Confirmation of New Supernova Remnants near the Galactic Centre

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Abstract. We have made deep observations with the GMRT at 330 MHz of seven, yet-unclassified objects in the Molonglo Galactic Centre Survey (MGCS) in order to confirm the nature of these sources. Based on morphology and non-thermal spectral indices, five of them are now confirmed to be SNRs. This makes the number density of SNRs in the region a factor of two higher than expected from a smooth distribution of SNRs in the Galaxy.

1. Introduction
Present catalogues of supernova remnants (SNRs) are thought to be incomplete because of selection effects against detection of old, low-surface-brightness, large SNRs, as well as small-diameter, young SNRs because of the poor resolution/poor sensitivity of previous surveys [1]. This problem is further compounded in the Galactic Centre (GC) region where there is a very complex distribution of sources. Eleven SNRs were identified within $-5^\circ \leq l \leq 5^\circ$, $-2.5^\circ \leq b \leq 2.5^\circ$ region of the Galaxy before the MOST Galactic Centre survey (MGCS). The MGCS [2] at 843 MHz detected 17 candidate SNRs in the region. These detections, if confirmed, indicate that the number density of SNRs in the GC region is twice that in the rest of the Galaxy [3]. Confirming that these candidates from the MGCS are SNRs is important as it suggests a possible correlation between the dense environment in the GC region and a higher SNR density. Out of these seventeen candidates, ten have already been studied and eight have been confirmed as SNRs [4], [5] [6] and [7]. Therefore, we have observed the seven remaining candidates from the above list at 330 MHz with the Giant Metrewave Radio Telescope (GMRT). The GMRT with its high sensitivity at metre wavelength and high angular resolution ($\sim 10''$) is well suited to discovering supernova remnants. Here we present preliminary results of these observations.

2. Observations and data reductions
We have observed 3 fields G355.5+00.0, G358.6+00.9 & G358.8−00.9 at 330 MHz such that all the 7 candidate SNRs G355.4+0.7, G355.6−00.0, G358.1+01.0, G358.7+00.7, G359.1+00.9, G358.5−00.9, and G359.2-01.1 remain within the FWHM of the primary beam of one of these fields. Observations of these 3 fields were carried out on 18th and 19th of March 2004 with the default spectral line mode of the correlator with a total IF bandwidth of 32 MHz. The multiple snapshot mode of observations was used to improve uv-coverage and the total time spent on each field was $\sim$3 hours. Absolute flux density calibration was performed using...
Table 1. Observed parameters of the SNRs confirmed by these observations

| Field name (Gl±b) | RA (J2000) | Dec (J2000) | Size ('') | Type | $S_{330\text{MHz}}$ (Jy) | $S_{843\text{MHz}}$ (Jy) | $S_{8.35\text{GHz}}$ (Jy) | $S_{14.35\text{GHz}}$ (Jy) |
|------------------|------------|-------------|-----------|------|--------------------------|--------------------------|--------------------------|--------------------------|
| G355.4+00.7      | 17 31 20   | −32 25 40   | 25        | S    | 8.9±1.3                  | 67                       | 1.0                      | 1.0                      |
| G355.6−00.0      | 17 35 15   | −32 38 05   | 6×8       | S    | 3.3±0.5                  | 2.6                      | –                        | 1.0                      |
| G358.1+01.0      | 17 37 00   | −29 58 59   | 20        | PS   | 6.0±2.5                  | 27                       | 0.9                      | –                        |
| G358.5−00.9      | 17 46 10   | −30 38 56   | 17        | S    | 8.0±2.5                  | –                        | 1.0                      | –                        |
| G359.1+00.9      | 17 39 36   | −29 10 50   | 11        | S    | 4.3±1.0                  | 4.3                      | 0.9                      | –                        |

3C286. 1822−096 and 1714−252 were used as secondary calibrators. In the absence of system temperature measurements, we have performed gain calibration following [8] with automatic level control (ALC) on. After calibration and editing, a pseudo-continuum data base was made to avoid bandwidth smearing within the primary beam. Images of the fields were formed by Fourier inversion and CLEANing (using the IMAGR task of the AIPS package). The initial images were improved by phase-only self-calibration (self-cal).

