A NEW RADIO DETECTION OF THE TRANSIENT BURSTING SOURCE GCRT J1745–3009

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Received 2005 August 11; accepted 2005 November 1

ABSTRACT

GCRT J1745–3009 is a transient bursting radio source located in the direction of the Galactic center, discovered by Hyman et al. in 330 MHz VLA observations from 2002 September 30–October 1. We have searched for bursting activity from GCRT J1745–3009 in nearly all of the available 330 MHz VLA observations of the Galactic center since 1989, as well as in 2003 Giant Metrewave Radio Telescope (GMRT) observations. We report a new radio detection of the source in 330 MHz GMRT data taken on 2003 September 28. Due to sparse sampling of the observation, only a single burst, already at or passed its peak, was detected. The maximum flux density detected was ~0.5 Jy, approximately 3 times weaker than the five bursts detected in 2002. We present tentative evidence suggesting that this burst is an isolated one, but we cannot rule out additional undetected bursts that may have occurred with the same ~77 minute periodicity observed in 2002 or with a different periodicity. Assuming the peak emission was detected, the decay time of the burst, ~2 minutes, is consistent with that determined for the 2002 bursts. Based on the total time for which we have observations, we estimate that the source exhibits bursting activity roughly 9% of the time.

Subject heads: Galaxy: center — radio continuum: general — stars: individual (GCRT J1745-3009) — stars: variables: other

1. INTRODUCTION

Transient radio emission has been detected from many astronomical sources, including flare stars, brown dwarfs, masers, gamma-ray bursts, pulsars, supernovae, neutron star and black hole X-ray binaries, and active galactic nuclei. Efficient blind searching for radio transients requires a telescope for which the product of the field of view $\Omega$, the sensitivity or collecting area $A$, and the ratio of the total observing time to the time resolution $T_{\text{obs}}/T_{\text{res}}$ is “large.” Generally, radio telescopes have been able to maximize only two of these three quantities. Thus, the majority of radio transients have been found by either monitoring objects thought to be potential radio emitters (e.g., flare stars and brown dwarfs) or by follow-up observations of objects detected at higher energies (e.g., X-ray binaries and gamma-ray bursts). Recent developments in low-frequency imaging techniques have produced wide-field images ($\approx 3^\circ$ FWHM) with uniform, high resolution across the field (LaRosa et al. 2000; Nord et al. 2004) thereby enabling efficient searches for radio transients (Hyman et al. 2002, 2003).

GCRT J1745–3009 is a novel bursting radio source (Hyman et al. 2005) whose notable properties include “flares” with approximately 1 Jy peak magnitude, lasting approximately 10 minutes each, and occurring at apparently regular 77 minute intervals. This object is located about 1°25 south of the Galactic center (GC; Fig. 1) and was identified from 330 MHz (90 cm) observations with the Very Large Array (VLA) on 2002 September 30.

The source GCRT J1745–3009 is notable because it is one of a small number of radio-selected transients. Moreover, with only a few exceptions (Melrose 2002) such as electron cyclotron masers from flare stars and the planets, plasma emission from solar radio flares, pulsar radio emission, and molecular-line masers, most radio transients are incoherent synchrotron emitters. For an incoherent synchrotron emitter, the energy density within the source is limited to an effective brightness temperature of roughly $10^{12}$ K by the inverse Compton catastrophe (Readhead 1994). The properties of GCRT J1745–3009 suggest strongly that its brightness temperature exceeds $10^{12}$ K by a large factor and that it is a member of a new class of coherent emitters (Hyman et al. 2005).

The discovery observations of GCRT J1745–3009 were based on VLA 330 MHz observations at a single epoch, from which only a limited amount of information about the source could be gleaned. This paper reports on a second detection of GCRT J1745–3009, made with the Giant Metrewave Radio Telescope (GMRT) in 2003, as well as on a series of 330 MHz nondetections resulting from archival observations and our Galactic center...
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radio transient monitoring program. The observations are summarized in § 2 and the results in § 3. We discuss briefly the environment of the source in § 4, and we present our conclusions in § 5.

2. OBSERVATIONS

Table 1 summarizes the 330 MHz observations with the two telescopes. Most observations consist of a few, long scans with occasional interruptions for phase calibration (see below). At a few epochs however, the duration of the observations was not obtained in a single observation, but in multiple short and widely spaced scans. About half of the observations had durations shorter than the 77 minute burst period observed in 2002. At both telescopes, both right and left circular polarization were recorded.

