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THE HYPER-ENERGETIC SN 1988Z

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RESUMEN

Presentamos el catálogo espectrofotométrico de la evolución de SN 1988Z, que combina observaciones multi-frecuencia con el propósito de ofrecer una panorámica de la evolución de la supernova y derivar la energía radiada desde su descubrimiento.

ABSTRACT

We present the spectro-photometric evolution of SN 1988Z, including radio, optical and X-ray data, with the aim of offering a comprehensive view of the evolution of this object and deriving the total energy radiated since discovery. The major contribution to the total radiated energy comes from optical to X-ray frequencies, with a total emission of at least 2×10^{51} erg (for $H_0 = 50$ km s^{-1} Mpc^{-1}) in 8.5 years. A model-dependent extrapolation of this value indicates that the total radiated energy may be as high as 10^{52} erg. The high value of the radiated energy supports a scenario in which most of the ejecta kinetic energy is thermalized and radiated in an interaction with a dense circumstellar medium. In this sense, 1988Z is not a supernova but a young and compact supernova remnant.

Key Words: **SUPERNOVAE: INDIVIDUAL (SN 1988Z) — SUPERNOVA REMNANTS**

1. INTRODUCTION

The explosion of massive stars is thought to lead to supernovae (SNe) with H lines in their spectra, and are classified as type II. These objects display a wide range of observational properties which justifies the existence of the two photometric sub-classes II-P and II-L (Barbon, Ciatti, & Rosino 1979), and the new peculiar spectroscopic sub-group IIn (Schlegel 1990). The spectra of SN IIn are characterized by prominent narrow emission lines sitting on top of broad components with a FWHM$\approx$ 15000 km s^{-1} at maximum light that do not show P-Cygni signatures (see the spectrum of SN 1988Z near maximum in Aretxaga et al. [1999]).

Several SN IIn, like SN 1988Z, are exceptionally peculiar in their spectro-photometric properties (Turatto et al. 1993; Van Dyk et al. 1993; Fabian & Terlevich 1996): *(a)* they are characterized by an extremely slow luminosity decay after maximum, which makes them at day 600 approximately 5 mag brighter in B and V-bands than SNe II-P or SNe II-L ; *(b)* they have strong Hα emission, with luminosities exceeding 10^{41} erg s^{-1} at day 200 ($H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0.5$), exceeding by 5 orders of magnitude those of SN 1987A; *(c)* at 2–20cm these are the most powerful radio-SNe in the sky, with luminosities up to 3000 times that of Cas A; *(d)* 6 yr after maximum they still show a hard X-ray emission of about 10^{41} erg s^{-1}; *(e)* multifrequency observations, described here, indicate a total radiated energy of several times 10^{51} erg, close to 10^{52} erg.

These properties have been interpreted in the light of a quick re-processing of the SN mechanical energy by a dense circumstellar medium (CSM; Terlevich et al. 1992; Chugai & Danziger 1994; Plewa 1995). Radiative cooling is expected to be important well before the thermalization of the ejecta is complete. As a result, the shocked material undergoes a rapid condensation behind both the leading and reverse shocks. These high-density thin shells, the freely expanding ejecta and the unperturbed interstellar gas are all ionized by the radiation produced by the shocks, and are responsible for the complex emission line structure observed in these objects. We will call these compact SN remnants (cSNR).

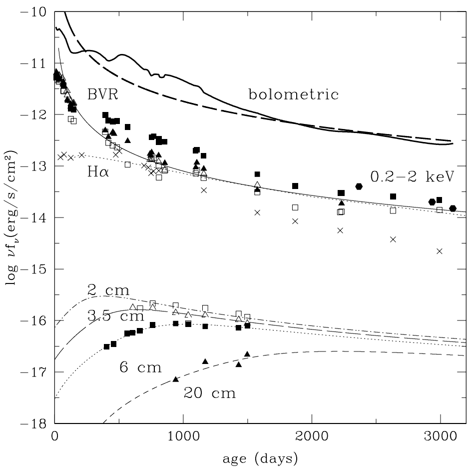

Fig. 1. Evolution of the νf_ν light curve in radio to X-ray bands. Age refers to time elapsed since 1988 December 12, the date of SN discovery. Upper figure: filled triangles correspond to B-band, empty triangles to V-band, filled squares to R-band, empty squares to an Hα line-free $R_{\rm cont}$ band, hexagons to the *ROSAT* 0.2–2 keV band, and crosses to Hα. The dashed lines are models for the bolometric light, and Hα evolution of a cSNR. Lower figure: the VLA radio data at 2, 5.5, 6 and 20 cm is represented with empty squares, empty triangles, solid squares, and solid triangles. The line fittings correspond to the models of Van Dyk et al. (1993). The thick lines in the upper figure represent two estimates of the total bolometric luminosity emitted by SN 1988Z (see text).

2. OBSERVATIONS

SN 1988Z was observed between December 1988 and February 1997, from radio to X-ray wavelengths. The data are presented in Figure 1. To estimate the emission at optical-UV wavelengths, we make an extrapolation of the B, V and $R_{\rm cont}$ (Hα line-free R-band) fluxes to cover the 912 Å to 1 μ range, assuming that the SED is a double power-law. The optical energy inferred in this way is of the order of 3.2×10^{50} erg. The ionizing energy, derived from the Hα flux, is about 8.7×10^{50} erg. To estimate the radiation at 0.2–2 keV, we have extrapolated the X-ray data to earlier times. If we adopt the $t^{-11/7}$ law the energy radiated in 3000 days in the 0.2–2 keV band could be as high as 6.0×10^{50} erg. If a complete bremsstrahlung spectrum of 1 keV is considered, the energy emitted in X-rays alone could be about 9.6×10^{50} erg, and if we consider internal absorption of the CSM by material which is not fully ionized (a model dependent correction), this could go up to 7.6×10^{51} erg.

Considering that half of the leading shock radiated energy is emitted outwards and the other half inwards, and is, therefore, reprocessed by the high density thin shell, the total energy produced by the event should include either twice the observed X-ray luminosity, or the sum of the observed X-ray luminosity and the inferred ionizing and optical luminosity, or twice the sum of the observed ionizing and optical luminosity. A lower limit of the total radiated energy is then $2 \times 8.7 \times 10^{50} + 3.2 \times 10^{50} \approx 2 \times 10^{51}$ erg. A model dependent estimate points towards values as high as $2 \times 7.6 \times 10^{51} \approx 10^{52}$ erg. The bolometric light curves that correspond to these two estimates are represented in Figure 1 with solid and dashed thick lines, respectively.

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