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Radio study of the Galactic Centre Environment

Subhashis Roy

National Centre for Radio Astrophysics (TIFR), Pune University Campus, Post Bag No. 3, Ganeshkhind, Pune 411007, India

Abstract. The central region of our milky way Galaxy still eludes a comprehensive understanding. With new observations, however, we are being able to know many of the observable properties of the sources, which allow us to better understand the actual physical processes operating in the region. Here, we discuss about the present status and the new observations in the radio wavelengths to constrain the source properties in this complex region.

1. Introduction

The central kiloparsec region of our Galaxy harbours a variety of unique and interesting phenomena which are yet to be properly understood. The gaseous component of the Interstellar Medium (ISM) in the region is characterised by high densities, large velocity dispersions, high temperatures and apparently strong magnetic fields. Most of the gas is concentrated in molecular clouds, with typical densities of ~ 10^4 molecules/cm^3, temperatures ~ 70 K, velocity dispersions ~ 10 km s^{-1} and possibly a strong magnetic field ~ 1 mG. Most of these quantities are about two orders of magnitude larger than that found in the disk of our Galaxy. This region is also believed to harbour a super-massive black hole at the centre of the Galaxy and have unique highly polarized linear filamentary structures (Yusef-Zadeh et al. 1984) which are thought to trace a strong, highly ordered magnetic field. The high density in the region, possibly due to a large gradient in the gravitational force, leads to the formation of massive, high luminosity stars with short life-spans. These stars end their lives in supernova explosions and many of the remnants can be seen at radio wavelengths.

Due to the high extinction at optical wavelengths, the Galactic Centre (GC) region has been investigated largely in the radio, infrared and x-ray wavelengths. For a detailed view of the continuum radio sources located in the region, we refer to Fig. 2 of Larosa et al. (2000), where a wide field schematic diagram of the Galactic Centre region has been presented.

*e-mail : roy@ncra.tifr.res.in

Due to the complex source distribution, however, a good detailed model of the region is still lacking and new observations are required to constrain the underlying physical processes. Here we discuss new observations which have been carried out recently at radio wavelengths. We will discuss about (i) the number density of supernova remnants (SNRs) in the region, (ii) new results from high resolution observation of the GC at 610 MHz, (iii) HI absorption line study and constraining the distances to the GC filamentary structures and (iv) study of the GC magnetic field.

2. Number density of supernova remnants in the GC region

Present catalogues of SNRs are thought to be incomplete due to different sensitivities and angular resolutions of various telescopes used for surveys. This problem is further compounded in the GC region, where, there is a very complex distribution of sources. 13 SNRs had been identified within $-5^\circ \le l \le 5^\circ, -2.5^\circ \le b \le 2.5^\circ$ region of the Galaxy before the MOST Galactic Centre Survey (MGCS). The MGCS at 843 MHz (Gray 1994b) detected another 17 candidate SNRs in the region. These detections, if confirmed, indicate the number density of SNRs in the GC region to be twice than that in the rest of the Galaxy (Gray 1994a). Confirming the SNRs from the MGCS is important as it suggests a possible correlation between the dense environment in the GC region and higher SNR density.

SNRs in the radio wavelengths are typically identified by their morphology and nonthermal spectrum therefore, observations at other wavebands are required to establish the true nature of the candidate SNRs detected during the MGCS. The Giant Metrewave Radio-Telescope (GMRT) (Swarup et al. 1991) with its large collecting area and high resolution at low radio frequencies is an ideal instrument for such studies and systematic observations to establish the true nature of the candidate SNRs are in progress. Out of the 17 candidate SNRs identified by Gray, eight namely, G3.1 – 0.6, G356.3 – 0.3, G356.6 + 0.1, G357.1 – 0.2 (Roy & Rao 2002), G001.4 – 0.1, G003.8 + 0.3, G356.3 – 1.5 and G004.2 + 0.0 (Bhatnagar 2001) have been observed with the GMRT at 330 MHz. Among the candidate SNRs observed, G356.3 – 0.3 and G356.6 + 0.1 have been suggested to be part of a single SNR (Fig. 1) (Roy & Rao 2002), whereas, G004.2 + 0.0 appears to be a thermal source (Bhatnagar 2001). The rest of the candidates studied with the GMRT are indicated to be SNRs. Two more objects from the MGCS, G3.7 – 0.2 (Gaensler 1998) and G0.33 + 0.0 (Kassim & Frail 1996) also have been confirmed to be SNRs. Clearly, more observations are required to establish the true nature of the remaining 7 candidate SNRs from the list of Gray (1994). However, as discussed above, new observations have already indicated 8 out of 10 candidates to be SNRs and it appears quite likely that most of the remaining candidates will turn out to be SNRs and the correlation of higher number density of SNRs with dense GC environment is likely to be established in the near future.

