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SHELLS, BUBBLES, AND CHIMNEYS IN THE SOUTHERN GALACTIC PLANE SURVEY

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RESUMEN

El *Southern Galactic Plane Survey* (SGPS) es el conjunto de datos ideal para explorar el impacto que tienen las estrellas masivas en el medio interestelar galáctico. Estamos utilizando el SGPS para estudiar las propiedades globales de las cáscaras de H I en escalas que van desde decenas hasta miles de parsecs. Aquí presentamos una chimenea galáctica intrigante y discutimos la distribución galáctica de cáscaras de H I grandes con respecto al radio galáctico y los brazos espirales.

ABSTRACT

The H I Southern Galactic Plane Survey (SGPS) is an ideal dataset with which to explore the impact of massive stars on the Galactic ISM. We are using the SGPS to study the global properties of H I shells over size scales ranging from tens of parsecs to kiloparsecs. Here we present an intriguing Galactic chimney and discuss the Galactic distribution of large H I shells with respect to Galactic radius and spiral arms.

Key Words: **ISM: BUBBLES — ISM: STRUCTURE**

1. INTRODUCTION

Neutral hydrogen (H I) shells are excellent tools for looking in detail at the interaction between massive stars and the interstellar medium. H I shells are usually detected as voids in the interstellar H I, with walls of swept-up H I. These shells display a wide range of physical properties with radii between tens of parsecs and kiloparsecs and formation energies between 10^{50} and 10^{53} erg. As such, they seem to trace the effects of massive stars over all stages of the stellar evolutionary cycle from main-sequence stars producing H II regions to Wolf-Rayet stars, to supernova remnants and even up to massive shells around stellar clusters.

The Southern Galactic Plane Survey (SGPS) is an ideal dataset for studying H I shells. The SGPS is a neutral hydrogen (H I) survey of the fourth quadrant of the plane of the Milky Way. The survey combines data from the Australia Telescope Compact Array (ATCA) and the Parkes Radio Telescope[5] for nearly complete sampling of angular scales between two arcminutes and several degrees. The data allow us to study the global properties of H I shells and to probe individual H I shells on size scales ranging from parsecs to hundreds of parsecs. Here we present an example from a catalog of large H I shells discovered in the SGPS. We also discuss the distribution of large H I shells in the Galaxy.

2. THE SHELL CATALOG

We have recently compiled a catalog of large H I shells in the SGPS region (McClure-Griffiths et al. 2002). The catalog contains nineteen new H I shells larger than two degrees in angular diameter. The physical properties of these shells cover a wide range of values: radii are between 40 pc and 700 pc, expansion velocities are between $6\,\mathrm{km\,s^{-1}}$ and $21\,\mathrm{km\,s^{-1}}$, and expansion energies are between 2×10^{50} erg and 4×10^{53} erg.

2.1. *Examples*

High resolution H I data afforded by the new Galactic surveys are highlighting many interesting new features in H I shells. For the first time we can explore the detailed physics of these very large-scale objects. Figure 1 is an H I image of the Galactic chimney GSH 277+00+36 (McClure-Griffiths et al. 2000). The image was made by combining Parkes multibeam data with a 1025 pointing mosaic from the ATCA for 3 arcmin resolution over the entire $10^\circ \times 10^\circ$ field. The chimney is at a distance of $\sim$ 6.5 kpc and is located on the edge of the Sagittarius-Carina spiral arm. It has a diameter of $\sim$ 600 pc and extends more than 1 kpc both above and below the

