1991ApJ...379L..49C

THE ASTROPHYSICAL JOURNAL, 379:L49–L51, 1991 October 1
© 1991. The American Astronomical Society. All rights reserved. Printed in U.S.A.

THE RADIO RECOVERY OF SN 1970G IN M101

JOHN J. COWAN
Department of Physics and Astronomy, University of Oklahoma, Norman, OK 73019
AND
W. M. GOSS AND R. A. SRAMEK
P.O. Box 0, National Radio Astronomy Observatory, Socorro, NM 87801
Received 1991 May 21; accepted 1991 July 15

ABSTRACT

Radio emission has been detected from the Type II SN 1970G in M101 20 yr after the explosion. This marks the third definite (and probably the fourth) radio detection of such intermediate-age supernovae, which fill the void between the young radio supernovae and the supernova remnants that are typically hundreds of years old. With a flux density of 0.21 ± 0.021 mJy at 20 cm, 0.08 ± 0.013 mJy at 3.5 cm, a spectral index of $\alpha = -0.56 \pm 0.11$, and an absolute luminosity of approximately 25% of Cas A, SN 1970G is similar to other extragalactic, intermediate-age radio supernovae such as 1957D in M83 and 1961V in NGC 1058. The radio emission from SN 1970G has been decaying since the last reliable detection in 1974 with a power-law index of -1.95 ± 0.17, indicating a steeper decay rate than in the early stages of radio supernova evolution.

Subject headings: nebulae: supernova remnants — stars: supernovae

1. INTRODUCTION

Radio emission has been detected from a number of supernovae within a few years of outburst, with the presence, intensity, and duration of this radio emission depending upon the extent of circumstellar material and hence the supernova type (Weiler et al. 1986; Weiler & Sramek 1988; Weiler et al. 1989). These radio supernovae typically fade within several years to a decade after optical maximum. Much later, typically hundreds of years, they appear as supernova remnants (SNRs).

Intermediate-age supernovae, with an age range ~10–300 yr after explosion, thus fill the void between young supernovae and the supernova remnants. These intermediate-age supernovae, however, are little understood as there have been so few that show radio emission. The first such objects detected were SN 1957D and probably SN 1950B in M83 (Cowan & Branch 1982, 1985). (A nonthermal radio source has been detected near the reported, approximate optical position of SN 1950B, but no accurate optical position is available to confirm this identification.) Neither SN 1957D nor SN 1950B were well observed optically and therefore cannot be classified. However, there have been no radio detections of Type Ia supernovae and only two Type Ib's with short-term detectable radio emission (Weiler et al. 1986). This, coupled with the fact that SN 1957D and 1950B are on inner edges of spiral arms in M83 (Cowan & Branch 1985), suggests that both are Type II's. SN 1957D was recently recovered optically by Long, Blair, & Krzeminski (1989).

Nonthermal radio emission was also detected from supernova 1961V in NGC 1058 (Branch & Cowan 1985; Cowan, Henry, & Branch 1988) marking the second definite such intermediate-age supernovae. SN 1961V had a very unusual spectrum and was Zwicky's prototypical Type V supernova—it would be classified as Type II peculiar today. It should also be noted that SN 1961V was the first, and until SN 1987A, the only supernova with a known progenitor. Optical emission has also been recently observed from the site of SN 1961V (Goodrich et al. 1989).

SN 1970G in M101 was the first supernova observed in the radio (Gottesman et al. 1972; Allen et al. 1976). Observations of this Type II supernova were limited, and no radio "light curve" has been determined (Weiler et al. 1986). At 20 cm SN 1970G maintained a relatively constant flux at ~5 mJy for approximately 3 yr before fading below detectability and was never detected at 6 cm (Weiler et al. 1986). Very Large Array (VLA)[1] observations in 1982 established a 6 cm upper limit of 0.3 mJy (Weiler et al. 1986).

We report here the successful radio recovery of supernova 1970G, now 20 yr old.

