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Studies of the ISM using the GMRT

Subhashish Roy*
NCRA-TIFR, Pune 411 007, India

Abstract. We summarise some of the works that have been carried out on the interstellar medium (ISM) with the Giant Metrewave Radio Telescope (GMRT) in the last few years. These include, (i) determination of the fraction of neutral hydrogen in unstable phase, (ii) turbulence in the ISM investigated through radio continuum and neutral hydrogen, (iii) turbulence in the ionised ISM giving rise to variations in pulsar dispersion measures, (iv) probing the denser ISM near the Galactic centre, (v) studies of HII regions and (vi) confirmation of new supernova remnants near the Galactic centre.

1. Introduction

Interstellar medium has multiple components, which include the cold and the warm neutral medium and the warm and the hot ionised medium (McKee & Ostriker, 1977). Among these components, the cold/warm neutral medium and the warm ionised component could be observed through radio frequency observations. The Giant metrewave radio telescope (GMRT) was used to study the cold and the warm phases of the neutral component through HI absorption, which is presented in Section 2. The warm ionised phase was studied through pulsar dispersion measures and observations of HII regions, which are presented in Section 3. Supernova remnants (SNRs) serve as a link between the stars and the ISM, and a higher number density of stars in the Galactic centre region could give rise to a larger number density of SNRs in the region, a study of which has been presented in Section 4.

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

2. Multiphase neutral ISM

It is believed that in a multiphase ISM, the cold dense neutral gas is embedded in either neutral or ionised low density warm gas, which in turn is embedded in a much lower density hot ionised gas. The typical temperatures are $\sim$100 K, $\sim 10^4$ K and $\sim 10^6$ K for the cold neutral medium (CNM), warm neutral medium (WNM), warm ionised medium (WIM) and hot ionised medium (HIM) respectively. All these different phases of the ISM in the Galaxy are believed to be in rough thermal pressure equilibrium (Field et al. 1969, Wolfire et al. 2003). It can be shown that the neutral hydrogen gas can be in pressure equilibrium only if the temperature lies within $\sim 40 - 200$ K for the CNM, and within $\sim 5000 - 8000$ K for the WNM (Wolfire et al. 1995). However, despite many observational studies, the details of the above model of the ISM, like the relative proportion of gas in different phases, attainment of equilibrium temperature for WNM, type of turbulence (density structures and velocity fluctuations) and the size-scales involved remain unclear.

2.1 Temperature of the neutral ISM

The Arecibo millennium HI survey data (Heiles & Troland 2003a, 2003b) produced absorption spectra towards 79 background radio sources, which were corrected for emission. After correcting for turbulence broadening of line-widths, it showed a large fraction of HI is in the unstable phase. However, these results were based on single dish observations, which are known to be susceptible to stray radiation entering via the side-lobes of the telescope and inaccurate subtraction of emission in the beam. Since interferometric observations are free of these problems, GMRT and the Westerbrook synthesis radio telescope (WSRT) observations of HI absorption were carried out by Roy (2009a) towards a large number of compact radio continuum sources. The resultant optical depth spectra were modelled as a combination of multiple Gaussian components. The best fit models for the absorption towards these sources consist of many narrow components due to CNM and a significant number of wide components which are interpreted to arise from WNM. Out of 175 components towards 18 line of sights, $\sim$75% of the components are due to CNM, $\sim$22% due to WNM in unstable phase, and $\sim$3% are due to WNM in stable phase. After applying corrections for line-broadening due to turbulence, column density fractions due to CNM, WNM in unstable phase and WNM in stable phase are 49 ± 07, 51 ± 07 and zero respectively (Roy 2009a). No detection of WNM in stable phase is quiet striking and could be due to sensitivity limitation of the observations. Considering 3σ upper limit on N(HI) of 2×10^{20} cm^{-2} and typical line of sight column density of $\sim 10^{21}$ cm^{-2} of HI, $<$20% of the total gas in the stable WNM phase could be missed. The above result confirms that a large fraction of the neutral medium is indeed in the unstable phase.

2.2 Magnetohydrodynamic turbulence in the ISM

Angular power spectrum of the synchrotron intensity fluctuations towards the shell type supernova remnant Cas A has been measured at 20 cm using the GMRT. Power spectrum of intensity fluctuations follow a power law with index -3.24 ± 0.03 (Roy et al., 2009b). This is consistent with the magnetohydrodynamic turbulence in the synchrotron emitting plasma. There is a break in the power spectrum and the power law index changes from -3.2 to -2.2 at large angular scale. The transition occurs at an angular scale about the size of the thickness of the shell of the Cas A. This is interpreted as a transition from three to two dimensional turbulence.

2.3 HI opacity fluctuation towards Cas A

Opacity fluctuation towards Cas A using the 21 cm HI line was studied by Roy (2009a) using a method which allows estimation of this quantity directly from interferometry data, rather than making images. The resultant power spectrum could be modelled with a power law with index of $\sim -2.86 \pm 0.1$ (for a linear scale range of $0.07-3.6$ pc). This is consistent with earlier results (Deshpande et al. 2000). However, it is significantly shallower than the Kolmogorov spectrum (power law index $-11/3$) for incompressible turbulent medium.

3. Study of warm ionised medium

3.1 Pulsar dispersion measure

Pulsar dispersion measures (DMs) were determined by Ahuja et al. (2005, 2006) from simultaneous dual frequency observations using the GMRT for 12 pulsars over a period of more than a year with observations about once every two weeks. This method could provide DMs from each epoch of observation with an accuracy of $\sim$1 part in 10^4. Time series of the DMs showed significant variations over time scales of weeks to months for most of the pulsars. It appears that constancy of DMs to better than 1 part in 10^3 cannot be taken for granted. Variations in DMs are generally associated with the density fluctuation in the line of sight medium due to turbulence in the ISM. For PSR B2217+47, a large-scale DM gradient was observed for over a year, which is modelled due to a $\sim$AU sized blob of enhanced electron density along the line of sight.

3.2 Nature of the scattering screen towards the Galactic Centre

From observations of the Galactic centre (GC) at 255 and 154 MHz by the GMRT, Roy & Rao (2008) detected 26 small diameter background sources at 255 MHz, which are believed to be mostly extragalactic in nature. Their scattering diameters determined from multifrequency observations were found to be anti-correlated with angular distance from the GC. The angular scale over which this decrease in scattering diameter is observed is $\sim$1 degree. This for the first time directly shows scatter broadening going down as a function of angular distance from the GC for a statistically large sample of extragalactic sources.

3.3 Studies of H II regions

Several studies of massive star forming regions have been carried out with the GMRT. These include observations of massive star forming regions IRAS 06055+2039 (Tej et al. 2006), IRAS 19111+1048 and IRAS 19110+1045 (Vig et al. 2006), IRAS 21413+5443 and IRAS 21407+5441 (Anandarao et al. 2008) and ultracompact HII region IRAS 20178+4046 (Tej et al. 2007). Radio frequency observations helped in determining the spectral type of the star responsible for photoionisation, and also in determining the physical properties of the HII regions.

4. Density of supernova remnants near the Galactic centre

Roy & Bhatnagar (2006) observed 7 candidate SNRs at 330 MHz with the GMRT, which was first identified in the Molonglo Galactic centre survey (MGCS). Five of the candidates have been confirmed as SNRs. They had earlier confirmed 6 more SNRs in the region. With 13 more SNRs, the number density of SNRs in the region is found to be $\sim$2 times higher than the rest of the Galaxy. Dense and turbulent environment is expected to give rise to a larger number of stars in the region which ended in supernova explosions, and this is the first evidence in this regard.

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