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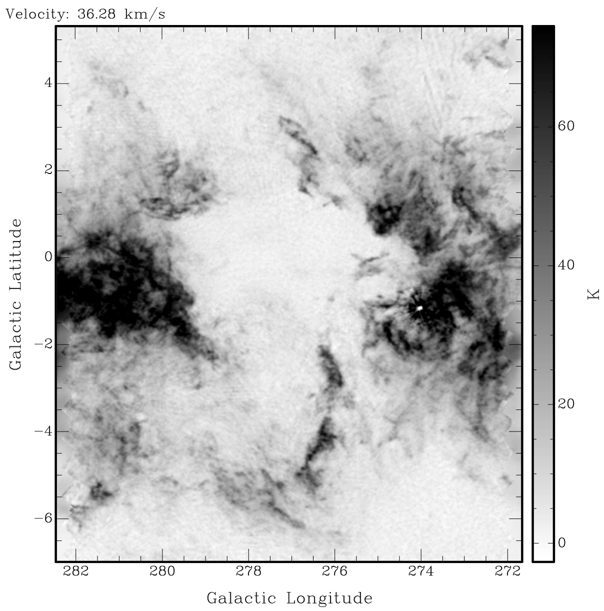

Fig. 1. H I shells GSH 277+00+36 at 3 arcmin resolution. This image is a 1025 pointing mosaic from the ATCA combined with Parkes data for full sensitivity.

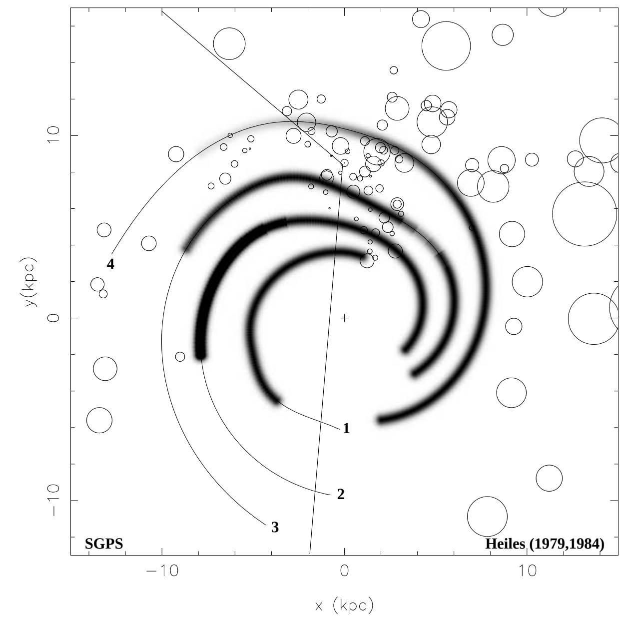

Fig. 2. Cataloged shells plotted on the spiral pattern of the Galaxy from Taylor & Cordes (1993). As marked, shells in the first and second quadrant are from Heiles (1984) and shells in the fourth quadrant are from this work. The spiral arms are labelled 1 to 4 according to the following: (1) Norma, (2) Scutum-Crux, (3) Sagittarius-Carina, and (4) Perseus. The Galactic center is marked by a cross-hair and the position of the Sun is marked by circle with a dot at the center. The SGPS survey region is marked by straight, solid lines. From McClure-Griffiths et al. (2002).

Galactic plane. These high-resolution data reveal a wealth of structure down to the smallest scales of ~ 5 to 15 pc. The shell walls are extremely thin and in some places, such as the upper left hand corner, appear to be breaking down into the ambient ISM. It is believed that H I shells eventually dissipate back into the ISM through the development of instabilities and ambient motions carving away at the structural integrity of the walls. Also noteworthy, is the emptiness of the shell interior. Even at a resolution of 3 arcmin there are very few clumps of emission greater than a few K of $T_{\rm B}$ near the center of the shell. Clearly, this region has been entirely voided of neutral hydrogen.

3. DISTRIBUTION OF LARGE H I SHELLS

One of the objectives of the SGPS large shell catalog is to explore the Galactic distribution of H I shells and to determine whether shell properties vary with Galactic position. To this end we first examined the properties of an azimuthally averaged sample of H I shells. It has been noticed in external galaxies, as well as the Milky Way, that the largest H I shells are also at large galactic radii (e.g., Heiles 1979; Deul & den Hartog 1990). Comparing shell radius to Galactic radius for the Heiles (1979, 1984) and SGPS shell catalogs we find that, indeed, the largest shells are far from the Galactic center. However, it is worth noting that in the Milky Way, selection effects tend to lead to more shells detected in the outer Galaxy.