2. OBSERVATIONS

Using the VLA, observations at 20 cm were made of supernova 1970G during 1990 April. At that time, the VLA was in the A-configuration. The results of 12 hr (including calibration) of observation are shown in Figure 1. The strongest source in the image is the H II region, NGC 5455. The second radio source, to the northwest of NGC 5455, has a peak flux density of 0.19 ± 0.025 mJy at a position of $\alpha(1950) = 14^h01^m14^s.45 \pm 0^s.05$ and $\delta(1950) = 54°28'56''.1 \pm 0''.4$ (see Table 1). This source is within approximately 1″ of the reported position of supernova 1970G (see Allen et al. 1976).

Additional observations were made at 3.5 cm in 1990 November when the VLA was in the C-configuration. The total observing time (including calibration) was 8 hr. The results of those observations are shown in Figure 2 and listed in Table 1.

3. RESULTS AND DISCUSSION

Comparing the flux densities at 20 and 3.5 cm, listed in Table 1, indicates that the radio source at the position of SN 1970G is nonthermal with a slope of $\alpha = -0.56 \pm 0.11$ ($S_\nu \propto \nu^\alpha$). This

[1] The National Radio Astronomy Observatory is operated by the Associated Universities, Inc. under cooperative agreement with the National Science Foundation.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1991ApJ...379L..49C

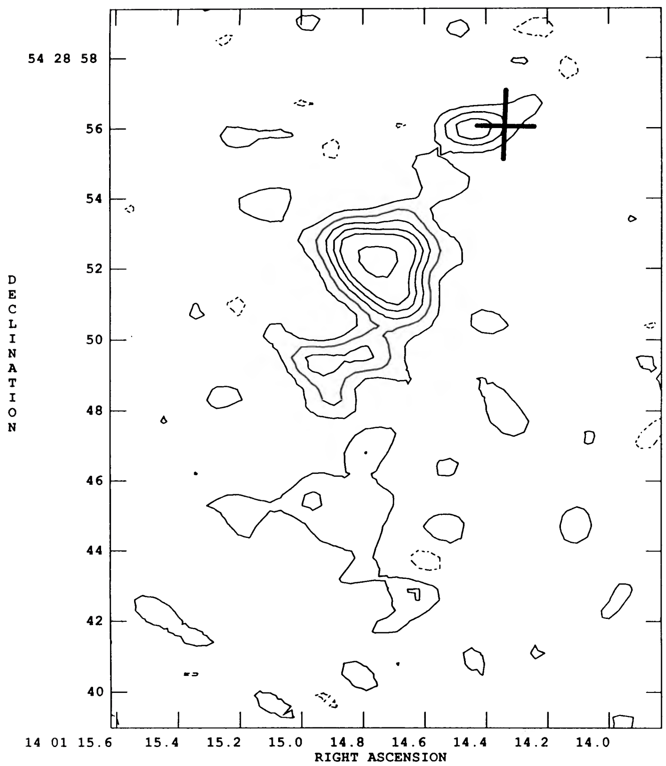

FIG. 1.—Radio contour map at 20 cm (1.5 GHz) of the H II region NGC 5455 (the strongest source in the center of the field) and supernova 1970G, the source to the northwest. Contour levels are −0.05 (*dashed contours*), 0.05, 0.1, 0.15, 0.2, 0.25, and 0.375 mJy beam^{-1} with a beamsize of 1.42 × 1.12 arcsec^2, p.a. = 71°, and an rms noise of 0.02 mJy. Observations were taken with the A-array of the VLA from 1990 April 30–May 1. Cross indicates the optical position of SN 1970G from Allen et al. (1976) with an uncertainty of ±1″.

