G359.3-0.82: An Unusual Radio Source

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Abstract: An unusual radio source exhibiting an axisymmetric, cometary morphology was recently reported by Yusef-Zadeh and Bally (1987) near the Galactic center. This source, G359.3-0.82, consists of a bright head containing a compact source followed by a tail exhibiting sinuous structure. Radio emission is highly polarized and has a nearly flat spectrum between λ6cm and λ20cm. Its location in the sky, spectrum, and lack of resemblance to any other extragalactic radio source suggested to us that this radio source is a Galactic object possibly lying near the Galactic center. New high-reslolution radio images obtained using the VLA[2] confirm the remarkable morphology and strengthen the distinction between G359.3-0.82 and any known extragalactic radio source. The characteristics of G359.3-0.82 suggest that it may be a nonthermal radio wake produced by an object moving through the interstellar medium at a high relative velocity.

Introduction

We recently reported the detection of G359.3-0.82 found during a radio continuum survey of the Galactic center region. This source has a striking axial symmetry and an unusual spectral index distribution. The morphology of G359.3-0.82, which we nicknamed the "Mouse" because of its shape, consists of a symmetric conical body and a tail whose surface brightness distribution displays a steady decay along its 12-arcminute length. At its western end, it crosses the eastern periphery of a circular shell SNR G359.1-0.5 (Reich and Fürst 1984). Figure 1a shows the λ20cm image of the "Mouse" surrounded by G359.1-0.5 to the west and another shell-type supernova remnant to the south. The λ6cm image in Figure 1b shows its axisymmetric structure in more detail. The "Mouse" is highly polarized at both λ6cm and at λ2cm and the comparison of the λ6cm & λ20cm brightness distributions indicates a gradual steepening of spectral index from α $\sim$+0.03 near the apex of the cone to α $\sim$-0.3 (where $F_\nu \propto \nu^\alpha$) near the western end of the cone (Yusef-Zadeh and Bally 1987, hereafter YB87).

This paper presents preliminary results of new high-resolution observations obtained with the VLA . The new images confirm the earlier suggestion that this object is very unlikely to be an extragalactic object such as narrow angle head-tail

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M. Morris (ed.), The Center of the Galaxy, 197–204.

