resulting maps are averaged.

**baseline-time order** — An ordered set of visibility measurements $\{ V_{ij}(t_k) \mid 1 \le i < j \le n,\ k = 1, \ldots, l \}$ recorded with an $n$ element interferometer at times $t_k$ is said to be in *baseline-time order* if the ordering is such that all of the data for the 1–2 baseline, sorted by time, occur first, followed by the data for the 1–3 baseline, again sorted by time, etc., etc. (This canonical ordering by baseline is the order $V_{12}, V_{13}, \ldots, V_{1n}, V_{23}, \ldots, \ldots, V_{n-1,n}$ .) Compare *time-baseline order*.

Baseline-time ordering of a *u-v data file* is convenient for purposes of data display.

**batch editor** — a *text editor* within the AIPS program which allows the user to prepare *batch jobs* (*q.v.*), to be run non-interactively.

**batch job** — AIPS may be run either interactively—allowing the user to make 'split-second' decisions—or in batch mode. In batch mode, the user first decides on a set strategy for reducing the data, and then, using the special AIPS *batch editor*, the user prepares a *text file*, containing those AIPS commands which are appropriate to the anticipated data reduction needs. The batch job is placed in a *batch queue*, and the job steps are executed by the *batch processor*, in a non-interactive mode.

**batch processor** — the server, or scheduler, for *batch jobs* (*q.v.*). The AIPS batch processor follows certain rules in scheduling: batch jobs requiring the use of an array processor (AP) often are scheduled to run only during nighttime hours; the processor serving one of the *batch queues* might refuse service, altogether, to a job requiring an AP; and batch jobs may be given lower priority than those AIPS tasks which are run interactively.

**batch queue** — a waiting line for *batch jobs*. The AIPS batch queue is a single-server queue—i.e., the server (the *batch processor*) initiates the execution of the jobs one after the other, rather than in parallel. However, AIPS can be configured with more than one batch queue, each with its own batch processor; this number varies according to site.

**"battery-powered" Clean algorithm** — a modified version of the Clark Clean algorithm, devised by Fred Schwab and Bill Cotton. At each major cycle of the algorithm, or perhaps less frequently, the residual map is computed not by convolving the current iterate with the dirty beam map, but rather by computing the visibility residuals, and then re-gridding and re-mapping. By this means, the edge effects are compensated, and hence one can search the full dirty map field of view for Clean components. Simultaneously, instrumental effects (finite bandwidth and finite integration time) and sky curvature (the $wz$ term) can be compensated for (i.e., the algorithm solves a more general equation than a convolution equation). See *Clark Clean algorithm.*

A "mosaicing" version of this algorithm is implemented in the AIPS task MX. The deconvolved image is defined over some number $1 \leq n \leq 16$ of rectangular patches. Within each patch, the data are corrected for sky curvature, by the correction appropriate to the center of the patch. Instrumental corrections are not included, at present.

**beam** — 1. in radio interferometry, the inverse Fourier transform ($\mathrm{FT}^{-1}$) of the *u-v sampling distribution*, or $\mathrm{FT}^{-1}$ of a weighted *u-v* sampling distribution, possibly convolved with a gridding convolution function—the idealized response to a point, or unresolved, radio source. 2. a numerical approximation to 1. 3. a digitized version of 2, sampled on a regular grid (usually regarded as a map or image). 4. ≈ *point spread function*, q.v. 5. (occasionally) as above, but taking into account instrumental effects, so that the beam depends on position in the sky. See *dirty map.*

Occasionally, any one of the above, other than 5, is termed the *synthesized beam.*

**beam patch** — in the Clark Clean algorithm, that portion of the central part of the beam which is used in the inner iterations, or the minor cycles. In the AIPS implementation, the beam patch size typically is set at 101 pixels × 101 pixels. See *Clark Clean algorithm.*

**beam squint** — In radio interferometry, direction dependent, or space-variant *instrumental polarization*, which is difficult to calibrate, can arise from *beam squint*. The beam squint effect, for the usual case of a pair of (nominally) orthogonally polarized feeds on each array element, is due to differences in their power patterns—in particular, to differences in the directions of their peak response.

**blanked pixel** — in a digital image, a pixel whose value is undefined. In computer storage of quantized digital images, some special numeric value is assigned to the blanked pixels, so that they may be recognized as undefined and given whatever special treatment is required. See *pixel.*

**BLC** — *bottom left corner* (of an image). See *m × n map.*

**blink** — See *TV blink.*

**boot** — A computer is restarted by means of a *boot*strapping procedure, whereby the operating system and the data management facilities are re-initialized in a succession of steps. This ritual, through which the computer gathers it wits, is termed the *boot.* A boot (≈ *re-boot*) is required after any system crash (e.g., after a power failure). Usually the sequence of steps required to accomplish the boot is posted in a notice located close to the system operating console, or on the CPU panel. On modern computers, such as the Vax, the boot procedure is highly automated. In fact, there may be an abbreviated boot procedure, termed a *quick boot*, to follow after a "soft" system crash. (On such systems, a quick boot should be attempted before resorting to a full boot.) Indeed, some systems (the Vax included) re-boot on their own initiative following a soft system crash—this is termed an *auto re-boot.*

**BOT marker** — (Beginning-Of-Tape marker) a short strip of metal foil attached near the front, or beginning, end of a computer magnetic tape. The tape drive uses the BOT marker in order to position the tape at its starting position.

**bpi** — (bits per inch) the basic unit of measurement used to specify the density at which information is recorded on a computer magnetic tape: the effective number of bits per inch per track. The standard recording densities are 800, 1600, and 6250 bpi. Modern computer tapes are nine-track tapes: eight recording tracks are used for the data, and the ninth track is used to record "parity bits" for error-checking. See *tape blocking efficiency.*

**broadband mapping technique** — a refinement of the radio interferometric method of *bandwidth synthesis* (*q.v.*), in which one solves simultaneously for the radio brightness distribution $f_{\nu_r}(x, y)$ at some reference frequency $\nu_r$, and for the (spatially varying) spectral index $\alpha(x, y)$ across the observing band. Assuming that the observing band is split into frequency channels centered at $\nu_1, \ldots, \nu_n$, one solves the simultaneous system of convolution equations $g_1 = b_1 * f_1, \ldots, g_n = b_n * f_n$, where $g_k$ is the *dirty map* from channel $k$, $b_k$ the *dirty beam* from that channel, and where $f_k$ is given by

$$f_k(x, y) = \left(\frac{\nu_k}{\nu_r}\right)^{\alpha(x,y)} f_{\nu_r}(x, y)\,.$$

All of the $b_k$ are identical, apart from a dilation factor. Assuming that the frequency channels are narrow enough, one can expand the *u-v coverage* considerably, with immunity to the *bandwidth smearing* effect. Fractional bandwidths as large as 20–30% can be used, depending on the linearity of the spectral index variations.

This mapping technique is described by Tim Cornwell [Broadband mapping of sources with spatially varying spectral index, VLB Array Memo. No. 324, Feb. 1984]. Extensive modification of one of the standard deconvolution algorithms is required. The requisite modification of the *Högbom Clean algorithm* is in progress.

**b-t order** — See *baseline-time order.*

**bug** — an actual or a perceived programming error or program deficiency. The bug may be in the eye of the beholder since the program user may fancy an application similar to, but differing from, the one for which the program is intended. In AIPS there is a formal mechanism for reporting program bugs; see *gripe file* for a description.

**byte** — a unit of eight bits of computer storage.

**carriage-return key** — One of the most used keys on any computer terminal keyboard is the carriage-return key ($C_R$). This is the button which ordinarily must be depressed when one has finished typing a command to the computer, in order for the computer to accept or acknowledge the command.

**catalog entry** — an entry within an AIPS *catalog file* ("CA" file) pertaining to a particular *primary data file.*

**catalog file** — In AIPS, each user has, for each disk on which he has data stored, his own *catalog file*, or "CA" file—a directory of all of his primary data files which reside on that disk. The AIPS *verb* CATALOG (as do its variants MCAT and UCAT) allows the user to see a summary listing of the contents of his catalog files. See *header record.*

**catalog slot** — in AIPS, a numbered space reserved in a *catalog file* for the insertion of a *catalog entry.*

**cell-averaging** — in radio interferometer mapping, gridding convolution which is achieved simply by averaging the visibility data which lie in each *u-v* grid cell. This is equivalent to use of a *gridding convolution function* equal to the *characteristic function* of the rectangle $\{|u| < \Delta u/2,\ |v| < \Delta v/2\}$, where $\Delta u$ and $\Delta v$ denote the grid spacing—i.e., it is equivalent to the use of a so-called *pillbox* function. The Fourier transform of the pillbox gridding convolution function is proportional to a separable product of two $\frac{\sin x}{x}$ functions; this function does not decay rapidly enough to yield very effective *aliasing* suppression. The zero-order *spheroidal* *functions* offer much better aliasing suppression, at somewhat increased computational expense (equivalent to averaging the data over a region 36 times larger, in the case of the default gridding convolution function used by the AIPS mapping tasks).

**cellsize** — in radio interferometer mapping, the size $\Delta u \times \Delta v$ of the *u-v* grid cells. Ordinarily, the visibility data are smoothed by an appropriate *gridding convolution function* and this convolution then is sampled at the coordinate locations of the centers of the grid cells. After appropriate weighting, the *discrete Fourier transform* yields the *dirty map.* $\Delta u$ and $\Delta v$ are chosen according to *Shannon's sampling theorem*: if the size of the dirty map is $x$ radians by $y$ radians, then $\Delta u = \frac{1}{x}$ wavelengths and $\Delta v = \frac{1}{y}$ wavelengths.

**cereal bowl map defect** — same as *negative bowl artifact.* See *zero-spacing flux.*

**characteristic function** — The characteristic function $\chi_A$ of a set $A \subset X$ is defined for all $x \in X$ by the formula

$$\chi_A(x) = \begin{cases} 1\,, & \text{if } x \in A\,, \\ 0\,, & \text{if } x \notin A \end{cases}$$

($\chi_A$ is also called the *indicator function* of $A$, and the notations $c_A$ and $1_A$ commonly are used in lieu of $\chi_A$.) Note that this usage of the term, which is standard in mathematical analysis, differs from its usage in probability and statistics, where it refers to the Fourier transform of a probability measure (i.e., to the FT of the distribution function of a random variable).

**chromaticity** — in visual perception, essentially the dominant wavelength and the purity of the spectral distribution of light, as perceived. *Hue* and *saturation* determine the chromaticity, which is independent of *intensity.* See *C.I.E. chromaticity diagram.*

**C.I.E. chromaticity diagram** — a two-dimensional diagram devised in 1931 by the Commission Internationale de l'Eclairage (International Commission on Illumination) to show the range of perceivable colors as a function of normalized chromaticity coordinates $(x, y)$, under standardized viewing conditions. The color, for an additive mixture of monochromatic red, green, and blue ($R, G, B$ denoting the intensities at 650, 520, and 380 nm. wavelengths) as perceived by a 'standard observer', is displayed in this diagram as a function of the normalized *chromaticity coordinates* $x = R/(R + G + B)$ and $y = G/(R + G + B)$.

Other chromaticity diagrams can be drawn for different choices of primary hues, for mixtures of nonmonochromatic light, or for 'nonstandard observers'. In digital imagery, such a diagram may be tailored to a particular color image display unit. See [G. S. Shostak, Color basics—a tutorial. In R. Albrecht and M. Capaccioli, I.A.U. Astronomical Image Processing Circular No. 9, Space Telescope Science Institute, Jan. 1983] and [G. Wyszecki and W. S. Stiles, *Color Science*, Wiley, New York, 1967], a comprehensive textbook on colorimetry.

**Clark Clean algorithm** — a modified version of the Högbom Clean algorithm, devised by Barry Clark in order to accomplish an efficient *array processor* implementation of Clean (see [B. G. Clark, An efficient implementation of the algorithm Clean, *Astron. Astrophys.*, **89** (1980) 377–378]). To operate on, say, an $n \times n$ map, the original Clean algorithm requires on the order of $n^2$ arithmetic operations at each iteration, and typically there may be hundreds or thousands of iterations. The Clark algorithm proceeds by operating not on the full residual map, but rather by picking out only the largest residual points, iterating on these for a while (during its *minor cycles* or inner iterations) and only occasionally (at the *major cycles*) computing the full $n \times n$ residual map, by means of the FFT algorithm. After each major cycle, it again picks out the largest residuals and goes into more minor cycles. And, for further economy, during these inner iterations the dirty beam is assumed to be identically zero outside of a relatively small box (termed the *beam patch*) which is centered about the origin. See *Högbom Clean algorithm.*

**Clean** — See *Högbom Clean algorithm.*

**Clean beam** — in the Högbom Clean algorithm, an elliptical Gaussian function $h$ with which the final iterate is convolved, in order to diminish any spurious high spatial frequency features—also termed *restoring beam.* $h$ is specified by its major axis (usually the FWHM), its minor axis, and the position angle on the plane of the sky of its major axis. Usually these parameters are set by fitting to the central lobe of the dirty beam. See *Högbom Clean algorithm* and *super-resolution.*

**Clean box** — a rectangular subregion of a *Clean window* (*q.v.*).

**Clean component** — in the Högbom Clean algorithm, a $\delta$-function component which is added to the $(n-1)$st iterate in order to obtain the $n$th iterate. Its location is the location of the peak residual after the $(n-1)$st iteration, and its amplitude is a fraction $\mu$ (the *loop gain*) of the largest residual. See *Högbom Clean algorithm.*

The AIPS task implementing the (Clark) Clean algorithm stores a list of the Clean components in an extension file which is termed a *components file.*

**Clean map** — an approximate deconvolution of the *dirty beam* from the *dirty map,* derived by an application of the Högbom Clean algorithm or one of its derivatives. See *Högbom Clean algorithm.*

**Clean speed-up factor** — in the *Clark Clean algorithm*, a number $\alpha$ in the range $[-1, 1]$ used in determining when to end a major cycle. Smaller $\alpha$ causes a larger number of major cycles to occur (at greater computational expense) but yields a result closer to that of the classical *Högbom Clean algorithm.*

**Clean window** — in the Högbom Clean algorithm, the region $A$ of the residual map which is searched in order to locate the *Clean components* comprising the successive approximants to the radio source brightness distribution. In the AIPS implementation, $A$ is a union of rectangles, called *Clean boxes,* which may be specified by the user. When $A$ is not explicitly specified, the algorithm searches over the central rectangular one-quarter area of the residual map. See *window Clean* and *Högbom Clean algorithm.*

**clipping** — the discarding (i.e., the *flagging*) of visibility data whose amplitudes exceed some threshold value, or the discarding of visibility data whose differences from some tentative source model are too large in amplitude. The AIPS task CLIP is used for clipping. See *u-v data flag.*

**closure amplitude** — Assume that the visibility observation on the $i$–$j$ baseline ($i < j$) is given by $\tilde{V}_{ij} = g_i \overline{g}_j V_{ij}$, where $V_{ij}$ is the true visibility and where $g_i$ and $g_j$ are the *antenna/i.f. gains* (ignore any additive error). Then, for certain combinations of (at least four) baselines, one may form ratios of observed visibilities (and their conjugates)—including each visibility only once—in such a manner that the $g$'s cancel one another. For example, if $i < j < k < l$, then

$$\frac{\tilde{V}_{ij}\tilde{V}_{kl}}{\tilde{V}_{il}\overline{\tilde{V}}_{jk}} = \frac{V_{ij}V_{kl}}{V_{il}\overline{V}_{jk}}\,.$$

The modulus of such a ratio is termed a *closure amplitude* (and its argument, a *closure phase*).

Closure amplitude is called a "good observable", since, under the above assumptions, it is not sensitive to measurement error. The closure amplitude and closure phase relations are exploited in the *hybrid mapping algorithm* (*q.v.*). Also see *self-calibration algorithm*.

**closure phase** — Assume that the visibility observation on the $i$–$j$ baseline ($i < j$) is given by $\tilde{V}_{ij} = g_i \overline{g}_j V_{ij}$, where $V_{ij}$ is the true visibility and where $g_i$ and $g_j$ are the *antenna/i.f. gains* (ignore any additive error). Then, for a combination of any three or more baselines forming a closed loop, one may sum the visibility phases in such a manner that the *antenna/i.f. phases* $\psi_k$ drop out. For example, if $i < j < k$, then $\arg \tilde{V}_{ij} + \arg \tilde{V}_{jk} - \arg \tilde{V}_{ik} = \arg V_{ij} + \psi_i - \psi_j + \arg V_{jk} + \psi_j - \psi_k - \arg V_{ik} - \psi_i + \psi_k$. Such a linear combination of observed visibility phases is termed a *closure phase*.

