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Radio emission from the transient bursting source GCRT J1745−3009 : New results

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GCRT J1745−3009 is a transient bursting radio source located $\sim 1^\circ$ away from the Galactic center with a brightness temperature possibly in excess of 10^{12} Kelvin. It was discovered from a 330 MHz VLA archival observation in 2002 and was rediscovered in a 330 MHz GMRT observation in 2003 by Hyman et al. Here we report a new radio detection of the source in 330 MHz GMRT data taken on 2004 March 20. The properties of this single burst differ significantly from those observed previously. The 2004 flux density was 0.05 Jy, about an order of magnitude lower than the single 2003 burst and the five bursts detected in 2002. We derive a very steep spectral index, $\alpha = -13.5 \pm 3.0$, across a bandwidth of 32 MHz, a new result not obtained from earlier 2 detections. This burst was detected for only 2 minutes in the middle of a scan, in contrast to the 10 minute duration observed in the earlier bursts.

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1. Introduction

GCRT J1745−3009 belongs to small number of radio selected transient sources with unique properties (Hyman et al. 2005, 2006, 2007). This source was discovered through detection of "bursts" with approximately 1 Jy peak flux density lasting approximately 10 minutes each and occurring at apparently regular 77 minute intervals. GCRT J1745−3009 was identified from archival 330 MHz (90 cm) observations taken with the Very Large Array (VLA) on 2002 September 30. A single burst from this source was subsequently detected with the Giant Metre wave Radio Telescope (GMRT) from our earlier observations done in 2003 September 28 at the same frequency. It is located about 1.25° south of the Galactic center and just outside, in projection, of the shell-type supernova remnant (SNR) G359.1−0.5 (Reich & Furst 1984). The environment of the source is discussed further in Hyman et al. (2006).

Other than a few exceptions (Melrose 2002) like coherent emission (electron cyclotron or plasma emission) from flare stars and the planets, 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 strongly suggest 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 (more details can be found in Hyman et al. 2005 and the contribution by Ray et al. in this conference).

The first two detections of GCRT J1745−3009 were based on VLA and GMRT 330 MHz observations from two different epochs, but from which similar source properties were observed. In this conference, we present a third 330 MHz serendipitous discovery of GCRT J1745−3009 in 2004 from observations carried out by two of us (S. Roy and S. Bhatnagar) as part of an unrelated project. In this detection, a single, much fainter and shorter burst is detected in contrast to the burst properties observed in 2002 and 2003. In addition, the burst is found to have a very steep spectrum, as expected for a coherent emitter, providing another important clue to understanding the nature of this enigmatic source. Details of the detection made from 2004 observations are given in Hyman et al. (2007).

Possible models for GCRT J1745−3009 include nearby objects, such as a flaring brown dwarf, flare star, or extrasolar planet, as discussed in Hyman et al. (2005, 2007).

2. Observations and Results

The observations were carried out with the GMRT on 20−21 March 2004, with antennas pointed 0.5° away from the location of GCRT J1745−3009 and consists of eleven 10 minute scans spread over six hours. The default observing mode with a total bandwidth of 16 MHz and 128 frequency channels were used in each of the two available sidebands. Typical error in amplitude calibration of sources is within 15%. Details of the calibration are given in Hyman et al. (2007).

We detect a single burst (averaged over the entire observing band) of flux density 57.9 ± 6.6 mJy from GCRT J1745−3009. This burst occured near the middle of the first scan beginning at approximately 21h 31m 00s (international astronomical time) on March 20 and lasted for about 2 minutes. The measured flux density of this burst in 2004 is much fainter than the 1 Jy peak flux density observed for the bursts in 2002 (Hyman et al. 2005) and the other burst detected in 2003 (Hyman et al. 2006). Due to the relatively short and infrequent scans in the 2004 observations, we detect only a single burst as in the 2003 epoch and cannot rule out the possibility that any other burst occured with the same 77 minute interval observed in 2002. However, we note that non-detections in additional scans made at multiples of 77 minutes after the detected 2003 burst suggest that this burst is actually an isolated one (Hyman et al. 2006).