The flux density of GCRT J1745–3009, even at its peak, is far less than the total flux density contributed by other sources in the field of view. Thus, the source can be detected only in images. In turn, because of the relatively large fields of view and the number of sources within the field, the entire field of view must be imaged.

Production of the images was conducted in a consistent manner from epoch to epoch. Calibration of the flux density was by reference to either 3C 48 or 3C 286. Initial calibration of the visibility phases was obtained by observations of a nearby VLA or GMRT calibrator, typically J1714–252. At 330 MHz, radio frequency interference (RFI) can be a substantial problem, and if not excised from the visibility data, it would limit the dynamic range of the final image. We examined the visibility data for RFI and excised it.

At 330 MHz, neither the VLA nor the GMRT can be assumed to be coplanar; in order to image the entire field of view, we used a polyhedral imaging algorithm to compensate for the non-coplanarity of the arrays (Cornwell & Perley 1992). In order to approach thermal noise limits in the images, several iterations of imaging, deconvolution (CLEANing), and self-calibration were used. In order to search for bursts from GCRT J1745–3009, the CLEAN components of all other sources in the field were subtracted from the \( \nu - \tau \) data, and the residual data were then imaged in 10 minute subsets. Noise levels of the 10 minute images range from approximately 10 mJy beam\(^{-1}\) for the GMRT and 20 mJy beam\(^{-1}\) for the most extended VLA configurations (A and B) to approximately 250 mJy beam\(^{-1}\) for the more compact configurations (C and D), which both have a lower angular resolution and are more susceptible to RFI and sidelobe confusion. If a burst was detected, the residual data were then imaged with a higher time resolution (from 5 to 30 s) in order to search for structure within the burst.

All but three of the 1989–2004 VLA observations and the five 2005 observations listed in Table 1 are pointed in the direction of Sgr A*, approximately 1°.25 north of GCRT J1745–3009. (Coincidentally, the discovery observations were pointed nearly directly at the source.) The GMRT observations are pointed approximately 0.5 west. The primary beam attenuation of the VLA and the GMRT reduces the apparent flux density of the source by a factor of approximately 2 and 1.5, respectively. While significant, this level of primary beam attenuation would not be sufficient to prevent the recovery of the source, provided that the peak magnitude of the bursts is approximately 1 Jy or higher. However, if the bursts have a range of magnitudes, significantly weaker bursts (\( \leq 150 \) mJy) could have gone undetected in the vast majority of our observations.

3. RESULTS

We detect GCRT J1745–3009 at two epochs, 2002 September 30–October 1 and 2003 September 28. The latter epoch is a new recovery of the source, while the former epoch is that of the discovery by Hyman et al. (2005). Figure 2 shows contour images before, during, and after the fourth burst detected on 2002 September 30. Figure 3 shows the light curves for the five 2002 September 30 bursts, with 30 s sampling, and the 2003 September 28 burst with 17 s sampling. Unfortunately, the recovery observation on 2003 September 28 consisted of approximately 10 minute scans spaced approximately an hour apart for several hours. Only a single burst, at or passed its peak, is detected at the beginning of a scan (2003 September 28 11:44:53, international astronomical time [IAT]). As shown in Figure 3, the shape of the decay profile for the 2003 September 28 burst is consistent with that seen for the 2002 September 30 bursts. Assuming that this burst is consistent in duration with those from 2002 September 30, the 2003 September 28 burst had a peak magnitude of approximately 0.5 Jy,
TABLE 1
330 MHz OBSERVATIONAL LOG