Closure phase is called a "good observable", since, under the above assumptions, it is not sensitive to measurement error. The closure phase relations are exploited in the *hybrid mapping algorithm* (*q.v.*). Also see *closure amplitude* and *self-calibration algorithm*.

**color contour display** — a color digital image display of a real-valued function $f$ of two real variables $(x, y)$, in which the color assignment (the *hue*) is a coarsely quantized function of $f(x, y)$. The visual effect of this type of *pseudo-color display*, in the case when $f$ is continuous, is similar to the traditional sort of contour display. One sees curves along which $f$ is constant, separated by swathes of constant hue—each hue corresponding to a distinct quantization level.

**color triangle** — Any three non-collinear points plotted on a chromaticity diagram determine a color triangle. Since the points are non-collinear, they correspond to basic, or *primary* hues. All of those colors on the chromaticity diagram which fall within the triangle determined by the three points may be produced by addition of the three hues. See *C.I.E. chromaticity diagram*.

**compact support** — See *support*.

**components file** — in AIPS, an extension file, associated with an image file containing a *Clean map,* whose content is a list of the positions and amplitudes of the *Clean components* included in that Clean map, as determined by the Clean algorithm. The source model specified by this list of components often is used in *self-calibration.*

**conjugate symmetry** — that property which characterizes a *Hermitian function* (*q.v.*). Generally an assumption of conjugate symmetry is implicit whenever one speaks of the *u-v coverage* corresponding to some radio interferometric observation.

**Conrac monitor** — the CRT unit of the $I^2S$ TV display device, in use at a number of AIPS installations. See $I^2S$.

**convolution theorem** — This theorem is well-known, but seldom is quoted in its distributional form: for two distributions, $f$ and $g$, the Fourier transform of the convolution of $f$ and $g$ is given by $\widehat{f * g} = \hat{f}\hat{g}$, whenever one distribution is of *compact support* and the other is a "tempered" distribution. (Loosely speaking, a tempered distribution is one which does not increase too rapidly at infinity.) See [Y. Choquet-Bruhat, C. Dewitt-Morette, and M. Dillard-Bleick, *Analysis, Manifolds, and Physics*, North–Holland, New York, 1977, ch. VI].

One ought to be aware of this form of the theorem, since often one must deal with convolution of functions that are not of compact support—*dirty beams, principal solutions, invisible distributions,* etc.—whose Fourier transforms do not exist as ordinary functions, but only as distributions or generalized functions.

Convolution of distributions, itself, is defined, in general, whenever the support of either distribution is compact, or (in one dimension) when the supports of both distributions are limited on the same side. For distributions which are absolutely integrable ordinary functions, and whose Fourier transforms possess the same property, the compact support assumption is not required here, or above. Related fact: convolution is not always associative (i.e., $f * (g * h) \neq (f * g) * h$), in general), but it is associative provided that all the distributions, with the possible exception of one, are of compact support. See the above-cited reference.

**convolving function** — See *gridding convolution function.*

**coordinate reference pixel** — in an AIPS *image file*, a *"pixel"* whose coordinates are recorded in the image *header* together with the coordinate increments (i.e., the pixel coordinate separations) that allow the physical coordinates of all other pixels in the image to be computed. This "coordinate reference pixel" may not actually be present in the image: all that matters are its physical coordinates and its pixel coordinates (which too are recorded in the header—and which may, in fact, be fractional).

Often, in a radio map (and by default, when the standard AIPS mapmaking tasks are executed), the position of the coordinate reference pixel coincides with the map center and with the *visibility phase tracking center*. See $m \times n$ *map* and *pixel coordinates.*

**correlator offset** — One of the basic assumptions of much of the VLA calibration software (e.g., the *self-calibration algorithm*) is that the systematic errors in the visibility measurements are multiplicative errors that are ascribable to individual array elements and their associated i.f./l.o. chains, and that—at a given instant—each such antenna-based error has an identical effect on each visibility observation involving that antenna/i.f. combination. Systematic measurement errors which do not conform to this model are called *correlator offsets* or *non-closing errors*. See *antenna/i.f. gain.*

Correlator offsets can be the limiting factor in obtaining high dynamic range VLA maps. Some observers have reported fairly large multiplicative correlator offsets which vary slowly with time and which do not appear to vary with the *phase tracking center* or with source structure. From observations of an external calibrator, one may estimate, and compensate for, such offsets. This mechanism is provided in the AIPS tasks BCAL1 and BCAL2. See [R. C. Walker, Non-closing offsets on the VLA, VLA Scientific Memo. No. 152].

**crash** — the abrupt failure of a computer system or program. More specifically, a *system crash* is the abrupt failure of a computer—or of a computer's operating system—causing the computer to halt the execution of programs; and a *program crash* is the abrupt failure of a computer program resulting either from a flaw in the logic of the program itself, or from some peculiar interaction with the operating system, the storage management facility, another program, or the user—or from an act of God. A *hardware crash* (e.g., a *disk crash*) is a crash which results from the failure of the computer electronics or electro-mechanics, and a *software crash* is one which results from a flaw or an inadequacy in program logic, or in operating system program logic. A *soft crash* is a crash from which it is easy to recover—i.e., easy to restart the computer and resume work—, and a *hard crash* is the opposite.

**crosshair** — 1. a marker on the *TEK screen*, or *green screen*, which may be moved about through the use of thumbwheel knobs which are located on the terminal keyboard panel. The position of the crosshair may be sensed by the computer program, and thus the user may point out to the program features that are of interest in the graphical display on the CRT screen. 2. a marker with the same function as just described, but on a TV display device, and more likely controlled by a *trackball* than by thumbwheels. Same as *TV cursor*; and see *trackball*.

**cube** — See *data cube*.

**cursor** — 1. a marker on an interactive computer terminal indicating the position on the CRT screen where the next character is to be typed. 2. *TV cursor*—on a TV display device, a marker whose manually controlled position may be sensed by the computer. See *crosshair*.

**data cube** — 1. in VLA spectral line data analysis, a three-dimensional map or "image" representing a function of three real variables—two spatial variables representative of position in the sky, and one variable related to frequency or velocity. 2. any $n$-dimensional *image*, $n \geq 3$.

Computer access of a multi-dimensional data array, residing in any standard type of storage medium such as disk or magnetic tape, is sequential, as if the data were one-dimensional. Spectral line data cubes are stored plane-by-plane, row-by-row, column-by-column. Permutation of the correspondence between plane, row, and column, and the coordinate axis numbering, is referred to as *transposition* of the data cube.

**database** — a computer filing system, or file structure system. For example, the AIPS database consists not only of the data themselves, but also of the directories and the cross-reference lists of all the AIPS data files (including extension files), the data format definitions, etc., as well as the rules and principles governing the use thereof.

**data file** — on a computer storage medium, such as disk or magnetic tape, the concrete, or physically present representation of a logically distinct grouping of data in a manner permitting repeated access by computer programs.

**data flag** — See *u-v data flag*.

**deconvolution** — the numerical inversion of a convolution equation, either continuous or discrete, in one or several variables; i.e., the numerical solution (for $f$) of an equation of the form $f * g = h +$ noise, given $g$ and given the right-hand side of the equation. Except in trivial cases, deconvolution is an ill-posed problem: In the absence of constraints or extra side-conditions, and in the case of noiseless data—assuming that some solution exists—there usually will exist many solutions. In the case of noisy data, there usually will exist no exact solution, but a multitude of approximate solutions. In the latter case, if one is not careful in the choice of a numerical method, the computed approximate solution is likely not to have a continuous dependence on the given data. The so-called *regularization method* (*q.v.*) (of which the *maximum entropy method* is a special case) is an effective tool for the deconvolution problem.

Discrete two-dimensional deconvolution is an everyday problem in radio interferometry, owing to the fact that—under certain simplifying assumptions—the so-called *dirty map* is the convolution of the *dirty beam* with the true celestial radio image. In addition to the maximum entropy method, the *Högbom Clean algorithm* is commonly applied to this problem. See Tim Cornwell and Robert Braun's Lecture No. 8 in the *Third NRAO Synthesis Imaging Summer School*.

**delay** — See *residual delay*.

**delay beam** — in radio interferometry, the *point spread function* or *beam*, taking into account *bandwidth smearing*, but ignoring other instrumental effects. See *bandwidth smearing*.

**DFT** — an abbreviation for *discrete Fourier transform* and *direct Fourier transform* (*q.v.*). When used in disciplines other than radio astronomy, it usually signifies the former.

**Dicomed Image Recorder (Model D47)** — a computer-controlled image display device intended for photographic reproduction of digital images. The film is exposed by a cathode ray tube. The device is capable of 4096 pixel × 4096 pixel resolution and of both black-and-white and color reproduction. The digital exposure control and eight-bit pixel input allow 256 discrete exposure levels. The CRT has a single electron gun and a screen with a white phosphor; color reproduction is accomplished by means of multiple exposures, with the insertion of red, green, and blue filters. There is a Dicomed recorder at the NRAO in Charlottesville, and another at the VLA.

**direct Fourier transform** — a term used imprecisely in radio astronomy to mean either: 1) a finite trigonometric sum, of the form

$$\sum_{j=0}^{n-1} a_j e^{2\pi i u_j x} ,$$

with $a_j$ complex, where the (real) $u_j$ are irregularly-spaced; 2) the brute-force *evaluation* of such a sum; or 3), the naïve, or brute-force evaluation (using $O(n^2)$ arithmetic operations) of the ($n$-point) *discrete Fourier transform*.

The direct Fourier transform, in senses 1) and 2) of the definition, arises in synthesis mapping applications because of the irregular distribution of the visibility measurements. Common practice is to use a *gridding convolution function* to interpolate the data onto a regularly-spaced lattice, so that, for computational economy, the *fast Fourier transform algorithm* may be used.

**dirty beam** — in radio interferometry, simply a *beam,* but computed with precisely the same operations as those used to compute some companion *dirty map* (i.e., with the same *u-v* coverage, the same manner of gridding convolution, the same *u-v* weight function and taper, etc.). In Cleaning a dirty map, only the companion dirty beam should be used.

**dirty map** — 1. ignoring instrumental effects, the inverse Fourier transform ($\mathrm{FT}^{-1}$) of the product of the visibility function $V$ of the radio source and the (possibly *weighted* and/or *tapered*) *u-v sampling distribution* $S$; i.e., $\mathrm{FT}^{-1}$ of the *u-v measurement distribution.* 2. a discrete approximation to 1; in this case, the product $SV$ is convolved with some function $C$, of *compact support,* and an inverse discrete Fourier transform of samples of $C * (SV)$ taken over a regular grid yields the *dirty map.* 3. as in 2, but corrected for the taper ($\tilde{C}$, the $\mathrm{FT}^{-1}$ of $C$) induced by the convolution. 4. any of the above, but now taking into account various instrumental effects (receiver noise, non-monochromaticity or finite bandwidth, finite integration time, sky curvature, etc.).

If it is assumed that $V \equiv 1$, then the map, or point source response, so obtained is termed the *beam* (*q.v.*). Also see *gridding convolution function, u-v taper function, u-v weight function, dirty beam,* and *principal solution.*

**discrete Fourier transform** — The (one-dimensional) discrete Fourier transform (DFT) $y_0, \ldots, y_{n-1}$ of a sequence of complex numbers $x_0, \ldots, x_{n-1}$ is given by the summation

$$y_k = \sum_{j=0}^{n-1} x_j e^{2\pi i jk/n} .$$

(The multi-dimensional generalization is straightforward). The $x_j$ are given by the *inverse DFT* of the $y_k$:

$$x_j = \frac{1}{n}\sum_{k=0}^{n-1} y_k e^{-2\pi ijk/n} .$$

(Frequently the forward and inverse transforms are defined in the manner opposite to that given here, and the $\frac{1}{n}$ normalization factor sometimes is moved about.) The DFT arises most naturally in numerically approximating the Fourier coefficients $c_m = \frac{1}{2\pi}\int_0^{2\pi} f(x)e^{-imx}\,dx$ of a $2\pi$-periodic function $f$ which is representable by the trigonometric series $\sum_{m=-\infty}^{\infty} c_m e^{imx}$. The *fast Fourier transform algorithm* (*q.v.*) can be used for efficient numerical evaluation of the DFT.

**disk hog** — a derogatory term, used to connote a computer user whose disk data files are excessively voluminous or numerous, therefore putting other computer users at a relative disadvantage. Unneeded data files should be *scratched*, or destroyed, in order to free up disk space. Large disk files which will not be needed for a time should be *backed-up* on magnetic tape and then deleted from disk.

**dynamic range** — a summary measure of image quality indicative of the ability to discern dim features when relatively stronger features are present—i.e., a measure of the ability to distinguish the dim features from artifacts of the *image reconstruction* procedure (in a radio map, from remnants of the sidelobes of stronger features) and from noise. The dynamic range achievable in a radio interferometer map is determined primarily by the uniformity of the *u-v coverage*, the density and extent of the coverage, the sensitivity of the array, and the quality of the calibration.

If the true radio source brightness distribution $f$ is known, one can define the dynamic range of a reconstruction $\tilde{f}$ as, say, the ratio of the maximum value of $|f|$ to the r.m.s. difference between $f$ and $\tilde{f}$. When $f$ is unknown, as is usually the case, an empirical measure of the dynamic range is used—perhaps the ratio of the maximum value of $|\tilde{f}|$ to the r.m.s. level in an apparently empty region of the map, or the ratio of the strongest feature to the weakest "believable" feature—, but there is no widely-accepted definition.

What one might wish to call the "true" dynamic range of a radio map is a spatially-variant quantity. The ability to discern a dim feature depends on its proximity to brighter features, because there are relatively stronger sidelobe remnants near the bright features. The quality of a map (and perhaps the dynamic range—depending on how it is defined) deteriorates away from the *phase tracking center*, because of the inability of the image reconstruction algorithms to compensate for various instrumental effects (e.g., bad pointing, *bandwidth smearing*, etc.).

**EDT** — a sophisticated text editor (a *screen editor*) used on the Vaxes. It makes use of the "keypad" feature of the fancier terminals. EDT can be run only on certain model terminals: on the DEC (Digital Equipment Corp.) Models VT–52 and VT–100, and on terminals such as the Visual–50's and the Visual–100's which are capable of emulating the DEC terminals. See *text editor*.

**EMACS** — a sophisticated text editor used on the Vaxes, as well as on many computers which run under the UNIX operating system. (There is also a version for the IBM-PC.) EMACS is a *screen editor*, and the one which is favored by most among those in the AIPS programming group. On terminals with the "keypad" feature, the keypad keys can be programmed by the user to perform many useful editing tasks; however, EMACS can be run from other models of terminals, as well. EMACS provides two powerful and convenient features which most other text editors do not offer: the ability to temporarily exit from the editor and "return to monitor level," and the ability to initiate an interactive "job control session," or initiate *sub-tasks*, in an EMACS buffer. See *text editor*.

**explain file** — in AIPS, a *text file* containing a detailed explanation of a particular AIPS *task* or *verb*, often including hints, suggested applications, algorithmic details, and bibliographical references. Issuing the AIPS verb EXPLAIN causes the contents of an explain file to be printed on the terminal screen or on a line printer. Compare *help file*.

**EXPORT format** — a visibility data magnetic tape format for transport of VLA data from the DEC–10 computer or the on-line computer at the VLA.

**EXPORT tape** — a magnetic tape containing data recorded in the *EXPORT format*.

**exp × sinc function** — a useful gridding convolution function: same as the *Gaussian-tapered sinc function* (*q.v.*), except that the exponent of the argument to the exponential function may be other than two.

**extension file** — in AIPS, a data file containing data supplemental to those contained in a *primary data file* (either a *u-v data file* or an *image file*). Whenever a primary data file is deleted by the standard mechanism within AIPS for file destruction, all extension files associated with that primary data file also are destroyed. Extension files, however, may be deleted without deleting the the associated primary data file.

