PROCEEDINGS OF SCIENCE

The expansion of SN 2008iz in M82

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We present first results from the ongoing radio monitoring of SN 2008iz in M82. The VLBI images reveal a shell-like structure with circular symmetry, which expands in a self-similar way. There is strong evidence of a compact component with a steep spectrum at the center of the shell. The expansion curve obtained from our VLBI observations is marginally decelerated ($m = 0.89$) and can be modelled simultaneously with the available radio light curves. While the results of this simultaneous fitting are not conclusive (i.e. different combinations of values of the magnetic field, CSM density profile, and electron energy distribution, provide fits to the available data with similar quality), additional observations should allow a more robust and detailed modeling.

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1. Introduction

Radio supernovae are rare events. So far only about two dozen have been detected, the majority of which were relatively distant or quite weak, making them difficult to study in great detail (see [2] for a recent review). To date, the best known example is SN 1993J in M81, which has been studied extensively [16, 5] due to the close distance of only 3.6 Mpc. The recent discovery of SN 2008iz during High Sensitivity Array observations of water masers in M82 [6, 7] offers the possibility to study another supernova at a very similar distance in great detail and to make a comparison to SN 1993J. SN 2008iz has been only detected in the radio range, probably because it exploded in or behind a very dense molecular cloud. Indeed, ^{12}CO (J=2$\rightarrow$1) line observations show a dense cloud toward the position of SN 2008iz with a H_2 column density of $\sim 5.4 \times 10^{22}$ cm^{-2} [8]. This explains the lack of optical, infrared [12], and X-ray detections [8], despite sensitive searches.

2. Observations

After the discovery of SN 2008iz, we initiated several projects to follow the evolution with the VLA (AB1328) from 1.4–43 GHz, the VLBA (BB272) from 1.6–15 GHz, the eEVN at 1.7 GHz (RB003) and later with the VLBA + Effelsberg (BB277) at 1.6–8.4 GHz. Fortunately, M82 was frequently observed between 2007 and 2009 as a flux calibrator source in a monitoring campaign of intraday variable sources with the Urumqui telescope at 5 GHz. These single dish observations were used to extract a well sampled 5 GHz lightcurve of SN 2008iz [15]. The detection of SN 2008iz lead also to intense monitoring of M82 with MERLIN, and resulted in the discovery of another new radio source [18, 19, 3].

Our first VLBI images at 22 GHz show a small ring, expanding at $\sim$21000 km s^{-1} [8], making it one of the fastest radio supernovae discovered so far. The VLA radio spectrum of SN 2008iz from the observation on 2009 April 27 shows a broken power-law with a spectral index of -1.08$\pm$0.08 in the optically thin part, and a turnover frequency of 1.51$\pm$0.09 GHz [8]. In our later epochs the VLA moved to C and D configuration making it more difficult to separate SN 2008iz from the strong extended emission of M82 at frequencies below 22 GHz. To extract the lightcurve at frequencies below 22 GHz, one has to make a pre-explosion model of M82 with the same resolution (which is possible due to the wealth of observations of M82 at all frequencies in the VLA archive) and subtract this model from the emission seen in our observations (current work in progress).

The single dish lightcurve has allowed us to obtain information on the precursor mass-loss rate, the strength of the magnetic field in the radiating region, the explosion date, and the deceleration of the expanding shock [15]. The expansion velocity from the VLBI observations, combined with an estimate of the deceleration from the 5 GHz lightcurve yields an explosion date in mid February 2008.

3. Modeling the SN 2008iz radio data

The standard Chevalier model of radio emission from supernovae [9, 10] describes the supernova ejecta interacting with the circumstellar medium (CSM) as a spherically-symmetric and self-similar expanding shock, consisting of a contact discontinuity, a reverse shock, and a forward shock, which extends into the CSM. The synchrotron radio emission is assumed to be produced in the shocked CSM region and, therefore, the structure of a radio supernova (RSN) should be shell-like. Indeed, shell-like structures, and eventually their self-similar expansion, have been reported for several RSNe: e.g., SN 1993J (e.g., [14]), SN 1986J (e.g., [20]), SN 1979C [1] and SN 2008iz [8], although strong inhomogeneities and deformations in the shells of some sources (e.g., SN 1979C and SN 1986J) have been reported, possibly due to large anisotropies in their CSM.

