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A DISTANCE DETERMINATION FOR THE SUPERNOVA REMNANT G27.4+0.0 AND ITS CENTRAL X-RAY SOURCE

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ABSTRACT

We have determined the distance to the supernova remnant G27.4+0.0, one of the handful of remnants with a bright central x-ray source. H I absorption data obtained with the VLA toward the remnant and adjacent H II regions allow us to constrain the distance to G27.4+0.0 to lie between 6 and 7.5 kpc. We briefly discuss the implications of this result for the nature of the central source.

1. INTRODUCTION

While the notion that compact objects are created in supernova explosions was established unequivocally 25 years ago with the discovery of the Crab Nebula pulsar, only a small fraction of the known supernova remnants (< 10%) show any evidence of harboring a neutron star or black hole (e.g., Helfand & Becker 1984; Seward 1990). The remnant G27.4+0.0 (Kes 73) is one example. Kriss *et al.* (1985) have presented high resolution radio and x-ray images of this object which reveal a bright compact x-ray source < 5″ in size lying at the center of the 4′ diameter remnant shell. This source has no counterpart at radio wavelengths. The large distance uncertainty for the remnant—from ~25 kpc using the Σ–*D* relation to ~3 kpc from comparing the x-ray luminosity and diameter to that of Tycho's SNR—made it difficult for Kriss *et al.* (1985) to constrain the origin of the x-ray emission. Models considered included thermal emission from the surface of a young neutron star, nonthermal, rotation-powered pulsar emission, and accretion-powered emission from a neutron star or black hole binary system.

We present here H I absorption observations for G27.4+0.0 which provide a well-constrained distance for the remnant. In Sec. 2 we describe the observations and data reduction procedures used to produce absorption spectra for the SNR and adjacent H II regions. Section 3 presents our interpretation of these spectra, from which we derive a distance to the remnant of between 6 and 7.5 kpc. The final section briefly outlines the constraints these observations place on the origin of the x-ray emission.

2. OBSERVATIONS AND DATA ANALYSIS

A field centered on G27.4+0.0 was observed in March 1992 with the C configuration of the NRAO[1] Very Large Array. A total bandwidth of 1.56 MHz (330 km s^{-1}) was centered at 1420.21575 MHz [+40 km s^{-1} with respect to the local standard of rest (LSR)] in order to cover the full range of velocities seen in the neutral hydrogen emission spectrum at $l=27°$. The bandpass was divided into 128 channels, each 12.2 kHz (2.57 km s^{-1}) wide. A total of 206 minutes of on-source observations were accumulated; 3C286 was observed as a flux density and bandpass calibrator, while 1819-096 was used as the phase calibrator.

The data were calibrated, edited, and reduced using standard Astronomical Image Processing Software (AIPS) routines. The emission spectrum from this ~40′ field of view centered on the remnant was obtained by deriving the scalar sum for each of the 128 channels; the spectrum is displayed in Fig. 1. The absorption spectrum was obtained by Fourier transforming the channel data to obtain 128 independent images, each of which was CLEANed using the AIPS algorithm for image restoration. On the basis of the emission spectrum and examination of the individual channel maps, channels 15–25 and 105–115 were summed to obtain the continuum image (Fig. 2). This continuum map was then subtracted from each channel to create the final position–velocity data cube.

An absorption spectrum was obtained for the remnant by integrating over a 30″×40″ box centered at α(1950) = 18 38 33.3, δ(1950) = −04 59 40 on the bright western limb of the source which includes a continuum flux density of ~260 mJy. This spectrum is displayed in Fig. 3(a); the velocity scale is with respect to the LSR. Spectra were similarly obtained for the other sources in the field; a spectrum for the object coincident with the *IRAS* source 18379-0500, scaled to the flux density of the remnant, is displayed in Fig. 3(b).

3. THE DISTANCE TO G27.4+0.0

The neutral hydrogen emission at this longitude extends from −45 km s^{-1} to +115 km s^{-1}. The spectrum shown in Fig. 1 matches well that given by Weaver & Williams (1974) for Galactic coordinates G27.5+0.0. Furthermore, the inferred tangent point velocity of 114 km s^{-1} is close to that determined in this direction by Burton & Gordon (1978—106.4±4.5 km s^{-1}).