Extension files are grouped into categories of named types. Examples: *plot files, history files, slice files, gain files,* etc.

When an AIPS task creates a new primary data file from an old one, generally it attaches, to the new file, clones of any extension files associated with the old file that remain relevant to the new one.

**false color display** — In digital imagery, a *false color display* is one which is generated by using a number $n > 1$ of real-valued functions $f_1(x, y), \ldots, f_n(x, y)$ to control the proportions, at each *pixel* coordinate $(x, y)$, of an additive mixture of three primary hues. In practical terms, the user of a digital display system supplies $f_1, \ldots, f_n$, and twists knobs that control the mapping $\mathbf{R}^n \to \mathbf{R}^3$ that sends the $n$ pixel values at each $(x, y)$ into the proper image *chromaticity* and *intensity*. Compare *pseudo-color display*.

A so-called *true color display* is obtained with $n = 3$ and with *transfer functions* chosen such that the color assignment corresponds in an approximate way to the actual coloration of a scene (as in a color photograph).

**fast Fourier transform algorithm** — a fast algorithm for the computation of the *discrete Fourier transform* (DFT) $y_0, \ldots, y_{n-1}$ of a sequence of $n$ complex numbers $x_0, \ldots, x_{n-1}$,

$$y_k = \sum_{j=0}^{n-1} x_j e^{2\pi ijk/n} ,$$

typically requiring only $O(n \log n)$ arithmetic operations — or a multi-dimensional generalization thereof. By contrast, straightforward, or naïve evaluation of the DFT requires $O(n^2)$ operations. The fast Fourier transform algorithms (FFT's) which currently are the most popular are the Cooley–Tukey (1965) algorithms, for the case of $n$ highly composite. For $n$ a power of two, the (radix-2) Cooley–Tukey FFT requires about $2n \log_2 n$ real multiplications and $3n \log_2 n$ real additions. More generally, the Cooley–Tukey algorithms require a few times $n\sigma(n)$ complex arithmetic operations, where $\sigma(n)$ is the sum of the prime factors of $n$, counting their multiplicities. S. Winograd has produced FFT algorithms which are more efficient than those of Cooley and Tukey, typically requiring about the same number of additions, but only about 20% the number of multiplications. (Computation of the required complex exponentials—or sines and cosines—is not counted, since these generally are either pre-computed and stored in compact tables, or generated recursively.)

A further advantage of the FFT algorithms is their avoidance of round-off error, which can build up severely when the DFT is evaluated by brute-force. There are related, fast algorithms for the convolution of sequences of real numbers, for the discrete cosine transform, etc. Algorithmic details may be found in [H. J. Nussbaumer, *Fast Fourier Transform and Convolution Algorithms*, Springer–Verlag, Berlin, 1982]. The computational complexity of the DFT is discussed by L. Auslander and R. Tolimieri [Is computing with the finite Fourier transform pure or applied mathematics, *Bull. (New Series) Amer. Math. Soc.*, **1** (1979) 847–897].

AIPS programs which use the FFT make use of the Cooley–Tukey algorithm. When an *array processor* is used to compute the large two-dimensional DFT's of data which reside on disk, as typically is required in synthesis mapping, the input/output time greatly exceeds the actual computation time.

**FFT** — See *fast Fourier transform algorithm.*

**FITS format** — (Flexible Image Transport System) a magnetic tape data format well-tailored for the transport of image data among observatories. The FITS format is recommended for bringing data into and out of AIPS. See [D. C. Wells, E. W. Greisen, and R. H. Harten, FITS: A flexible image transport system, *Astron. Astrophys. Suppl. Ser.*, **44** (1981) 363–370]. Also see *u-v FITS format* and *FITS tape.*

**FITS tape** — a magnetic tape containing data recorded in the *FITS format.* FITS format data blocks are 2880 bytes in length. The resultant *tape blocking efficiency* is 83%, 75%, and 61% at recording densities of 800, 1600, and 6250 bpi, respectively.

**flagging** — in AIPS, the act of discarding one or more visibility data points by setting a *u-v data flag* (*q.v.*). Compare *clipping.*

**fringe rotator** — in a correlating-type radio interferometer, a mechanism to introduce a time-varying phase shift into the local oscillator signal of a receiver, in order to reduce the frequency of the oscillations of the correlator output. Fringe rotation allows the correlator output (whose amplitude is proportional to visibility amplitude) to be sampled at a lower rate. The natural fringe frequency can be as high as 200 Hz on the VLA. The fringe rotation is chosen so that the fringe frequency for a point source located at the so-called *fringe stopping center* would be reduced to zero, or at least close to zero. Usually the fringe stopping center and the *delay tracking center* coincide; both then are called the *visibility phase tracking center.* For further details, see A. R. Thompson's Lecture No. 2 and L. R. D'Addario's Lecture No. 4 in the *Third NRAO Synthesis Imaging Summer School*, and see R. M. Hjellming and J. Basart's Ch. 2 of the *Green Book.*

**full-synthesis map** — in earth-rotation aperture synthesis, with stationary interferometer elements, a *map* derived from an observation which is of such lengthy duration that the fullest possible *u-v coverage* is obtained (i.e., from an observation extending from "horizon to horizon"). Compare *snapshot.*

**gain file** — in AIPS, an *extension file*, associated with a *u-v data file*, in which a table of approximate *antenna/i.f. gains* (typically obtained by *self-calibration*) is stored.

**Gaussian-tapered sinc function** — A useful *gridding convolution function* (*q.v.*), of *support width* equal to the width $m\Delta u$ of $m$ *u-v* grid cells, is given by the separable product of two Gaussian-tapered sinc functions, each of the form

$$C(u) = \begin{cases} \left(\frac{\pi u}{b\Delta u}\right)^{-1} e^{-\left(\frac{\pi u}{a\Delta u}\right)^2} \sin\frac{\pi u}{b\Delta u}\,, & |u| < \frac{m\Delta u}{2}\,, \\ 0\,, & \text{otherwise}\,. \end{cases}$$

The choice $m = 6$, $a \simeq 2.52$, and $b \simeq 1.55$, yields what is, in a certain natural sense, an optimal gridding convolution function of this particular parametric form (see [F. R. Schwab, Optimal gridding, VLA Scientific Memo. No. 132]). Also see *spheroidal function.*

**Gerchberg–Saxton algorithm** — a simple iterative algorithm which, in the field of signal processing, is used for the extrapolation of band-limited signals—and, in image processing, for deconvolution. Assume that the Fourier transform $\hat{f}$ of an image $f$ has been measured over a region $B$, and that $f$ is known to be confined to a region $A$. Let $\chi_A$ denote the *characteristic function* of $A$ and $\chi_B$ that of $B$. Denote the measured data by $\hat{g}_{\rm approx}$—i.e., $\hat{g}_{\rm approx} = \chi_B\hat{f} + {\rm error}$. From the initial approximant $f_0$ ($f_0 \equiv 0$ may be used) a sequence $f_n$ of successive approximants to $f$ is obtained, via the formula

$$f_{n+1} = f_n + \mu\chi_A \cdot (\hat{g}_{\rm approx} - \chi_B\hat{f}_n)^{\check{}}\,.$$

Here, $\check{}$ denotes inverse Fourier transform, and $\mu$ is a fixed scalar, analogous to the *loop gain* parameter of the Högbom Clean algorithm.

To apply the algorithm in radio interferometry, one may identify $\chi_B$ with the *u-v sampling distribution* and think of $A$ to be analogous to a *Clean window.* Denoting the *dirty map* by $g$ and the *dirty beam* by $b$, the iteration can be written as

$$f_{n+1} = f_n + \mu\chi_A \cdot (\hat{g} - \hat{b}\hat{f}_n)^{\check{}} \quad (= f_n + \mu\chi_A \cdot (g - b * f_n))\,.$$

The Gerchberg–Saxton algorithm has been implemented by Tim Cornwell in an AIPS program named APGS. APGS includes an *ad hoc* nonnegativity constraint—at each iteration, any pixel value which would be driven negative is modified to become nonnegative. Convergence usually is sluggish.

Some algorithms which are very similar to the Gerchberg–Saxton algorithm are the Lent–Tuy algorithm, which is used in medical imaging, the Papoulis, or Papoulis–Youla algorithm, used in signal processing, and the so-called method of alternating orthogonal projections, used in image reconstruction. See [J. L. C. Sanz and T. S. Huang, Unified Hilbert space approach to iterative least-squares linear signal restoration, *J. Opt. Soc. Am.*, **73** (1983) 1455–1465] and references cited therein.

**Gibbs' phenomenon** — in the neighborhood of a discontinuity of a periodic function $f$, the overshoot and oscillation (or ringing) of the partial sums $S_n$ of the Fourier series for $f$. In the vicinity of a simple jump discontinuity, $S_n$ always overshoots the mark by about 9%, regardless how large $n$. See [H. S. Carslaw, *Introduction to the Theory of Fourier's Series and Integrals*, Dover, New York, 1930, ch. IX].

In harmonic analysis, often the Fourier coefficients are multiplied by a weight function tending smoothly to zero at the boundaries of its *support,* in order to smooth out the discontinuities and thereby reduce the ringing in the synthesized spectrum. (This degrades the spectral resolution, however.) See *Hanning smoothing.* For a discussion of Gibbs' phenomenon in the context of VLA cross correlation analysis, see Larry D'Addario's Lecture No. 4 in the *Third NRAO Synthesis Imaging Summer School*.

**GIPSY** — (Groningen Image Processing System) a data reduction system, similar in scope to AIPS, used in the Netherlands for analysis of Westerbork Synthesis Radio Telescope (WSRT) data.

**global fringe fitting algorithm** — an antenna-based algorithm (in the spirit of the *self-calibration algorithm*) for VLBI fringe search. For an $n$ element array, the classical VLBI fringe fitting technique, a correlator-based method, requires the estimation of $n^2 - n$ parameters. The global fringe fitting method reduces this number to $3n - 3$. Expressing the *antenna/i.f. gain* for antenna $k$ of the array as $g_k(t,\nu) = a_k e^{i\psi_k(t,\nu)}$ (here we include a frequency dependence) one has that the observed visibility on the $i$–$j$ baseline, to first-order, is given by

$$V_{ij}(t,\nu) = a_i a_j V_{ij}(t_0,\nu_0) \times e^{\sqrt{-1}((\psi_i-\psi_j)(t_0,\nu_0)+(r_i-r_j)(t-t_0)+(\tau_i-\tau_j)(\nu-\nu_0))}$$

where $V_{ij}$ is the true visibility, and where the $r_k$ are the *antenna residual fringe rates* and the $\tau_k$ the *antenna residual delays*.

Given a source model, one may solve for the $\psi_k(t_0,\nu_0)$, the $r_k$, and the $\tau_k$, using either a least-squares method or a Fourier transform method. Because of the overdeterminacy provided by a simultaneous solution for the parameters, this method allows proper delay and fringe rate compensation of data on baselines of too low signal-to-noise for the correlator-based method to work effectively. A full description of the method is given in [F. R. Schwab and W. D. Cotton, Global fringe search techniques for VLBI, *Astron. J.*, **88** (1983) 688–694]. This algorithm is implemented in the AIPS program CALIB.

**graphics overlay plane** — same as *graphics plane*.

**graphics plane** — a storage area within a TV display device, such as the $I^2S$, in which a full screen load of one-bit graphics information (labeling, plotting, axis lines, etc.) is stored. A typical $I^2S$ unit is equipped with four graphics planes, each 512 pixels × 512 pixels in area. Compare *image plane*.

**gray-scale display** — a black-and-white display of a digitized *image*—typically either a photographic or a video display.

**gray-scale memory plane** — same as *image plane*.

**Green Book** — *An Introduction to the NRAO Very Large Array*, edited by R. M. Hjellming, NRAO, Socorro, NM—a useful reference on many of the technical aspects of the VLA.

**green screen** — same as *TEK screen*.

**gridding convolution function** — in radio interferometer mapmaking, a function $C$—usually supported on a square the width of, say, six $u$-$v$ grid cells—with which the $u$-$v$ measurement distribution is convolved. The purpose is twofold: 1) to interpolate and smooth the data, so that samples may be taken over the lattice points of a rectangular grid (in order that the fast Fourier transform algorithm may be applied) and 2) to reduce aliasing (the convolution in the $u$-$v$ plane induces a taper in the map plane). See *aliased response, gridding correction function, cell-averaging, dirty map,* and *uniform weighting*.

With judicious choice of $C$, a high degree of aliasing suppression is possible. A high degree of suppression is desirable, even when there are no "confusing" radio sources very near the field of interest, because the effect is not only to reduce the spurious responses due to sources lying outside of the field of view, but also to reduce the response to sidelobes of the source of interest, which too are aliased into the map from outside the field of view. See *spheroidal function*.

**gridding correction function** — in radio interferometry, the reciprocal $1/\hat{C}$ of the Fourier transform (FT) of the *gridding convolution function* $C$. Since the map plane taper induced by the gridding convolution usually is very severe, the dirty map normally is corrected by pointwise division by the FT of the convolution function. Obviously $C$ should be chosen such that $\hat{C}$ has no zeros within the region that is mapped. See *dirty map*.

**gripe** — in AIPS, an entry in the *gripe file* (*q.v.*).

**gripe file** — in AIPS, a disk file repository for formal reports of program *bugs*, and for formal complaints and suggestions of a more general nature. A mechanism by which the user may enter gripes into the gripe file is activated by the issuance of the AIPS verb *GRIPE*. The AIPS group provides prompt, written responses to all *gripes*.

**Hanning smoothing function** — in the analysis of power spectra, a weight function $w$ by which the measured correlation function is multiplied, in order to reduce that oscillation (*Gibbs' phenomenon*) in the computed spectrum which is due to having sampled at only a finite number of lags. $w$, as a function of lag, is given by

$$w(\tau) = \begin{cases} \frac{1}{2}\left(1+\cos\frac{\pi\tau}{\tau_{\max}}\right), & |\tau| < \tau_{\max}, \\ 0, & \text{otherwise}. \end{cases}$$

This is equivalent to convolving the discrete spectrum with the sequence $\{\frac{1}{4}, \frac{1}{2}, \frac{1}{4}\}$.

Hanning smoothing sometimes is applied to the cross correlation measurements obtained in VLA spectral line observing, in order to reduce the effect of sharp bandpass filter cutoffs. It also is used frequently in radio astronomical autocorrelation spectroscopy. See *Gibbs' phenomenon*, and for more on smoothing see [R. B. Blackman and J. W. Tukey, *The Measurement of Power Spectra*, Dover, New York, 1958].

**hard copy** — computer output printed on paper (rather than, say, written on magnetic tape); e.g., a printed contour plot or gray scale display, or a listing of a catalog file.

**hardware mount** — the combined acts of installing a computer external storage module, such as a disk pack or a reel of magnetic tape, in some electro-mechanical unit (e.g., a disk drive or a tape drive) that provides computer access to this data storage medium, and placing that unit in readiness to be operated under computer control (e.g., positioning a magnetic tape at the *BOT marker*). Compare *software mount*.

**header record** — a distinguished record within a *data file*—generally the first record—which serves to define the contents of the other records in the file by supplying relevant parameters, units of measurement, etc.; also termed simply *header*.

In AIPS, however, the header record of each *primary data file* is stored apart from that file, in a file which is termed a "CB" file. And a directory, termed a *catalog file* (*q.v.*), or "CA" file, of all of each user's primary data files on a given disk is stored on that disk. AIPS *extension file* headers are stored within the extension files themselves.

**help file** — in AIPS, a *text file*, whose contents may be displayed on the terminal screen of the interactive user, giving a brief explanation of a particular AIPS verb, adverb, pseudoverb, task, or miscellaneous general feature. Compare *explain file*.

**Hermitian function** — a complex-valued function, of one or more real variables, whose real part is an even function and whose imaginary part is odd. The Fourier transform (FT) of a real-valued function is Hermitian, and the inverse FT of a Hermitian function is real.

Since each of the radio brightness distributions $I(x,y)$, $Q(x,y)$, $U(x,y)$, and $V(x,y)$ representing *Stokes' parameters* is real-valued, *Stokes' visibility functions* have the property of *conjugate symmetry*: $V_I(-u,-v) = \overline{V}_I(u,v)$, $V_Q(-u,-v) = \overline{V}_Q(u,v)$, $V_U(-u,-v) = \overline{V}_U(u,v)$, and $V_V(-u,-v) = \overline{V}_V(u,v)$. (Here, $V_I = \hat{I}$, $V_Q = \hat{Q}$, etc., where $\hat{}$ denotes FT.)