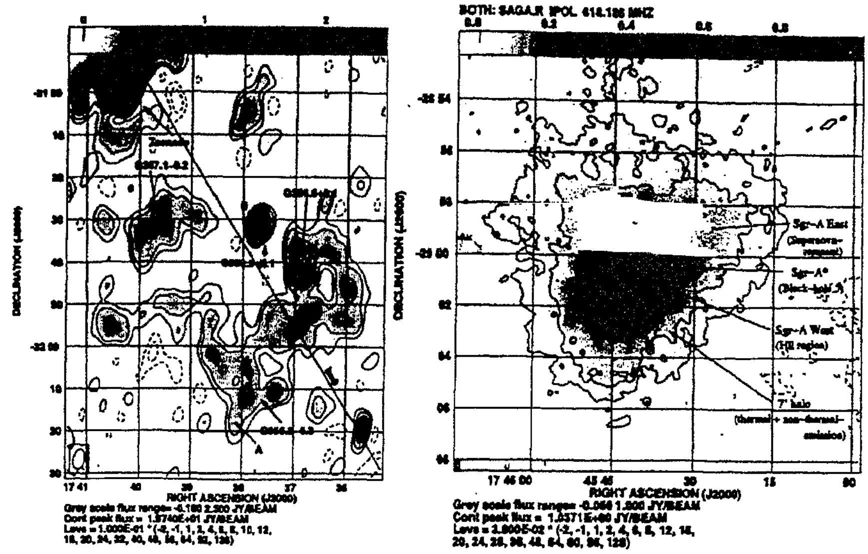

Figure 1. GMRT continuum map of the field containing the candidate SNRs G356.3 – 0.3 and G356.6 + 0.1 at 330 MHz (Roy & Rao 2002) (left). The continuum map of the central 15′ region of the Galaxy at 610 MHz (right).

3. High resolution observation of the Galactic centre at 610 MHz

This region has been observed previously in high resolution by the Very Large Array (VLA) at 330 MHz (Anantharamaiah et al. 1991, LaRosa et al. 2000), 1.4 GHz and 4.8 GHz, and several sources have been identified within the central half a degree region of the Galaxy. At the very centre of the Galaxy is the $2.6 \times 10^6\ M_\odot$ black hole candidate, which coincides with a point source in radio-emission known as Sgr-A*. Along this point source in projection is a dense HII region known as the Sgr-A West. Near Sgr-A West, is seen the supernova remnant Sgr-A East. In this region, a 7′ halo which is thought to be a mixture of thermal and non-thermal emission can also be identified. Though, the properties of some of the sources described above can be explained on the basis of the existing observations, the properties of a few sources are not well understood and warrant further observations.

Therefore, observations of this region have been carried out with the GMRT at 610 MHz (Roy & Rao 2002b). The 610 MHz map of the central 15′ region is shown in Fig. 1. The interesting preliminary results from the 610 MHz observations are: (a) Sgr-A* ($2.6 \times 10^6\ M_\odot$ black hole candidate) is visible in the 610 MHz map, which is the lowest frequency detection of this object. (b) Lack of thermal free-free absorption towards this object indicates that Sgr-A* (seen along the Sgr-A West HII region in projection) is located in front of the Sgr-A West HII region. The Sgr-A West region is found to have an optical depth of more than unity from the 610 MHz map . (c) A comparison of Sgr-A* flux at 610 MHz and the upper limit estimated from VLA 330 MHz map indicate that if this source is not variable, its spectral index between 610 MHz and 330 MHz is inverted and is more than 2.9 (in case of synchrotron self absorption, the spectral index is 2.5).

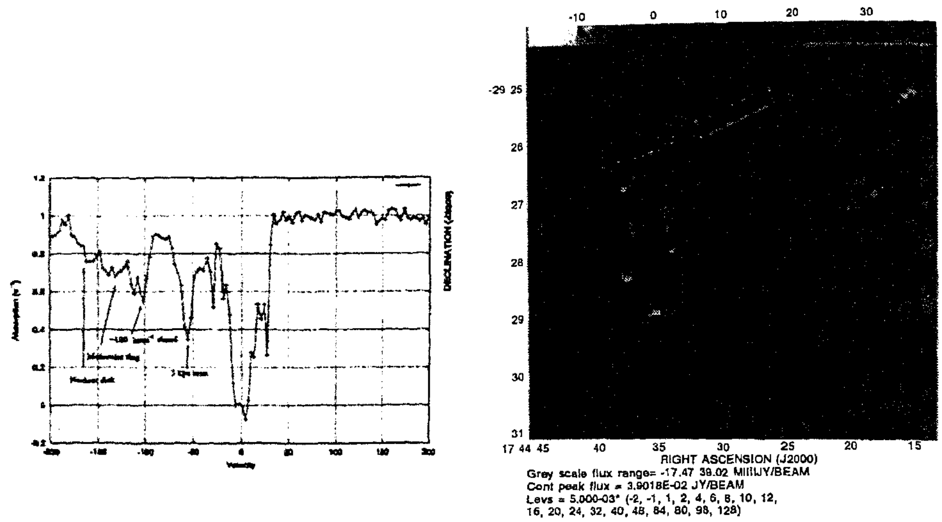

Figure 2. The left side plot is the HI absorption spectrum towards central bright part (marked 'A' in the continuum image of the filament) of the Sgr C filament shown on right. The bandwidth is 2 MHz. RMS noise in the spectrum is 0.034. (Roy 2002a).

