The Metrewavelength Sky
ASI Conference Series, 2014, Vol. 13, pp 263 – 266
Edited by J. N. Chengalur & Y. Gupta

Discovery of a young supernova remnant G354.4+0.0

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Abstract. We have discovered a shell like structure G354.4+0.0 of size 1.6′ which shows the morphology of a shell supernova remnant. Part of the structure show polarized emission in NRAO VLA sky survey (NVSS) map. Based on 330 MHz, 1.4 GHz Giant Metrewave Radio Telescope (GMRT) observations and existing observations at higher frequencies, we conclude the partial shell structure showing synchrotron emission is embedded in an extended HII region of size $\sim 4'$. We find the spectrum of the diffuse HII region to turn over between 1.4 GHz and 330 MHz. HI absorption spectrum puts a lower limit of 5 kpc on its distance from Sun. Based on morphology, non-thermal polarized emission and size, this object is found to be one of the youngest supernova remnants discovered in the Galaxy with an estimated age of $\sim 100 - 500$ years.

Keywords : supernova remnants – radio lines: ISM – H II regions – radio continuum

1. Introduction

Galactic OB star counts, pulsar birth rates, iron abundance and estimates of supernova rates in Local Group galaxies suggest that there should be more than 1000 supernova remnants (SNRs) in our Galaxy (Tammann et al. 1994). However, only 274 are presently cataloged (Green 2009). This lack of detection is partly due to poor angular resolution of existing surveys which works against detection of small diameter SNRs (Green 1991). Supernova rate in our Galaxy is about 2.8 per century (Li et al. 2011). Hence, in the last 400 years more than ten supernova explosions have taken place in the Galaxy. However, only two of them (Cas A and G1.9+0.3) have been reported.

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There are only three SNRs of angular size $\lesssim 1.5'$ listed in the catalog of Green (2009). We had conducted observations of a few regions close to the Galactic center (GC) with the Giant Metrewave Radio Telescope (GMRT) at 330 MHz (Roy & Bhatnagar 2006). From one of these fields, a small diameter ($\sim 1.5'$) object G354.46+0.07 with partial shell morphology was identified. This field was re-observed with the GMRT at 1.4 GHz and 330 MHz. Here we describe its confirmation as a newly discovered young SNR in the Galaxy. Details of observations and data analysis procedures are described in Roy & Pal (2013). The results and discussions are presented in Sect. 2 and 3 respectively.

2. Results

The continuum map of this source made from 330 MHz data is shown in Fig. 1 (left). The size of the object G354.4+0.0 is $\sim 1.5'$ and the structure shows morphology of a partial shell. To detect any polarized emission and thereby confirm non-thermal emission, we have searched the NRAO VLA sky survey (NVSS) (Condon et al. 1998) map at the same location of the sky, and the polarization vectors from NVSS (resolution $45''$) are overlaid on Fig. 1 (left). We do detect significant (~ 7 times rms noise) polarized emission from near the two brightest parts of the shell like structure with peak polarized flux densities of $\sim 2.2 \pm 0.3$ mJy beam^{-1}. The percentage polarization of the northern and southern components are 0.6 ± 0.1 percent and 0.75 ± 0.1 percent respectively.

The 1.4 GHz continuum map of the shell without any short *uv* cut-off showed extended emission (size $\sim 4'$). To image the shell structure at a higher resolution and to measure its flux density, we resolved out any extended structure of size $> 3'$ using a short *uv* cut-off of 1000 λ to the data during imaging. We also avoided the frequency channels having HI absorption during imaging. The resultant image is shown in Fig. 1 (right). As can be seen from Fig. 1, the morphology of the source is of shell type. The mean angular diameter of the shell is found to be $\sim 94''$ or about $1.6'$ with an rms error of $\sim 5''$. To measure flux density at 330 MHz and spectral index of the shell between 330 MHz and 1.4 GHz, this object was further imaged from 330 MHz data with a short *uv* cut-off of 1000 λ (same as at 1.4 GHz). Measured flux densities are 0.7 ± 0.1 and 0.9 ± 0.1 Jy at 1.4 GHz and 330 MHz respectively. The observed spectral index between 1.4 GHz and 330 MHz is -0.2 ± 0.1, that is quite flat and unexpected for a shell type supernova remnant.