**history file** — in AIPS, an *extension file* containing a summary of all, or most of the processing, by AIPS tasks, of the data recorded in all associated files.

**Hogbom Clean algorithm** — a deconvolution algorithm devised by Jan Högbom for use in radio interferometry [J. A. Högbom, Aperture synthesis with a non-regular distribution of interferometer baselines, *Astron. Astrophys. Suppl. Ser.,* **15** (1974) 417–426]. Denote (the discrete representations of) the dirty map by $g$ and the dirty beam by $b$. The algorithm iteratively constructs discrete approximants $f_n$ to a solution $f$ of the equation $b * f = g$, starting with an initial approximant $f_0 \equiv 0$. At the $n$th iteration, one searches for the peak in the residual map $g - b * f_{n-1}$. A $\delta$-function component, centered at the location of the largest residual, and of amplitude $\mu$ (the *loop gain*) times the largest residual, is added to $f_{n-1}$ to yield $f_n$. The search over the residual map is restricted to a region $A$ termed the *Clean window.* The iteration terminates with an approximate solution $f_N$ either when $N$ equals some iteration limit $N_{\max}$, or when the peak residual (in absolute value) or the r.m.s. residual decreases to some given level.

To diminish any spurious high spatial frequency features in the solution, $f_N$ is convolved with a narrow elliptical Gaussian function $h$, termed the *Clean beam.* Generally $h$ is chosen by fitting to the central lobe of the dirty beam. Also, one generally adds the final residual map $g - b * f_N$ to the approximate solution $f_N * h$, in order to produce a final result, termed the *Clean map,* with a realistic-appearing level of noise. See *super-resolution.*

**host computer** — In the parasitic relationship of a computer program or program package, such as AIPS, to the computer on which it runs, the latter is termed the *host computer.* Also, in the master–slave relationship of a computer to one of its peripheral devices, such as an array processor, the master may be termed the *host.*

**hue** — one of the three basic parameters (*hue*, *intensity*, and *saturation*) which may be used to describe the physical perception of the light that reaches one's eye. Hue, which is also termed *tint*, or simply *color*, refers to the dominant wavelength of the coloration, at a given location in an image or scene. The term also may be used to describe a multimodal color spectrum—e.g., one speaks of a purple hue. Different spectral distributions of light, of identical intensity and saturation, are capable of producing identical retinal responses; these unique responses comprise the set of perceptible hues.

Color matching tests have established that there are three basic types of human retinal receptors, whose peak responses are to red, green, and blue light. These are the three *primary hues* used in additive color mixing—e.g., in digital image display. They may be used to produce all, or virtually all, of the perceptible hues.

See *C.I.E. chromaticity diagram.*

**hybrid mapping algorithm** — an algorithm for calibration of radio interferometer data which is essentially equivalent to the *self-calibration algorithm* (*q.v.*) (used in VLA data reduction), except in that it makes explicit use of the *closure phase* and *closure amplitude* relations, rather than explicit use of the relation $\tilde{V}_{ij} = g_i \overline{g}_j V_{ij}$ relating observed visibility to the product of the true visibility and a pair of *antenna/i.f. gains.* Hybrid mapping, which is used extensively in VLBI data reduction, is described in [A. C. S. Readhead *et al.*, Mapping radio sources with uncalibrated visibility data, *Nature*, **285** (1980) 137–140].

Either algorithm (assuming that one cares to make some distinction) can be applied to data obtained with connected- (e.g., the VLA) and non-connected-element interferometers (e.g., VLBI arrays). Any differences in the results produced by the two algorithms would be attributable primarily to differences in the effective weighting of the data (in particular, early implementations of both algorithms discarded data which could have been used to obtain overdetermined solutions for the calibration parameters).

**IIS** — See $I^2S$.

**image** — in the context of AIPS, any finite-volume, linear, rectangular, or hyper-rectangular array of pixels; e.g., a digitized photograph, or a radio map. The term also is used (less technically) to refer to the *display* of data—e.g., a television picture of a radio map.

**image catalog** — in AIPS, a disk file containing data records describing the data stored on the TV display device *image planes.* These records are essentially identical in structure to the *header records* stored in the *catalog file.* The data in the image catalog furnish the information that is required for proper axis labeling, pixel value retrieval, etc.

**image file** — in AIPS, a *primary data file* whose content is an *image.*

**image plane** — a storage area within a TV display device, such as the $I^2S$, in which a full screen load of single word pixels is stored. A typical $I^2S$ unit is equipped with four image planes, each 512 pixels × 512 pixels in area (each pixel is represented by eight bits). Often several image planes are used at one time—either for black-and-white or *pseudo-color* display of a large image, sections of which may occupy different image planes—or for *false color* or *true color* display of a smaller image, now using, say, three image planes—one to control each of the three electron guns (for red, green, or blue phosphor) in the TV display. Compare *graphics plane.*

**image reconstruction** — the attempted recovery of an *image* after it has undergone the distorting effects, the blurring, etc., produced by some physical measurement and recording device, such as a camera, a radio interferometer, or a tomography machine. The operation of many measurement devices can be adequately modeled by a linear Fredholm integral equation of the first kind. In the two-dimensional case, e.g., one assumes that the measurement $g(x,y)$ is related to the undistorted image $f(x,y)$ by the equation

$$g(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} K(x,y,x',y')f(x',y')\,dx'\,dy' + \epsilon(x,y)\,.$$

(Often it is convenient to use the more compact, operator notation, $g = \mathbf{K}f + \epsilon$.) The kernel $K$ of the equation is called the *point spread function*, (*q.v.*). Measurement error and the error arising from any simplifying assumptions are lumped together into the $\epsilon(x,y)$ term. Some particularly well-behaved measurement systems can be adequately modeled by a simple convolution equation, in which case $K$ is given by

$K(x,y,x',y') = h(x-x', y-y')$. This is the case, e.g., when the VLA is used to observe a small 'unconfused' radio source; then $g$ may be identified with the *dirty map* and $h$ with the *dirty beam*. Or when $K$, considered as a function of $(x,y)$, is given at each $(x',y')$ by the *delay beam* for that position, the equation models the *bandwidth smearing effect* (*q.v.*); as the bandwidth $\rightarrow 0$, the convolution model again becomes valid.

Except in trivial cases, solution of the Fredholm equation always is an ill-posed problem. Mild conditions on $K$ and $f$ (the classical 'Picard conditions'—see F. Smithies [*Integral Equations*, Cambridge Univ. Pr., London, 1958]) ensure the existence of (non-unique) solutions when $\epsilon \equiv 0$. But, because of the effect of measurement noise, one usually does not seek an exact solution, but rather an approximate solution—one which fits the data to within the measurement errors. Uniqueness and regularity of the computed approximate solution are obtained by imposing such constraints as known *support*, nonnegativity, and smoothness conditions. See *regularization method*. Also see H. C. Andrews and B. R. Hunt [*Digital Image Restoration*, Prentice–Hall, Englewood Cliffs, NJ, 1977] and *phaseless reconstruction*.

**inputs file** — in AIPS, a *text file*, whose contents may be displayed on the terminal screen of the interactive user, giving a summary of the *adverbs* relevant to a given *verb* or a given AIPS *task*.

**instrumental polarization** — any contamination of a polarization measurement by an instrument's response to an undesired polarization state. In radio interferometry, the instrumental polarization arises mainly from feed imperfections and from plumbing leaks between the feeds and the receiver front-ends. One tries to remove the instrumental polarization by applying corrections derived from observations of calibration sources whose polarization properties are known. Within AIPS, there is, at present, no facility for polarization calibration. The polarization calibration of VLA data normally takes place on the DEC–10 computer at the VLA. For more details, see Carl Bignell's Lecture No. 4 in the *1985 Summer School Proceedings*. See *beam squint*.

**intensity** — one of the three basic parameters (*hue*, *intensity*, and *saturation*) which may be used to describe the physical perception of color. Intensity is a measure of the energy of the spectral distribution, at a given point in an image or scene, weighted by the spectral response of the visual system. *Luminance* is the energy of the physical spectrum, but not weighted by the visual response. *Brightness* sometimes is used synonymously with either term.

See *C.I.E. chromaticity diagram*.

**invisible distribution** — in the context of radio interferometry, a function $f$ (or a generalized function—or distribution) whose Fourier transform $\hat{f}$ vanishes everywhere that the interferometer pairs have sampled. This term was introduced by R. N. Bracewell and J. A. Roberts [Aerial smoothing in radio astronomy, *Austr. J. Phys.*, **7** (1954) 615–640]. Also see *principal solution*.

For an actual interferometer, there exist fewer physically plausible invisible distributions than for an idealized interferometer. This is because each visibility sample is not a point sample of $\hat{f}$, but rather some kind of local average. By the *Paley–Wiener theorem*, if $\hat{f}$ is nontrivial and vanishes in some open neighborhood, then $f$ cannot be of *compact support*, and hence it may be considered implausible.

**IPL** — (Initial Program Load) same as *boot*.

**isoplanaticity assumption** — in the context of radio interferometry (the term is used too in optics), the assumption that over each element of an array all wavefronts arriving from different parts of the sky to which the interferometer pairs are sensitive are subject to identical atmospheric phase perturbations. A patch of sky over which the assumption is valid is referred to as an *isoplanatic patch*.

Approximate validity of the isoplanaticity assumption is a necessary condition for the success of calibration (*self-calibration*, in particular) of radio interferometer data (from an earth-based array) if one is to rely on a model incorporating time-varying *antenna/i.f. gains*, one per antenna, whose arguments (or phases) are to include the atmospheric phase corruption. However, see F. R. Schwab [Relaxing the isoplanatism assumption in self-calibration; applications to low-frequency radio interferometry, *Astron. J.*, **89** (1984) 1076–1081].

**I$^2$S** — (International Imaging Systems Models 70 and 75) a TV display device, capable of both black-and-white and color display, manufactured by the Stanford Technology Corporation. At an AIPS site typically it is equipped with four 512 pixel × 512 pixel eight-bit *image planes*, four one-bit *graphics planes*, a *trackball,* and sometimes an *ALU*. The eight-bit pixel representation (in the image planes) allows the intensity of each of the three electron gun beams to be set at any of 256 discrete levels. (Actually, 1024 levels can be used, because of an extra two bits of capability provided in the *transfer function* tables and the internal arithmetic unit.) An I$^2$S is attached to three of the NRAO's computers on which the AIPS system runs (the VLA and Charlottesville Vaxes).

**line editor** — a *text editor* (*q.v.*) which allows the modification of single lines or records within a text file, but one which does not allow the simultaneous modification of more than one line. *SOS* and *SEDIT* are both line editors. *Screen editors* (*q.v.*) are more versatile than line editors.

**lobe rotator** — same as *fringe rotator*, (*q.v.*).

**loop gain** — in the Högbom Clean algorithm, the fraction $\mu$ of the largest residual which is used in determining the amplitude, or flux, of a *Clean component*. Convergence can be achieved for $\mu$ in the range $(0,2)$, but generally a small value, say $\mu = \frac{1}{10}$, is recommended, especially in dealing with extended sources. See *Högbom Clean algorithm*.

**luminance** — See *intensity*.

**$l_1$ solution algorithm** — See *self-calibration gain solution algorithm*.

**$l_2$ solution algorithm** — See *self-calibration gain solution algorithm*.

**major cycle** — In the *Clark Clean algorithm* (*q.v.*), a number of minor cycles, or inner iterations, followed by the computation by the FFT algorithm of the full residual map, comprise a major cycle.

**map** — an *image,* one or more of whose coordinate axes represents some spatial coordinate.

**maximum entropy method** — a *regularization method* (*q.v.*) for the numerical solution of ill-posed problems, given noisy data, in which the regularizing (or smoothing) term—which measures the roughness of the computed approximate solution $\tilde{f}$—is given by the negative of the Shannon entropy of $\tilde{f}$, $-H(\tilde{f})$: in the continuous case, letting $A$ denote the domain of definition of $\tilde{f}$, $H(\tilde{f}) \equiv -\int_A \tilde{f}(x)\log\tilde{f}(x)\,dx$, where $\tilde{f}$ has been normalized so that $\int_A \tilde{f}(x)\,dx = 1$ (and $0\log 0 \equiv 0$); and in the discrete case, $H(\tilde{f}) \equiv -\sum \tilde{f}(x_i)\log\tilde{f}(x_i)$, where $\tilde{f}$ has been normalized so that $\sum \tilde{f}(x_i) = 1$. The underlying philosophy of the method, espoused early on by Jaynes ("Jaynes' method of prior estimation", [E. T. Jaynes, Prior probabilities, *IEEE Trans. Syst. Sci. Cyb.*, **SSC-4** (1968) 227–241]) and by J. P. Burg at a 1967 meeting of the Society of Exploration Geophysicists, is that one is being "maximally noncommittal" in regard to the insufficiency of the data if one maximizes the entropy, and thus minimizes the "information content", of $\tilde{f}$, subject to the constraint that $\tilde{f}$ should agree with the given data.

For one-dimensional discrete convolution equations, with noiseless, regularly-spaced data, there exists a closed-form solution—for other cases, iterative methods are used, as with other forms of the regularization method.

Use of the method in radio astronomy was encouraged by J. G. Ables in 1972 in public lectures, and it now is in common use in radio interferometry (cf. [S. F. Gull and G. J. Daniell, Image reconstruction from incomplete and noisy data, *Nature*, **272** (1978) 686–690]). Nonnegativity of the computed solution is a natural by-product of the method. For reconstruction of polarized brightness distributions in interferometry (Stokes' $Q$, $U$, and $V$), which, unlike the total intensity, may assume negative values, Ponsonby has derived an appropriate generalization of the method [J. E. B. Ponsonby, An entropy measure for partially polarized radiation..., *Mon. Not. R. Astr. Soc.*, **163** (1973) 369–380]. See *Variational Method.*

**memory page** — See *virtual memory page.*

**memory paging** — same as *virtual memory page swapping.*

**memory thrashing** — an excessive amount of *virtual memory page swapping* (*q.v.*) on a computer (such as the Vax) with a virtual memory operating system. A condition of memory thrashing is likely to occur whenever too many programs with large memory requirements are active (a single program with excessive memory requirements also can cause memory thrashing).

**message file** — in AIPS, a *text file* containing progress report messages generated during the execution of AIPS *tasks* and also containing a chronicle of the user's interaction (via *verb* commands) with AIPS. Each AIPS user is assigned a message file, the contents of which may be printed out, typed upon a terminal display screen, or emptied—at will—by invoking the appropriate verb command. See *AIPS monitor.*

**message terminal** — same as *AIPS monitor.*

**minor cycle** — in the *Clark Clean algorithm* (*q.v.*), an inner iteration, in which the peak residual over a subregion (the *Clean window*) of the full residual map is found and is used to obtain the next successive iterate. Compare *major cycle.*

**microcode** — See *array processor microcode.*

**monitor** — See *AIPS monitor* or *Conrac monitor.*

$m \times n$ **map** — The convention adopted for AIPS is opposite the standard matrix algebra terminology: whereas an $m \times n$ matrix is comprised of $m$ rows and $n$ columns, an $m \times n$ *map* or *image* in AIPS has, in the usual display format, $m$ pixels along the horizontal axis (usually termed the $x$-axis) and $n$ pixels along the vertical axis (usually termed the $y$-axis). Moreover, pixels of a two-dimensional map in the usual display format are numbered from the bottom left-hand corner: the pixel location specified by the ordered pair $(i, j)$ is in column number $i$ and row number $j$, counting from the bottom left. In other than two-dimensional "images", the $(1, \ldots, 1)$ pixel is also said to be at the "bottom left corner" (BLC), just as in the two-dimensional case. See *data cube*, *pixel coordinates*, and *coordinate reference pixel.*

**MX** — See *"battery-powered" Clean algorithm.*

**natural weighting** — See *uniform weighting.*

**negative bowl artifact** — See *zero-spacing flux.*

**non-closing offset** — See *correlator offset.*

**Nyquist sampling rate** — the slowest rate of sampling which, according to the *Shannon sampling theorem* (*q.v.*), would allow a band-limited function $f(t)$ to be recovered via the *Shannon series.* If the smallest symmetric interval which contains the *support* of the Fourier transform of $f$ is the interval $[-a, a]$, then the Nyquist sampling rate for $f$ is $2a$; i.e., the interval between samples (the *sampling period*) must be less than the *reciprocal bandwidth* $1/2a$. The terms *oversampling* and *undersampling* refer to sampling at rates faster or slower than the Nyquist rate. The difference between $f$ and the Shannon series formed from too coarsely spaced samples is called *aliasing.*

**operating system** —

**page** — See *virtual memory page* and *terminal page.*

**page swapping** — See *virtual memory page swapping.*

**Paley–Wiener theorem** — The classical Paley–Wiener theorem says that a square-integrable complex-valued function $\hat{f}$, defined over the real line, can be extended off the real line as an entire function of exponential type $\leq 2\pi a$ if and only if $f(x) \equiv 0$ for $|x| > a$—i.e., iff $\hat{f}$ is band-limited to $[-a, a]$ (here $\hat{}$ denotes Fourier transform). (An everywhere-analytic function $g(z)$ is said to be of exponential type $\leq A$ if $\exists c$ such that, for all $z$, $|g(z)| \leq ce^{A|z|}$.) For a derivation, see H. Dym and H. P. McKean [*Fourier Series and Integrals*, Academic Press, 1972]. The *Shannon series* is a means of extending $\hat{f}$ to $\mathbf{C}$. The extension of the Paley–Wiener theorem to the case of generalized functions (to tempered distributions) is called the Paley–Wiener–Schwartz theorem.