3. Results

3.1. Field G355.5+00.0
A low resolution 330 MHz GMRT image of this field is shown in Fig. 1. Two candidate SNRs G355.4+00.7 & G355.6−00.0 are located in this field. Based on MOST maps, G355.4+00.7 is described in [2] as an SNR with a wispy structure, brightened northern cap and a diameter of about 25′. A bridge of emission appear to connect it to a HII region ∼30′ south of it. This candidate SNR as seen in Fig. 1 matches its above description. A higher resolution image of this field in Fig. 2 also shows a diffuse southern boundary of this object. To determine the spectral index of this and all the other candidate SNRs, we estimate the upper limit on the flux densities of these objects from either 8.35 or 14.35 GHz NRAO single dish images [9] of these fields. Total flux densities of G355.4+00.7 at different frequencies are given in Table 1. In this table, $S_{330\text{MHz}}$, $S_{843\text{MHz}}$, $S_{8.35\text{GHz}}$ and $S_{14.35\text{GHz}}$ indicates flux densities at frequencies of 330 MHz, 843 MHz, 8.35 GHz and 14.35 GHz respectively. Type code 'S' indicates shell type, and 'PS' indicates partial shell. From Table 1, spectral index $\alpha$ $(S(\nu) \propto \nu^\alpha)$ for G355.4+00.7 is estimated to be $\leq −0.6$. A non-thermal spectral index and a shell-like morphology confirms it as a SNR.

The other candidate SNR G355.6−00.0 is described in MGCS to have a shell structure of size 6′. It appears the same in Fig. 1. Based on its flux densities at different frequencies in Table 1, we determine a spectral index of $\leq −0.3$. A non-thermal spectral index and a shell-like morphology confirms it as a SNR.

3.2. Field G358.6+00.9
A 330 MHz GMRT image of this field is shown in Fig. 2. Three candidate SNRs G358.1+01.0, G358.7+00.7, and G359.1+00.9 are located in this field. G358.1+01.0 is a low-surface-brightness partial shell as seen in Fig. 2. The major feature of this object is the vertical feature running from the southern rim to the centre of the shell. The same feature is also seen in the MOST image of this object. Total flux densities of this object at different frequencies are given in Table 1, which shows its spectral index to be $\leq −0.6$. A non-thermal spectral index and a shell-like morphology confirms it as a SNR.

In MGCS, G358.7+00.7 is described as a partial shell of very weak emission with a diameter of about 17.5′. The estimated flux density is ∼2 Jy for this object at 843 MHz. However, we could not detect this object in our observations (see Fig. 2). Based on the non-detection at 330 MHz, we put a upper limit on the flux density at 330 MHz as 2 Jy, suggesting that it does not
Figure 1. 330 MHz image made with the GMRT of the field containing the source G355.5+00.0. The images in the left and the right panels are at a resolution of 3′ and 1′ respectively.

have a spectral index consistent with non-thermal emission. This source therefore, is unlikely to be a supernova remnant.

G359.1+00.9 appears to be a shell-like object in Fig. 2. Its morphology is the same in MGCS. It has a diameter of about 11′ and the pulsar PSR B1736−29 is located few arc-minutes away. Total flux densities of this object at different frequencies are given in Table 1, which shows its spectral index to be \( \leq -0.5 \). A non-thermal spectral index and a shell-like morphology confirms it as a SNR.

Figure 2. 330 MHz image made with the GMRT of the field containing the SNR G358.6+00.9.

3.3. Field G358.8−00.9
A 330 MHz GMRT image of this field is shown in Fig. 3. Two candidate SNRs G358.5−00.9 and G359.2−01.1 are located in this field. G358.5−00.9 is described as a faint barrel-like object in MGCS. We barely detect this structure in Fig. 3. It has a size of about 17′. The total flux densities of this object at different frequencies are given in Table 1, which shows its spectral index to be \( \leq -0.6 \). A non-thermal spectral index and a shell-like morphology indicates it as a SNR.

Figure 3. 330 MHz image made with the GMRT of the field containing the SNR G358.8−00.9.
SNR. However, future observations with better signal-to-noise ratio will be useful to establish its structure.

G359.2-01.1 is located adjacent to G359.0-0.9. In MGCS, it is described as an asymmetric shell-type object with rather diffuse edges, as opposed to the sharp edges normally associated with SNRs. This object shows an irregular structure in the 330 MHz GMRT image. As SNRs do not show this morphology, we rule out that this object is a SNR.

4. Discussions
Out of the 7 candidate SNRs observed, 5 have been confirmed to be SNRs from the present study. This makes the total number of supernova remnants confirmed from MGCS to be 13. With 24 SNRs within $-5^\circ \leq l \leq 5^\circ$, $-2.5^\circ \leq b \leq 2.5^\circ$ of the Galaxy, this makes the number density of SNRs in the region to be almost a factor of 2 higher than expected ($\sim$14) from a smooth distribution of SNRs in the Galaxy [3]. This indicates that these SNRs are the Galactic Centre (GC) component of the SNR distribution in the Galaxy. Massive stars are more likely to form in the GC, which ends up in supernova explosion and our results support such a scenario.

5. Conclusions
We have observed the 7 yet-unclassified candidate SNRs from the MGCS at 330 MHz with the GMRT. Our observations confirm 5 of these to be SNRs. This makes the number density of SNRs in this region almost a factor of 2 higher than expected and suggests a possible correlation of dense and turbulent GC ISM with a higher number density of SNRs.

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