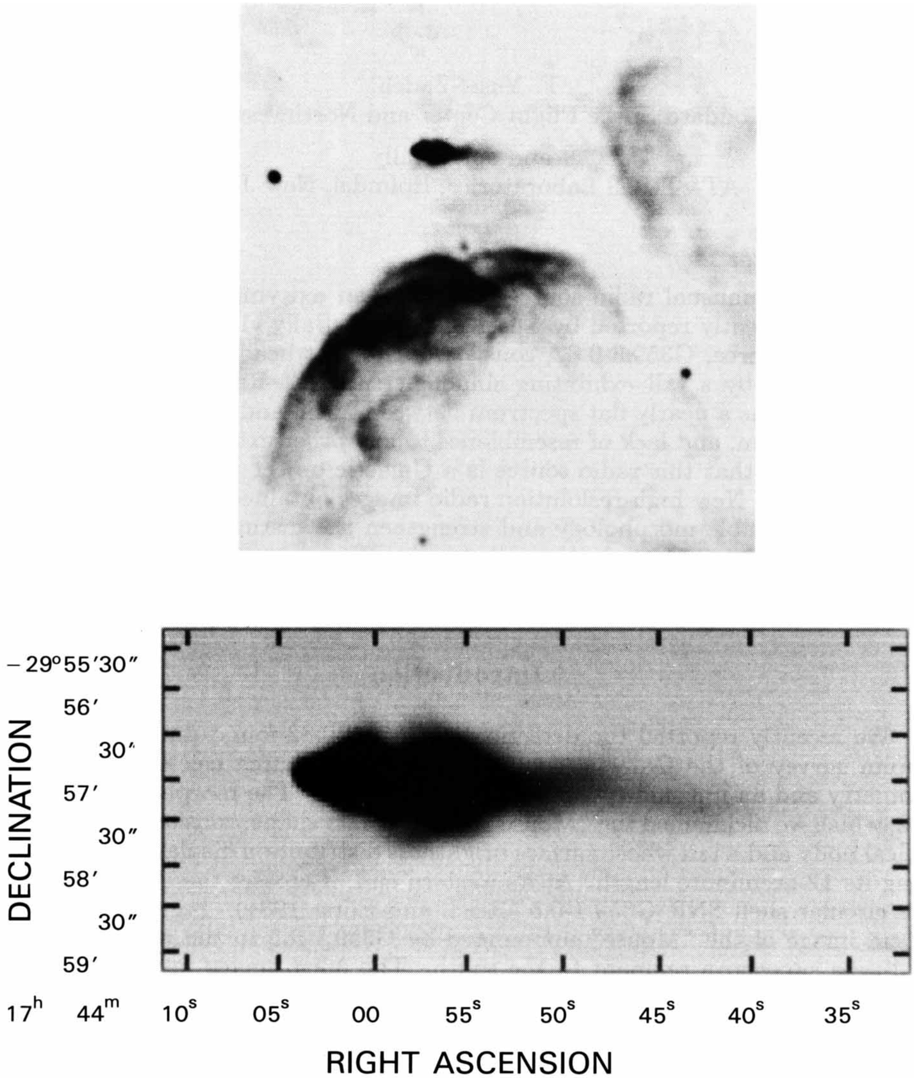

Figure 1a,b: [top] The 20cm radiograph showing radio continuum emission from the inner 30' of G359.3-0.82 with a resolution of 22" × 30". [bottom] The 6cm radiograph showing G359.3-0.82 with a resolution of 13.5" × 11" (PA=55°).

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radio galaxy seen edge on. The closest example of a radio source with characteristics similar to that of the "Mouse" is a Galactic object, G357.7-0.1, which also lies toward the inner few degrees of the Galactic center region (Shaver *et al.* 1985; Becker and Helfand 1985; Helfand and Becker 1985).

Observations and Morphology

The observations and data processing will be reported in detail elsewhere. Briefly, the λ6cm images presented here were obtained by combining data taken in the hybrid A/B, B/C and C/D arrays. In all λ20, λ6 and λ2cm observations, we used 3C286 and NRAO530 as the flux density calibrator and phase calibrator, respectively. Most data were self-calibrated separately for each array configuration prior to combination into a single data base for imaging. Because of the southerly declination of the Galactic center, we used hybrid configurations in order to obtain images that have circular synthesized beams. We used the CLEAN algorithm MX in AIPS (Clark 1980) to deconvolve sidelobes from all images presented here.

Figures 2(a-b) show the λ6cm radiograph of G359.3-0.82 with two different transfer functions and Figure 3c shows the 6cm contour map at a spatial resolution $\sim$ 1.3" $\times$ 1.1". Morphologically, the brightest part of G359.3-0.82 consists of three components: 1) A 10 mJy compact, but resolved source is located near the apex of the cone at α=17^h 44^m 3.54^s, δ=-29°56$'$ 58.44". The intrinsic angular size of this object, estimated by a Gaussian fit, is FWHM=2.7" $\times$ 1.7" (PA=13°), larger than the size of the synthesized beam, indicating that the compact source is resolved. Higher resolution images at λ2cm also show that the compact source is elongated in the north-south direction and is highly resolved at a resolution of $\sim$ 0.5" $\times$ 0.5". 2) A weak parabolic feature is noted at the extreme eastern edge of G359.3-0.82 and appears to follow the curvature of the eastern periphery of the elongated compact source (figure 2b). 3) A ridge of emission emanating from the compact source runs along the major axis of G359.3-0.82 for $\sim$ 5". This ridge links the compact radio source to the remarkable conical-shaped radio nebula which has an opening angle of $\sim$30°. This conical-shaped feature has a mean flux density of 1 mJy/beam area. Its surface brightness drops by a factor of 4.5 west of $\alpha = 17^h 44.00^m$ where the cone ends and the diffuse emission constituting the "tail" of the "Mouse" (see Figure 1b) starts and extends for $\sim$ 10$'$ due west along the major axis of the source.

