Recent results at 150 MHz from the GMRT

Dharam Vir Lal, C.H. Ishwara-Chandra and A. Pramesh Rao

National Centre for Radio Astrophysics, Pune University Campus, Pune 411 007, India.
DVL: dharam@ncra.tifr.res.in, CHI: ishwar@ncra.tifr.res.in and APR: pramesh@ncra.tifr.res.in

Abstract

The Giant Metrewave Radio Telescope (GMRT) is a synthesis instrument operating at frequencies 1.4 GHz and below. The Frequency bands between 1400 and 240 MHz were in use for astronomical observations since 1999. The 150 MHz band of the GMRT was severely affected due to radio frequency interference (RFI) from Television signals and locally generated RFI. It had been in the test stage and there have been several upgrades to improve the performance of the 150 MHz band.

A $\sim$12 deg^2 field at the North celestial pole, has been imaged at 150 MHz with the GMRT, with an angular resolution of $\sim$22 arcsec and sensitivity of 3–5 mJy. The detected sources are compared with those in existing surveys, the NRAO VLA sky survey (NVSS), the VLA low-frequency sky survey (VLSS), the Westerbork northern sky survey (WENSS), etc., to establish the credibility and the reliability of the GMRT images. We present the preliminary results of the GMRT observations at this frequency for a few galactic and extra-galactic fields of astronomical interests, *e.g.* (i) Upsilon Andromedae, (ii) Hubble Deep Field (North) and (iii) Coma cluster.

The field of Upsilon Andromedae is the only extra-solar planet system for which three planets are known and this field is imaged at 151 MHz as a part of larger programme to search for extra-solar planets with the GMRT. The source is not detected, however there are several background sources, most of them being point sources. Both, the HDF(N) and the Coma cluster field have been studied extensively in all parts of the electromagnetic spectrum. We would supplement our new 150 MHz results for these fields. In addition, we would put constraints on the existence of the Coma radio halo and the formation models.

Our prime motivation to study these fields, has been to detect faint radio emission at very low frequencies, which are due to low energy electrons. Here, we present the images, scientific results that we have obtained and discuss the issues like sensitivity, dynamic range, etc. from the radio images obtained at this band.

1 INTRODUCTION

Radio observations allow us to probe the nuclear regions of galaxies which are obscured by gas and dust in other wavebands. On morphological grounds, high sensitive and high resolution radio observations can distinguish between emission that is driven by star-formation and that is driven by Active Galactic Nuclei (AGN). Since radio observations are sensitive to a wide range of redshifts and to a mix of starburst and AGN activity, it provide complimentary information on the population of distant galaxies. Furthermore, distant luminous radio galaxies and diffuse cluster radio emission, the sources with steep spectrum ($S_\nu \propto \nu^\alpha$, $\alpha < -0.7$) are the best candidates for low frequency observations. Such sources pinpoint the most distant radio galaxies and have also been identified to be amongst the most massive and oldest galaxies in the early universe. Similarly, on the other hand, extremely intense radio emission can be generated in the planets if magnetic field and energetic electrons (keV) are present. Such radio emissions are seen in some of the planets in our Solar System (Jupiter, Saturn, Uranus, Neptune and Earth), however such emission is not so common in stars.

We report here the results from our test observations, study of the sources found in a 12 deg^2 field. These represent amongst the most sensitive 150 MHz observations yet made and together with their high angular resolution, these data allow, for the first time, detailed imaging of features in a galactic and a few extra-galactic fields.