Figure 1 shows how the burst strengths and shape has evolved from 2002 to 2004. While only the 2 minute decay portion of the 2003 burst was detected due to its coincidence with the beginning of a scan, the 2004 burst is sampled completely within one scan. It is detected only for 2 minutes compared with the 10 minute duration observed for the bursts in 2002.

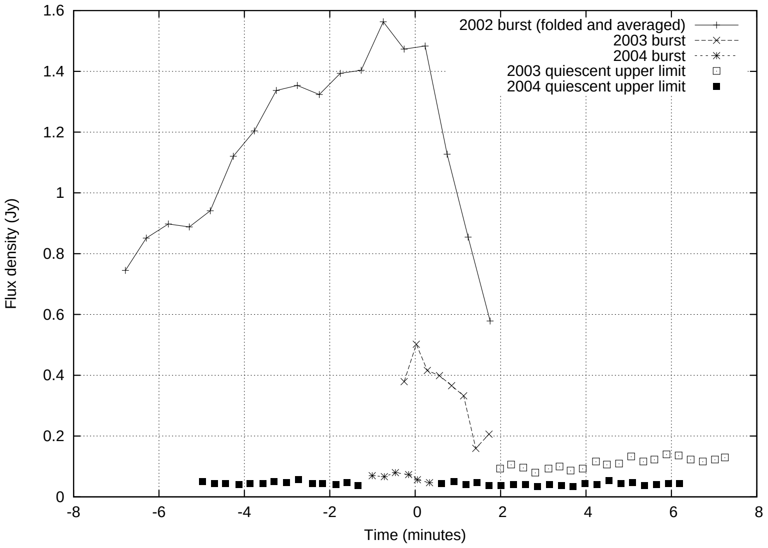

Figure 1: Bursts from the GCRT J1745−3009 in 3 epochs

GCRT J1745−3009 is unresolved during all three bursts. The resolution for the 2004 epoch is approximately $20'' \times 10''$, comparable to the 2003 epoch, about a factor of 3 higher than the 2002 epoch VLA BnC array observations. Since ionospheric refraction could cause positional errors to the sources, we have tried to rectify their positions. The L band catalogues of Galactic plane radio sources (GPRS) by Zoonematkermani et al. (1990), and Helfand et al. (1992) have much higher resolving power than the NRAO VLA sky survey (NVSS). Therefore, we compared the positions of small diameter sources with the GPRS rather than the NVSS, that was used in Hyman et al. (2007). To get accurate position of sources from GPRS to about $1''$, we used sources which have peak flux densities of $>$20 mJy.beam^{-1}, ratio of peak to total flux density $>$0.5 and positional offset from the pointing centre of $<15'$ (positional error as a function of distance from the phase centre is explained in the GPRS catalogue papers). Since GPRS has a resolution of $\sim 5''$ and noting the GMRT resolution, we consider sources to have counterparts in our 330 MHz map only if their positions differ by not more than $\sim\ 7''$ (only one source was rejected following this criteria for sources located within $15''$ of each other from the GPRS and the GMRT catalogue of sources). Twelve sources from GPRS were found to have counterparts in our 330 MHz map made from the data taken over the full observations in that day. The ionospheric refraction corrections for the source positions have a mean value of 0.08 sec in RA, and $1.1''$ in DEC in the 2004 data with an rms error the same as the mean value. These results should however be considered preliminary. A Gaussian fit to the 2004 detection yields a position of R.A.=$17^h45^m5.08^s$, DEC.=$-30^\circ09'50.9''$ (J2000.0), which differs in DEC. by $6''$ from Hyman et al. (2007). The error on this position is less than $2''$, which is 5 times more accurate than the 2002 position. The positions at all three epochs are consistent to within $\sim\ 1.5\sigma$.