The spectral index distribution determined from 6 and 2cm data taken with the B/C and D-array configurations, respectively, is shown in Figure 3a. Total intensity maps, as shown in Figures 3(b-c), with a resolution of $\sim$ 8.3" $\times$ 3.9" (PA=0°) were used to construct the spectral index map. Figure 3a shows that α ranges between -0.1 to -0.3 and steepens in the direction away from the compact source suggesting that the radio source is more evolved along the tail. Synchrotron radiative losses may be steepening the slope of the power law describing the energy distribution of the radiating particles as a smooth function of the distance from the compact source. This spectrum is consistent with the flat spectral index derived from 6 and 20cm measurements (YB87).

The high-resolution linear polarization measurements indicate that many of the features including the ridge and the conical structure are highly polarized at 6cm with a degree of polarization of order $\sim$10 to 20%. Low-resolution polarization

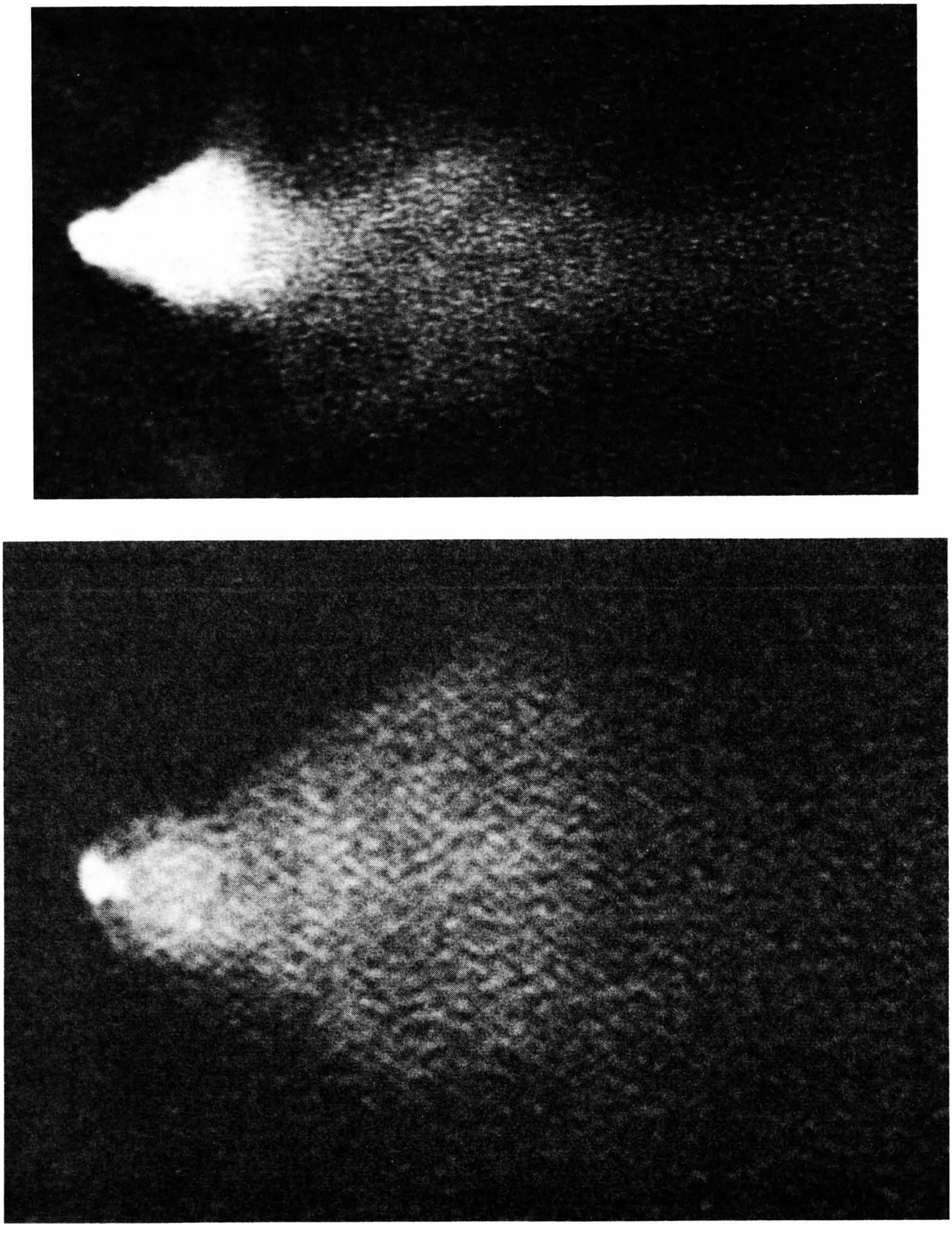

Figure 2a,b: [top] The 6cm radiograph of the brightest component of G359.3-0.82 with a resolution of 1.3" × 1.1" (PA=13.3°.). [bottom] The same as Figure 2a except that the contrast levels and the scales are different.

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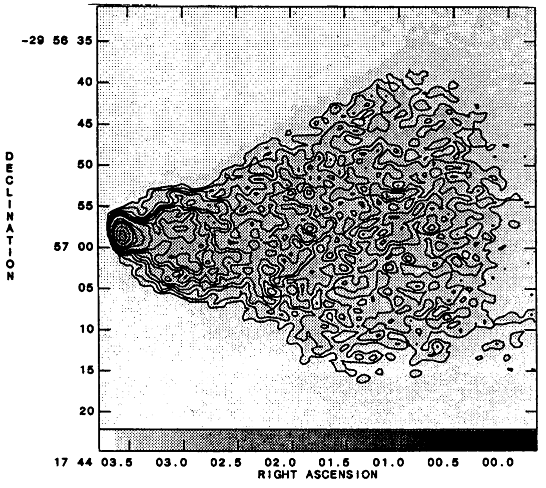

Figure 2c: The same as Figure 2a with contour levels set at (5, 7, 9, 11, 13, 15, 17.5, 20, 30, 40, 50, 70, 90)×96.8 μJy/beam area. The RMS noise is 70 μJy/beam area.

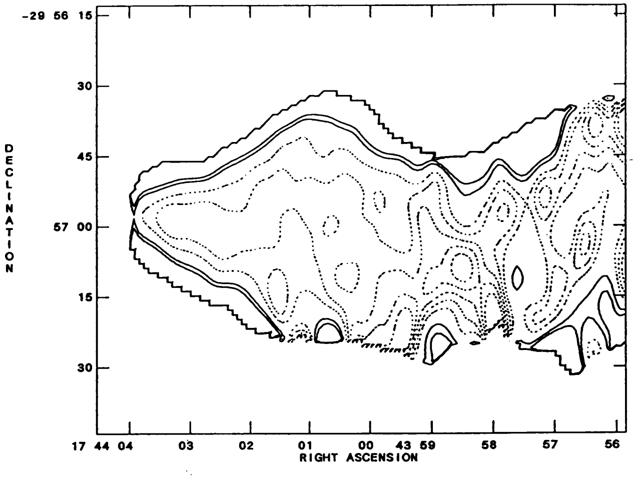

Figure 3(a): Spectral index map determined from 6 and 2cm maps. Contour levels are set at -0.5, -0.4, -0.3, -0.2, -0.1, 0.1, 0.2. Contours at the boundary of the source may not be significant.