2 OBSERVATIONS

The GMRT has a hybrid configuration (Swarup et al. 1991) with 14 of its 30 antennas located in a central compact array with size $\sim$1.1 km and the remaining antennas distributed in a roughly ‘Y’ shaped configuration, giving a maximum baseline length of $\sim$25 km. The hybrid configuration gives reasonably good sensitivity for both compact and extended sources. The 150 MHz band of GMRT has been in the test stage and there have been several upgrades to improve the performance, Following several test astronomical observations, it has now has been released for observations to the scientific community. We made full-synthesis observations of several fields of astronomical interests in this band, in the standard spectral line mode with a spectral resolution of 125 kHz. The visibility data were converted to FITS and analysed using standard AIPS. The flux density calibrator 3C 147/3C 48 was observed in the end for each source as an amplitude calibrator and also to estimate and correct for the bandpass shape. We used the flux density scale which is an extension of the Baars et al. (1977) scale to low frequencies, using the coefficients in AIPS task 'SETJY'. Sources 2350+646, 3C 48, 3C 286 and 1021+219/3C 295 were used as the phase calibrator for North celestial pole, Upsilon Andromedae, Hubble Deep Field (North) (HDF(N)) and Coma cluster, respectively and were observed once every 35 min. The error in the estimated flux density, both due to calibration and systematic, is $\lesssim$ 10 %. The data suffered from scintillations and intermittent RFI. In addition to normal editing of the data, the scintillation-affected data and channels affected due to RFI were identified and edited, after which the central channels were averaged using AIPS task 'SPLAT'. To avoid bandwidth smearing, $\sim$5.5 MHz of clean band was reduced to 8 channels of $\lesssim$0.7 MHz in each case.

While imaging, 150 to 175 facets, spread across $\sim$3.5°×3.5° field were used to map each of these fields using AIPS task 'IMAGR'. We used 'uniform' weighting and the 3−D option for W term correction throughout our analysis. The presence of a large number of point sources in the field allowed us to do phase self-calibration to improve the image. After 2–3 rounds of phase self-calibration, a final self-calibration of both amplitude and phase was made to get the final image. At each round of self-calibration, the image and the visibilities were compared to check for the improvement in the source model. The final maps were combined using AIPS task 'FLATN'.

The full synthesis radio images shown in Figs. 1 have nearly complete UV coverage, an angular resolution $\sim$22 arcsec, the rms noise $\lesssim$3.0 mJy beam^{-1} and the dynamic ranges in the maps are in the range, $\sim$10 to $\sim$1000.

3 OUR FIELDS

3.1 North Celestial Pole

The North celestial pole has been observed at 150 MHz by GMRT on a number of occassions, as part of testing the performance of the system. The map shown in Fig 1 (Upper left panel) is from the full synthesis observations of 5 Jun 2005 and has not been corrected for the primary beam. The North pole data were edited for interefernce, channel averaged to give 10 channels of 0.5 MHz each and self calibrated to give the image. The restoring beam in the image is 30 × 20 arcsec^2 at a postion angle of 60 deg.

The dominant feature of the map, in addition to the compact sources, most of which are seen in the WENSS map, is the circular ring like features centred on the North pole. This feature is due to the terrestrial interference (mostly broad band and is seen at short spacings), which mimics as an uncalibrated feature at the North pole. The rms in the image in the central region is $\sim$8 mJy beam^{-1} and is less at regions away from the centre. The detected field sources compare well with those in the existing surveys and we confirm that there are no artifacts.

3.2 Upsilon Andromedae

We have observed the extra solar planet system Upsilon Andromedae (Butler et al. 1999) at 151 MHz with GMRT as part of larger programme to search for radio emissions from extrasolar planets (Winterhalter et al. 2005). The emission is extremely sporadic and exhibits variability on time scales of milli seconds to hours. The emission is also highly polarised (*e.g.*, Bastian et al. 2000). Radio emission is a *direct* detection of the planets as compared to optical methods. Moreover, it provides an understanding of the basic nature of magnetic field of the planet and this is the only method to study magnetic field of the planet. The presence of magnetic field on the surface of the planet, may be a necessary condition required for most forms of life to exist.

Here, we present the GMRT observations of extrasolar planet system Upsilon Andromedae at 151 MHz observed on 17 Jul 2004. The Upsilon Andromedae was not detected (Fig 1, Upper right panel) and we put a 3 σ upper limit of 9 mJy. Several hundreds of background sources were detected, most of them are point sources. Due to the limitation of the primary beam correction, we have considered only the central 1 deg^2 area for comparing the sources detected in our image with the available data in the literature at other radio frequencies. We have measured the spectral index between 151 and 1400 MHz (NVSS, Condon et al. 1998) for 14 point sources detected in this area. While the major fraction of the sources exhibit spectral index close to 0.6, one source was found to have flat spectra and three sources with steeper spectra. There is also a weak trend for the faint sources at 151 MHz to have relatively flatter spectra. It will be useful to further follow up these sources with flat and steep spectra and they need to be investigated with more future measurements.

