G359.87+0.18: A YOUNG SUPERNOVA REMNANT CANDIDATE NEAR THE GALACTIC CENTER?

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ABSTRACT

Subarcsecond radio continuum observations of the Galactic center region at \( \lambda = 6 \) and 2 cm reveal a 0\(^{\prime}\)5 diameter source with a shell-like morphology. This source is linearly polarized at a level of 16% at 6 cm and has a steep nonthermal spectrum with a spectral index of 1.6 between 6 and 2 cm. The distance to this source is not known, but the large rotation measure value of 3000 rad m\(^{-2}\) suggests that G359.87+0.18 is likely to be located in the inner Galaxy or at an extragalactic distance. We discuss possible interpretations of this object as a recent supernova, a very young supernova remnant, a nova remnant, or an extragalactic source. All possibilities are highly problematic.

Subject headings: galaxies; ISM — Galaxy: center — ISM: magnetic fields — supernova remnants

1. INTRODUCTION

Recent surveys of radio supernova remnants (SNRs) indicate a underrepresentation of small-diameter young SNRs in the Galaxy (Green 1994). This deficiency, which is in part due to the lack of high-resolution observations, is particularly noticeable for SNRs having diameters less than 1'. There are only four such sources with diameters less than 4' in the catalog of Green (1994). Because of its large concentration of dense molecular clouds and massive star formation, the Galactic center may be considered a good target for searching for small-diameter SNRs. There is a possibility that SNRs in the Galactic center region may be preferentially smaller in diameter than elsewhere, because of confinement by a dense interstellar medium in this region (Gray 1994). However, a search for such objects suffers from considerable confusion because of the bright and extended radio continuum features associated with H II regions, planetary nebulae, and nonthermal sources in the Galactic center.

A radio continuum survey of the Galactic center region in search of planetary nebulae detected a continuum source, since named G359.87+0.18, at \( \lambda = 20 \) cm using the Westerbork Synthesis Radio Telescope with the beam size of 22\(^{\prime}\) \( \times \) 120\(^{\prime}\) (Isaacman 1981). VLA observations of this source were reported with a resolution of \( \approx 10^{\prime} \) by Yusef-Zadeh (1986). These observations were then followed up by Lazio (1997), who studied the scattering medium toward the Galactic center region and found that the source is not heavily scattered. Here we report high-resolution observations of this radio continuum source, showing that it is resolved into two components. The brighter component is characterized by a nonthermal spectrum, a linear polarization, and a shell-like morphology. The subarcsecond diameter of this shell-like polarized source makes it a possible candidate for a young SNR lying about 15' from the Galactic center along the rotation axis of the Galaxy.

2. OBSERVATIONS

Radio continuum observations of compact radio sources in the Galactic center were carried out with the Very Large Array of the National Radio Astronomy Observatory\(^1\) in its A configuration at \( \lambda = 2 \) and 6 cm in 1986 May. Each source was observed for about 5 minutes at each wavelength using 100 MHz of bandwidth. A more detailed account of the observations and the results of all the observed compact sources will be given elsewhere. Here we present the results of one of these compact sources, which is described by Yusef-Zadeh (1986) and Lazio (1997) as source J. Standard calibration of all four Stokes parameters was done in the Astronomical Image Processing System using 3C 286 and 1720–130 as the flux and phase calibrators. The synthesized beam sizes are 0.98 \( \times \) 0.34 and 0.36 \( \times \) 0.13 at 6 and 2 cm, respectively. The 20 cm continuum emission reported here is based on A-array observations described by Yusef-Zadeh et al. (1994). The rms noise at this frequency is 1.4 mJy beam\(^{-1}\), with a beam size of 2.68 \( \times \) 0.94 (P.A. = -19\(^\circ\)). Because the phase center of this observation is offset considerably from the position of the source, bandwidth smearing increases the source size in the east-west direction to an estimated 0.8'.

3. RESULTS

Figure 1 shows contours of the total intensity of G359.87+0.18 at 6 cm, with rms noise of 0.19 mJy. This source breaks up into two components, A and B, with the respective peak flux densities of 22.4 and 6.5 mJy. Gaussians fitted to these components are at positions \( \alpha (1950) = 17^{h} 41^{m} 26^{s}.45, \delta (1950) = -28^\circ 55' 55.7'' \) for source A \( (l = 359^\circ 872, b = 0^\circ 178) \) and \( \alpha (1950) = 17^{h} 41^{m} 26^{s} 21, \delta (1950) = -28^\circ 55' 57.5'' \) for source B \( (l = 359^\circ 871, b = 0^\circ 178) \). The brighter source A shows a 5 \( \sigma \) elongated protrusion with a size of \( \approx 0.5' \) running in the east-west direction.

