THE PROBABLE DETECTION OF SN 1923A: THE OLDEST RADIO SUPERNOVA?

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ABSTRACT

Based on the results of VLA observations, we report the detection of two unresolved radio sources that are coincident with the reported optical position of SN 1923A in M83. For the source closest to the SN position, the flux density was determined to be $0.30 \pm 0.05$ mJy at 20 cm and $0.093 \pm 0.028$ mJy at 6 cm. The flux density of the second nearby source was determined to be $0.29 \pm 0.05$ mJy at 20 cm and $0.13 \pm 0.028$ mJy at 6 cm. Both sources are nonthermal, with spectral indices of $\alpha = -1.0 \pm 0.30$ and $-0.69 \pm 0.24$, respectively. SN 1923A has been designated a Type II-P. No Type II-P (other than SN 1987A) has been detected previously in the radio. The radio emission from both sources appears to be fading with time. At an age of approximately 68 yr when we observed it, this would be the oldest radio SN (of known age) yet detected.

Subject headings: circumstellar matter — galaxies: individual (NGC 5236) — supernovae: general — supernovae: individual (SN 1923A)

1. INTRODUCTION

Some Type II (SNe) supernovae have exhibited radio emission within a few years of explosion, including SNe 1970G in M101 (Gottesman et al. 1972; Allen et al. 1976), 1978K in NGC 1313 (Ryder et al. 1993), 1979C in M100 (Weiler et al. 1986), 1980K in NGC 6946 (Weiler et al. 1986, 1992), 1981K (van der Hulst et al. 1983; Weiler et al. 1986), 1986J in NGC 891 (Rupen et al. 1987), 1988Z in MCG +03-28-022 (Van Dyk et al. 1993b), and 1993J in NGC 3031 (Van Dyk et al. 1994). In addition, SN 1987A was detected in the radio shortly after outburst (see Turtle et al. 1987), but at a level significantly below that seen from the more distant Type II SNe and from the Galactic SNR Cas A. Radio emission was also detected for a brief period from two Type Ib SNe, 1983N and 1984L (Panagia, Sramek, & Weiler 1984; Weiler et al. 1986; Weiler & Sramek 1988), and from the Type Ic SN 1990B (Van Dyk et al. 1993a). No Type Ia SNe have been detected in the radio despite several searches (see, e.g., Cowan, & Branch 1995, 1996; Eck, Cowan, & Branch 1998), SNe 1950B and 1957D in M83 (Cowan & Branch 1985; Cowan, Roberts, & Branch 1994, hereafter CRB94), SN 1968D in NGC 6946 (Hyman 1995), and SN 1970G in M101 (Cowan, Goss, & Sramek 1991) have been detected in the radio more than a decade after explosion. (SN 1961V was also detected [Branch & Cowan 1985; Cowan, Henry, & Branch 1988], but there is uncertainty about whether it really was an SN [Filippenko et al. 1995].) We also note that while the radio emission from SN 1980K has abruptly dropped after approximately 10 yr (Weiler et al. 1992; Montes et al. 1998), SN 1979C (at a greater distance than SN 1980K) is still emitting at detectable levels (Weiler et al. 1991).

In this paper we report the probable detection of SN 1923A in M83, which at an age of ~68 yr would be the oldest intermediate-age SN of known age.

2. OBSERVATIONS AND DATA REDUCTION

SN 1923A was discovered in M83 by Lampland (1936); it is classified as an SAbc starburst galaxy at 4.1 Mpc (Saha et al. 1995), and is home to five other SNe (SNe 1945B, 1950B, 1957D, 1968L, 1983N). Its position via offsets to the center of M83 is 109° east and 58° north. A recent reanalysis of the map of M83 from CRB94 revealed two faint sources near the optical position of SN 1923A.

Observations of M83 were made at the VLA at two epochs for each wavelength, 20 and 6 cm, in different configurations so that the beam sizes were circular and approximately the same for all observations.3 The different “hybrid” configurations were used at the VLA to obtain...
circular beam sizes for observations of M83 at low declination. The phase and pointing centers for all images were at R.A. (1950) = 13°34'12.2", decl. (1950) = −29°35'36.0", and the strong radio source 3C 286 was used as a primary flux calibrator for all observations.