The Fourier transform $\hat{f} : \mathbf{R}^n \rightarrow \mathbf{C}$ of a function $f$ with support in a given $n$-dimensional convex compact set $K$ can be analytically extended to all of $\mathbf{C}^n$. Growth properties on $\hat{f}$ which are sufficient in order for the converse to hold are given by K. T. Smith, D. C. Solomon, and S. L. Wagner [Practical and mathematical aspects of the problem of reconstructing objects from radiographs, *Bull. Amer. Math. Soc.*, **83** (1977) 1227–1270] (in addition to the classical version of the multi-dimensional Paley–Wiener theorem, for rectangular $K$, they give versions with tighter growth bounds, and for arbitrary convex $K$). Smith *et al.* use the Paley–Wiener theorems to establish indeterminacy theorems for tomographic reconstruction. Their results are also relevant to Fourier synthesis, because of the connection between the two-dimensional Fourier transform and the one-dimensional Radon transform. The Paley–Wiener theorems have also been used in establishing results on the problem of *phaseless reconstruction* (*q.v.*) and in proving the convergence of constrained *Gerchberg–Saxton*-type algorithms (see A. Lent and H. Tuy [An iterative method for the extrapolation of band-limited functions, J. Math. Anal. Appl., **83** (1981) 554–565]).

**phaseless reconstruction** — the reconstruction of an image $f$ (see *image reconstruction*) from knowledge of (only) the magnitude $|\hat{f}|$ of the Fourier transform of $f$ (and usually from only partial knowledge of $|\hat{f}|$). Phaseless reconstruction has been considered for the NRAO's proposed millimeter wave interferometer array [T. J. Cornwell, Imaging of weak sources with compact arrays, NRAO Millimeter Array Memo. No. 12]. Recent results on phaseless reconstruction appear in the JOSA Feature Issue on Signal Recovery [*J. Opt. Soc. Am.*, **73** No. 11 (Nov. 1983)]. Also see the papers by J. R. Fienup and by R. H. T. Bates *et al.* in the *1983 Sydney Conference Proceedings.*

**phase tracking center** — same as *visibility phase tracking center*, (*q.v.*).

**physical memory** — core or semiconductor memory within a computer (as opposed to slower memory—virtual memory, disk storage, magnetic tape footage, etc.). A typical Vax is equipped with a physical memory 3–4 megabytes in size.

**pillbox** — See *cell-averaging*.

**pixel** — (*pic*ture *el*ement) an element of a digitized image (or of a map). A pixel is characterized by its position in the image and by its numerical value. See $m \times n$ *map*, *coordinate reference pixel*, and *pixel coordinates*.

**pixel coordinates** — in an AIPS *image file*, the *pixels* are numbered consecutively, beginning with $(1, \ldots, 1)$ at the bottom left corner (*BLC*) of the image. See *coordinate reference pixel* and $m \times n$ *map*.

**plot file** — an AIPS extension file containing plotting information, in the form of the commands which are necessary in order for a line drawing peripheral device, such as a Calcomp or other pen plotter, a green screen, or an electrostatic printer/plotter, to generate a plot.

**point source response** — same as *point spread function*.

**points per beam** — in a digitized radio map, the characteristic width, somehow defined, of the major lobe of the *beam* pattern, or *point spread function*, divided by the *pixel* separation. Ordinarily the number of points per beam is calculated by measuring the narrowest diameter of the 50% contour level of the major lobe of the beam. To avoid excessively severe discretization error, deconvolution algorithms such as the *Högbom Clean algorithm* and the *maximum entropy method* require, as a rule-of-thumb, at least three (and preferably 4–5) points per beam.

**point spread function** — (PSF) 1. the response of a system or an instrument to an impulsive, or point source, input. 2. in radio interferometry, the response of the instrument to a point, or unresolved, radio source—a fancy term for *beam*. Ignoring instrumental effects, such as finite bandwidth and finite integration time, the response does not depend upon the displacement of the source away from the *visibility phase tracking center*—hence the term *space-invariant PSF (SIVPSF)*, and the contrary term *space-variant PSF (SVPSF)*.

A so-called linear space invariant measurement system (i.e., a linear system with an SIVPSF) is equivalently described as a system which can be modeled by a convolution equation; a linear space-variant measurement system is modeled by a more general linear Fredholm integral equation of the first kind. See *image reconstruction*.

**POPS** — (People-Oriented Parsing System) the parser, or command interpreter, embedded within the AIPS program; that part of the AIPS program which attempts to interpret the user's commands (*POPS symbols*) and then initiate the appropriate reaction. POPS is used in other astronomical data reduction programs at the NRAO: in Condare, TPOWER/SPOWER, and the Tucson 12 m single-dish packages.

**POPS procedure** — See *POPS symbols*.

**POPS symbols** — The AIPS user's primary means of communicating his wishes to AIPS is by typing commands, termed *POPS symbols,* at the keyboard of a computer terminal. There are four classes of POPS symbols: *adverb, verb, pseudoverb,* and *procedure.* An *adverb* is a *symbol* representing the storage area for a datum or for data that are used to control the action of verbs, tasks, and procedures; that is to say that the adverb symbols are used to set *control parameters.* A *verb* is a symbol which causes POPS (or AIPS) to initiate some action after POPS has finished interpreting, or compiling, the command line typed at the computer terminal. A *pseudoverb* is a symbol which suspends, temporarily, the normal parsing of an input line and which causes some action to take place while the line is being compiled, and, possibly, after compilation. A *procedure* is a symbol representing a pre-compiled sequence of POPS symbols. Also see *task*.

**primary beam correction** — in radio interferometry, the multiplicative correction of a radio *map* by the reciprocal of an average of the power patterns of the array elements. Measurements of the primary beam parameters of the 25 m VLA elements are given by Peter Napier and Arnold Rots in the memorandum [VLA primary beam parameters, VLA Test Memo. No. 134, Feb. 1982]. There an average power pattern and its reciprocal are approximated by radial functions, polynomials in the distance from the pointing position. The AIPS task PBCOR is used to apply this correction to VLA maps. The appropriate correction at large distances from the pointing position is not well-determined, thus PBCOR "blanks" the map pixel values beyond a certain radius (see *blanked pixel*).

**primary data file** — in AIPS, either a *u-v data file*, containing measurements of the visibility function of a radio source, or an *image file*, containing a digitized image or a radio map. Compare *extension file*.

**principal solution** — in the context of radio interferometry, the inverse Fourier transform of the *u-v measurement distribution*; i.e., the *dirty map* (*q.v.*) in sense 1 of the definition. This term was introduced by R. N. Bracewell and J. A. Roberts [Aerial smoothing in radio astronomy, *Austr. J. Phys.*, **7** (1954) 615–640]. Except in the trivial case, the principal solution to the mapping problem in interferometry is a physically implausible solution, because the principal solution has not the property of *compact support*.

An *invisible distribution* (*q.v.*) added to the principal solution yields another solution—i.e., another brightness distribution which is consistent with the observations.

**procedure** — See *POPS symbols*.

**prolate spheroidal wave function** — an eigenfunction of the finite, or truncated, Fourier transform—more precisely, for given $c$, one of the countably many solutions of the integral equation

$$\nu f(\eta) = \int_{-1}^{1} e^{ic\eta t} f(t)\, dt\,;$$

equivalently, a solution of the differential equation $(1-\eta^2)f'' - 2\eta f' + (b - c^2\eta^2)f = 0$; or, equivalently, a solution of the wave equation in a system of prolate spheroidal coordinates. The eigenfunction of the above equation associated with the largest eigenvalue $\nu$ is termed the 0-order solution.

If we want a gridding convolution function $C$, of *support width* equal to the width of $m$ grid cells, that is optimal in the sense that its Fourier transform $\hat{C}$ has the property that the concentration ratio

$$\frac{\iint_{\text{map}} |\hat{C}(x,y)|^2\, dx\, dy}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} |\hat{C}(x,y)|^2\, dx\, dy}$$

is maximized, then $C$ is the separable product of two 0-order prolate spheroidal wave functions, with $c = \pi m/2$. See *gridding convolution function* and *spheroidal function*.

**prompt character** — a character (often the dollar sign "$" or the greater-than sign ">") which the computer program or the operating system prints on the terminal screen of the interactive user in order to prompt, or invite, a typed response from the user. The AIPS program's standard prompt character is the greater-than sign, and on the Vaxes at the NRAO the operating system's prompt character is the dollar sign. On most UNIX systems, the prompt character is the percent sign. Thus, most commands (or *POPS symbols*) peculiar to AIPS must be typed on a line beginning with the >-character, and any command to the operating system, such as the command to mount a tape, must be typed on a line beginning with the $- or %-character.

When operating in some lesser-used, special modes, AIPS employs other prompt characters: ":" for procedure building, ";" for procedure editing, "!" for entry of gripes, "<" for batch file preparation, and "#" for parameter reading.

**Prussian helmet Clean algorithm** — a modified version of the Högbom Clean algorithm, devised by Tim Cornwell. The idea is to drive the Clean algorithm toward an approximate solution $f$ of minimal Euclidean norm—i.e., to find an $f$ consistent with the data, confined to the Clean window, comprised of a small number of point components, and such that $\iint_{\substack{\text{Clean}\\\text{window}}} [f(x,y)]^2\, dx\, dy$ is minimized. This is accomplished by adding a $\delta$-function of amplitude $\omega$, centered at the origin, to the dirty beam, and then just proceeding as normal with the Clean algorithm. Proper choice of $\omega$ depends on the distribution of measurement errors. See [T. J. Cornwell, A method of stabilizing the Clean algorithm, *Astron. Astrophys.*, **121** (1983) 281–285]. A provision for this modification is incorporated in the AIPS tasks APCLN and MX. See *regularization method*.

**pseudo-AP** — See *pseudo-array processor*.

**pseudo-array processor** — in AIPS, the term which is applied to a collection of Fortran subroutines which may be used to emulate the operation of an FPS Model AP–120B array processor. At those AIPS sites which do not have an array processor, the AIPS tasks which normally would make use of an array processor use the pseudo-array processor subroutines instead. See *array processor*.

**pseudo-color display** — In digital imagery, a *pseudo-color* display is one which is derived from a single real-valued function $f(x, y)$ and a mapping $\mathbf{R}^1 \rightarrow \mathbf{R}^3$ that controls the *hue*, *intensity*, and *saturation*—or, equivalently, the proportions in an additive mixture of three primary hues—of the coloration at each *pixel* coordinate $(x, y)$ of the display, according to the value of $f(x, y)$. A pseudo-color display might be used, for example, to represent measurements of the intensity of the radio continuum flux density of a source.

Compare *false color display* and see *color contour display*.

**pseudo-continuum u-v data file** — in VLA spectral line data reduction, a *u-v data file* containing the visibility measurements from a small number of spectral line channels, recorded in the same format as continuum visibility data. The purpose is to enable the use, for spectral line data analysis, of programs originally intended only to handle continuum data reduction.

**pseudoverb** — See *POPS symbols*.

**PSF** — See *point spread function*.

**Q-routine** — in AIPS, a primitive level subroutine designed to function on a particular manufacturer's production model of an *array processor*. A goal of the AIPS project is to construct libraries of Q-routines—one library appropriate to each model of array processor which might be used in conjunction with AIPS—with identical names, argument lists, and functionality. Existing Q-routines emulate the standard library of Floating Point Systems, Inc.'s, model *AP–120B array processor*.

**quick boot** — an abbreviated boot procedure. See *boot*.

**RANCID** — (Real (or Radio) Astronomical Numerical Computation and Imaging Device) the name by which the AIPS data reduction system formerly was known.

**re-boot** — Having booted once already, one *re-boots*. See *boot*.

**regularization method** — in the numerical solution of ill-posed problems, given noisy data, a method in which the original problem is converted into a well-posed problem by requiring of the solution to the modified problem (which now is an approximate solution to the original problem) that it satisfy some smoothness constraint. The prototypical ill-posed problem has the form $Kf = g + \epsilon$, where $K$ is a known linear integral operator (e.g., a convolution operator), where $g + \epsilon$, which is given, represents some noisy measurement, and where $f$ is unknown. In the context of radio interferometry, one may take $g+\epsilon$ to be the *dirty map* and $K$ to be the operator which convolves the "true" radio source brightness distribution $f$ with the *dirty beam*. Now, denoting our approximate solution to the ill-posed problem by $\tilde{f}$, $\tilde{f}$ is found by minimizing the expression

$$(1 - \lambda)\|g - K\tilde{f}\|^2 + \lambda S(\tilde{f})\,,$$

for some given choice of the *regularization parameter* $\lambda$, $0 < \lambda < 1$. $\|g - K\tilde{f}\|^2$ is the mean squared residual (occasionally some other measurement of the error is used), and $S(\tilde{f})$ is a measure of the roughness of the computed solution—say, some power of a norm or seminorm of $\tilde{f}$, or a similar quantity, such as the negative of the (Shannon) entropy of $\tilde{f}$.

Proper choice of $\lambda$ must be based on statistical considerations which depend on the distribution of measurement errors; often, one chooses $\lambda$ in order achieve an *a priori* reasonable value of the mean squared residual. The *maximum entropy method, Tikhonov regularization*, and the *Prussian helmet Clean algorithm* are special cases of the regularization method. Appropriate choice of $S$ is discussed by J. Cullum [The effective choice of the smoothing norm in regularization, *Math. Comp.*, **33** (1979) 149–170], and the choice of $S$ and $\lambda$, by a statistical method known as "cross validation", is described by G. Wahba [Practical approximate solutions to linear operator equations when the data are noisy, *SIAM J. Numer. Anal.*, **14** (1977) 651–677]. Often, some Sobolev norm is chosen for $S$.

Usually, in addition to the smoothness constraint, $f$ is assumed to be of known, *compact support*. Other constraints, such as nonnegativity, may be included as well. In the case in which the data are exact—i.e., when $\epsilon = 0$, so that $g = Kf$—one may obtain the regularized solution corresponding to $\lambda = 0$ as the limit of regularized solutions $\tilde{f}_\lambda$ as $\lambda \rightarrow 0$. See *Variational Method*. Also see D. M. Titterington [General structure of regularization procedures in image reconstruction, *Astron. Astrophys.*, **144** (1985) 381–387].

**regularization parameter** — in the *regularization method* (*q.v.*) for the solution of ill-posed problems, a smoothing parameter $\lambda$, $0 < \lambda < 1$, which controls the trade-off between an error term, measuring agreement of the computed solution $\tilde{f}$ with the given data, and a term $S(\tilde{f})$, which measures the roughness of $\tilde{f}$. I.e., $\lambda$ controls the amount of "regularization". See *super-resolution*.