The Gaussians fitted to sources A and B indicate that they are partially resolved at 6 cm. This is supported by the 2 cm data, with 3 times higher resolution than the 6 cm data. Figure 2 shows the 2 cm image with a resolution of 0.36 \( \times \) 0.13 and

\(^1\) The National Radio Astronomy Observatory is a facility of the National Science Foundation, operated under a cooperative agreement by Associated Universities, Inc.
rms noise of 0.34 mJy. Source A is resolved into a shell source with a barrel-shaped appearance and a diameter of about 0.5. No significant polarized emission is detected at 2 cm, with an upper limit to the degree of polarization of 28%. Source B is also resolved into an unresolved compact source and a weak extended structure at a level of 0.8 mJy to the north of the compact source. The flux density of the compact component of source B peaks at a level of 2 mJy at the position of \( \alpha(1950) = 17^{h}41^{m}26^{s}.21, \delta(1950) = -28^{\circ}55^{\prime}57^{\prime\prime}.5 \). More support for the extended nature of these sources comes from multiwavelength observations indicating that sources A and B are not compact and are not affected by the scattering medium toward the Galactic center region (Lazio 1997).

Figure 3 shows the polarized intensity image of source A at 6 cm with rms noise of 0.16 mJy, superposed on the distribution of electric field vectors. Source A has a peak polarized flux density of 2.1 mJy and appears asymmetric. There are two polarized clumps having fractional polarization of 16.5% and 6% to the west and to the east, respectively. The polarized clumps coincide with the eastern and western edges of the total intensity image as shown in Figure 1. The true distribution of the magnetic field cannot be determined with the present data because of the large Faraday rotation at 6 cm. The mean rotation measure (RM) toward source A is about 3000 rad m\(^2\), based on two closely spaced frequencies (4860.1 and 4885.1 MHz).

The east-west sides of the barrel-shaped structure noted in the total intensity image of Figure 2 coincide with the clumps of polarized emission seen in Figure 3. This indicates that the lack of polarized emission from the position of the peak of the 6 cm total intensity is due not to depolarization but rather to the shell-like morphology of the source, as displayed in Figure 2. Because of the shell-like morphology of the total intensity at 2 cm and the polarized intensity at 6 cm, the lack of polarized emission between the clumps is unlikely to be due to the rotation of the plane of polarization across the synthesized beam or to internal Faraday depolarization. We consider it more likely that the polarized flux shares the shell morphology of source A, as discussed below.

The Gaussian fitted peak flux densities at 6 and 2 cm with identical beam sizes of 0.98 x 0.34 (P.A. = -39\(^\circ\)) are 22.47 (6.48) and 3.53 (1.52) mJy beam\(^{-1}\) for source A(B), respectively. Using the rms noises of 0.19 and 0.34 mJy for the 6 and 2 cm images, the estimated values of spectral index \( \alpha \), where \( F_v \propto \nu^{-\alpha} \), between 2 and 6 cm for sources A and B are 1.6 \pm 0.2 and 1.3 \pm 0.5, respectively. The spectral index estimate of source A is based on using identical \( u-v \) coverage between 50 and 500 k\( \lambda \), whereas that of source B is based on slightly different
\( \nu - \nu \) coverage; thus, the spectral index estimate may be an upper limit because some of the 2 cm flux may have been resolved out. The spectral index between 6 and 20 cm, although uncertain because of unmatched resolutions and bandwidth smearing, is about 1.19 when the fluxes from both A and B sources are added. The source diameter and spectral indices of this source have also been measured at a number of frequencies in order to study the characteristics of the scattering screen toward the Galactic center, although with different spatial resolutions (Lazio 1997). This again suggests that sources A and B have steep spectral indices between 2 and 20 cm.

4. DISCUSSION

A number of studies indicate a “missing” population of small-diameter SNRs in the Galaxy (e.g., Green 1991). Such small-diameter SNR candidates have been identified in the past, but a majority of them turned out to be thermal sources. The initial interpretations as SNR candidates were based primarily on shell-like morphology, a nonthermal interpretation of the high-frequency spectrum, and a lack of radio recombination line emission (Green 1986; Cowan et al. 1989; Subrahmanyan et al. 1993; de Muizon et al. 1988; Reich et al. 1985). We believe that the strongest argument that distinguishes this source from thermal sources such as G25.5+0.2 and G70.68+1.20 is the evidence for linearly polarized emission from source A of G359.87+0.18. Thus, even if enough flux is missing from the 2 cm data to allow a flat spectrum, the interpretation of the emission as nonthermal seems secure.