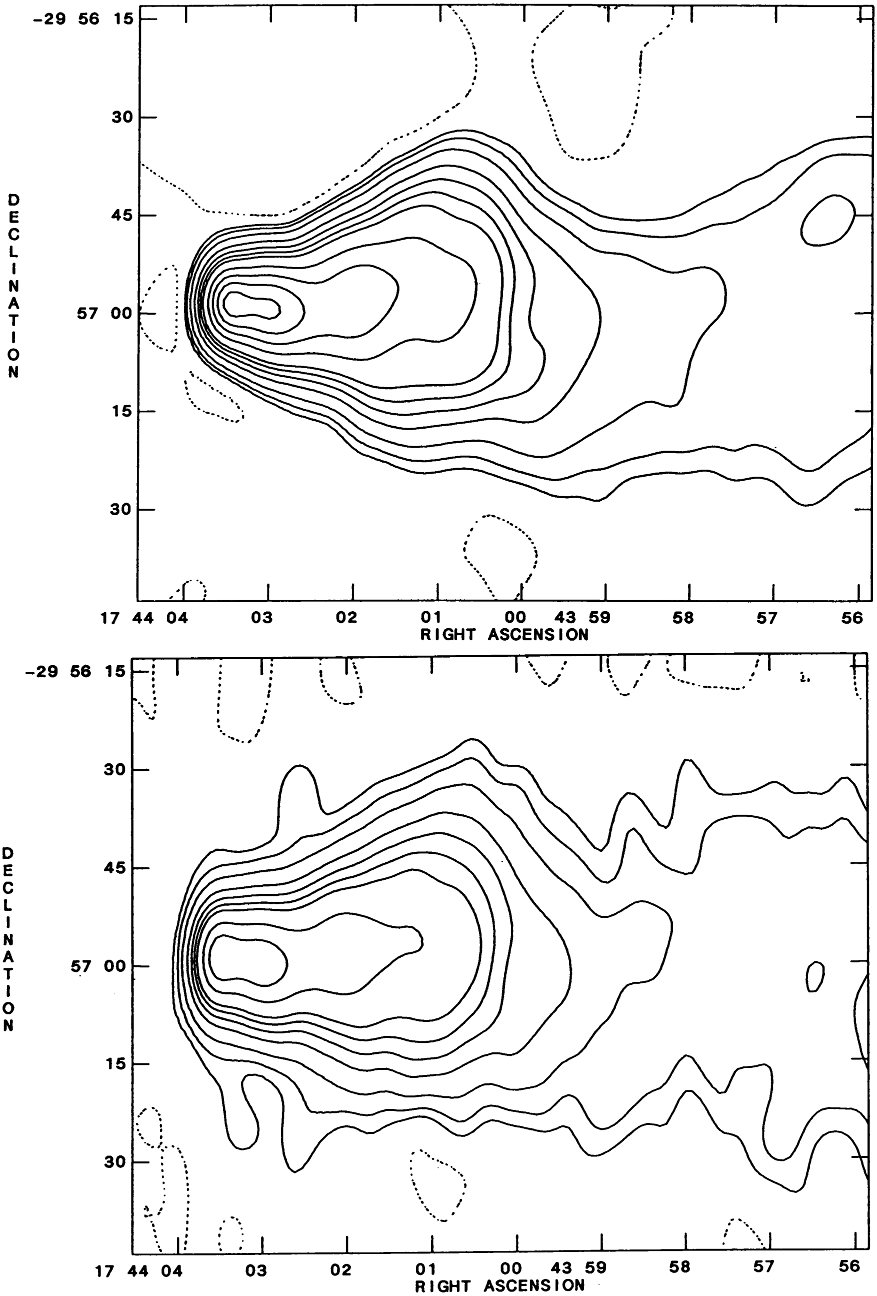

Figure 3b,c: Contours of total intensity at 4635 MHz (top figure) and 14964 MHz (bottom figure) are set at -0.5, 0.5, 1, 2, 4, 6, 8, 10, 15, 20, 25, 30 mJy/beam area, respectively.

maps indicate a steady increase in the degree of polarization away from the compact source which appears to be depolarized at λ6cm (YB87).