| Epoch | Date       | Time (IAT) | Telescope | Bandwidth (MHz) | Duration (minutes) |
|-------|------------|------------|-----------|----------------|--------------------|
| 1899 Mar 18 | 09:49:40 | VLA:B | 12.5 | 331.8 |
| 1995 Oct 14 | 22:49:40 | VLA:B | 1.6 | 30.7 |
| 1996 Oct 19 | 23:03:30 | VLA:A | 6.2 | 173.5 |
| 1996 Oct 19 | 19:48:50 | VLA:A | 6.2 | 176.0 |
| 1997 Feb 06 | 13:57:10 | VLA:BnA | 6.2 | 76.7 |
| 1998 Nov 29 | 16:52:20 | VLA:C | 3.1 | 380.7 |
| 1998 Sep 26 | 02:24:30 | VLA:B | 3.1 | 124.0 |
| 1998 Sep 25 | 21:08:00 | VLA:B | 3.1 | 277.5 |
| 1998 Mar 14 | 14:40:50 | VLA:A | 3.1 | 208.5 |
| 1998 Mar 14 | 10:06:10 | VLA:A | 3.1 | 231.8 |
| 1999 May 31 | 04:53:00 | VLA:D | 3.1 | 376.7 |
| 2001 Sep 05 | 00:40:60 | VLA:C | 3.1 | 376.7 |
| 2002 Mar 26 | 10:46:30 | VLA:A | 3.1 | 29.7 |
| 2002 Mar 26 | 11:18:50 | VLA:A | 3.1 | 34.7 |
| 2002 Apr 27 | 09:10:40 | VLA:A | 3.1 | 83.8 |
| 2002 May 17 | 08:51:50 | VLA:AB | 3.1 | 34.5 |
| 2002 Jun 24 | 09:22:00 | VLA:B | 3.1 | 34.5 |
| 2002 Jul 21 | 06:05:50 | VLA:B | 3.1 | 59.2 |
| 2002 Sep 30 | 02:48:30 | VLA:BC | 6.2 | 289.7 |
| 2003 Oct 01 | 02:34:45 | VLA:BC | 6.2 | 53.8 |
| 2003 Jan 20 | 15:27:40 | VLA:CD | 6.2 | 187.8 |
| 2003 Jul 03 | 08:09:50 | VLA:A | 6.2 | 34.5 |
| 2003 Jul 08 | 06:28:10 | VLA:A | 6.2 | 59.2 |
| 2003 Jul 12 | 04:12:50 | VLA:A | 6.2 | 34.5 |
| 2003 Jul 14 | 04:04:40 | VLA:A | 6.2 | 34.5 |
| 2003 Jul 28 | 07:09:20 | VLA:A | 6.2 | 34.5 |
| 2003 Aug 09 | 01:52:50 | VLA:A | 6.2 | 59.2 |
| 2003 Aug 18 | 23:43:40 | VLA:A | 6.2 | 59.2 |
| 2003 Sep 28 | 10:06:26 | GMRT | 15 | 63 |
| 2003 Sep 29 | 11:51:10 | GMRT | 15 | 45 |
| 2003 Oct 14 | 00:32:50 | VLA:BC | 6.2 | 59.2 |
| 2003 Oct 21 | 07:27:09 | GMRT | 15 | 45 |
| 2003 Oct 24 | 00:23:30 | VLA:B | 6.2 | 59.0 |
| 2003 Nov 23 | 21:16:40 | VLA:B | 6.2 | 39.7 |
| 2003 Dec 29 | 18:55:10 | VLA:B | 6.2 | 64.0 |
| 2005 Mar 25 | 13:13:30 | VLA:B | 4.7 | 72.0 |
| 2005 Sep 17 | 01:09:50 | VLA:C | 7.0 | 130.0 |
| 2005 Sep 17 | 23:37:10 | VLA:C | 7.0 | 129.0 |
| 2005 Sep 22 | 23:47:30 | VLA:C | 7.0 | 157.0 |

* We provide the IAT start time of the observation for use in a later analysis. However, depending upon the observing program, the duration of the observation may not have been obtained in a single observation, but in multiple shorter ones at the epoch.

* The notation "VLA:A" refers to the A configuration of the VLA.

* Source detected at this epoch.

* This epoch consists of multiple, short scans taken over several hours.

compared to 1–1.5 Jy for those on 2002 September 30. Clearly, a longer burst duration implies a higher peak.

In Hyman et al. (2005) we presented exponential fits to the rising and decay portions of the 2002 bursts, and compare the shape of the light curves to those for known classes of radio transients. The fitted rise and decay times are 9.9 ± 0.7 and 1.9 ± 0.5 minutes, respectively, and the fitted, peak flux density is 1.67 ± 0.05 Jy. None of the apparent structure in the light curves in Figure 3 deviates from the exponential fits by more than 2σ. Light curves made at the full 5 s sampling (not shown) contain no additional structure.

The source is unresolved in both epochs. The angular resolution may not have been obtained in a single observation, but in multiple shorter ones at the epoch. The source is unresolved in both epochs. The angular resolution may not have been obtained in a single observation, but in multiple shorter ones at the epoch.

Fitting a Gaussian to the source yields a position of (J2000) right ascension 17h45m52s23 ± 0.3s, declination −30°09′53″ ± 5″, which is approximately a factor of 2 more accurate in each dimension than determined in the 2002 September 30 observation.