Because of the nonthermal nature of the late-time radio emission from SNe, M83 was observed initially at 20 cm at the first epoch and then at 6 cm to determine the spectral index of the observed sources. At the second epoch a problem with the online systems at the VLA corrupted the 20 cm data taken in the hybrid BnA configuration. The observations were repeated later in B configuration instead, resulting in a slightly different beam size than at the first epoch at 20 cm. Table 1 summarizes the relevant parameters for each wavelength and epoch.

The data reduction was done using the Astronomical Image Processing System (AIPS) software provided by the NRAO. Details of the original data reduction techniques are described in the papers regarding the observations of M83 (Cowan & Branch 1985; CRB94).

While a maximum entropy method was used in the original image processing to reconstruct the diffuse structure, we have used CLEAN for the second epoch observations in order to get a higher signal-to-noise ratio for isolated point sources (i.e., SN 1923A) where the diffuse structure was not important.

We initially attempted simultaneously to fit the two nearby point sources with two Gaussian components using JMFIT; however, the relatively low signal-to-noise ratio of the two sources prevented convergence. Therefore, all but one of the flux densities and positions were determined by fitting a quadratic function to each source using the MAXFIT program of the AIPS package. For the other datum, the fit using MAXFIT failed, so we report the peak flux using the AIPS routine IMSTAT. A background level was estimated using TVSTAT at all wavelengths and epochs. The background level was determined to be on the order of the rms noise, and therefore it was included in the error estimation. PBCOR was used to correct the fluxes for primary beam attenuation. Images of the field of view can be seen in Figure 1, and results for positions and fluxes are given in Table 2 along with the optical SN position from Pennington, Talbot, & Dufour (1982). Figure 1a shows approximately half of M83 at 20 cm as well as several sources CRB94 observed, which are labeled here as in that paper. Figure 1b shows the region surrounding SN 1923A (zoomed in from Fig. 1a) and includes both SN candidates. Figure 1c is a 6 cm map of approximately the same region as in Figure 1b. To within the uncertainties, both unresolved sources are coincident with the optical position. Although we tentatively report the western (closer) source as probably being from SN 1923A, we cannot exclude the possibility that either source may be SN 1923A. Calculation of the spectral index, \( \alpha (S \propto \nu^\alpha) \), between 20 and 6 cm (at second epoch only) reveals that both candidates are non-thermal, with the western source at \( \alpha = -1.0 \pm 0.30 \) and

TABLE 1
PARAMETERS FOR RADIO OBSERVATIONS

| Parameter | 1983–1984 Observations | 1990–1992 Observations |
|-----------|------------------------|------------------------|
|           | 1983 Dec 15 | 1984 Mar 13 | 1992 Jan 4 | 1990 Oct 14 |
| Wavelength (cm) | 20 | 6 | 20 | 6 |
| Frequency (GHz) | 1.446 | 4.873 | 1.515 | 4.848 |
| Bandwidth per IF (MHz) | 12.5 | 25 | 25 | 25 |
| Number of IFs | 2 | 2 | 2 | 2 |
| Observing time (hr) | 6 | 6.5 | 8 | 8.5 |
| VLA configuration | BnA | CnB | B | CnB |
| Primary beam HPBW (arcmin) | 30 | 8 | 30 | 8 |
| Resolution (\( \alpha \times \delta \)) (arcsec) | 3.5 \times 3.5 | 3.9 \times 2.8 | 2.3 \times 5.2 | 3.2 \times 2.8 |
| rms noise (mJy beam\(^{-1}\)) | 0.19 | 0.054 | 0.050 | 0.028 |

TABLE 2
RADIAN OBSERVATION

| Source | R.A. (1950) | Decl. (1950) | 20 cm | 6 cm | Age (yr) |
|--------|------------|-------------|-------|------|---------|
| SN 1923A* | 13°34'19.92'' ± 0.18 | −29°35'46.3'' ± 5.2' | <0.57\(^a\) | ... | 60.6 |
| | | | 0.19 ± 0.05 | 60.8 |
| | | | 0.093 ± 0.03 | 67.4 |
| | | 0.30 ± 0.05 | ... | 68.6 |
| Eastern Source | 13°34'20.18'' ± 0.18 | −29°35'46.6'' ± 5.2' | <0.57\(^a\) | ... | 60.6 |
| | | | 0.21 ± 0.05 | 60.8 |
| | | | 0.13 ± 0.03 | 67.4 |
| | | 0.29 ± 0.05 | ... | 68.6 |

* Optical position at \( a(1950) = 13°34'20.0'' ± 0.02', \( \delta(1950) = −29°35'48'' ± 0.24' \) from Pennington, Talbot, & Dufour 1982.