Discussion

YB87 noted the possibility that the "Mouse" is a background head-tail radio source seen from a direction lying within the plane containing the two bent radio jets. The new high-resolution images show structural details which show no resemblance to any known head-tail radio source. The flat spectral index distribution, and the bow-shock morphology make it unlikely that G359.3-0.82 is a background extragalactic radio source. This source also resembles the unusual Galactic object G357.7-0.1. The proximity of the "Mouse" to the Galactic center in the plane of the sky makes it possible that this unusual object is a Galactic center object. However, measurements of HI absorption are needed to verify this hypothesis.

The new observations confirm the impression, initially based on low resolution maps, that the "Mouse" is a cometary radio source with a compact core and a one-sided tail. The new data show that the core has a diameter of order 1" ($\sim 10^{17}$cm at 8.5 kpc) in size while the tail can be traced for nearly $12'$ ($\sim$ 30 pc at 8.5 kpc) across the sky. The highest resolution maps reveal a sharp edge to the radio emission on the east side of the compact source. This edge has a parabolic shape reminiscent of a bow-shock produced by the supersonic motion of an object through a medium. Figure 2a shows that this parabolic edge is separated from the much larger fan-shaped inner tail by a narrow gap in the intensity of the radio emission. The opening angle of the fan, as measured from the position of the compact radio source, decreases from a value of nearly 30 degrees in the bright, inner part of the fan to a value of only a few degrees at the western end of the tail. This behavior can find a simple explanation in the bow-shock or wake model of this source. If the radio emitting plasma is energized by processes such as particle injection or *in-situ* particle acceleration near the position of the compact source and cools by processes such as radiative energy loss or adiabatic expansion, the expansion rate in the transverse direction (direction orthogonal to the motion of the compact source through the medium) will decrease, and may eventually stop as the internal pressure comes into equilibrium with the pressure of the external medium. For a constant velocity source, the transverse radius measured from the axis of the symmetry of the source, r, is proportional to x^{β}, where x is the downstream distance, and β is $\sim$1/2 to 1/3. Stagnation of the transverse expansion may also be aided by the sweeping up of the medium at the outer boundary of the wake.

We speculate that this source may be the result of the expulsion of a compact object such as a neutron star or a runaway binary system (Helfand and Becker 1985) from SNR G359.1-0.5. This hypothesis has been suggested previously to account for Cir-X1 which lies $\sim 7'$ to the north of the boundary of the shell SNR G321.9-0.3 (Clark *et al.* 1975). X-ray observations of the Galactic center region show a bright hard X-ray source a few arc-minutes away to the south-west from the head of the "Mouse" (Skinner *et al.* 1987). If the X-ray source is not related, the lack of X-ray emission from the "Mouse" undermines the suggestion that G359.3-0.82 is powered in a manner similar to that of Cir-X1 system. Another possibility for the origin of the "Mouse" is that this source is produced by fast-moving, dense, non-stellar ejecta expelled from G359.1-0.5. In recent high-resolution radio continuum observations of Cas A supernova remnant, Braun *et al.* (1987) identify a number of fast-moving features having a bow-shock appearance. These features are interpreted in terms of high-velocity clumps which generate a bow-shock as they pass through the slow-moving expanding shell. If this situation applies to SNR G359.1-0.5, we would expect a number of fast-moving features surrounding this remnant.

If a single neutron star or a neutron star in a binary system (Helfand and Becker 1985) is responsible for radio emission in G359.3-0.82, the radiating particles may be ejected by the compact object. On the other hand, if either a dense clump of ejecta or possibly a powerful wind from a binary is responsible, then *in-situ* particle acceleration may produce the emission. In either case, G359.3-0.82 may prove to be an ideal laboratory for testing models of particle acceleration, injection and evolution.

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