Observations at 330 MHz are affected strongly by ionospheric phase fluctuations. Their impact includes refractive position shifts. We used eight nearby small-diameter sources from the NRAO VLA Sky Survey (NVSS; Condon et al. 1998) to register our images. The NVSS was conducted at 1400 MHz and has a substantially better astrometric accuracy of 0″5 in both right ascension and declination for bright sources. We found an average ionospheric-induced refraction of 0″23 ± 0″24 in right ascension and −4″6 ± 3″4 in declination. The source position and uncertainty cited above include a correction for this refraction.

No frequency dependence was detected in the 2002 September 30 bursts, and none is detected across the 60 channel, 15 MHz bandpass for the 2003 September 28 burst.

A power-law fit across the 15 MHz bandpass of the 2003 September 28 observation yields a wavelength dependence of $S \propto \lambda^{-3}$. No circular polarization is detected in the bursts with an upper limit of 15%. A similar upper limit was determined for the discovery observation (Hyman et al. 2005). Linear polarization measurements are not available for either the discovery or recovery observations.

No emission is detected from GCRT J1745−3009 when imaging the 2003 September 28 observation at times when the burst is not occurring. We are able to improve the (5σ) upper limit for 330 MHz interburst emission from 75 mJy, for the discovery observations, to 25 mJy, for the recovery observation. The upper limit on quiescent emission during periods of no burst activity is 15 mJy at 330 MHz (Hyman et al. 2005). Nondetections on 2005 March 25 at both 330 and 1400 MHz also yield an upper limit of 15 mJy at 330 MHz, but a significantly reduced upper limit of 0.4 mJy at 1400 MHz, as compared to a 35 mJy upper limit obtained from a 2003 January observation at that frequency. We have also learned that GCRT J1745−3009 has been observed in early- and mid-2005 with the Westerbork Synthesis Radio Telescope (WSRT) at both 330 and 1400 MHz. Upper limits on any emission are approximately a few millijanskys (R. Braun 2005, private communication). A search of 200 hr of archival GC observations obtained at 843 MHz by the Molongo Observatory Synthesis Telescope (MOST) from 1987–2005 resulted in no detections, with burst upper limits ranging from 200 to 600 mJy (S. Fine 2005, private communication). The closest of the observations to either of our detections was on 15 August 2002, about 1.5 months prior to our discovery epoch.

As Hyman et al. (2005) reported, during the discovery epoch (2002 September 30–October 1) the bursts from the source had an approximate 77 minute periodicity. As noted above, the recovery on 2003 September 28 occurs in the midst of a set of 10 minute scans, spread over several hours. Assuming that the source was emitting periodic bursts at this epoch, each of 10 minute duration, we have determined the periods at which bursts could occur while being consistent with the gaps and nondetections during the 2003 September 28 epoch. There are 212 minutes between the detected burst and the end of the observation. Thus, we can place no constraints on periods longer than 212 minutes. For shorter periods, only the following ranges of periods are allowed: 36–37 minutes, 71–78 minutes, 107–112 minutes, 131–160 minutes, and 179–195 minutes. We estimate that the uncertainty in making these determinations is perhaps 1 minute, which results from slightly varying noise levels within the scans and the assumption that the duration of the bursts remains fixed at 5 s.
10 minutes. Thus, while consistent with the gaps and nondetections, the possible 36–37 minute periodicity is perhaps only marginally so. A 77 minute periodicity remains consistent with the 2003 September 28 observations.

We cannot use the interval between 2002 September 30 and 2003 September 28 to constrain the burst activity, because the uncertainty on the 77 minute period determined from the 2002 September 30 observations is sufficiently large (~15 s) that we cannot connect the phase between the two observations. Indeed, the nearest observation to the 2002 September 30 observation precedes it by 70 days, while the nearest to the 2003 September 28 observation, other than that on 2003 September 29, follows it by 16 days. The current uncertainty is large enough that a single burst could not be connected in phase over these intervals, even if the source had been detected. In addition, the sparse sampling of the observation made one day after the 2003 September 28 detection does not include any scan at multiples of 77 minutes later, nor do the scans, when taken together with those on September 28, significantly alter the allowed ranges of other periods given above. Thus, we cannot use the nondetection on 2003 September 29 to place limits on the duration of the active period of the source.