3.1 Expansion curve and discovery of a central component

The radio structure of SN 2008iz is remarkably circularly symmetric, and its self-similar expansion has been detected [8] and monitored with VLBI at several frequencies (these proceedings). In Fig. 1 we show a composite of the images obtained from our observations at 8.4 and 5 GHz, analyzed to date. A *dynamic beam* (see, e.g. [13]), equal to 1/3 times the shell radius, has been used to convolve the CLEAN model components in all epochs. The shell-like structure of SN 2008iz can be readily seen in all cases. Remarkably, there is strong evidence of a compact source at the center of the shell, which is detected in some epochs at 5 GHz, but not at higher frequencies. Such a compact component was detected also in the center of the SN 1986J radio shell [4], which the authors identified as either pulsar emission or related to accretion onto a black hole. Note that the Effelsberg telescope, which provides the longest and most sensitive baselines, had technical difficulties in the last two epochs. Therefore these two epochs have a significantly lower sensitivity and angular resolution, which might explain why the central component is not visible anymore. Our continued monitoring of SN 2008iz will certainly solve this issue and a detailed discussion of the steep-spectrum compact component discovered in the center of our SN 2008iz VLBI images will be published in a forthcoming paper.

3.2 Simultaneous fit of expansion and radio light curves

The Chevalier model [9, 10] can be used to relate the parameters of the model radio light curves to those of the expansion curve, by means of simple analytic expressions (e.g., [21]). The 5 GHz light curve of SN 2008iz, taken with the Urumqi telescope [15] was fitted with the model from [21]. An expansion index[1] of $m = 0.89$ was then derived (or *predicted*) by [15] to properly explain their data. It is worth noticing that the expansion index reported in [15] fits remarkably well to our expansion curve, obtained from the VLBI observations recently analyzed.

Although the model of [21] has been successfully used in the modeling of several RSN light curves, it neglects the radiative losses of the electrons, which can notably affect the evolving flux density. Therefore, incorrect estimates of the model parameters can be obtained when using only this model. The case of SN 1993J is an excellent example of this: if radiative losses are not considered, there is strong evidence of a CSM density profile shallower than that corresponding to a standard stellar wind[2] (e.g., [17, 22]); however, if radiative cooling is properly introduced in the model, the data turn out to be in excellent agreement with a standard wind [11, 16].

[1] The expansion index, m is such that $R \propto t^m$, R being the shell radius and t the time after explosion

[2] The density profile of the CSM is modeled as $\rho \propto r^{-s}$, r denoting the distance to the explosion center and $s = 2$ (for a standard stellar wind).

