RADIO SUPERNOVAE: THE DETECTION OF SN 1961V IN NGC 1058

John J. Cowan, Richard B. C. Henry, and David Branch
University of Oklahoma
Norman, OK

Abstract : We report the radio detection of supernova 1961v in NGC 1058. SN 1961v has a spectral index of -0.4 ± 0.1. At the distance of NGC 1058, the absolute monochromatic luminosity of this source is comparable to that of Cas A. A second nonthermal source with a spectral index of -0.3 ± 0.1 was also detected in NGC 1058 and is likely to be a remnant of a supernova that was not optically detected. The two radio sources, and two optically faint H II regions that coincide with the radio sources, are separated by only 3.5″.

Introduction : Until recently radio emission had only been observed from supernovae within a few years of optical maximum (see *e.g.* Gottesman *et al.* 1972; Weiler *et al.* 1981; Sramek, Panagia, and Weiler 1984; Weiler *et al.* 1986) or from supernova remnants several hundred years old. Cowan and Branch (1985) detected radio emission from supernova 1957d in M 83 and probably from supernova 1950b in the same galaxy. The detection of radio emission from supernovae decades after optical maximum indicates that at least some supernovae remain radio bright at "intermediate- age".

In an attempt to detect more of these objects, Branch and Cowan (1985) used the Very Large Array (VLA) to observe NGC 1058. This galaxy contains the unusual supernova 1961v, as well as SN 1969l. SN 1961v is the primary example of a Type V supernova (Zwicky 1965). While the spectra of this supernova contain hydrogen lines (like the spectra of ordinary Type II supernovae), the expansion velocity of SN 1961v, determined from spectral line widths, was very low compared to normal Type II supernovae (Bertola 1964; Branch and Greenstein 1971). Until the discovery of SN 1987a in the Large Magellanic Cloud, SN 1961v was the only supernova with a known progenitor - a star seen near 18th magnitude in NGC 1058 for decades before the explosion (Zwicky 1964). The optical light curve of SN 1961v was also unusual and declined very slowly over more than six years (Bertola and Arp 1970; Doggett and Branch 1985). No other supernova has been followed optically for more than two years after optical maximum. The observed properties of SN 1961v suggest the explosion of a very massive star (Utrobin 1984).

Results : Branch and Cowan (1985) had previously reported the detection of radio emission at 20 cm from two sources in NGC 1058, with one of the sources very near the reported position of supernova 1961v. Recently, we used the VLA to observe NGC 1058 at 6 cm. Using the program IMEAN, the peak flux at 20 cm

https://doi.org/10.1017/S0252921100102052 Published online by Cambridge University Press

from the eastern source in the field of view was determined to be 0.18 mJy, while the western source had a measured peak flux of 0.14 mJy. At 6 cm the peak flux of the eastern source was 0.14 mJy and the western source had a peak flux of 0.10 mJy. These values lead to spectral indices of -0.4 $\pm$ 0.1 for the eastern source and -0.3 $\pm$ 0.1 for the western source. At an assumed distance of 12 Mpc for NGC 1058 (Kirshner and Kwan 1974; Schurmann, Arnett, and Falk 1979), the measured flux values are comparable in absolute radio luminosity to Cas A.

The position, determined at both 20 cm and 6 cm, for the eastern source was $\alpha(1950) = 02^h40^m29.^s70 \pm 0.3''$ and $\delta(1950) = 37° \; 08' \; 01.''6 \pm 0.3''$ and for the western source was $\alpha(1950) = 02^h40^m29.^s51 \pm 0.3''$ and $\delta(1950) = 37° \; 08' \; 01.''89 \pm 0.3''$. Since the two sources are faint the positional accuracy is no better than approximately 0.3$''$. Klemola (1986) has measured with astrometric precision the position of SN 1961v to be $\alpha(1950) = 02^h40^m29.^s694 \pm 0.1''$ and $\delta(1950) = 37° \; 08' \; 01.''64 \pm 0.1''$. It is therefore clear that the peak radio emission from the eastern source comes from the remnant of the supernova 1961v. The western source is most likely a remnant from a supernova that was not optically identified. We did not detect the Type II supernova 1969l in NGC 1058 at a 3 σ limit of 0.09 mJy at 6 cm. This upper limit corresponds to an absolute luminosity that is less than that of Cas A.