The 2003 September 28 and 29 observations were part of a series of GMRT observations designed to survey the entire Galactic center region. These include a number of other pointings, not included in Table 1, that potentially could be used to detect GCRT J1745–3009, albeit with much larger primary beam attenuation. In particular, there are scans on Sgr A, some 1.3 away...
The arrows represent 3/C27 the observations were interrupted for calibration observations. The 2003 September 28 burst, not known at the time of the observation, the full burst is not captured as the 5 minute observation of GCRT J1745–3009 was not known at the time of the second from the top panel. The y-axis ranges from 0 to 1 Jy in the top panel and 0 to 2 Jy in the other panels. For the 2002 September 30 bursts, the light curve has been folded at the apparent 77.1 minute periodicity. For the 2003 September 28 burst, the light curve has been aligned in time to be consistent with the decay portions of the 2002 bursts. In many cases, because the existence of GCRT J1745–3009 was not known at the time of the observation, the full burst is not captured as the observations were interrupted for calibration observations. The 2003 September 28 observations consisted of one 7 minute scan per hour for several hours. The arrows represent 3 σ upper limits for nondetections. The vertical dotted line is placed at the fitted position of the fourth 2004 burst for reference.

from both GCRT J1745–3009 and the recovery observation’s pointing center, that end approximately 10 minutes before, 77 minutes before, and 154 minutes after the decay portion of the burst detected in the recovery observation. We estimated the amount of primary beam attenuation by measuring the peak flux density of Sgr A from the recovery observation of GCRT J1745–3009. The primary beam attenuation is approximately a factor of 10. Thus, in the scans on Sgr A, if the transient were emitting bursts with peak magnitude of about 1 Jy, it would appear as a 100 mJy source. Such a source would still be well above the noise level in the images for each scan, but GCRT J1745–3009 is not detected in any of them. These nondetections would imply an upper limit for the duration of the detected burst of approximately 13 minutes, which is consistent with the 10 minute duration observed for the 2002 September 30 bursts. Furthermore, the 77 minute period and the range of other periods allowed by considering only the recovery observation scans (see above) would be largely ruled out by nondetections in the Sgr A scans from 2003 September 28, suggesting that the burst was an isolated one in contrast to the 2002 September 30 bursts.

We also note that our northern GC-pointed GMRT scans, centered ~2°5 to the northeast of GCRT J1745–3009 and the bright source, [GWC93] 46 (see Fig. 2), detect [GWC93] 46, but at a very low level due to severe primary beam attenuation (~200 times). One of these northern pointings lasted from 11:36 to 11:44 on 2003 September 28, just before the burst’s decay phase was detected at 11:45 at the beginning of the southern pointing that followed. Since [GWC93] 46 is located only 0.1 closer to the pointing center than GCRT J1745–3009, we have corrected the 5 minute noise level at the position of GCRT J1745–3009 by ~200 times primary beam attenuation factor to crudely estimate the upper limit of the peak of the 2003 detected burst. An upper limit of ~5 Jy is obtained, consistent with the 1.5 Jy peak values observed in the 2002 bursts. However, we consider this result and the evidence that the burst is an isolated one to be tentative, since the location of GCRT J1745–3009 is far out on the primary beam for these pointings. Our estimates of the degree of primary beam attenuation assumes that the primary beam is symmetric, an assumption known to break down with increasing distance from the pointing center.

As an initial crude estimate of the activity of the bursting behavior of GCRT J1745–3009, we compare the time during which the source is observed to be active to the total amount of observing time. The total observing time is almost exactly 80 hr. The 2002 September 30 bursts lasted for at least 6 hr; because only a single burst was detected on 2003 September 28, we assume that the source was active for 1 hr. Thus, GCRT J1745–3009 exhibits bursting activity approximately 9% of the time.

Finally, we note that both the original discovery and the recovery observation occur in late September and that they are separated by ~1 yr. However, given that the discovery and recovery observations occurred with different telescopes and that there was no detection in our 6 hr 1998 September 25 observation nor in our recent 2005 September observations, we can identify no seasonal nor instrumental explanation that would indicate that the source is not a celestial object. Possible models proposed for GCRT J1745–3009 thus far are a nulling pulsar (Kulkarni & Phinney 2005), a double pulsar (Turolla et al. 2005), a transient white dwarf pulsar (Zhang & Gil 2005), and a precessing radio pulsar (Zhu & Xu 2006). Alternatively, the source might be a nearby object (e.g., a flaring brown dwarf, flare star, or extrasolar planet), but as discussed in Hyman et al. (2005), the properties of GCRT J1745–3009 (e.g., noncircularly polarized emission) do not easily fit these classes.