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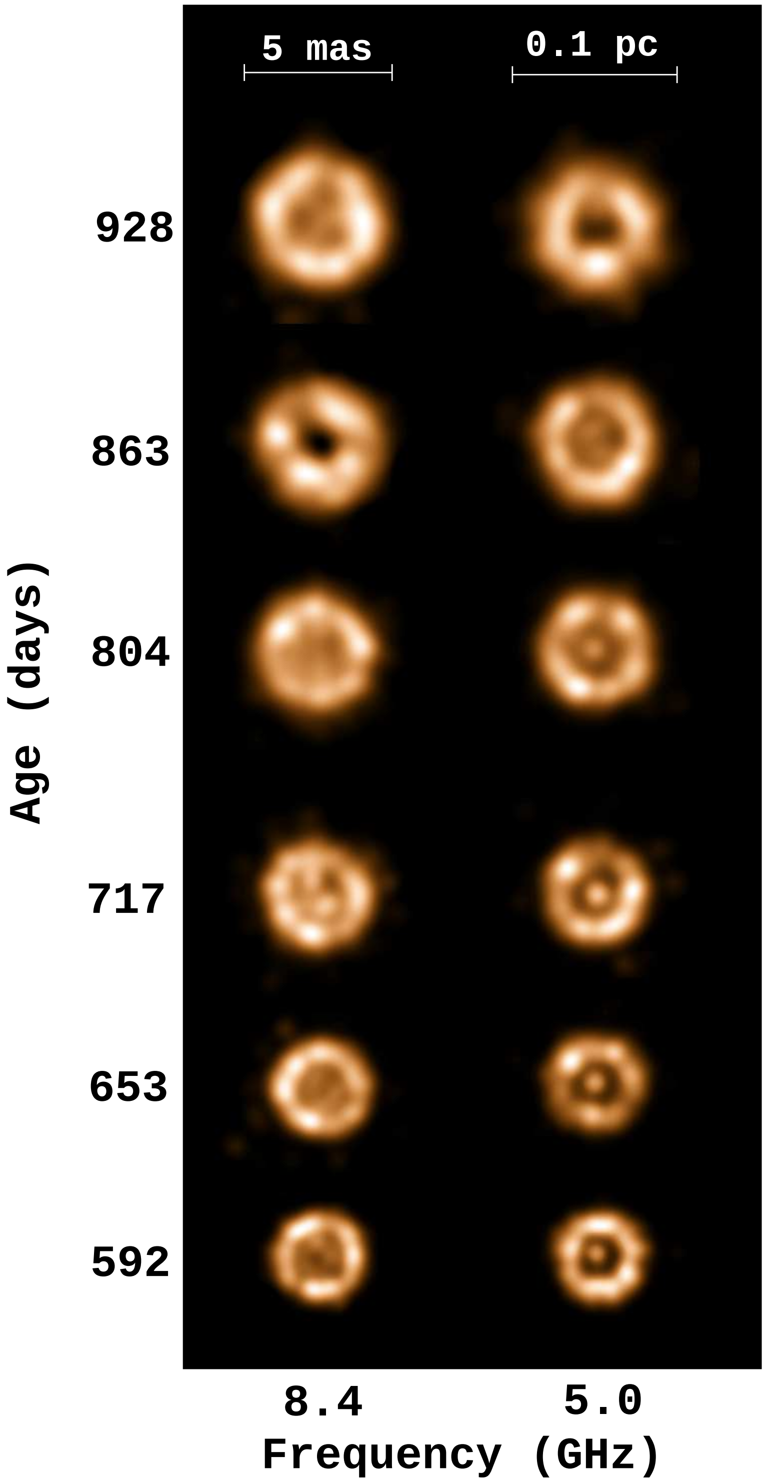

Figure 1: VLBI images of SN 2008iz at 8.4, and 5 GHz. Emission intensity is shown as linear color scale, running from 0 Jy/beam (black) to the peak intensity of each image (white). CLEAN components are convolved with a *dynamic beam*, i.e., a Gaussian of FWHM equal to 1/3 of the shell size at each epoch. *Age* is time since 20 February 2008. Note that the Effelsberg telescope was missing in the last two epochs.