The size of the radio emitting region at the positions of SN 1961v and the western source is slightly larger than the beam and thus is partially resolved. Optical H_α observations, using the 2.1 meter telescope at Kitt Peak National Observatory, indicate faint H II regions, first found by Fesen (1985), at the exact positions of the two radio sources. These H II regions are most likely responsible for the extended radio emission around the two supernova remnants. In both the H_α and [S II] images, these two H II regions are relatively faint, but otherwise normal, in comparison to a number of other H II regions in NGC 1058.

Discussion and Summary : The radio observations at 20 cm and 6 cm confirm the nonthermal nature of the two sources in NGC 1058, and the accurate position of Klemola (1986) confirms the identification of the eastern source with SN 1961v. This detection marks the second definite (and most probably third) detection of a supernova decades after optical maximum. The first of these "intermediate-age" supernovae detected was supernova 1957d in M 83 (Cowan and Branch 1985). We also detected a nonthermal radio source very close to the reported position of supernova 1950b, but no accurate position is available for this supernova. It is, therefore probable, but not definite, that SN 1950b was detected.

It is not clear why the two radio sources, the supernova remnants, are so close together in NGC 1058. At a distance of 12 Mpc, the 3.5$''$ separation between the two sources corresponds to a linear separation of approximately 200 parsecs. Whether or not this small separation is coincidental is not obvious.

No spectra were obtained for supernova 1957d in M 83, but its position on the inner edge of the spiral arm suggests that its progenitor star was massive (Cowan and Branch 1985). SN 1961v was the prototypical Type V supernova (Zwicky

1965). Utrobin (1984) argued, on the basis of the very slow decay of the light curve, that the progenitor of SN 1961v lost 2000 $M_{\odot}$ prior to supernova outburst. Thus, both "intermediate-age" supernova so far detected may have resulted from the explosion of a massive star, with extensive mass loss prior to outburst. This extensive mass loss might be necessary to produce detectable radio emission from supernovae decades after optical maximum.

Radio emission has been detected from the Type II supernovae 1970g in M 101 (Gottesman *et al.* 1972), SN 1979c in M 100 (Weiler *et al.* 1981) and SN 1980k in NGC 6946 (Weiler *et al.* 1982). Chevalier (1984a, b) has explained radio emission from supernovae as coming from the interaction of the supernova ejecta with the surrounding circumstellar material, which was lost from the supernova progenitor as a result of mass loss. Both this "mini-shell" model of Chevalier (1984a, b) and pulsar driven models (see *e.g.* Pacini and Salvati 1973), also known as "mini-plerion" models, provide reasonable fits to the observations of the supernovae 1979c and 1980k (Weiler *et al.* 1986). Radio observations have also been made of SN 1981k in NGC 4258 by van der Hulst *et al.* (1983). On the basis of its radio properties (no optical spectra were obtained), Weiler *et al.* (1986) argue that SN 1981k was also a Type II supernova. Upper limits on radio emission from several other Type II supernovae have been reported by Branch and Cowan (1985) and Cowan and Branch (1985).

No classical Type I (*i.e.*, Type Ia) has yet been seen at radio wavelengths (Weiler *et al.* 1986), possibly owing to a lack of circumstellar material. Radio emission has been detected from the peculiar Type I (*i.e.* Ib) supernovae 1983n in M83 (Sramek, Panagia, and Weiler 1984) and 1984l in NGC 991 (Weiler *et al.* 1986).

It is not clear whether the "intermediate-age" supernovae that have been detected are the result of fading radio supernovae. Extrapolation of models of Chevalier (1984a, b) for the linear Type II radio supernovae SN 1979c and SN 1980k bracket the radio emission of SN 1957d and SN 1961v at their present ages. On the other hand, SN 1957d or SN 1961v (or possibly both) could be very young supernova remnants that are just starting to brighten. Models by Gull (1973) [see also Cowsik and Sarkar (1984)] might also be able to account for the radio emission from SN 1957d and SN 1961v. These models predict radio emission from young remnants as a result of synchrotron emission when the mass of swept-up interstellar material exceeds the mass of ejected material from the supernova explosion. We will have to study SN 1957d and SN 1961v over a long time period to determine whether their radio emission is decreasing or increasing with time. We will also have to detect additional such "intermediate-age" supernovae to learn more about this class of objects.