In addition to the SNR, the continuum map (Fig. 2) reveals several other sources in the field which are useful in determining the distance to the remnant. The source positions, flux densities, and sizes are listed in Table 1 along with additional information from the *Galactic Plane Survey*

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

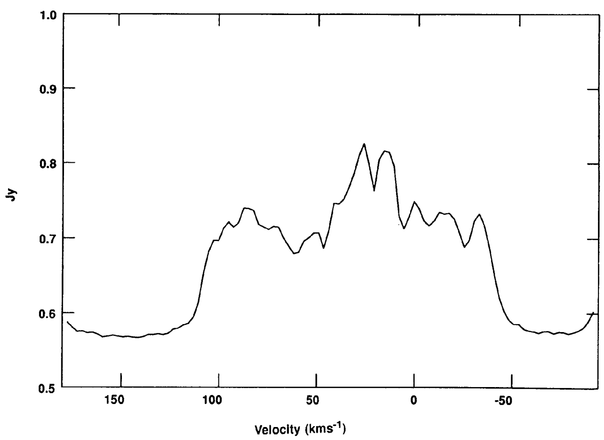

FIG. 1. The neutral hydrogen emission spectrum in the direction of G27.4+0.0 derived from the scalar sum of the 40′ image obtained as described in Sec. 2. Velocity scale is with respect to the LSR.

(*GPS*) catalogs of Zoonematkermani *et al.* (1990) and Helfand *et al.* (1992). Four of these sources are extended, three of which are coincident with entries in the *IRAS Point-Source Catalog* (*PSC*); *IRAS* maps of the region at 60 and 100 μm are given in Shull *et al.* (1989). The other sources are most likely extragalactic background objects.

The problems of using H I absorption and emission spectra in the direction of a source to determine its distance are well known: velocity crowding, velocity streaming, the distance ambiguity between the near side and beyond the tangent point, the inhomogeneous nature of the H I distribution both in space and in temperature, etc. (e.g., Frail & Weisberg 1990). In this instance, however, we are fortunate to have two Galactic radio sources only 12′ apart which are at a moderately high Galactic longitude and on opposite sides of the tangent point: the SNR G27.4+0.0 and *IRAS* 18379-0500. Comparison of the scaled absorption spectra for these two sources (Fig. 3) leads to the following conclusions:

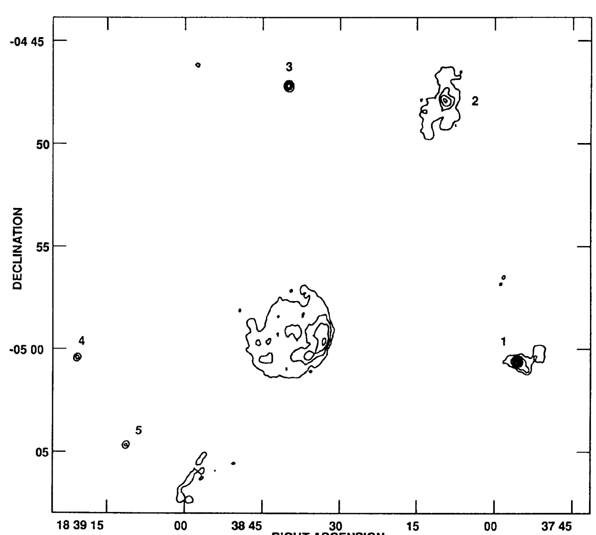

FIG. 2. Continuum map of the 20 cm emission in the field containing G27.4+0.0. Source parameters are given in Table 1.