3.3 Hubble Deep Field (North)

We have mapped the HDF(N) and the surrounding Hubble flanking fields region using the GMRT on 16 Feb 2004 and we report the initial results from the first observations at 150 MHz.

Using our and earlier astrometrically aligned images, we attempted to make identifications of the 371 radio sources (Muxlow et al. 2004 and Richards et al. 1998) obtained within the 1.4 GHz VLA images. Within a 40 arcmin^2 region centered on the HDF(N) we have confirm detection for earlier detected (Richards et al. 1998) one source at 150 GHz above 5 σ (Fig 1, Lower left panel). This bright object in our map is almost certainly J123725+621128, which is a steep spectrum ($\alpha_{1.4}^{8.4} = -1.35$) wide-angled tail (WAT) radio source (Tom Muxlow, private communication) and the optical host is an elliptical galaxy. In addition, we probably detect new sources as well. We are in the process of doing a detailed comparison with other catalogues.

3.4 Coma cluster of galaxies (Abell 1656)

The gaseous medium as a probe in galaxy clusters through the study of the radio emission of "halo sources" reveals important information on physical processes in clusters. To understand the origin of relativistic particles and the associated magnetic field, complementary information about the hot, nonrelativistic gas is required from data at other wavebands. Therefore, to understand the global picture, of the particle acceleration and its diffusion in the intracluster medium, the relation to the galaxy dynamics, the role played by the magnetic fields and the global evolution of galaxy cluster, the data at every band needs to be combined. Unfortunately, the low surface brightness of cluster radio halos makes it difficult to image them accurately. Added to this, is the challenge to distinguish true diffusion emission from a blend of weak, discrete sources, at lower resolution, where beam averaging enhances the detectability of extended radio emission. Therefore, there are a very few clusters with unambiguously detected radio halo emission.

Coma cluster (Abell 1656) was observed on 19 Sep 2004 using GMRT and we employ the method of "peeling" to detect the diffuse component called as Coma C (Fig 1, Lower right panel). It has an extent of $\sim$50 arcmin and an integrated flux density of 9.8 $\pm$0.2 Jy at 150 MHz, thereby giving a spectral index, α_{150}^{430} = 0.77 $\pm$0.07 (Hanisch & Matthews 1979). Here, the uncertainties in our estimates of flux densities and the limits for undetected sources are determined by background source confusion, errors in the removal of strong source confusion and fluctuations in the nonthermal galactic emission, which are much smaller than the calibration and the systematic errors. Following, Jaffe & Rudnick (1979), it should be possible to detect halo sources up to several times weaker than presently known in more distant clusters with the GMRT, by subtracting point sources and convolving the residual map to a resolution comparable to the expected size of a radio halo. We therefore, propose to follow the detection of radio halo at 150 MHz using GMRT in a few more cluster radio sources with one or more radio tail galaxies in the cluster centre (Giovannini et al. 1993).

4 SUMMARY AND CONCLUSIONS

The first and foremost conclusion to be drawn is that the results from the new GMRT 150 MHz band are reliable and robust. Furthermore, the new GMRT 150 MHz observations are the first high sensitive, high angular resolution results. These observations also provide high dynamic range, meaning that, for the first time, we are able to compare the flux measurements of fainter sources with those of bright sources. Furthermore, our main results from these observations are:

- We do not detect Upsilon Andromedae and put a 3σ upper limit of 9 mJy.
- We detect HFF 123725+621128, a WAT source detected earlier in the 40 arcmin^2 HDF and HFF region.
- Coma C radio halo source has an extent of $\sim$50 arcmin and an integrated flux density of 9.8 $\pm$0.2 Jy at 150 MHz, thereby giving a spectral index, α_{150}^{430} = 0.77 $\pm$0.07.