**re-IPL** — same as *re-boot*.

**residual delay** — Expressing the *antenna/i.f. phase*, $\psi_k$, for antenna $k$ of a VLBI array as a function of frequency as well as of time, the residual delay on the $i$–$j$ baseline at $(t_0, \nu_0)$ is given by $\tau_{ij} \equiv \left.\frac{\partial(\psi_i - \psi_j + \phi_{ij})}{\partial \nu}\right|_{(t_0,\nu_0)}$, where $\phi_{ij}$ denotes the visibility phase on the $i$–$j$ baseline. (The partial w.r.t. $t$ is called the *residual fringe rate.*) Usually the major contributor to residual delay is the difference in the station clock errors. The residual delay is a group delay, rather than a phase delay. It is termed residual because it is assumed that geometric effects have already been compensated for.

The "antenna components" of $\tau_{ij}$, namely $\tau_k \equiv \left.\frac{\partial \psi_k}{\partial \nu}\right|_{(t_0,\nu_0)}$, are called the *antenna residual delays.* They are among the solution parameters of the global fringe fitting algorithm for VLBI. See *residual fringe rate* and *global fringe fitting algorithm.*

**residual fringe rate** — Expressing the *antenna/i.f. phase*, $\psi_k$, for antenna $k$ of a VLBI array as a function of frequency as well as of time, the residual fringe rate on the $i$–$j$ baseline at $(t_0, \nu_0)$ is given by $r_{ij} \equiv \left.\frac{\partial(\psi_i - \psi_j + \phi_{ij})}{\partial t}\right|_{(t_0,\nu_0)}$, where $\phi_{ij}$ denotes the visibility phase on the $i$–$j$ baseline. (The partial w.r.t. $\nu$ is called the *residual delay.*) Usually the major contributor to residual fringe rate is the drift of the station clocks.

The "antenna components" of $r_{ij}$, namely $r_k \equiv \left.\frac{\partial \psi_k}{\partial t}\right|_{(t_0,\nu_0)}$, are called the *antenna residual fringe rates.* They are among the solution parameters of the global fringe fitting algorithm for VLBI. See *residual delay* and *global fringe fitting algorithm.*

**resolution** — See *spatial resolution.*

**restoring beam** — same as *Clean beam.*

**roam** — See *TV roam.*

**run file** — in AIPS, a *text file* written by an AIPS user and containing a sequence of AIPS commands (*POPS symbols*). Run files are useful for the storage of strings of commands which one might wish to execute repeatedly (in particular, for the storage of lengthy *procedures*). The run files for all users at a particular AIPS installation are stored in a common area. These files ordinarily are created through use of one of the standard *text editors* of AIPS' host computer.

**sampling theorem** — See *Shannon sampling theorem.*

**saturation** — one of the three basic parameters (*hue*, *intensity*, and *saturation*) which may be used to describe the physical perception of color. Saturation is a measure of the (perceived) narrowness of the color spectrum, or the difference of the hue from a gray of the same intensity. Neutral gray—or a "white" spectrum—is termed 0% saturated, and a monochromatic spectrum is termed 100% saturated.

See *C.I.E. chromaticity diagram.*

**scratch** — 1. The act of deleting a data file—i.e., surrendering the storage medium space which that file occupies—is termed *scratching* the data file. Use of the term *delete* may be preferable, but *scratch* is more common among AIPS users. One who is about to delete a data file may wish first to create a back-up copy. See *back-up.* 2. an adjective meaning *temporary*, as in *scratch file.*

In AIPS a primary data file and all of its associated extension files can be deleted by means of the verb ZAP.

**scratch file** — a data file intended for temporary storage (esp., of data which represent intermediate results—i.e., *scratch*work). Many of the AIPS tasks use scratch files; the necessary scratch files are created and destroyed automatically by the tasks. However, when an AIPS task *crashes,* sometimes a scratch file remains.

**screen editor** — a *text editor* (*q.v.*) which, unlike a *line editor*, allows the simultaneous modification of more than one line or record within a text file. For example, a mechanism to facilitate alignment of margins often is incorporated by a screen editor. *EDT*, *EVE*, *vi* and *EMACS* are screen editors.

**scroll** — See *terminal scroll* and *TV scroll.*

**self-calibration algorithm** — Many of the systematic errors affecting interferometer visibility measurements may be assumed to be multiplicative and ascribable to individual array elements. That is, in an $n$ element array, the observations on the $n(n-1)/2$ baselines are afflicted by $n$ sources of systematic error, the so-called *antenna/i.f. gains* $g_k(t)$. Given a rough estimate of the true source visibility, a model obtained, say, by mapping and Cleaning roughly calibrated data, one may solve for the unknown gains—and it is not unreasonable to do so, because there are $(n-1)/2$ times more observations than antenna gains. The number of degrees of freedom can be held further in check by assuming that the $g_k(t)$ are slowly-varying or that they are of unit modulus (i.e., that no amplitude errors are present), or by designing an array with redundant spacings.

Having once solved for the unknown $g_k$, one may correct the data, make another map, and repeat the process. This iterative scheme, which yields successive approximations to the true radio source brightness distribution, is known as *self-calibration.* Self-calibration is essentially identical to the technique of *hybrid mapping*, which is widely used in VLBI. See *self-calibration gain solution algorithm*; also see Tim Cornwell and Ed Fomalont's Lecture No. 9 in the *Third NRAO Synthesis Imaging Summer School* and the review paper by T. J. Pearson and A. C. S. Readhead [Image formation by self-calibration in radio astronomy, *Ann. Rev. Astron. Astrophys.*, **22** (1984) 97–130].

**self-calibration gain solution algorithm** — In self-calibration, the unknown *antenna/i.f. gains* $g_k(t)$ may be approximated by minimizing a functional $S(g_1, \ldots, g_n)$ given by a weighted discrete $l^p$ norm of the residuals:

$$S(\mathbf{g}) = \left( \sum_{1 \le i < j \le n} w_{ij} \left| \tilde{V}_{ij} - g_i \overline{g}_j V_{ij} \right|^p \right)^{1/p} .$$

Here $\tilde{V}_{ij}$ is the visibility measurement obtained on the $i$–$j$ baseline (at a given instant), $V_{ij}$ is the corresponding *model* visibility, and $w_{ij}$ is a suitably chosen weight. Usually the $g_k$ may be assumed not to vary too rapidly with time, so that one may minimize, instead, the functional

$$S(\mathbf{g}) = \left( \sum_{1 \le i < j \le n} w_{ij} \left| \left\langle \tilde{V}_{ij}/V_{ij} \right\rangle - g_i \overline{g}_j \right|^p \right)^{1/p} ,$$

where $\left\langle \tilde{V}_{ij}/V_{ij} \right\rangle$ is the time-average of the ratio of observed visibility to model visibility, over a time period during which the $g_k$ may be assumed constant.

The AIPS implementation allows the choices $p = 1$ and $p = 2$. Choosing $p = 2$ yields the least-squares solution for $\mathbf{g}$. When one chooses $p = 1$, so that a weighted sum of the moduli of the residuals is minimized, the computed gain solutions are less influenced by wild data points, but there is some loss of statistical efficiency—i.e., the least-squares solutions are superior when the distribution of measurement errors is well-behaved. (Probably the choice $p \simeq 1.2$ would offer a better compromise between efficiency and robustness).

See [F. R. Schwab, Robust solution for antenna gains, VLA Scientific Memo. No. 136] for further details.

One may wish to solve only for the *antenna/i.f. phases* $\psi_k(t)$ rather than for the $g_k$ if, for example, atmospheric phase corruption is believed to be the dominant source of systematic error. In this case, one minimizes

$$S(\Psi) = \left( \sum_{1 \le j < k \le n} w_{jk} \left| \tilde{V}_{jk} - e^{i(\psi_j - \psi_k)} V_{jk} \right|^p \right)^{1/p} ,$$

or the version thereof incorporating time-averages.

Cornwell and Wilkinson [A new method for making maps with unstable radio interferometers, *Mon. Not. R. Astr. Soc.*, **196** (1981) 1067–1086] suggest adding to $S$ terms which arise by assuming prior distributions for the $g_k$; these "penalty terms" would be chosen so as to increase in magnitude as the solution parameter deviates from a prior mean which one might take, say, as the running mean of previous gain solutions. The widths of the prior distributions could be based on empirical knowledge of the behavior of the array elements. Such a modification can be useful when the array is composed of antenna elements of differing collecting area. This modification is used in order to constrain the moduli of the computed gains in one version of the AIPS task for self-calibration which is used primarily for VLBI data reduction (VSCAL).

**Shannon sampling theorem** — Suppose the complex-valued function $f$ of the real variable $t$ to be square-integrable, and assume that $f$ is band-limited; i.e., that its Fourier transform $\hat{f}(x) = \int_{-\infty}^{\infty} f(t) e^{2\pi i x t}\, dt \equiv 0$ for $|x| > a$. Then $f$ is completely determined by its values at the discrete set of sampling points $n/2a$, $n = 0, 1, 2, \ldots$, and $f$ can be recovered via the *Shannon series* (also called the cardinal series)

$$f(t) = \sum_{n=-\infty}^{\infty} f\left(\frac{n}{2a}\right) \frac{\sin 2\pi a(t - n/2a)}{2\pi a(t - n/2a)} .$$

The series converges both uniformly and in the mean-square sense.

The Shannon series can be derived by expanding $\hat{f}$ in a Fourier series, and then applying Fourier inversion—or it can be derived from the classical Poisson summation formula. It is sometimes referred to as Whittaker's cardinal interpolation formula or the Whittaker–Shannon sampling series, having first been studied in detail by E. T. Whittaker in 1915 and later introduced into the literature of communications engineering by Shannon in 1949. By the *Paley–Wiener theorem*, since $f$ is band-limited, it can be analytically extended from the real line to the full complex plane, as an entire function of slow growth. The Shannon series, which converges for complex as well as real $t$, is one means of doing so. Whittaker referred to the series as "a function of royal blood in the family of entire functions, whose distinguished properties separate it from its bourgeois brethren."

Suppose that $f(t)$ is "small" for $|t| > b$ (no nontrivial signal is both band-limited and time-limited). Then, assuming that $b$ is integral, the number of terms in the Shannon series that really matter is $4ab$. This suggests that the space of "essentially band-limited" and "essentially time-limited" signals has dimension equal to the *time-bandwidth product* $4ab$. The precise sense in which this is so, together with a discussion of the *prolate spheroidal wave functions* (*q.v.*), which are relevant to the problem, is described by H. Dym and H. P. McKean [*Fourier Series and Integrals*, Academic Press, New York, 1972] and by David Slepian [Some comments on Fourier analysis, uncertainty and modeling, *SIAM Rev.*, **25** (1983) 379–393].

The multi-dimensional extension of the sampling theorem to rectangles implies that if an "unconfused" radio source $f(x, y)$ is confined to a small region of sky $|x| < x_0$, $|y| < y_0$ (radians), then it can be reconstructed unambiguously from a discrete set of visibility samples $\hat{f}(m\Delta u, n\Delta v)$, $m, n = 0, 1, 2, \ldots$, with $\Delta u = 1/2x_0$ and $\Delta v = 1/2y_0$ wavelengths. See *cellsize* and *Nyquist sampling rate*. Other useful extensions of the sampling theorem—for example, to various multi-dimensional sampling configurations (e.g., 2–D hexagonal sampling lattices), to the case of stochastically jittered sampling, to derivative sampling (e.g., in 1–D, $f$ can be recovered from samples of $f$ and its derivatives through order $r$ taken at intervals $(r+1)\frac{n}{2a}$), etc.—and sampling theorems for functions whose transforms of other than Fourier type are of *compact support*—are described in survey articles by A. J. Jerri [The Shannon sampling theorem—its various extensions and applications: a tutorial review, *Proc. IEEE*, **65** (1977) 1565–1596] and J. R. Higgins [Five short stories about the cardinal series, *Bull. (New Ser.) Amer. Math. Soc.*, **12** (1985) 45–89].

**Shannon series** — See *Shannon sampling theorem*.

**shed** — See *sub-task*.

**SIVPSF** — See *point spread function*.

**slice** — a one-dimensional cut across an *image*. E.g., the slice of a two-dimensional image $f$ which passes through $(x_0, y_0)$ and has orientation angle $\phi$ is the *subimage* $h$ given by $h(t) = f(x_0 + t\cos\phi, y_0 + t\sin\phi)$. In AIPS, a slice may be excised from an image by issuing the *verb* command SLICE. Since AIPS deals only with digitized images, the program must interpolate to obtain data along the cut, except when the slice is taken along a row or column of the image.

**slice file** — in AIPS, an *extension file*, associated with an *image file*, in which a digitized *slice* (*q.v.*), or one-dimensional subimage, of the primary image is stored. In order to display a slice, one may issue the *verb* command SL2PL, which causes AIPS to read the contents of a slice file and generate a *plot file*.

**snapshot** — in earth-rotation aperture synthesis interferometry, an observation which is of such short duration that Earth's motion does not significantly enhance the *u-v coverage*, or a *map* derived from such a brief observation. Compare *full-synthesis map*.

For a thorough discussion of the use of the VLA in snapshot mode, see §5 of A. H. Bridle's Lecture No. 16 in the *1985 Summer School Proceedings*.

**software mount** — a computer's reaction to the issuing of a command to it informing it that the *hardware mount* of some external storage module, such as a disk pack or a reel of magnetic tape, has occurred, and that the computer should open the channel of access to this module. See *hardware mount*.

**sort order** — the ordering of visibility measurements within a *u-v data file*. *Time-baseline order* is convenient for purposes of calibration, *baseline-time order* for data display, and so-called *x-y order* for gridding and subsequent mapping.

**source editor** — same as *text editor*. (Formerly, computers were used mainly for numerical computations and text editors primarily for the editing of program source code—hence the name *source editor*).

**spatial resolution** — In digital image analysis, this term refers rather imprecisely to the minimum size of details which can be discerned. The spatial resolution is determined by three factors: the inherent indeterminacy of whatever *image reconstruction* problem underlies the method by which the image was produced (and the properties of the image reconstruction *algorithm* which produced the image); the measurement noise; and the *pixel* size—i.e., the size of the squares or the rectangles comprising the reconstruction matrix.

In radio interferometry, the inherent spatial resolution goes roughly in inverse proportion to the physical size scale $D$ of the array (measured in wavelengths). For observations at a wavelength $\lambda$, the inherent spatial resolution, with a filled aperture, is essentially $\lambda/D$ radians. However, with a synthesis array with large gaps in the *u-v coverage*, the effective resolution is somewhat coarser. Often, some measure of the spread of the central lobe of the *dirty beam* (say, the FWHM) is quoted as the spatial resolution. However, some reconstruction methods (e.g., the *regularization methods*) produce images in which the resolution of bright features may be much finer than that of dim features. This property of regularization methods may be viewed as either good or bad: $S/N$ dependent spatial resolution complicates the interpretation of an image, but, on the other hand, one may gain additional contrast resolution—i.e., low surface-brightness features may become more readily discernible. An honest statement concerning the spatial resolution of an image must be based upon empirical knowledge of the reconstruction method that was used. See *super-resolution*.

**spawn** — See *sub-task*.

**spheroidal function** — an eigenfunction $\psi_{\alpha n}$ of a finite, weighted-kernel Fourier transform—more precisely, for given $c$ and given $\alpha > -1$, one of the countably many solutions of the integral equation

$$\nu f(\eta) = \int_{-1}^{1} e^{ic\eta t}(1-t^2)^{\alpha} f(t)\, dt\,;$$

equivalently, a solution of the differential equation $(1-\eta^2)f'' - 2(\alpha+1)\eta f' + (b - c^2\eta^2)f = 0$. The eigenfunction $\psi_{\alpha 0}$ of the equation above associated with the largest eigenvalue $\nu$ is termed the 0-order solution. The choice $\alpha = 0$ of weighting exponent yields the family $\{\,\psi_{0n} \mid n = 0,1,2,\dots\,\}$ of prolate spheroidal wave functions.