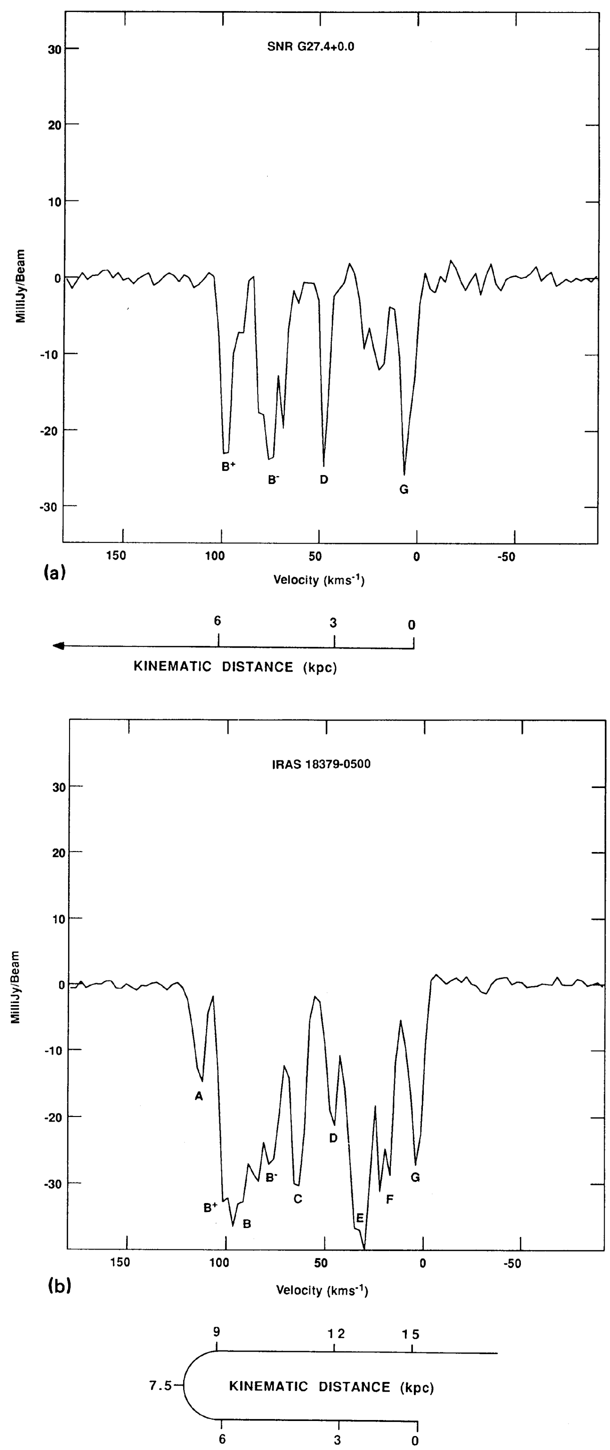

FIG. 3. (a) Absorption spectrum of the brightest region on the western limb of the SNR Velocity scale is with respect to the LSR. The Galactic rotation curve of Fich *et al.* (1989) has been used to construct the velocity–distance relation. (b) Absorption spectrum of source 1.

TABLE 1. Radio sources near G27.4+0.0.

Source	GPS Name[a]	RA (1950)	Dec (1950)	Flux Density Peak (mJy)	Flux Density Integrated (mJy)	Size (arcsec)	IRAS Name (PSC)	Comments[a]
1	27.280 + 0.145	18 37 55.56	−05 00 35.9	172	252	17.0	18379-0500	I,A,H76,R343,RL
2	27.494 + 0.191	18 38 09.48	−04 47 54.5	45	249	32.7	18381-0447	I,A,H78,R443,RL
3	27.565 + 0.084	18 38 40.03	−04 47 11.8	42	61	16.8		A
4	27.446 − 0.167	18 39 20.78	−05 00 24.6	22	24	0.0		
5	27.365 − 0.165	18 39 11.32	−05 04 39.6	20	23	15.0	18391-0504	I,R439

[a]From the Galactic Plane Survey of Zoonematkermani et al. (1990) and Helfand et al. (1992).

(i) The clear absorption feature in the *IRAS* 18379-0500 spectrum near the tangent point velocity (feature A at 114 km s^{-1}) is completely absent in the spectrum of the remnant. This establishes an upper limit on the distance to G27.4+0.0; the remnant must be on the near side of the tangent point. Using a solar galactocentric radius $R_0=8.5$ kpc (Kerr & Lynden-Bell 1986) yields a tangent point distance at this longitude of $D=R_0 \cos l=7.5$ kpc.

(ii) Since the *IRAS* source is more distant than the remnant, every feature which appears in the SNR spectrum must have a counterpart in the spectrum of this source. The features labeled B^+, B^-D, and G meet this criterion and thus must represent clouds on the near side of the tangent point and in front of the remnant (B, C, and E are largely absent in the remnant spectrum). The highest velocity feature in this group, B^+ with $v=+100$ km s^{-1}, establishes a lower limit to the remnant distance. Using the International Astronomical Union (IAU) adopted values of $R_0=8.5$ kpc and the circular velocity at the solar distance of $\theta_\odot=220$ km s^{-1} (from the Galactic rotation curve of Fich 1989), we find a lower limit to the distance of this feature of 6.0 kpc (Fig. 3).

Thus, our distance limits for G27.4+0.0 are 6.0 and 7.5 kpc based on pure circular rotation. Frail & Weisberg (1990) estimate that noncircular motions along a typical line of sight introduce errors of ± 7 km s^{-1} which translate to an uncertainty on our limits of ± 1 kpc for the tangent point distance and ± 0.3 kpc for the 100 km s^{-1} feature. We conclude that the remnant distance is $\sim 6.7^{+1.8}_{-1}$ kpc.