4. ENVIRONMENT OF GCRT J1745–3009

If GCRT J1745–3009 is located at the Galactic center, prevailing models explain it as a compact object, most likely a neutron star (e.g., Turolla et al. 2005). Motivated by a prediction in Turolla et al. (2005), we have examined images that contain the field around GCRT J1745–3009 in an effort to detect any faint nebulosity, such as might result from a supernova remnant. We have examined images at 330 MHz (LaRosa et al. 2000; Nord et al. 2004), 1400 MHz (Yusef-Zadeh et al. 2004), and 2 μm (2MASS); the number of images that we can search is small because the location of the source is outside of the field of view of many images of the Galactic center region.

As seen in Figure 1, GCRT J1745–3009 is located approximately 10' from the center, and just outside, of the shell-type supernova remnant SNR 359.1–00.5 (Reich & Furst 1984). At a distance of 8D⊙kpc, this angular distance corresponds to a transverse distance of approximately 25D⊙pc. The SNR itself is old, as evidenced by its size and the extent to which the shell appears "broken up." Assuming that its age is 107T⊙yr, if GCRT J1745–3009 and the SNR are related, then GCRT J1745–3009 would have to have a velocity of about 225D⊙/T⊙kms⁻¹ to have reached its current location. This velocity is well within those observed for neutron stars detected as isolated radio pulsars (Arzoumanian et al. 2002). While it is generally above velocities detected in binaries (Lyne & Lorimer 1995), there are also strong selection effects against detecting high-velocity objects, leading to an observed distribution of binaries that is likely biased low.

In general, there is no diffuse emission surrounding the location of GCRT J1745–3009. One possible exception is some faint emission from the shell of SNR G359.1–0.5, which lies about 1° north of the position of the transient. While this close proximity could be indicative of a connection between the SNR and GCRT J1745–3009, there is otherwise no distortion in the shell of the
SNR, akin to that seen for G5.4−1.2 and PSR B1757−24 (Frail & Kulkarni 1991), nor does GCRT J1745−3009 have a cometary appearance similar to a pulsar wind nebula (PWN) like the Mouse (Gaensler et al. 2004).

5. CONCLUSIONS

We have summarized a series of Very Large Array and Giant Metrewave Radio Telescope observations of GCRT J1745−3009 (Table 1). We detect GCRT J1745−3009 at two epochs, 2002 September 30–October 1 and 2003 September 28. The latter epoch is a new recovery of the source, while the former epoch is that of the discovery by Hyman et al. (2005).

The two sets of detections of GCRT J1745−3009 are consistent with the source producing bursts with approximately 1 Jy peak magnitude; we cannot exclude the possibility that the source produces significantly weaker bursts (<150 mJy) more frequently. Hyman et al. (2005) reported that the bursts appear to have a 77.1 ± 0.3 minute periodicity; we have provided tentative evidence indicating that the 2003 September 28 burst is an isolated one. Given the epochs of observations, we estimate crudely that the source is active roughly 9% of the time.

We have examined the field around GCRT J1745−3009 at radio and infrared wavelengths. We find possible nebulosity at 1.4 GHz in the shell of SNR 359.1−00.5 near the location of the source, but otherwise no connection between the SNR and the transient. The velocity required for GCRT J1745−3009 to have originated at the center of SNR 359.1−00.5 and reached its current transverse separation is only roughly 225 km s⁻¹. While well within the range of velocities observed for various neutron stars, there is also no compelling reason to think that GCRT J1745−3009 and the SNR are related.

Additional observations are required to determine more about the nature of GCRT J1745−3009. As well as additional searches, such as those that we report here, infrared observations to search for a counterpart, a periodicity search for weaker pulsed emission, and X-ray observations to search for quiescent X-ray emission would all be useful.

We thank W. Cotton for providing us with the 20 cm image from Yusef-Zadeh et al. (2004) to search for possible nebulosity near GCRT J1745−3009. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc. S. D. H. is supported by funding from the Jeffress Memorial Trust and Research Corporation. Basic research in radio astronomy at the NRL is supported by the Office of Naval Research. We thank the staff of the GMRT who have made these observations possible. The GMRT is run by the National Centre for Radio Astrophysics of the Tata Institute of Fundamental Research.

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