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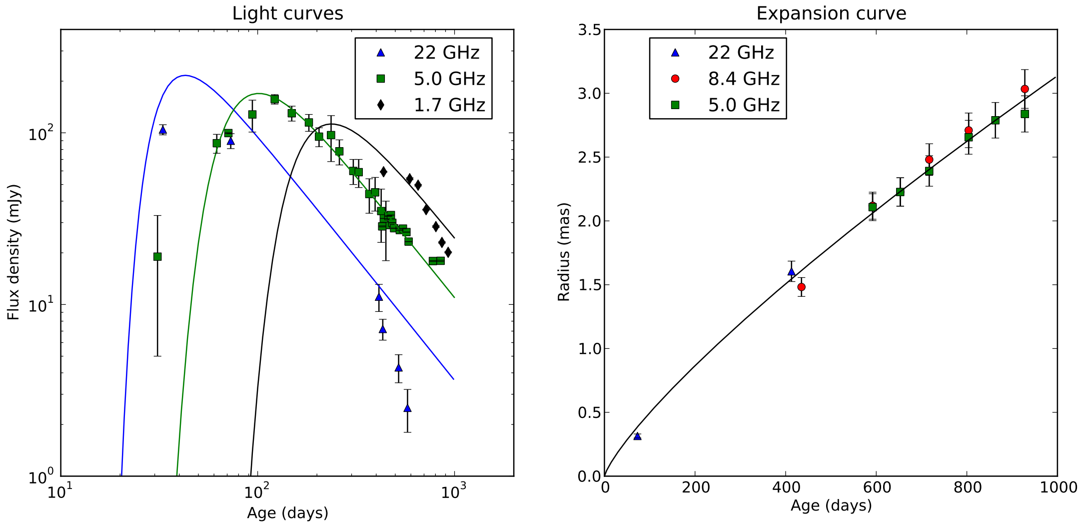

Figure 2: Left, radio light curves of SN 2008iz, taken with the Urumqi telescope and Merlin (data at 5 GHz; [15, 19]), the VLA (22 GHz; [6]), and the VLBA + Effelsberg observations (1.7 GHz). Right, expansion curve obtained from our VLBI data. Lines correspond to our (preliminary) simultaneous fit to all data. *Age* is time since 20 February 2008.

We have simultaneously modeled the VLBI expansion curve, and the available flux-density observations of SN 2008iz, using the model described in [16], which takes into account electron cooling and was used to successfully model all the available radio data of SN 1993J. Since the radio light curves of SN 2008iz are not nearly as complete as those of SN 1993J, we had to make several assumptions for the model, fixing some parameters that were left free in the fit to the SN 1993J radio data.

We show in Fig. 2 our preliminary simultaneous fit to the radio light curves and the expansion curve for SN 2008iz. We use an expansion index of $m = 0.89$, which properly describes both, the expansion curve and the flux-density decay rate. However, different combinations of values of the magnetic field, CSM density profile, and electron energy distribution, provide fits with similar quality, and a more detailed analysis (together with the inclusion of additional data points) is necessary to arrive at more robust results. For instance, a magnetic field as low as ~ 2 G at day 5 after explosion, together with an electron energy index[3] of $p = 3$ and a CSM resulting from a standard stellar wind (i.e., $s = 2$) fit the data acceptably (see Fig. 2). However, a very large magnetic field (~ 100 G at day 5) with a smaller energy index ($p = 2.6$) and a CSM profile steeper than that of a standard stellar wind ($s = 2.4$) lead to a fit of similar quality. This last possibility, however, implies a magnetic field much larger than that derived from particle-field energy equipartition [15], but should not be discarded using only the equipartition argument.

We notice that the latest flux-density measurements at 22 GHz decrease much faster in time than predicted by the model. However, the same model fits the flux-density evolution at 5 GHz acceptably. This enhanced flux-density decay at 22 GHz (but not at 5 GHz) could be indicative of a high-energy cutoff in the relativistic electron population. A detailed analysis of the light curves

[3] The number of electrons is $N \propto E^{-p}$

shown in Fig. 2 will be reported elsewhere.

4. Summary

We have observed SN 2008iz with VLBI at several frequencies and epochs. Monitoring of this supernova with VLBI, and the EVLA, is still in progress. The VLBI images reveal a shell-like structure with circular symmetry, which expands in a self-similar way. There is strong evidence of a compact component with a steep spectrum at the center of the shell. A discussion on this component will be given in a forthcoming publication. The expansion curve obtained from our VLBI observations is marginally decelerated ($m = 0.89$) and can be modeled simultaneously with the available radio light curves. The results of this simultaneous fit are not conclusive, due to the lack of data, but addition of new size measurements, and flux densities, will allow a more detailed modeling.

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