Weighted 0-order spheroidal functions $(1-\eta^2)^{\alpha}\psi_{\alpha 0}$ are optimal gridding convolution functions in the same sense that the *prolate spheroidal wave functions* (*q.v.*) are optimal, except that now the weighted concentration ratio

$$\frac{\iint_{\text{map}} |\hat{C}(x,y)|^2 (1-(2x\Delta u)^2)^{\alpha} (1-(2y\Delta v)^2)^{\alpha}\, dx\, dy}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} |\hat{C}(x,y)|^2 |1-(2x\Delta u)^2|^{\alpha} |1-(2y\Delta v)^2|^{\alpha}\, dx\, dy}$$

is maximized (see the paper by F. R. Schwab in the *1983 Sydney Conference Proceedings*). The weighting exponent $\alpha$ is used to trade off the effectiveness of the aliasing suppression at the edge of the field of view, against that in the central region of the map. The choice $\alpha = 1$, with a *support width* of six *u-v* grid cells, yields an effective gridding convolution function, emphasizing aliasing suppression in the central region of the map; this function, $\psi_{10}$, with $c = 3\pi$, is the default function used in the AIPS mapping program. See *gridding convolution function*.

**Stokes' parameters** — the four coordinates relative to a particular basis for the representation of the polarization state of an electromagnetic wave propagating through space. Consider a wave propagating along the $z$-direction in a right-handed $(x,y,z)$ Cartesian coordinate system. At a fixed point in space, let the instantaneous components of the electric field vector, in the $x$- and $y$-directions, be denoted by $E_x(t)$ and $E_y(t)$, respectively; and assume them to be stationary (in the weak sense, and square-integrable) stochastic processes. Form the matrix

$$S = \begin{pmatrix} \langle E_x(t)\overline{E}_x(t+\tau)\rangle^{\frown} & \langle E_x(t)\overline{E}_y(t+\tau)\rangle^{\frown} \\ \langle E_y(t)\overline{E}_x(t+\tau)\rangle^{\frown} & \langle E_y(t)\overline{E}_y(t+\tau)\rangle^{\frown} \end{pmatrix}.$$

Here, the bracketed expressions are expectation values, or correlation functions, in the lag variable $\tau$, and $\frown$ denotes Fourier transform with respect to $\tau$. Thus each element of $S$ is a function of frequency $\nu$. $S$ is Hermitian (conjugate symmetric), owing to the stochasticity assumptions. The three Pauli spin matrices, together with the $2 \times 2$ identity matrix, form a basis for the algebra of $2 \times 2$ Hermitian matrices; i.e., each such matrix $S$ can be represented in the form

$$\begin{aligned} S(\nu) &= \sigma_1(\nu)\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} + \sigma_2(\nu)\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \\ &\quad + \sigma_3(\nu)\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} + \sigma_4(\nu)\begin{pmatrix} 0 & i \\ -i & 0 \end{pmatrix}. \end{aligned}$$

The four (real) coefficients, $\sigma_1, \dots, \sigma_4$, of the representation of $S$ in this basis are called Stokes' parameters. They commonly are denoted by $I(\nu)$, $Q(\nu)$, $U(\nu)$, and $V(\nu)$, respectively. In other words,

$$S(\nu) = \begin{pmatrix} I(\nu)+Q(\nu) & U(\nu)+iV(\nu) \\ U(\nu)-iV(\nu) & I(\nu)-Q(\nu) \end{pmatrix},$$

with $I$, $Q$, $U$, and $V$ real.

Stokes' parameter $I$ measures the total intensity of the radiation field, $Q$ and $U$ the linearly polarized intensity, and $V$ the circularly polarized intensity. $I$ always is nonnegative. For a totally unpolarized wave, $Q = U = V = 0$; for a partially polarized wave, the ratio $\sqrt{Q^2+U^2+V^2}/I$ measures the total degree of polarization, $\sqrt{Q^2+U^2}/I$ the degree of linear polarization, and $\frac{1}{2}\arctan\frac{U}{Q}$ the orientation angle of the linearly polarized component. $Q + iU$ is called the complex linear polarization. The IAU and IEEE orientation/sign conventions have the $z$-axis directed toward the observer, the $x$-axis directed north, and a $+i$ in the argument of the exponential kernel of the FT. Positive $V$ corresponds to right circular polarization, and conversely. The polarization response of an interferometer can be described by forming the so-called cross-spectral density matrix, which is like the $S$ above but is formed from measurements of the electric field taken at two points in space. For further details, including a description of the polarization response of an interferometer, for various feed configurations, see Carl Bignell's Lecture No. 6 in the *1982 Summer Workshop Proceedings*.

**Stokes' visibility functions** — Stokes' visibility functions, $V_I$, $V_Q$, $V_U$, and $V_V$, are the Fourier transforms (FT's) of the radio brightness (spatial) distributions of *Stokes' parameters*, $I(x,y)$, $Q(x,y)$, $U(x,y)$, and $V(x,y)$. (Here, $V_I = \hat{I}$, $V_Q = \hat{Q}$, etc., where $\hat{}$ denotes FT.)

For a radio interferometer with ideal circularly polarized feeds, the relations between Stokes' visibility functions and the visibilities, $V_{RR}$, $V_{LL}$, $V_{RL}$, and $V_{LR}$, obtained by correlating right circular response with right, left with left, etc., are $V_I = \frac{1}{2}(V_{RR} + V_{LL})$, $V_Q = \frac{1}{2}(V_{LR} + V_{RL})$, $V_U = \frac{i}{2}(V_{LR} - V_{RL})$, $V_V = \frac{1}{2}(V_{RR} - V_{LL})$. Note that each of Stokes' visibility functions is *Hermitian.* On the assumption that circular polarization is absent (i.e., that $V(x, y) \equiv 0$), $V_{RR}$ is equal to $V_{LL}$, and both are Hermitian.

Components of the systematic errors affecting visibility measurements are i.f.-dependent; hence VLA *u-v* data files usually do not contain Stokes' visibilities, but rather $V_{RR}$, $V_{LL}$, $V_{RL}$, and $V_{LR}$—as these are what is required for calibration purposes. Stokes' visibility functions generally are constructed only within the mapping programs. (But the AIPS visibility data format is designed to accommodate either type of visibility function, and the mapmaking tasks are able to recognize the form of their input data and deal with them appropriately.)

**subimage** — in AIPS parlance, any linear, rectangular, or hyper-rectangular section of an *image.*

**sub-task** — a task, or computer program, whose execution is initiated by the action of another program. The act of initiating the execution of the sub-task is called *task shedding* or *task spawning.* See *task.*

**super-resolution** — The problem of image reconstruction in radio interferometry is one of finding an approximation to an unknown function $f$ (generally assumed to be of *compact support*) from *partial knowledge* of its Fourier transform $\hat{f}$ — i.e., from a finite number of measurements of the visibility. Any of the techniques which are applied to the problem—the *Högbom Clean algorithm*, the *regularization method*, etc.—may be thought of as methods of smoothing, interpolating, and extrapolating the noisy measurements. *Super-resolution* is a term which refers to the extrapolation aspect: Cautious extrapolation yields an image whose *spatial resolution* is $\approx \lambda/D$, where $D$ is the diameter of the largest centered region in the *u-v* plane which has been reasonably well sampled. Less cautious extrapolation yields super-resolution; spurious detail appears as caution is abandoned.

Super-resolution in a *Clean map* is effected by choosing an artificially narrow *Clean beam.* With regularization methods (in image reconstruction, and more generally), super-resolution comes about by choosing a small value of the *regularization parameter.* The spatial resolution achieved by a regularization method may be signal-to-noise dependent—bright features may be super-resolved, and dim ones not.

**support** — The closure of that subset of the domain of definition of a function $f$ (or of a generalized function, or distribution) on which the function assumes a nonzero value is called the *support* of the function, and is denoted by supp$(f)$. I.e., $\mathrm{supp}(f) = \overline{\{\, x \mid f(x) \neq 0 \,\}}$.

For example, the support of the function $f(x) = x$ is the whole real line, even though $f(0) = 0$. And the support of

$$f(x,y) = \begin{cases} 1\,, & x^2 + y^2 < 1\,, \\ 0\,, & \text{otherwise}\,, \end{cases}$$

is the *closed* unit disk, $\left\{ (x,y) \;\middle|\; x^2 + y^2 \leq 1 \right\}$.

In Euclidean space, a function $f$ whose support is bounded—i.e., such that $f \equiv 0$ "far-out"—is said to be of *compact support.* The Fourier transform of a nontrivial function of compact support (such as a *u-v measurement distribution* or a *gridding convolution function*) cannot itself be of compact support; i.e., it has "sidelobes" extending to infinity.

**support width** — of a function whose *support* is a rectangle or a hyper-rectangle (e.g., the Fourier transform of a band-limited function), the linear measure of one of the edges of its *support.*

**SVPSF** — See *point spread function.*

**Synthesis Imaging in Radio Astronomy** — A collection of lectures from the 1988 (Third) NRAO Synthesis Imaging Summer School edited by R. A. Perley, F. R. Schwab and A. H. Bridle. (Astronomical Society of the Pacific Conference Series, Volume 6 (1989)). A very useful reference book for the reduction of radio interferometric data. This volume supersedes the proceedings from the earlier workshops.

**synthesized beam** — in radio interferometry, the *beam*—but always ignoring instrumental effects. Hence, the synthesized beam is fully determined by the *u-v sampling distribution*, the *u-v weight function*, the *u-v taper function*, and the *gridding convolution function.* See *beam.*

**tape blocking efficiency** — Data are stored on magnetic tape in units of *blocks.* An *inter-record gap*—essentially wasted space—separates one block from the next. The *tape blocking efficiency*, or the fraction of unwasted space, is the ratio

$$\frac{\frac{\text{block length}}{\text{recording density}}}{\frac{\text{block length}}{\text{recording density}} + \text{length of an inter-record gap}}\,.$$

The length of an inter-record gap is about $\frac{3}{4}$, $\frac{3}{5}$, and $\frac{3}{10}$ inch at recording densities of 800, 1600, and 6250 bpi, respectively.

**taper** — See *u-v taper function.*

**task** — used in two senses: 1) the execution of a computer program and 2) the program itself. Thus, if two computer users are (independently) running the same program at the same time, it may be said either that two tasks are running, or that two incarnations of the same task are in existence. A *sub-task* (*q.v.*) is a task whose execution is initiated by the action of another program. Many of the more complicated and the more specialized functions of AIPS are accomplished by the action of sub-tasks shed by the AIPS program. (Simpler functions are invoked by the issuance of *verb* commands—see *POPS symbols.*)

**t-b order** — See *time-baseline order.*

**TEK screen** — a cathode ray tube (CRT) terminal and display device appropriate for pictorial display of data, in the form of contour plots, graphs, etc., as well as for display of textual data. The Tektronix company's Model 4012 terminal (with a green P4 phosphor, hence the synonymous term *green screen*) is the canonical device of this type. The "make copy" button on this device can be used to produce a copy, on paper, of the image shown on the CRT screen. Each of the NRAO's AIPS data reduction computers is outfitted with a *TEK screen.*

**TEK4012** — same as *TEK screen.*

**Telex 6250 tape drive** — a model of tape drive used on the VLA Vaxes, capable of operation at 1600 and 6250 bpi.

**terminal page** — Many modern computer terminals contain a semiconductor memory with a capacity of several CRT screen loads ($\approx 24$ lines) of character data. A *terminal page* is a unit of one screen load of such data. Certain terminal keys allow one to cause data which previously appeared on the

CRT screen to reappear—this feature is called *terminal scroll* (*q.v.*). A typical terminal at the NRAO has three terminal pages of memory.

**terminal scroll** — that feature present on certain models of computer terminals which allows data which previously appeared on the CRT screen to be made to reappear. Often, depressing one key on the terminal will cause earlier information to reappear line-by-line (this is termed *line scroll*), while the action of another key will cause a whole earlier screen load to reappear (this is termed *page scroll*).

**text editor** — a computer program designed for the creation, manipulation, and modification of computer files containing textual data such as reports, documentation, alphanumeric command lines, and program source code. Generally, one or more text editors are supplied by the computer manufacturer. Three text editors are in widespread use on the Vax—*SOS*, *EMACS* and *EDT*. *vi*, *edt* and *emacs* are used on NRAO's Convex computers. See *line editor* and *screen editor*.

**text file** — a computer data file containing only textual data, as might be written by a *text editor* (*q.v.*). Programs such as the AIPS tasks sometimes write messages, especially progress report messages, into a text file—see *message file*.

**Third NRAO Synthesis Imaging Summer School** — The 1988 Summer School on Synthesis Imaging which was held in Socorro, New Mexico in June 1988. The lectures were formally published in *Synthesis Imaging in Radio Astronomy*.

**thrashing** — See *memory thrashing*.

**time-baseline order** — An ordered set of visibility measurements $\{\, V_{ij}(t_k) \mid \; 1 \le i < j \le n,\; k = 1, \ldots, l \,\}$ recorded with an $n$ element interferometer at times $t_1 < t_2 < \ldots < t_l$ is said to be in *time-baseline order* if the ordering is such that all of the data obtained at time $t_1$, sorted into the canonical ordering by baseline, occur first, followed by the data obtained at time $t_2$, again ordered canonically, etc., etc. (The canonical ordering by baseline is the order $V_{12}, V_{13}, \ldots, V_{1n}, V_{23}, \ldots, \ldots, V_{n-1,n}$ .) Compare *baseline-time order*.

Time-baseline ordering of a *u-v data file* is convenient for calibration purposes. The AIPS task for self-calibration requires that its input *u-v* data file be time-baseline ordered.

**time smearing** — in a radio interferometer map, the space-variant broadening of the *point spread function* (or *beam*) which is due to time averaging of the data. When, for example, the visibility data along a *u-v* track are averaged, with equal weight, over time intervals of width $\Delta t$ sec., the visibility amplitude of a point source is reduced by a factor $\approx \frac{\sin\gamma}{\gamma}$ — where $\gamma \equiv \pi(u'x + v'y + w'z)\Delta t$, where the primes denote the time rate of change of the spatial frequency coordinates $(u, v, w)$ along the track (wavelengths/sec.), and where $(x, y, z)$ denotes the direction cosines of the location of the point source with respect to the *phase tracking center*. For further details, see A. R. Thompson's Lecture No. 2 and Alan Bridle and Fred Schwab's Lecture No. 13 in the *Third NRAO Synthesis Imaging Summer School*. Compare *bandwidth smearing*.

**trackball** — a spherical ball mechanism, about the size (10 cm., or so, in diameter) of a tennis ball, which may be oriented manually by the interactive user of a television display device such as the $I^2S$. The ball can be rotated about any axis, and its orientation, which is sensed by the computer, typically is used to control the enhancement or the coloration of the displayed data (i.e., to control the TV *transfer function(s)*), or to position the *TV cursor*, in order to point out to a program features in the displayed image which are of particular interest.

**trackball button** — On the unit which houses the trackball for the $I^2S$ Model 70 TV display device are the four *trackball buttons*, labeled A, B, C, and D. These are switches that are used, in conjunction with the display routines, to exert additional control over the TV display. Occasionally these buttons are put to other use in AIPS, such as stopping the Clean deconvolution program.

**transfer function** — a transform which can be used to describe the output of a device (say, an electrical transducer) as a function of the input to the device. See *TV look-up table*.

**TRC** — *top right corner*, the corner of an image diagonally opposite the BLC. See $m \times n$ *map*.

**true color display** — a type of *false color display*, (*q.v.*).

**TU77 tape drive** — a model of tape drive used on the NRAO's Vaxes, capable of operation at 800 and 1600 bpi.

**TU78 tape drive** — a model of tape drive used on the VLA Vaxes, capable of operation at 1600 and 6250 bpi.

**TV blink** — a feature of a computer-controlled TV display device, such as the $I^2S$, intended to facilitate the comparison of a pair of images stored on two different *image planes*. The TV display is made to alternate between the two images. The AIPS implementation of blinking allows the user, by manipulating the *trackball*, to control the rate of alternation and the fraction of time that each image is displayed.

**TV cursor** — See *crosshair*.

**TV image catalog** — See *image catalog*.

**TV look-up table** — a memory within the control unit of a TV display device which is used for storage of the *transfer functions* controlling the intensity of the display, as a function of pixel value. Within AIPS, the transfer functions may be altered through the use of interactive verbs and manipulation of the *trackball*.

**TV roam** — a feature of a computer-controlled TV display device such as the $I^2S$ which allows contiguous parts of a single large image, stored on more than one *image plane*, to be displayed as if the image were stored on a single, larger image plane. On the $I^2S$ unit, the portion of the image to be displayed on the TV screen is selected by manipulation of the *trackball*. See *image plane*.