This value is wholly consistent with the limited data available on the x-ray absorption along the line of sight to this source. Kriss *et al.* (1985) find x-ray column densities ranging from 0.4 to 2.0×10^{22} cm^{-2} when a variety of spectral forms are fitted to the *Einstein* data. We have determined the column density of neutral gas to the remnant by summing the intensity of those components in the emission profile which correspond to features we see in absorption toward the remnant. Converting these to a neutral hydrogen column density,

$$N_{\rm H\,I}=1.82\times10^{18}\ {\rm cm}^{-2}\int T_B\, dv=4.8\times10^{21}\ {\rm cm}^{-2},$$

where the integral has been performed only over the velocities corresponding to features in the SNR absorption spectrum and a conversion factor of 3.1 K mJy^{-1} has been adopted. Since this value represents only the neutral atomic gas whereas the x-ray absorption reflects an integral of the molecular, atomic, and ionized material along the line of sight, we expect a ratio $N_{\rm H_{x\text{-}ray}}/N_{\rm H\,I}\sim$ 2–3, consistent with the x-ray value derived from the power law fit to the Imaging Proportional Counter (IPC) spectrum by Kriss *et al.* (1985). The value is also roughly consistent with the average interstellar medium density of 10^{21} cm^{-2} kpc^{-1} (Allen 1973).

4. DISCUSSION

The 6.5 kpc distance we infer for G27.4+0.0 implies a physical diameter for the remnant of ~8 pc and an x-ray luminosity of $\sim 2\times10^{35}$ erg s^{-1} (0.3–4 keV), comparable to Tycho's SNR ($D\sim2.5$ kpc) in size and in x-ray luminosity, using Seward's (1990) value for 2–10 keV fluxes from the *Einstein* Monitor Proportional Counter (4.7 and 27.5 ct s^{-1} for G27.4+0.0 and Tycho, respectively). The lower limit to the x-ray absorption to the source implied by the neutral hydrogen column density of 5×10^{21} cm^{-2} and the distance effectively rules out one of the three possible origins for the x-ray emission from the central point source: no reasonable combination of radius and temperature characterizing thermal emission from a neutron star can fit both the x-ray spectrum and count rate for the object. Our distance determination also renders improbable the "re-energization" scenario applied to this object by Shull *et al.* (1989), since they argue that a distance of >10 kpc is required to explain the association of the x-ray/radio remnant with a putative far-infrared shell nearby. The high x-ray temperature of the diffuse emission found by Kriss *et al.* (1985) also argues against an age of $\sim10^5$ years for this remnant suggested by Shull *et al.*

The remaining options to explain the x-ray emission—a rotation- or accretion-powered pulsar remain viable. The x-ray luminosity of the point source (25% of the total remnant luminosity in the soft band and an undetermined fraction at higher energies) is consistent with that of the

Crab pulsar although there is no surrounding bright synchrotron radio and/or x-ray nebula as is found for the Crab. The luminosity is also consistent with a neutron star accreting at a few percent of the Eddington rate from a companion. A search for periodicities and/or aperiodic variability in a recently completed *ROSAT* observation of this source (Becker 1992) as well as spatially resolved spectroscopy of the object achievable with the Japanese ASTRO-D mission scheduled for launch in February 1993 will be most helpful in determining the appropriate model for this rare example of an x-ray point source at the center of a young supernova remnant.

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REFERENCES

Allen, C. W. 1973, Astrophysical Quantities (Athalone, London), p. 265
Becker, R. 1992, private communication
Burton, W. B., & Goron, M. A. 1978, A&A, 63, 7
Fich, M., Blitz, L., & Stark, A. A. 1989, ApJ, 342, 272
Frail, D. A., & Weisberg, J. M. 1990, AJ, 100, 743
Helfand, D. J., & Becker, R. H. 1984, Nature, 307, 215
Helfand, D. J., Zoonematkermani, S., Becker, R. H., & White, R. L. 1992, ApJS, 80, 211
Kerr, F. J., & Lynden-Bell, D. 1986, MNRAS, 221, 1023
Kriss, G. A., Becker, R. H., Helfand, D. J., & Canizares, C. R. 1985, ApJ, 288, 703
Seward, F. D. 1990, ApJS, 73, 781
Shull, J. M., Fesen, R. A., & Saken, J. M. 1989, ApJ, 346, 860
Weaver, H. F., & Williams, D. R. W. 1974, A&AS, 17, 1
Zoonematkermani, S., Helfand, D. J., Becker, R. H., White, R. L., & Perley, R. A. 1990, ApJS, 74, 181