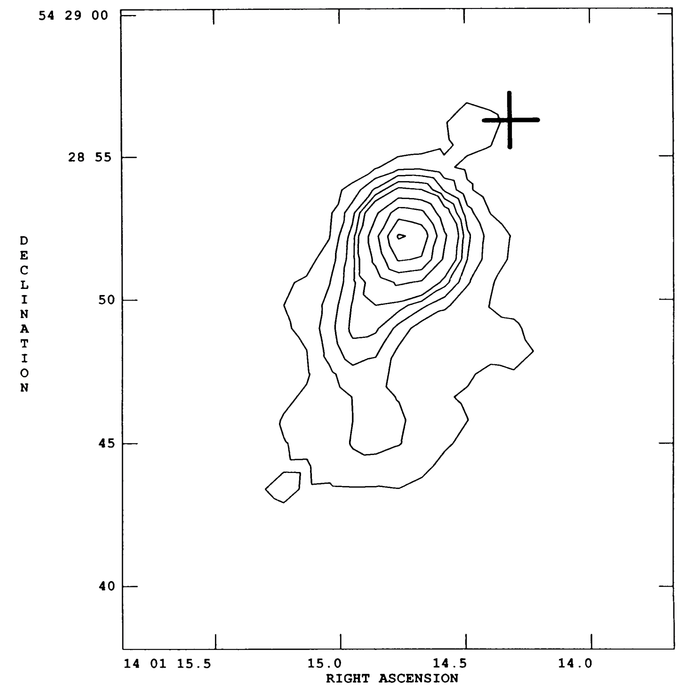

FIG. 2.—Radio contour map at 3.5 cm (8.4 GHz) of the H II region NGC 5455 (the strongest source in the center of the field) and supernova 1970G, the source to the northwest. Contour levels are 0.05, 0.1, 0.15, 0.2, 0.25, 0.375, 0.5, 0.625, and 0.75 mJy beam^{-1} with a beamsize of 2.15 × 2.15 arcsec^2, p.a. = −46°, and an rms noise of 0.01 mJy. The observations were taken with the C-array of the VLA on 1990 November 15.

nonthermal spectrum confirms that the radio source is associated with the supernova (as they have nonthermal spectra) and is not a thermal emission feature associated with NGC 5455, which our observations indicate has a flat radio spectrum. While the radio luminosity at 20 cm during the first 4 yr was significantly larger than that of Cas A, it is now fainter than Cas A. Distance estimates to M101 vary with values as low as 5.0 Mpc (see, e.g., Humphreys & Aaronson 1987) and as high as 7.2 Mpc (Sandage & Tammann 1974). Assuming a distance of 5.4 Mpc (Tully 1988), the 20 cm radio luminosity of SN 1970G at 20 yr of age is approximately 25% of that of Cas A.

TABLE 1

POSITIONS, FLUX DENSITIES, LUMINOSITIES, AND SPECTRAL INDICES OF EXTRAGALACTIC, INTERMEDIATE-AGE SUPERNOVAE

	SN 1950B[a]	SN 1957D	SN 1961V	SN 1970G
R.A. (1950)	13^{h}34^{m}03^{s}05	13^{h}34^{m}14^{s}34 ± 0^{s}05	02^{h}40^{m}29^{s}69 ± 0^{s}03	14^{h}01^{m}14^{s}45 ± 0^{s}05
Decl. (1950)	−29°36′40″5 ± 0″4	−29°34′24″0 ± 0″4	37°08′01″6 ± 0″3	54°28′56″1 ± 0″4
Distance (Mpc)[b]	4.7	4.7	9.1	5.4
To galaxy	M83	M83	NGC 1058	M101
20 cm				
Flux density (mJy)	0.83 ± 0.02	2.6 ± 0.02	0.27 ± 0.02	0.21 ± 0.02
L_λ (ergs s^{-1} Hz^{-1})	2.2 × 10^{25}	6.9 × 10^{25}	2.7 × 10^{25}	7.35 × 10^{24}
Ratio to Cas A L_λ	0.7	2.3	0.9	0.25
6 cm				
Flux density (mJy)	0.48 ± 0.04	1.82 ± 0.04	0.14 ± 0.01	...
L_λ (ergs s^{-1} Hz^{-1})	1.3 × 10^{25}	4.8 × 10^{25}	1.4 × 10^{25}	...
Ratio to Cas A L_λ	1.8	6.9	2.0	...
3.5 cm				
Flux density (mJy)	...	...	...	0.08 ± 0.01
L_λ (ergs s^{-1} Hz^{-1})	...	...	...	2.8 × 10^{24}
Ratio to Cas A L_λ	...	...	...	0.4
α ($S_\nu \propto \nu^\alpha$)	−0.45 ± 0.08	−0.30 ± 0.02	−0.54 ± 0.20	−0.56 ± 0.11