In summary, we have observed NGC 1058 at 6 cm and 20 cm and detected two nonthermal radio sources. One of the sources is coincident with the position of supernova 1961v. The second source, located 3.5″ to the west of SN 1961v, probably is a remnant of a supernova that was not seen optically. The detection of SN 1961v represents the second (and probably the third) detection of a supernova

https://doi.org/10.1017/S0252921100102052 Published online by Cambridge University Press

of intermediate age. The observed spectral index of SN 1961v is -0.4 ± 0.1, while the western source has a spectral index of -0.3 ± 0.1. The absolute radio luminosity at 20 cm of SN 1961v, at the distance of NGC 1058, is 4.7 x 10^{34} ergs sec^{-1} - comparable to Cas A. The absolute radio luminosity of the western source is only slightly less. Optical images of NGC 1058, taken using the 2.1 meter telescope at KPNO, indicate the presence of two faint H II regions at the positions of SN 1961v and the western source. Both radio sources are partially resolved, probably indicating additional thermal radio emission from the underlying H II regions. While the two supernovae apparently exploded inside the H II regions, brightness comparisons among several bands indicate that these two H II regions are normal with respect to the many optically brighter H II regions in NGC 1058. Radio emission was not detected from these optically bright H II regions.

This work has been supported by NSF grants AST-8521705 and AST-8419734.

REFERENCES

Bertola, F. 1964, *Ann. Ap.*, **27**, 319.
Bertola, F., and Arp., H. 1970, *P.A.S.P.*, **82**, 894.
Branch, D. and Cowan, J.J. 1985, *Ap. J. (Letters)*, **297**, L33.
Branch, D., and Greenstein, J. L. 1971, *Ap. J.*, **167**, 89.
Chevalier, R. A. 1984a, *Ann. N. Y. Acad. Sci.*, **422**, 215.
Chevalier, R. A. 1984b, *Ap. J. (Letters)*, **285**, L63.
Cowan, J. J., and Branch, D. 1985, *Ap. J.*, **293**, 400.
Cowsik, K. R., and Sarkar, S. 1984, *M.N.R.A.S.*, **207**, 745.
Doggett, J. B., and Branch, D. 1985, *A. J.*, **90**, 11.
Fesen, R. A. 1985, *Ap. J. (Letters)*, **297**, L29.
Gottesman, S.T., Broderick, J.J., Brown, R.L., Balick, B., and Palmer, P. 1972, *Ap.J.*, **174**, 383.
Gull, S.F. 1973, *M.N.R.A.S.*, **161**,47.
Kirshner, R. P., and Kwan, J. 1974, *Ap. J.*, **193**, 27.
Klemola, A. 1986, *P.A.S.P.*, **98**, 464.
Pacini, F. and Salvati, M., 1973, *Ap.J.*, **186**, 249.
Schurmann, S. R., Arnett, W. D., and Falk, S. W. 1979, *Ap. J.*, **230**, 11.
Sramek, R., A., Panagia, N., and Weiler, K. W. 1984, *Ap. J. (Letters)*, **285**, L59.
Utrobin, V. P. 1984, *Ap. Sp. Sci.*, **98**, 115.
van der Hulst, J. M., Hummel, F., Davies, R. D., Pedlar, A., and van Albada, G. D. 1983, *Nature*, **306**, 566.
Weiler, K.W., van der Hulst, J.M., Sramek, R.A., and Panagia, N. 1981, *Ap.J.(Letters)*, **243**, L151.
Weiler, K.W., Sramek, R.A., van der Hulst, J.M., and Panagia, N. 1982, in *Supernovae: A Survey of Current Research*, eds. M.J. Rees and R.J. Stoneham (Dordrecht:Reidel), p. 281.
Weiler, K. W., Sramek, R. A., Panagia, N., van der Hulst, J. M., and Salvati, M. 1986, *Ap. J.*, **301**, 790.
Zwicky, F. 1964, *Ap. J.*, **139**, 514.
Zwicky, F. 1965, in*Stellar Structure*, ed. L. H. Aller and D. B. McLaughlin (University of Chicago Press: Chicago), p. 367.