Separate images were made with the data from upper (333 MHz) and lower (317 MHz) sidebands of the observations, and the flux densities are 42.1±7.2 and 72.5±9.5 mJy respectively. No significant differences are found in the shapes of the separate light curves generated for each sideband. Figure 2 shows the spectrum of GCRT J1745−3009 obtained after dividing each sideband into groups of 20 channels and imaging each group. The first and last 20 channels near the edges of each sideband were not used due to their significantly reduced sensitivity. A power law fit shows a very steep spectrum of $S \propto \nu^{-13.5\pm3.0}$ for the 2004 burst from this source. An identical analysis of the data for the nearby strong compact source G358.638−1.160 yields a spectral index of −1.5±0.5, consistent with the determination of Nord et al. (2004), which found a spectral index of −1.2±0.1 between 330 and 1400 MHz for this source.

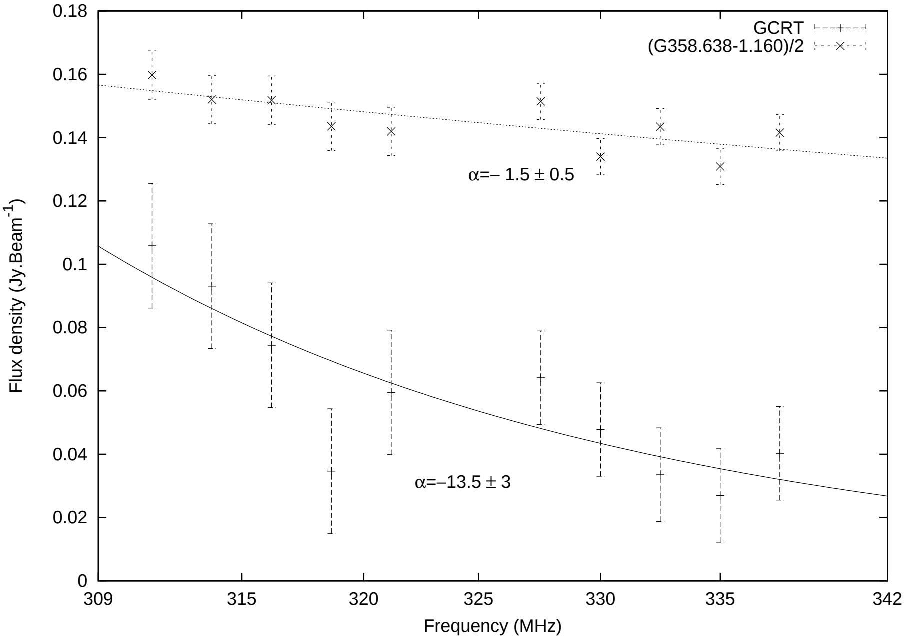

Figure 2: Spectra of GCRT J1745−3009 and the nearby strong source, G358.638−1.160 (Hyman et al. 2007). Groups of 20 adjacent channels were averaged and images made across the 16 MHz bandpass of the upper and lower sidebands. The derived spectrum for GCRT J1745−3009 is $S \propto \nu^{-13.5\pm3.0}$. In contrast is the spectrum of G358.638−1.160, which is far less steep, and is consistent with that obtained by Nord et al. (2004). The flux densities plotted for G358.638−1.160 are scaled down by a factor of 2 and the gap in the center of the spectrum is due to excision of low-sensitivity channels near the edges of the upper and lower sidebands.

A Monte Carlo simulation was carried out to assess the confidence level of the steep spectrum obtained for the 2004 detection of GCRT J1745−3009. Our simulated spectrum was based on the fitted spectral index of −13.5 normalised to the observed flux density at a particular channel. This simulation ascribes a confidence level of 99.7% (equivalent to 3 σ) to our result.

Unfortunately, a similar study of the spectrum of the 2003 GMRT detection (Hyman et al. 2006) was not possible because of large closure error with the part of the correlator dealing with the lower side band of the observations. With only the upper sideband, we were not able to detect reliable evidence of a steep spectrum. Also, the 2002 VLA observations were of much lower resolution than the 2003 and 2004 observations, and being centred on a region where sidelobe from Sgr A is seen prominently, resulting in a much higher confusion noise in the map and lack of reliable measurements of its spectral index.

3. Discussion and summary

Emission from a compact object may show variations in time and frequency due to interstellar scattering and scintillation. Therefore, we have considered whether the transient emission observed from GCRT J1745−3009 could be affected by scattering, and conclude that its spectral and temporal characteristics are unlikely to have been significantly affected by interstellar scintillation or scattering (see Hyman et al. 2007). This also argues against any pulsar based models, as the observed steep spectrum presented here is not known for pulsars (unless affected by interstellar scattering and scintillation in short timescale).

