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MASS LOSS FROM THE PROGENITOR OF SN 1006?

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RESUMEN

Se observó el remanente de la SN 1006 a 1.4 GHz con alta resolución y sensibilidad. Estos datos se combinaron con observaciones anteriores con el fin de medir la expansión de la cáscara. Se encontró que el parámetro de expansión δ, definido como $R \propto t^{\delta}$, vale ~ 0.62 para los lóbulos brillantes. De acuerdo con modelos teóricos, este valor significaría que la materia expulsada está interactuando con una distribución de densidad circunestelar que decrece como r^{-2}, la cual se explica si hubo una pérdida de masa continua antes de la explosión. Sin embargo, éste podría no ser el caso si SN 1006 aún se encuentra en la etapa evolutiva donde la masa estelar expulsada supera a la masa interestelar barrida.

ABSTRACT

We have observed the remnant of SN 1006 with high resolution and sensitivity at 1.4 GHz. These data are combined with observations performed 11 years before to measure the expansion of the radio shell. The expansion parameter δ, defined as $R \propto t^{\delta}$, is found to be ~ 0.62 for the brightest lobes. According to theoretical models, this value appears to be compatible with ejecta interacting with a circumstellar density profile decreasing as r^{-2}, characteristic of steady presupernova mass loss. However, this could not be the case if SN 1006 is still in the ejecta-dominated evolutionary stage.

Key Words: ISM: supernova remnants — radio continuum: ISM — stars: mass loss — supernova: individual (SN 1006)

1. INTRODUCTION

Type Ia supernovae (SN) are thought to arise from ignition of a white dwarf, hence the interstellar medium around them is not expected to have been appreciably altered. However, mass loss from the companion may modify the environment in the vicinity of the progenitor binary system (Dwarkadas & Chevalier 1998). We present preliminary results of a radio expansion study of the remnant of the prototypical type Ia SN 1006 which indicate that a steady wind might have been evacuating the circumstellar medium (CSM) before the explosion.

In radio and X-ray wavelengths, this supernova remnant (SNR) appears as a 30′ diameter ring with two bright symmetrical lobes (Reynolds & Gilmore 1986; Bamba et al. 2003). The X-ray emission is mostly non-thermal. In the optical regime, bright filaments appear to the NW between the two lobes, while a ring of fainter emission delineates the rest of the shell (Winkler et al. 2003).

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2. OBSERVATIONS AND DATA REDUCTION

Observations were performed in 2003 with the Australia Telescope Compact Array (ATCA) and with the Very Large Array (VLA). Most of the ATCA observations were carried out with the array in the more expanded configurations, which yield a maximum baseline of 6 km, while additional data in the 750C configuration were obtained to complete the uv plane with spatial frequencies from 46 to 750 m. The correlator configuration was set on two 128 MHz bands (over 32 channels) centered at 1384 and 1704 MHz. Observations with the VLA were carried out during 4 hrs in the CnD configuration. Two frequencies were observed simultaneously, 1370 and 1665 MHz, with a bandwidth of 12.5 MHz. Calibration was performed following standard procedures.

Both ATCA and VLA data, including all frequencies, were combined in the uv plane using the MIRIAD package. A uniform weighting was applied. The final image has a resolution of $\sim 6'' \times 9''$ and a sensitivity of 0.02 mJy beam^{-1}. No primary beam correction was performed at this stage. The first epoch image was obtained by re-calibrating archival VLA data from 1991/1992 using a reduced uv range, compatible with the 2003 observations.

A more detailed description of the observations and data reduction process will be given elsewhere.

3. EXPANSION MEASUREMENT

To compute the expansion parameter for the rim of SN 1006 we followed a similar method to that described in Reynoso et al. (1997). A possible expansion center was chosen by fitting a circle to the bright rim. Adopting this position, we constructed azimuthal averages over radial sectors spaced by 5° each. To solve for the expansion rate, first epoch radial cuts were contracted and expanded by a factor e, which was varied from 0.9 to 1.5 in steps of 0.001. The interpolated brightness values were subtracted from the second epoch radial cuts and the minimum rms of the difference profile was assumed to give the expansion factor for each azimuthal sector.

The expansion parameter δ was computed as $(\Delta R/R)/(\Delta t/t)$, or $(e-1)/(\Delta t/t)$, where t is the age of SN 1006, R is the radius and ΔR is the expansion undergone within the time interval Δt. Allowing for the intrinsic time spread within each epoch observations, $(\Delta t/t)$ was found to be 0.012 ± 0.006. Due to the dispersion in the distribution of δ as a function of the azimuthal angle, a Hanning smoothing was applied to the data. The average expansion parameter along the rim is estimated to be 0.53 ± 0.40. However, δ falls almost to zero in the fainter regions of the rim, while in the rest, the variations are not very large. Taking into account only the bright lobes, $< \delta >$ increases to 0.62 ± 0.22. This value corresponds to an expansion of 0.6 arcsec yr^{-1}.

4. DISCUSSION

In a previous study, Moffett, Goss, & Reynolds (1993) determined an expansion parameter of 0.48 ± 0.13 based on VLA data separated by 7.87 yr. Their result was compatible with SN 1006 being in transition from a two-shock system to the Sedov stage. They called the attention to evident azimuthal variations. Our new result is in agreement with the expansion parameter predicted by Hamilton, Sarazin, & Szymkowiak (1986) to fit X-ray spectra.

We compared our result with the plots δ vs t' shown in Figures 2e and 2f in Dwarkadas & Chevalier (1998), where the authors model the evolution of physical parameters for different ejecta and CSM density profiles. In their plots, t' is the age of the SNR scaled with the time at which the ejected mass equals the swept-up mass: $T' \simeq 248\, E_{51}^{-1/2}\, (M_{\rm ej}/M_{\rm Ch})^{5/6}\, n_0^{-1/3}$ yr, where $M_{\rm Ch} = 1.4\ M_\odot$. For consistency with observations, n_0 is constrained between 0.05 and 0.1 cm^{-3} (Hamilton, Sarazin, & Szymkowiak 1986), therefore $t' = 1.5$ to 1.9 for canonical values of E and $M_{\rm ej}$. However, variations of $\sim 30\%$ in these parameters can result in $t' < 1$ or $t' > 2$.

From the δ vs t' plots, if $0.1 \lesssim t' \lesssim 1$ there is a high probability that the SNR is in transition to the Sedov stage, and the ejecta, either with a power-law or an exponential density profile, is interacting with a constant density CSM. The same scenario might be valid if $1 \lesssim t' \lesssim 1.5$, but in this case the ejecta would have a flat density profile. However, higher values of t', as appears to be the case here, can only be explained by steady mass loss prior to the explosion. It is therefore crucial to estimate with high accuracy the energy of the explosion and the total ammount of the ejected mass to constrain the value of t'. Further work on these data is projected to improve the accuracy of the determination of δ as well as to measure the expansion of the reverse shock, which might also help to solve out for the different models.

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DISCUSSION

G. Koenigsberger - So, would the ejected pre-SN material come from the progenitor or from a now-runaway companion?
E. Reynoso - From the companion. That is why it would be so important to find the surviving companion, as it was found in Tycho's SNR (Ruiz-Lapuente, P. 2006, IAU JD 9, 9).