2.1 Diffuse emission and spectral index of the shell

As discussed in detail in Roy & Pal (2013), the diffuse emission around the shell was found to have a size $\sim 4'$. It is found to be an HII region with emission measure and temperature of $1.7 \pm 0.09 \times 10^4$ cm^{-6} pc and 2300 ± 350 K respectively. Assuming the source to be spherical and located at the distance of the GC (8 kpc), the electron

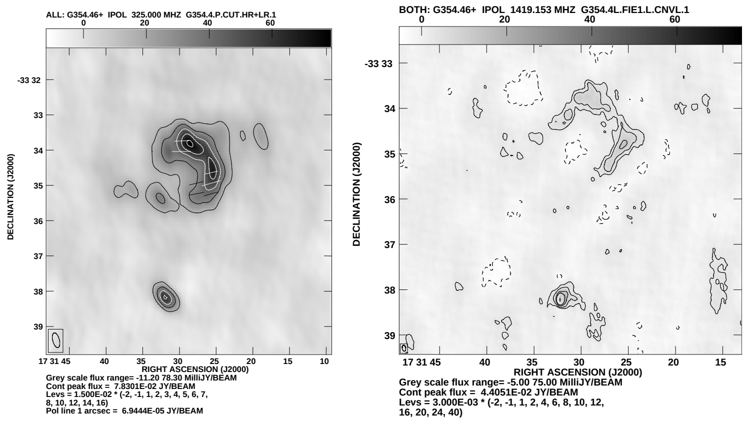

Figure 1. 330 MHz continuum map (Gray scale and contour) of the source G354.4+0.0 with a resolution of $26'' \times 11''$ with an rms noise of 3 mJy beam^{-1}. Superimposed are the polarization vectors from 1.4 GHz NVSS map (resolution $45''$). A polarized flux density of 1.0 mJy corresponds to $15''$ of the polarization vectors. (left). In right, 1.4 GHz high resolution continuum map of the source G354.4+0.0. The resolution is $8'' \times 4''.4$, and rms is 1.5 mJy beam^{-1}.

density in the diffuse emitting region is estimated to be 44±1 cm^{-3}. This gas will have a free-free absorption depth (τ) of about 0.4 at 330 MHz. Considering the location of the shell to be (i) inside the HII region, (ii) behind or (iii) in front the HII region do not change the above estimated parameters of the HII region significantly. After correcting for the Galactic background emission and free-free absorption by the HII region, the spectral index of the shell like emission is found to be −0.5, −0.6 and −0.36 respectively, which is consistent with known spectrum observed for shell type Galactic supernova remnants (Green 2009). Polarized emission along with inferred steep spectrum shows synchrotron emission from the shell. Therefore, based on the shell type morphology, and synchrotron emission, the source G354.4+0.0 is classified as a newly discovered SNR.

2.2 Distance from HI absorption

Discussed in detail in Roy & Pal (2013), the HI spectrum towards the shell of G354.4+0.0 show strong absorption near 0 km s^{-1} that is believed to be caused by local gas rotating almost perpendicular to our line of sight seen near the direction of the GC. HI absorptions are also seen near −40 and −80 km s^{-1}. The line of sight velocity of the 3 kpc arm at the longitude of this SNR is about −80 km s^{-1} (Cohen & Davies 1976). Presence of absorption by this feature shows the distance of G354.4+0.0 to be at least 5 kpc from Sun. Compared to HI absorption spectrum of a small diameter Galactic HII region in the field, the spectrum of the shell shows a significantly narrow absorption profile between +15 to −40 km s^{-1}, suggesting that G354.4+0.0 is located significantly closer than the compact HII region. It is likely that the HII region lies behind the GC, and the SNR is located at a distance of 5 kpc to the GC distance of 8 kpc from Sun.

3. Discussions

3.1 Evolutionary phase of the SNR and its age

If the SNR is located outside the HII region, it will be expanding in typical ISM. Given the assumed distance and the angular size of the remnant, it will be in the free expansion stage. Hence, the structure of the shock front and the corresponding shock acceleration of energetic particles would not depend significantly on the structure of the ISM in which it is expanding. Therefore, the synchrotron emission from the shell should roughly be circularly symmetric. However, the shell appears fragmented towards East, and only some parts of it are seen in Fig. 1. This is possible if the shell is no longer in the free expansion stage. Given the angular size and the distance to the SNR (~8 kpc), its linear diameter is about 3.7 pc. If it is within the dense HII region, given its electron density, the SNR has swept up about 20 $M_{\odot}$ of material from the surrounding ISM during its expansion. Hence, we prefer a scenario where the shell is expanding in the HII region (diffuse emission of $\sim 4'$). Kinetic energy of ejecta from a supernova explosion lies in the range of $\sim 10^{51} - 10^{52}$ ergs (Woosley & Bloom 2006). Depending on the type of explosion, the ejecta mass varies from $\sim 0.4\ M_{\odot}$ (type Ia) (Stritzinger et al. 2006) to $\sim 20\ M_{\odot}$ (core collapse) (Taddia et al. 2012). As the mass of the swept up material in this case is comparable to or more than the typical ejected mass from supernova explosion, there will be appreciable slowdown of its expansion. This phase of expansion is known as the adiabatic phase (Weiler & Sramek 1988), and given the morphology discussed above, the SNR is likely expanding in a denser than ISM environment. Assuming energy conservation between the supernova ejecta and the swept up material and given the range of initial ejecta mass, the age of the SNR is estimated from numerical integration of $\frac{dr}{v(r)}$ considering its slow down due to expansion in the dense environment. The range of age possible for this remnant is found to be ~100−500 years.

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