[a] Optical positional uncertainty prevents positive identification.
[b] From Tully 1988.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1991ApJ...379L..49C

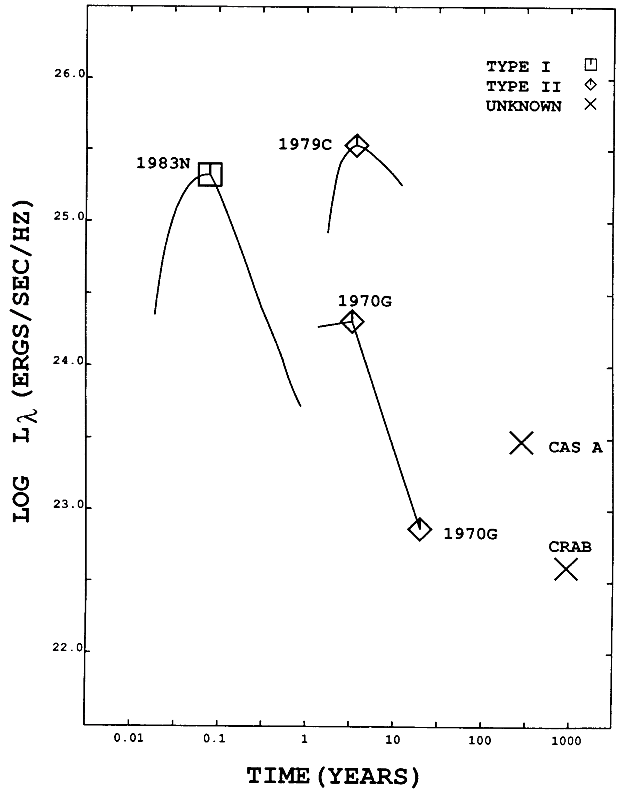

FIG. 3.—Radio light curve for SN 1970G at 20 cm compared to several radio supernovae and supernova remnants.

Supernova 1970G is now the only intermediate-age supernova for which we have radio observations over such a long period, at this point for about 20 yr. The 20 cm flux density of SN 1970G remained near 5 mJy for approximately 3 yr before fading in 1974 October (Weiler et al. 1986). Comparing the last reliable value of the flux density (5.9 ± 1.6 mJy) with our current measurement of 0.2 mJy indicates that the radio emission has been decaying with a power-law index of $\beta = -1.95 \pm 0.17$ since 1974 (see Fig. 3). This power-law index indicates a steeper decay rate than found for young, Type II radio supernovae such as 1979C, 1980K, and 1981K (Weiler et al. 1986). Figure 3 illustrates the radio light curve at 20 cm of SN 1970G over 20 yr compared with the 10 yr radio light curve of SN 1979C (Weiler et al. 1991). Also shown for comparison is the radio emission as a function of time for the Type Ib supernova 1983N, which had a very steep decay spectrum and quickly disappeared. The figure also illustrates that SN 1970G, now 20 yr old and fading in luminosity, is fainter than Cas A, the brightest Galactic SNR, and more comparable to the Crab Nebula at 20 cm. Finally, it should again be noted that this intermediate-age supernova, with an age of 20 yr, occupies a region in time between what is traditionally thought to be a supernova and the much older SNRs.