4. H I absorption line study of the GC filamentary structures

The long narrow nonthermal filamentary structures observed within the central ~2° region (length ~10 pc, width < 1 pc) of the Galaxy are found to be highly polarized at high radio-frequencies and are believed to trace a strong (B ~ 1 mG) highly ordered magnetic field in the central few hundred pc region of the Galaxy (Morris & Serabyn 1996, and the references therein). While these structures are located close to the Galactic Centre (GC) in the sky, it needs to be established that they are really located in the GC region and are not a superposition of foreground or background object. While H I absorption towards the GC 'Radio-arc' (Lasenby et al. 1989) and the 'Snake' (Uchida & Guesten 1995) have indicated that they are physically located close to the GC, the distances to the remaining 6 filaments are not observationally constrained. Therefore, GMRT observations have been carried out (Roy 2002a) to measure H I absorption towards three non-thermal filaments Sgr C, G359.54 + 0.18 and G359.79 + 0.17.

Since the NTFs are located close to '$l=0^{\circ}$', Galactic rotation cannot be used to predict their distances. Hence, to constrain their distances, H I absorption by anomalous velocity H I features, whose velocities and distances from the GC are already known (Cohen 1979) are used. Fig. 2 shows the absorption spectra towards the central bright portion of the Sgr C filament (marked 'A' in the continuum map), the details of which are given in Roy (2002a). Using H I absorption by the various known H I features, it is shown in Roy (2002a) that the Sgr C filament is located within a few hundred pc from the GC. The H I absorption study also indicates the distances to the G359.54 + 0.18 and G359.79 + 0.17 to be between 5.5 and 10.5 kpc from the Sun.

5. Largescale magnetic field in the GC region

Magnetic field can play an important role in the central region of a galaxy. However, except the central 200 pc region of our Galaxy, the magnetic field in the rest of the inner 5 kpc region is not observationally constrained. Even the magnetic field within the central 200 pc have been determined mainly towards some peculiar objects like the Nonthermal Filaments. If the NTFs themselves are mainfestations of a favourable local environment, inferences drawn from them for the magnetic field in the Galactic Centre can be misleading. Therefore, observations have been carried out to constrain the line-of-sight magnetic field of the central 2 kpc region ($354^{\circ} \leq l \leq 6^{\circ}$, $-1.8^{\circ} \leq b \leq 1.8^{\circ}$) by estimating the Faraday Rotation Measure (RM) towards a large number of suspected background extragalactic sources (Roy et al. 2002c). Since the RM towards these sources are suspected to be quite high (~ 1000 rad m^{-2}), these observations have been carried out in higher radio frequency bands of 5 and 8 GHz with the Australia Telescope Compact Array (ATCA) and the Very Large Array (VLA).

Out of 65 sources observed, polarized emission have been detected from 42 sources. The RM towards most of these sources are found to be positive and large (~ 500 rad m^{-2}). Further, the RM do not show any change of sign from positive to negative Galactic longitude, which was expected for an axisymmetric model of the magnetic field in the GC region. Also, the RM for the observed sources do not appear to show any systematic variation as a function of the Galactic longitude. Using the rms fluctuations of the RM as a function of angular distance (RM structure function) computed from various sources, the upper and a lower limit on the scale-size of the Faraday Screen over which it remains coherent is about 2 pc and 30 pc respectively. The RM, which remains positive for $-6^{\circ} < l < 6^{\circ}$, combined with the coherence length scale of the Faraday screen indicates that the total magnetic field in the region is a combination of two different types of magnetic fields which vary in their coherent length scale and in strength. One possible preliminary model to explain the above results could be the following :

There is a largescale field which remains coherent over several degrees. Along with this field, there is a smallscale field which is much stronger, but changes orientation frequently

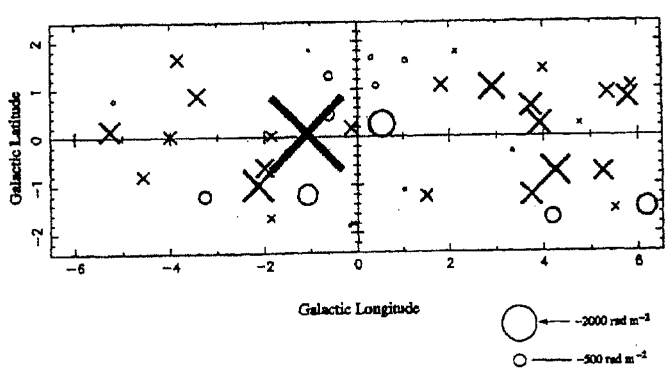

Figure 3. The plot of the RM towards various sources as function of the Galactic longitude and latitude. The 'cross' symbol indicates '+ve' RM and the circle '–ve', where the symbol size increases linearly with the absolute value of the RM.

along our line of sight. The typical line of sight averaged smallscale field appears to have a field strength ($|B_{avg}|$) which is similar in magnitude to the largescale field.

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