**TV scroll** — a feature of a computer-controlled TV display device such as the $I^2S$ which allows the display of an image stored on a single *image plane* to be moved about the display screen. This feature, which also is called panning, commonly is used in combination with the *TV zoom* capability. On the $I^2S$ unit, the scroll ordinarily is controlled by manipulation of the *trackball*. Compare *TV roam*.

**TV zoom** — a magnification feature of a computer-controlled TV display device such as the $I^2S$. On the $I^2S$, the three available magnification factors (which multiply the linear dimensions of the original display of the image by a factor of 2, 4, or 8) generally are selected by depressing one of the *trackball buttons*. Since the magnification is achieved by pixel replication (i.e., by piecewise linear interpolation)—rather than by a smooth interpolation—the visual impression may be somewhat displeasing. The entire magnified image may not fit on the TV screen, so zoom usually is used in combination with the *TV scroll* feature.

**uniform weighting** — A *dirty map* obtained by computing the inverse Fourier transform (FT) of a weighted *u-v measurement distribution* in which each visibility sample has been weighted in inverse proportion to the local density of the *u-v coverage* is said to have been computed using *uniform weighting*. When a radio map is computed via the fast Fourier transform algorithm, uniform weighting may be achieved by computing normalized discrete convolution summations $\sum_{i=1}^{N} C(u-u_i, v-v_i)\tilde{V}_i/N$, where $(u,v)$ denotes the spatial frequency coordinates of a given *u-v* grid cell, where $C$ is an appropriately chosen *gridding convolution function*, and where the $\tilde{V}_i$ are the $N$ visibility measurements obtained at positions $(u_i, v_i)$ in some neighborhood of $(u,v)$, the size of which is determined by the *support* of $C$. The uniform weighted map is given by the inverse discrete FT of data interpolated and smoothed in this manner, onto the lattice points of a rectangular grid. So-called *natural weighting* is achieved by using unnormalized convolution sums, rather than by dividing by $N$. The AIPS mapmaking tasks use a weighting scheme which is slightly more complicated than that described here.

Since the density of *u-v* coverage typically is greater in the inner regions of the *u-v* plane, a map computed using uniform weighting has finer *spatial resolution* than one computed with natural weighting. With natural weighting, low surface-brightness extended features may be more easily discernible than with uniform weighting. Essentially the same effect can be achieved with uniform weighting, when accompanied by use of a *u-v taper function*.

**UNIX** — a "universal" computer operating system developed at the Bell Telephone Laboratories. Its virtue is that program packages such as AIPS—once having been made to run under one UNIX-based operating system—ought to run on any other such system, even on a computer of different manufacture, with no alterations. Many Vaxes operate under UNIX, though not the NRAO's. The Convexes C-1 in Charlottesville and at the AOC operates under UNIX. See *operating system*.

**user-coded task** — an AIPS *task* written by a user, rather than by a professional programmer or a member of the AIPS programming group. One of the design goals for AIPS, not yet fully realized, is that it should be relatively easy for a user who is not an experienced programmer to write an AIPS task suited to his own needs—i.e., that it should be fairly simple for him to make some sense of the AIPS database, and to get at his data and manipulate it as he sees fit. The AIPS task named FUDGE is intended to serve as a paradigm for user-coded tasks for manipulation of *u-v data files*; two other tasks, TAFFY and CANDY, are paradigms for *image file* manipulation. A useful reference is the manual by W. D. Cotton and a 'cast of AIPS' [*Going AIPS! A Programmers Guide to the NRAO Astronomical Image Processing System*, NRAO, Charlottesville, VA, 1990].

The addition to AIPS of new *verbs*, and modification of the functioning of existing verbs, requires modifying the AIPS program itself; this is best left to the AIPS programming group.

**u-v coverage** — the *support* of the *u-v sampling distribution* (*q.v.*). Also see *conjugate symmetry*.

**u-v data file** — in AIPS, a *primary data file* designed to accommodate the measurements of the visibility function of a radio source.

**u-v data flag** — In an AIPS *u-v data file*, each visibility measurement is accompanied by a real-valued weight, which ordinarily is (positive and) proportional to the length of the integration period over which the measurement was obtained. A non-positive weight represents a *u-v* data flag, which signifies that the visibility measurement ought to be ignored. See *flagging* and *clipping*.

**u-v FITS format** — an extension of the *FITS format* (originally designed for the interchange of image data) to accommodate radio interferometer visibility data [E. W. Greisen and R. H. Harten, An extension of FITS for groups of small arrays of data, *Astron. Astrophys. Suppl. Ser.*, **44** (1981) 371–374]. See *FITS format*.

**u-v measurement distribution** — in radio interferometry, a linear combination of shifted Dirac $\delta$-functions, one located at the position in the *u-v* plane of each visibility measurement, and each weighted by the visibility measurement obtained at that location. Denoting the *u-v* coverage by $\{(u_i, v_i)\}_{i=1}^{n}$, the visibility function by $V$, and the measured visibility by $\tilde{V}$, the (two-dimensional) *u-v* measurement distribution $S$ is given by $S(u,v) = \sum_{i=1}^{n} \tilde{V}(u_i, v_i)\delta(u-u_i, v-v_i)$. Compare *u-v sampling distribution*.

This definition may be modified to incorporate two types of weight function, yielding a *weighted* and/or *tapered* measurement distribution—see *u-v taper function* and *u-v weight function*.

The visibility measurements $\{\tilde{V}(u_i, v_i)\}$ are not actual samples of $V$, but rather are error-corrupted samples of a function which represents some sort of *local average* of the visibility—this is a distinction which it is worthwhile to note, and then to ignore. Various systematic errors affecting the measurements may be corrected by proper calibration—see *antenna/i.f. gain* and *instrumental polarization*.

**u-v sampling distribution** — in radio interferometry, a linear combination of shifted Dirac $\delta$-functions, one located at the position in the *u-v* plane of each visibility measurement. Sometimes termed *u-v transfer function*. See *beam*.

If $\{(u_i, v_i)\}_{i=1}^{n}$ (the *u-v coverage*) is the set of spatial frequency coordinates at which the source visibility has been sampled, then the (two-dimensional) *u-v* sampling distribution $S$ is given by $S(u,v) = \sum_{i=1}^{n} \delta(u-u_i, v-v_i)$.

Occasionally the term *u-v sampling distribution* is used in the same sense as the term *u-v measurement distribution* (*q.v.*).

**u-v taper function** — an even, real-valued weight function (typically, an elliptical Gaussian), smooth and peaked at the origin, which may be incorporated into the definition of *u-v measurement distribution* or *u-v sampling distribution*, above, serving to control the spatial resolution of the radio map or the beam; i.e., to enhance the response to extended features in the radio source brightness distribution by giving relatively higher weight to the measurements at short *u-v* spacings. Compare *u-v weight function*.

**u-v transfer function** — same as *u-v sampling distribution*, but always explicitly incorporating any *u-v* weight function or *u-v* taper function.

**u-v weight function** — a real-valued function which may be incorporated in the definition, above, of *u-v measurement distribution* or *u-v sampling distribution*, serving to weight each measurement either according to an estimate of the statistical measurement error, or according to the local density of sampling, or both. Compare *u-v taper function* and see *uniform weighting.*

**Varian printer** — an electrostatic printer/plotter manufactured by the Varian Corp.

**Variational Method** — the name which applies to Tim Cornwell's AIPS implementation (in the program VM) of the *maximum entropy method*, to solve the image deconvolution problem $g = b * f$, where $g$ and $b$ are given, and $f$ is unknown. The regularizing term $S(\tilde{f})$ (see *regularization method*), a function of the computed approximate solution $\tilde{f}$, is given by the negative of an entropy expression, of the form

$$H(\tilde{f}) = -\int_A \tilde{f}(x) \log \frac{\tilde{f}(x)}{h(x)}\, dx\,.$$

Here $A$ denotes the (assumed known) support of $f$, and $h$ is a prior estimate of $f$; when $h \equiv$ constant, this agrees with the standard formulation of the maximum entropy method. A weighted sum $\chi^2(\tilde{f}) + \lambda S(\tilde{f})$ of a $\chi^2$ error term and $S$ is minimized, and the regularization parameter $\lambda$ is chosen so that the r.m.s. residual corresponding to the final iterate is approximately equal to an input value. For optical data the $\chi^2$ term is taken as $\|g - b * \tilde{f}\|^2$, whereas for radio data the $\chi^2$ term is evaluated in the visibility domain, where the measurement errors may more properly be assumed to be statistically independent. Also, $\int_A \tilde{f}$ is constrained to be near an estimate of the *zero-spacing flux* which is supplied by the user. The minimization is done using a Newton-type method, with a diagonal approximation to the Hessian of the objective function and intricate control of the steplength. In terms of execution speed, this method is competitive with the *Clark Clean algorithm*—at least in the case of large objects of complex structure observed with the VLA—and superior results usually are obtained for this class of objects. See [T. J. Cornwell, Deconvolution with a maximum entropy type algorithm, VLA Scientific Memo. No. 149].

**verb** — See *POPS symbols.*

**Versatec printer** — an electrostatic printer/plotter manufactured by the Versatec Corp., and used on the NRAO's AIPS computer systems.

**Very Long Baseline Interferometry — Techniques and Applications** — Proceedings of the NATO Advanced Study Institute held at Castel S. Pietro Terme, Bologna, Italy in 1988. Edited by M. Felli and R. E. Spencer. Kluwer Academic Publishers, Dordrecht (1989). This volume contains much useful information on the planning and execution of VLBI observations as well as on the reduction of VLBI data.

**vi** — a moderately sophisticated text editor (a *screen editor*) used on computers which run the UNIX operating system. See *text editor.*

**virtual memory page** — on a computer running under a virtual memory operating system, one unit of *virtual memory storage*. At a typical Vax installation, the size of a virtual memory page is 512 bytes.

**virtual memory page swapping** — on a computer running under a virtual memory operating system, the action (initiated automatically by the operating system) of reading new virtual memory pages into the physical memory, and storing on disk (i.e., in the *virtual memory*) the data which thus have been displaced. Each occurrence of the displacement of a memory page is referred to as a *page fault.* See *memory thrashing.*

**virtual memory storage** — computer storage—typically disk storage—in an area apart from the *physical memory* of a computer. Access to virtual memory storage is controlled by the operating system, in a way intended to give the programmer the illusion that a large amount of physical memory is present. Access to virtual memory may be much slower than access to physical memory, and the operating system may incur a significant amount of overhead in managing the virtual memory. See *memory thrashing.*

**visibility phase tracking center** — In a correlating-type radio interferometer usually the *fringe stopping center* and the *delay tracking center* coincide. When this is the case, both are referred to as the visibility phase tracking center.

**VM** — See *Variational Method.*

**VMS** — (Virtual Memory System) the operating system used on the NRAO's Vax computers. See *virtual memory storage* and *operating system.*

**wedge** — a legend, or scale—generally in the form of a bar graph with gradations in *intensity* and *chromaticity*—which may be displayed adjacent to a photographic or video display of a digitized *image.* The wedge is a visual representation of the *transfer function* that was used in generating the display. The wedge is either colored or gray, depending on whether the display is a *pseudo-color display* or a *gray-scale display.*

Note that a *false color display* would require more than one wedge (or a multi-tiered wedge) to display the several transfer functions, as well as an additional wedge to display the possible color mixtures.

**window Clean** — an application of the *Högbom Clean algorithm*, with an explicit specification, by the user, of the Clean window. Generally the user should specify a Clean window whenever it is possible to make a reasonably valid and restrictive estimate of the *support* of the true radio source brightness distribution. At the termination of the algorithm, it is prudent to examine a display of the residual map for the presence of large residuals outside of the Clean window; their presence could suggest that an inappropriate window was selected. See *Clean window.*

**working set size** — on a computer running under a virtual memory operating system, the amount of *physical memory* allocated to a task. Any program memory requirement in excess of the working set size is relegated to *virtual memory storage.* At a typical Vax installation, the working set size is set at $\frac{1}{4}$ or $\frac{1}{2}$ megabyte.

**x-y order** — An ordered set of visibility samples $\{V(u_i, v_i, w_i)\}_{i=1}^n$ arranged according to descending absolute value of the spatial frequency coordinate $u$ — i.e., with $|u_1| \geq |u_2| \geq \ldots \geq |u_n|$ — is said to be in *x-y order.*

*x-y* order is a convenient ordering for the operation of gridding convolution; hence the AIPS mapping tasks require that their input *u-v data files* be sorted accordingly. See *sort order.*

**Y-routine** — in AIPS, a subroutine designed to aid in the use of a specific model of TV display device, such as the $I^2S$ Model 70. AIPS requires a relatively small core of Y-routines implementing basic TV display functions; complicated display functions then are accomplished by combining these basic functions that are supposed to be common to many models of TV display device. At present there are approximately 25 Y-routines for use at those AIPS installations equipped with an $\mathrm{I^2S}$. Compare *Z-routine.*

**zero-spacing flux** — The visibility $V(u,v) \equiv \hat{f}(u,v)$ ( $\hat{}$ denotes Fourier transform) of a source brightness distribution $f$ in a neighborhood of $u = v = 0$ is inaccessible to an interferometer composed of elements of finite collecting area. The *zero-spacing flux* is equal to the total, or integrated flux density of the source—i.e., it is given by $V(0,0) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x,y)\,dx\,dy$ . Because the hole in the *u-v coverage* in the neighborhood of the origin may be fairly large, image reconstruction methods, such as the *Högbom Clean algorithm*, may do a poor job, within this central region, of interpolating the measured data. This frequently is manifested by the appearance of a *negative bowl artifact*—a negative 'baseline' beneath the reconstruction of $f$ —owing to the reconstruction method having underestimated the zero-spacing flux. The *Variational Method* for maximum entropy reconstruction requires that the user supply an estimate of $V(0,0)$. The Clean algorithm, too, may benefit if a datum at $u = v = 0$ is included when the *dirty map* is constructed.

A zero-spacing estimate can be derived from single-dish measurements. Providing a proper estimate is difficult, because of contamination of single-dish measurements by 'confusing sources.' The estimate ought to correspond to a telescope with the same primary beam response as the array elements; and it is not just a single datum $V(0,0)$ which is missing, but rather a region—so proper weighting of the zero-spacing information is tricky. See Tim Cornwell and Robert Braun's Lecture No. 8 in the *Third NRAO Synthesis Imaging Summer School*.

**zoom** — See *TV zoom.*

**Z-routine** — in AIPS, a subroutine—generally designed to perform some routine, often needed function—written for a specific model of *host computer* or for a specific host computer operating system. The implementation of certain basic functions, especially those for file access and file management, generally is machine dependent and operating system dependent. The typical AIPS installation requires 50–100 Z-routines. Compare *Y-routine.*

**1978 Groningen Conference Proceedings** — *Image Formation from Coherence Functions in Astronomy. Proceedings of IAU Colloquium No. 49 held at Groningen, the Netherlands, August 10–12, 1978*, edited by C. van Schooneveld, D. Reidel, Dordrecht, Holland, 1979—contains many papers on aperture synthesis techniques, including some of the early papers on *hybrid mapping*.

**1982 Summer Workshop Proceedings** — *Synthesis Mapping. Proceedings of the NRAO–VLA Workshop held at Socorro, New Mexico, June 21–25, 1982*, edited by A. R. Thompson and L. R. D'Addario, NRAO, Green Bank, WV, 1982—a collection of the fifteen lectures which comprised this short course on aperture synthesis techniques—a useful introduction to VLA data reduction methods.

**1983 Sydney Conference Proceedings** — *Indirect Imaging: Measurement and Processing for Indirect Imaging. Proceedings of an International Symposium held in Sydney, Australia, August 30–September 2, 1983*, edited by J. A. Roberts, Cambridge Univ. Press, Cambridge, 1984—contains a number of interesting papers on aperture synthesis techniques.

**1985 Summer School Proceedings** — lecture notes from the second NRAO summer short course on radiointerferometric imaging (in preparation). This volume supersedes the *1982 Summer Workshop Proceedings.*

**1988 Summer School Proceedings** — lecture notes from the third NRAO Summer School on radio interferometric imaging. The lectures have been published as *Synthesis Imaging in Radio Astronomy* (*q.v.*).

**4012** — See *TEK screen.*

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