\(^a\) With a 3 \( \sigma \) upper limit.

\(^b\) Without a fitting routine such as JMFIT to estimate positional uncertainty, we can only report the beam size as representative of the positional uncertainty, although it is probably less than this.
FIG. 1a.

Fig. 1.—(a) 1.515 GHz (20 cm) contour map of approximately half of the field of view for M83 taken at the VLA in the B configuration on 1992 January 4. The beam size ($\alpha \times \delta$) is $2.3 \times 5.2$, and the rms noise level is 0.050 mJy beam$^{-1}$. The contour levels are at 0.17, 0.27, 0.60, 0.89, 1.19, 1.49, 1.79, 2.08, 2.38, 2.68, 2.98, 5.95, 8.93, 11.9, 14.9, 17.9, 20.8, 23.8, 26.8, and 29.5 mJy beam$^{-1}$. SN 1957D (CRB94) and SN 1923A are both visible in the map, as well as several other sources from CRB94, including the radio bright central regions of M83. (b) A (20 cm) contour map of the region immediately surrounding the site of SN 1923A, magnified from the map in Fig. 1a. Included in the map are both SN candidates visible near the center of the map in Fig. 1a. A cross marks the optical position for SN 1923A from Pennington et al. (1982). The contour levels are $-$0.071, 0.071, 0.14, 0.17, 0.19, 0.21, 0.24, 0.26, 0.27, 0.29, and 0.30 mJy beam$^{-1}$. The peak flux for the SN 1923A candidate is $0.30 \pm 0.05$ mJy beam$^{-1}$. (c) A (6 cm) contour map of the region immediately surrounding the site of SN 1923A taken at the VLA in the CnB configuration on 1990 October 14. The beam size ($\alpha \times \delta$) is $3.5 \times 2.8$, and the rms noise level is 0.028 mJy beam$^{-1}$. A cross marks the optical position for SN 1923A from Pennington et al. (1982). Both SN candidates are visible with peak flux positions consistent (to within uncertainties) with the 20 cm peak flux positions. The angular separation of the peaks of the two sources is nearly identical (3'5) in the 6 cm map and in the 20 cm map. The contour levels are $-$0.065, 0.065, 0.076, 0.087, 0.098, 0.11, 0.12, and 0.13 mJy beam$^{-1}$. The peak flux for the candidate nearest the optical SN position is $0.093 \pm 0.03$ mJy beam$^{-1}$.
the eastern source at $\alpha^h_0 = -0.69 \pm 0.24$. Some caution must be exercised in interpreting this value since the flux densities were measured at slightly different times. We can compare this value to the late-time spectral indices of other Type II SNe ($\alpha^h_0 = -0.57$, 1950B, CRB94; $-0.23$, 1957D, CRB94; $-0.60$, 1961V, Cowan et al. 1988; $-0.92$, 1968D, Hyman et al. 1995; $-0.59$, 1970G, Cowan et al. 1991; $-0.74$, 1979C, Weiler et al. 1991).

Since there are 6 cm flux densities at two epochs, it is tempting to try to fit the data to a power law in time ($S \propto t^p$) for comparison with other events ($\beta_{20\, \text{cm}} = -2.9$, $\beta_{6\, \text{cm}} = -1.7$, 1957D, CRB94; $\beta_{20\, \text{cm}} = -1.95$, 1970G, Cowan, Goss, & Sramek 1991). For SN 1923A we find $\beta_{6\, \text{cm}} = -6.9 \pm 4.0$ and $-4.7 \pm 3.3$ for the western and eastern sources, respectively. Since the flux densities appear to be decreasing with time, both sources are consistent with being in the later stages of radio SN evolution. While it is likely that both sources are fading radio SNe, it is not clear which source is SN 1923A.