The spectrum of GCRT J1745−3009 is among the steepest ever of a source known, and a concern is the narrow frequency range of 32 MHz from which it has been determined. A related problem is that if its spectrum remains the same at lower frequencies the source would be exceedingly bright at those frequencies (e.g., 10 MJy at 80 MHz!). Hence, it would easily have been detectable in lower frequency Galactic center observations (e.g., LaRosa & Kassim 1985; Kassim et al. 1986). However, our simulations and the spectrum of G358.638−1.160 suggest that we can determine spectra reliably over this narrow bandwidth. It is likely that the short duration of a single burst and the low duty cycle of source activity during repeated bursts have adversely affected their detection. Hence, unless GCRT J1745−3009 or similar sources were both in an active state and observed for the duration of a single burst, they might have been missed in previous lower frequency observations and the upcoming low frequency arrays with dedicated resources for detecting transients will be extremely useful to detect any such strong bursts in low radio frequencies.

We note that coherent processes are often marked by steep spectra. Indeed, the spectrum of Jupiter's coherent decametric emission from the electron-cyclotron masers in its auroral regions has a spectral index of about −10 near the cutoff frequency of 40 MHz (Carr et al. 1983). Hence, if interpreted as an electron-cyclotron maser, the spectrum we find for GCRT J1745−3009 at 330 MHz is at least as steep as Jupiter's and could imply that our observations are coincidentally just below its cutoff frequency and in turn that the magnetic field in the emitting region is approximately 120 G. On the other hand, if the emission is produced by the electron-cyclotron process, we would expect to have detected very strong circular polarisation, as has been observed from flare stars at low frequencies (Bastian et al. 1990) and predicted for extrasolar giant planets (Farrell et al. 1999; Lazio et al. 2004). We have reanalysed the September 2003 GMRT observations of the GCRT data and our preliminary results show high fraction of circularly polarised emission from this source reaching several tens of percent of Stokes I during the burst; the details of which will be published elsewhere.

Since most of the known Galactic cyclotron maser operated sources are located within few tens of parsecs from us, GCRT J1745−3009 could also be located within this distance. We note that such an object will have an effective diameter of the order of Sun or much smaller than it, and this could ensure the object to have a brightness temperature exceeding the 10^{12} K, expected for the emission mechanism considered above. Lack of detection in other wavebands (e.g., null detection in 2 MASS K band image) would however indicate that the emission could not be from a star within tens of parsecs (see also the contribution by Ray et al. on sensitive infrared observations towards this source in this conference).

GCRT J1745−3009 has been detected in three significantly different observed states. Its flux density during bursts varied from 1 to 0.05 Jy, burst duration from 10 to 2 minutes, and regularly repeating vs. isolated bursts. Given the high variability in flux density detected, and the very steep spectrum of the 2004 burst, unless the emission is limited to a small frequency range, it is likely that bursts much stronger than 1 Jy will be detected at frequencies lower than 330 MHz. It is also entirely possible that the bursts are now continually decreasing in strength at all emitting frequencies.

All three detections suggest strongly that GCRT J1745−3009 has a very high brightness temperature which is possible if the source emits coherently. Although the 2004 burst is much weaker than the previous bursts it also appears to have much shorter rise and decay times as seen in Figure 1.

In summary, we have made a new serendipitous detection of GCRT J1745−3009 from March 2004 observations at GMRT close to the GC. We detect a single 50 mJy burst lasting for only 2 minutes. The burst exhibited a very steep spectrum ($\alpha = -13.5 \pm 3.0$). Its peak emission is significantly weaker than the $\sim$1 Jy peaks detected in 2002 and 2003. The duration of the bursts have reduced from 10 minutes in 2002 to 2 minutes in 2004 detection. Like the 2003 detection, the single burst detected in 2004 appears to be an isolated one, although the sparse sampling of the observation does not completely rule out the possibility that additional bursts were emitted at the same 77 minute period observed in 2002.

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