Another objective of the catalog is to explore the distribution of H I shells with respect to Galactic structure. Because H I shells are believed to be stellar by-products a priori we might expect H I shells to be distributed where the massive stars are, i.e., in the spiral arms. We find, however, that many shells are not in spiral arms, but between the arms. Figure 2 shows the distribution of H I shells from the SGPS and Heiles (1979, 1984) catalogs overlaid on the Taylor & Cordes (1993) model for the spiral arms. Shell positions and sizes are based on their kinematic distances and angular sizes. It seems from this figure that many of the shells are away from spiral arms and that many large shells are at far Galactic radii. Several uncertainties arise, however, because the positions of the spiral arms are not well known and we are forced to assume a rotation curve for shell positions. A less biased approach is to compare the shell distribution with respect to the longitude-velocity (l-v) diagram of some spiral tracer, such as CO emission. The advantage of this method is that it relies only on directly measured quantities and does not require an assumed rotation curve. Figure 17 of McClure-Griffiths et al. (2002) shows the distribution of SGPS shells in l-v space overlaid on CO emission from the Dame et al. (1987) survey. In this view, as in Figure 2, very few of the shells are coincident with spiral tracers, but instead lie well outside the spiral arms.

In McClure-Griffiths et al. (2002) we explore possible scenarios that might result in a population of large H I shells between the spiral arms. There are two main ideas to explain this distribution. The first is a simple timescale argument whereby the difference in linear velocities between the spiral pattern and gas disk results in a separation between evolved shells and the spiral arms. For example, for a spiral pattern speed of $\Omega_{\rm p} \sim 15\,{\rm km\,s^{-1}\,kpc^{-1}}$, the spiral arms at a distance of 8 kpc from the Galactic Centre travel with a linear velocity of $v = \Omega_{\rm p} R_{\rm gal} \approx 120\,{\rm km\,s^{-1}}$, whereas the disk gas rotates at $\sim 220\,{\rm km\,s^{-1}}$, so in the ~ 30 Myr formation time for a large shell, the shell can cross through the ~ 3 kpc wide spiral arm. Therefore, if an H I shell were formed in a spiral arm, by the time it reached its maximum size it would have migrated out of the spiral arm.

An alternative effect may be that H I shells formed on the edge of spiral arms reach exaggerated sizes because of their expansion into the less dense interarm regions. These shells expand rapidly along the density gradient leading from arm to interarm region. This effect is well-known for shells expanding out of the Galactic plane towards the halo. Simulations have shown that shells expanding out of the plane tend to elongate along that direction, forming chimneys. We create a simple model for the H I density in the Galactic plane as a result of spiral arms in order to explore the strength of the density gradient away from spiral arms and to compare that with the density gradient away from the plane. Using this simple model we find that, at a distance of ~ 8 kpc from the Galactic center, the density gradient away from spiral arms is comparable to the density gradient away from the Galactic plane (McClure-Griffiths et al. 2002). This suggests that shells expanding at the edge of spiral arms may experience exaggerated expansion into interarm regions in a manner that is analogous to chimney formation. If this is true, we should expect to see a population of extra-large shells in between spiral arms.

4. CONCLUSIONS

We have presented some results from a catalog of large H I shells in the SGPS. We focus on the distribution of these objects, noting in particular that many very large shells lie at large Galactic radii and that many shells are between the spiral arms. We suggest that the latter may be a joint effect of shells migrating out of spiral arms as they grow as well as growing larger as they expand into inter-spiral arm regions.

The new high resolution, H I Galactic Plane surveys provide excellent datasets with which to study H I shells. These datasets offer sensitivity to spatial scales ranging from parsecs to hundreds of parsecs and are allowing us, for the first time, to study the physical details of H I shells throughout the Galaxy.

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