However, the source’s extremely small size makes detailed interpretation difficult. The RM toward source A is about 3000 rad m\(^{-2}\), more than 2 orders of magnitude greater than RMs toward sources in the outer Galaxy. Such rotation measures have been measured for a number of sources located within a degree of the Galactic center (Inoue et al. 1984; Yusef-Zadeh & Morris 1987; Gray 1994; Yusef-Zadeh, Wardle, & Parataran 1997), suggesting that the Faraday rotation occurs close to or beyond the Galactic center. A milligauss magnetic field strength with an electron density of 0.03 cm\(^{-3}\) in the inner 50 pc of the Galactic center can account for the observed RM (Koyama et al. 1996; Yamauchi et al. 1990; Yusef-Zadeh & Morris 1987). Thus, the high RM indicates that G359.87+0.18 is no closer than the Galactic center. Let us initially assume that it is at the Galactic center, at a distance of 8.5 kpc, where \( v_e = 0.04 \) pc; then the source angular radius of about 0’25 corresponds to a linear radius of only 0.01 pc.

We first consider an interpretation as a radio SN or SNR. The mass contained in this tiny sphere is only \( 1.6 \times 10^{-7} n_o M_\odot \), where \( n_o \) is the mean atomic hydrogen density, so unless G359.87+0.18 is in an exceptionally high density environment, even for the Galactic center, it has not swept up an appreciable amount of mass and should still be freely expanding. Then the age is only \( 10 v_e^{-1} \) yr, where \( v_e \) is the ejection velocity in units of 1000 km s\(^{-1}\), expected to be of order 5 for Type Ib or II SN and 10 for Type Ia SN. A core-collapse supernova should have emitted a neutrino flux larger than that of SN 1987A by (55 kpc/8.5 kpc)\(^2\) or about 42, so it might have been seen by any neutrino detectors operating during the early 1980s. Furthermore, the mean surface brightness of G359.87+0.18 source A is 6200 Jy arcmin\(^{-2}\), 45 times higher than that of Cas A, which is itself far brighter than any other Galactic SNR (see data in Green 1991). Thus, a supernova remnant interpretation is really inappropriate, and we should consider the possibility that G359.87+0.18 is a radio supernova.

Typical radio supernovae are detected by the VLA with fluxes in the range of millijanskys. For example, van Dyk et al. (1993) report on five bright radio supernovae. All have radio spectral indices of order 1 or less (with errors of order 0.2), much flatter than G359.87+0.18 source A. Furthermore, all these have radio fluxes at 6 cm of typically tens of millijanskys, comparable to that of G359.87+0.18, even though they are farther away by factors of 1000 or more. Other radio supernovae (see, e.g., Weiler et al. 1986) are similar in flux density and spectral index. So all the radio supernovae we know are more luminous than G359.87+0.18 by 6 or more orders of magnitude. (Of course, radio supernovae as faint as G359.87+0.18 could not be seen in external galaxies, but the point is that G359.87+0.18 does not resemble known radio supernovae.)

Could G359.87+0.18 be a nova remnant? One radio-shell remnant of a classical nova is known (GK Per; Reynolds & Chevalier 1984; Seaquist et al. 1989). But a standard equipartition analysis of G359.87+0.18 (e.g., Pacholczyk 1970) gives a minimum energy in magnetic field and relativistic electrons of \( 4 \times 10^{44} \) ergs, only a factor of 2 less than the total energy emitted in a classical nova outburst and 50 times larger than that of GK Per. So G359.87+0.18 cannot be a nova remnant. (The equipartition energy varies with distance \( d \) as \( d^{-1/7} \), so moving G359.87+0.18 farther away does not help and the RM constraint prevents us from moving it closer.) However, the equipartition magnetic field one derives is not unreasonable, at about \( 6(d/8.5 \text{ kpc})^{17/14} \) \( \mu \)G, so that the synchrotron interpretation of the radio emission is sensible.

Based on different spectra of sources A and B and their morphology, it is unlikely that these sources are related to each other and therefore unlikely that G359.87+0.18 is an extragalactic double radio source. However, it is possible that source A alone is extragalactic. Its morphology would be unusual, and its steep spectral index very rare but not unprecedented. Such “ultrasteep spectrum” radio sources have been interpreted as radio galaxies at redshifts of order 1. Additional problems with the extragalactic interpretation is related to the scattering studies carried out toward this source by Lazio (1997). This author concludes that this source is unlikely to be extragalactic and to be affected by a scattering screen seen toward the Galactic center (e.g., van Langevelde et al. 1992). This conclusion is based on the predicted value of the observed diameter of this source at 0.33 GHz being 25% larger than the observed value. The predicted source diameter assumes minimal scattering toward this source and an intrinsic source size \( \theta = 0 \) (Lazio 1997).

We are forced to conclude that G359.87+0.18 is not well explained by any known class of nonthermal radio source. Further observations are clearly called for to resolve its nature.

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