At this time we do not know the time variation in radio emission from other intermediate-age supernovae, but we can compare some of their other properties with those of SN 1970G (see Table 1). We note that SN 1957D in M83, at a distance of 4.7 Mpc (Tully 1988), is the brightest of the group, but is still only a factor of 2.3 times brighter than Cas A. Supernova 1957D also has the flatest of the nonthermal spectra at $\alpha = -0.3 \pm 0.02$. In contrast, SN 1950B has a slightly steeper spectrum and is fainter than SN 1957D. While all the intermediate-age radio supernovae are comparable, SN 1950B is somewhat more similar to SN 1970G than is SN 1957D. The spectral index for SN 1961V, -0.54 ± 0.20 (see Table 1), is virtually identical to that for SN 1970G. The radio luminosities of these two intermediate-age radio supernovae are comparable, with L_λ for SN 1970G (at 20 cm) ~ 0.3 that of SN 1961V. We also note that the successful optical recovery of SN 1957D and SN 1961V might suggest a similar search for optical emission from the site of SN 1970G.

All of the other intermediate-age supernovae that have been detected previously in the radio may have been massive stars. In the case of supernova 1961V, for example, the very low ejection velocities, narrow well-defined spectral lines, and other features suggest a massive progenitor. The positions on the inner edges of the spiral arms in M83 also suggest that SNs 1950B and 1957D had massive progenitors and presumably large presupernova mass-loss rates. In the model of Chevalier (1984), radio emission is produced as a result of synchrotron radiation arising from the region of interaction between the ejected supernova shell and the circumstellar shell that resulted from prior mass loss. In such models, the intensity and extent of radio emission depends critically upon the presupernova mass-loss rates (Chevalier 1984). Observational studies also suggest that this is the critical factor for the presence or lack of radio emission from supernovae (Weiler et al. 1989). These results, therefore, suggest a massive progenitor and large presupernova mass-loss rates for the Type II supernova 1970G.

The evolution of supernovae into supernova remnants is poorly understood, but the intermediate-age supernovae, which bridge these two classes of objects, should provide clues about such an evolution. The recovery of SN 1970G marks the third definite intermediate-age supernova with detectable radio emission, but this is the first such object for which we have measured changes in the radio behavior over such a long (i.e., 20 yr) time period. The continued monitoring of SN 1970G will provide important new information about the time behavior of radio emission from supernovae. In time, we may be able to follow the evolution of this radio supernova into its eventual brightening as an SNR.

We thank D. Roberts for help with the data reduction, D. Lasseter for technical assistance, and T. Lozinskaya for helpful comments.

REFERENCES

Allen, R. J., Goss, W. M., Ekers, R. D., & de Bruyn, A. G. 1976, A&A, 48, 253
Branch, D., & Cowan, J. J. 1985, ApJ, 297, L33
Chevalier, R. A. 1984, Ann. NY Acad. Sci., 422, 215
Cowan, J. J., & Branch, D. 1982, ApJ, 258, 31
———. 1985, ApJ, 293, 400
Cowan, J. J., Henry, R. B. C., & Branch, D. 1988, ApJ, 329, 116
Goodrich, R. W., Stringfellow, G. S., Penrod, G. D., & Filippenko, A. V. 1989, ApJ, 342, 908
Gottesman, S. T., Broderick, J. J., Brown, R. L., Balick, B., & Palmer, P. 1972, ApJ, 174, 383
Humphreys, R. M., & Aaronson, M. 1987, AJ, 94, 1156
Long, K. S., Blair, W. P., & Krzeminski, W. 1989, ApJ, 340, L25
Sandage, A., & Tammann, G. A. 1974, ApJ, 194, 223
Tully, R. B. 1988, Nearby Galaxies Catalog (Cambridge: Cambridge Univ. Press)
Weiler, K. W., Panagia, N., Sramek, R. A., Van der Hulst, J. M., Roberts, M., & Nguyen, L. 1989, ApJ, 336, 421
Weiler, K. W., & Sramek, R. A. 1988, ARA&A, 26, 295
Weiler, K. W., Sramek, R. A., Panagia, N., Van der Hulst, J. M., & Salvati, M. 1986, ApJ, 301, 790
Weiler, K. W., Van Dyk, D., Panagia, N., Sramek, R. A., & Discenna, J. L. 1991, ApJ, in press

© American Astronomical Society • Provided by the NASA Astrophysics Data System