3. DISCUSSION AND CONCLUSIONS

Although the detected sources are relatively weak, the nonthermal nature and the apparent positional coincidence with the location of SN 1923A (as shown in Table 2) make it probable that we have detected radio emission from this SN. The sources are separated by about 3:5, which at the distance to M83 (4.1 Mpc) corresponds to almost 70 pc; therefore, the sources cannot both be from SN 1923A. Past optical studies of the site of SN 1923A have shown evidence for an H II region at or near the SN site. Rumstay & Kaufman (1983) list an H II region—59 in their paper—within 1°–2° of the SN position, based on offsets with respect to the center of its parent galaxy. Richter & Rosa (1984) refer to Rumstay & Kaufman (1983) H II region 59 as an H II region associated with and lying 1° from SN 1923A. Pennington et al. (1982) also note that SN 1923A appears to be coincident with an H II region. A map of H II regions by de Vaucouleurs, Pence, & Davoust (1983), when overlaid with the scaled radio map, has our source for SN 1923A directly over the H II region. Since the progenitor star of SN 1923A has been estimated to have been massive, $\approx 18 M_\odot$ (Pennington et al. 1982), it should not have moved much prior to explosion, and the H II region near the radio source may be associated with the progenitor of the SN. The presence of an H II region at the SN site reduces the chances that the two sources are actually background sources. There is evidence for other similar associations of radio supernovae (RSNe) and H II regions (Van Dyk 1992), including SN 1957D (also estimated to have resulted from a massive star) in M83 (CRB94). Clearly, new examinations of the area surrounding the site of SN 1923A in M83 to search for an optical counterpart to the radio source are warranted.

On the basis of what is known about the shape of its light curve, SN 1923A has been tentatively designated as a subluminous Type II-P (Patat et al. 1994; Schaefer 1996). No Type II-P (other than SN 1987A) has been detected previously in the radio. In Figure 2 we plot the radio luminosity at 20 cm of the new source, assuming it to be SN 1923A, along with several other extragalactic RSNe and two Galactic SNRs, as a function of time since outburst. Data and fits were taken (solid lines) in Figure 2 from Weiler et al. (1986, 1991) for the well-studied Type II-L SN 1979C, from Weiler et al. (1986, 1992) for the Type II-L SN 1980K, from Weiler et al. (1986) and Cowan & Branch (1985) for the Type Ib SN 1983N, from Cowan et al. (1991) for the Type II-L SN 1970G, from Hyman et al. (1995) for the Type II-L SN 1968D, and from CRB94 for SNe 1950B and 1957D. The distance to M83 (4.1 Mpc) was taken to be the Cepheid-based distance to NGC 5253 (Saha et al. 1995), a fellow member of the Centaurus group. As Figure 2 illustrates, the luminosity of SN 1923A is comparable to, but slightly below, the two other intermediate-age SNe we have detected in M83, SNe 1957D and 1950B. (These two SNe are suspected to have had massive progenitors, but their actual SN types are unknown.) SN 1957D may actually be somewhat less luminous than plotted, because emission from an associated H II region may have contributed to the observed flux. The radio emission from SN 1923A falls between that of Cas A and the Crab Nebula.

At an age of approximately 68 yr when last observed, SN 1923A would be the oldest RSN yet discovered. Detectable radio emission from SNe decades after explosion (but before the SNR phase) may in fact be uncommon, as evidenced by the small class of such known objects. Observations of several other SNe over a number of years also support that conclusion. While SN 1979C is still detectable, SN 1980K has dropped off sharply after a decade of being followed. Recently, Montes et al. (1997) have reported early-time radio emission from SN 1986E, while we were unable to detect this SN at an intermediate age despite a deep VLA search (Eck et al. 1996). Montes et al. (1997) argue that SN 1986E is a typical Type II-L, similar to SN 1980K, and that the fading radio emission can be adequately explained in terms of the Chevalier model.

What is the cause of the radio emission of SN 1923A? No Type II-P events have been observed to undergo a prompt,
bright circumstellar interaction such as that of RSNe. SN 1987A, having been a subluminous Type II-P, underwent a prompt but dim circumstellar interaction that would not have been detectable in a galaxy beyond the local group, but now it is beginning what promises to be a stronger, delayed interaction with a detached circumstellar shell that originated back in its red giant days. If SN 1923A was a subluminous Type II-P, it may now be fading from the kind of delayed interaction that SN 1987A is just beginning.

The key radio observations needed now (apart from more firmly establishing the presence of a nonthermal radio source at the site of SN 1923A) are to trace the radio evolution of these sources, one of which is likely to be SN 1923A, the oldest RSN yet detected. While we noted above that theoretical models have suggested a minimum time of 100 yr for the onset of the SNR (and a brightening) phase, radio emission from the SNe at this age have never previously been detected or studied. Our observations at one wavelength seem to indicate that the source closest to the SN position is still fading with time, but our uncertainties are large. Additional observations of SN 1923A will help to understand more about the nature of radio emission as SNe evolve from the intermediate-age to the SNR phase.

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