It is therefore clear that observations using 150 MHz band of GMRT will help reveal the nature of a variety of sources and it would be instrumental in the studies of many scientific subjects of astronomical interests.

5 ACKNOWLEDGEMENTS

We thank the staff of the GMRT who have made these observations possible. GMRT is run by the National Centre for Radio Astrophysics of the Tata Institute of Fundamental Research.

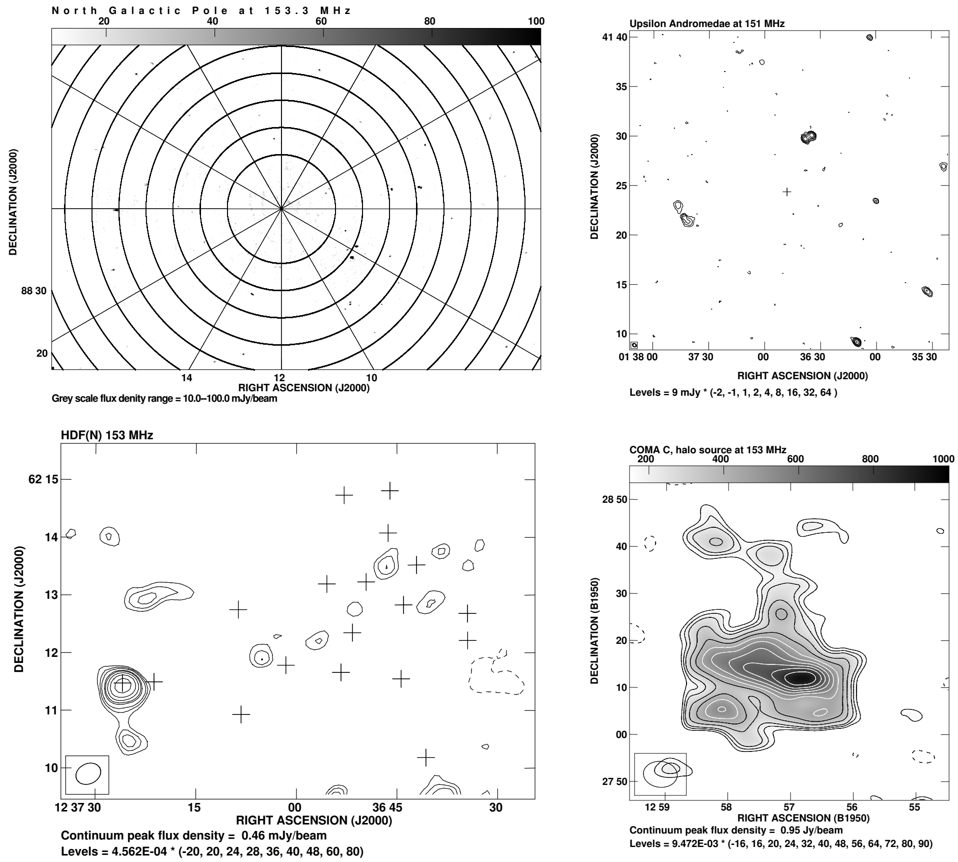

Figure 1: *Upper, left panel* GMRT image of North celestial pole–Concentric circles in the map are half a degree apart. The rms in the central part of the map is $\sim$8 mJy beam^{-1} and is dominated by interefernce that does not get "fringe stopped". The rms away from the field centre is $\sim$3 mJy beam^{-1}. *Upper, right panel* Upsilon Andromedae–GMRT image of the Upsilon Andromedae at 151 MHz. The position of the Upsilon Andromedae is indicated by '+'. (*Lower, left panel*) HDF(N)–Radio emission from the HDF and HFF at 150 MHz. The crosses, '+', represent the positions of 18 sources detected earlier using VLA at 8.4 GHz (Fomalont et al. 1997) and we have confirm detection of HFF 123725+621128 source. (*Lower, right panel*) Radio halo, "Coma C" source–Subtracted map of the Coma cluster to show the morphology of diffuse, halo radio emission.

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