Extended sources from deep GMRT 150 MHz observations

S. J. George¹ and C. H. Ishwara-Chandra²

¹School of Physics & Astronomy, University of Birmingham, UK
²National Centre for Radio Astrophysics, TIFR, Ganeshkhind, Pune 411 007, India

Abstract. We present results of deep 150 MHz observations with the GMRT which show several extended radio sources with a range of morphologies. These sources have then further followed up at higher frequencies (610 and 1400 MHz) with the GMRT. GMRT J0137+4121 was a candidate double–double radio galaxy for which we have also used the VLA-A array at C band to resolve the core. These observations have allowed us to determine that this source is a normal radio galaxy with a core and a one sided jet. Prominent amongst the other extended sources is the giant radio galaxy, 4C39.04.

1. Introduction

The field of Upsilon Andromeda was observed with the GMRT at 150 MHz as part of a search for extrasolar planets (Winterhalter et al. 2005). The rms noise of the images was $\sim 1.5$ mJy beam$^{-1}$ with a resolution of $\sim 20''$. Though the extrasolar planet was not detected, the low rms noise along with the superior resolution at the low frequency of 150 MHz enabled us to detect a few hundred-background radio sources. Cross-correlation of these sources at higher frequencies was used to obtain ultra-steep spectrum (USS) sources, which are potential candidates for high-redshift radio galaxies (Ishwara-Chandra & Marathe 2007). Further investigation of the image revealed several radio sources with a range of morphologies like compact double, diffuse, one-sided, etc. Here we present the images at 150 MHz for some of the sources and results of follow-up observations of one interesting radio source which appeared like a double–double radio galaxy.

2. Observations and data analysis

The 150 MHz observations of this field were carried with GMRT on July 27, 2004 using a bandwidth of 5.5 MHz. GMRT consists of 30 antennas, each of 45 meter diameter located 90 km from Pune, India and operates at five frequency bands from 150 MHz to 1450 MHz. For determining the flux scale, the standard flux calibrator 3C48 was observed and the flux at 150 MHz was estimated using Baars formula. The data of Upsilon Andromeda was analysed in AIPS using standard procedures for wide field imaging with appropriate care taken while averaging channels to avoid bandwidth smearing. A few iterations of phase-only self calibration and one iteration of amplitude and phase self-calibration was applied to improve the image quality. The final rms noise
achieved at 150 MHz near the centre of the field was $\sim 1.5 \, \text{mJy beam}^{-1}$ and resolution of $\sim 20''$.

3. Results and Discussion

Apart from the hundreds of background sources which are largely unresolved, we identified 4 extended objects of interesting morphology to follow-up at higher frequencies. Below we discuss their characteristics from 150 MHz up to 5 GHz.

**GMRT J0137+4121**: This radio source is near the centre of the field and has diffuse lobes on either side of a bright central component (see Fig. 1). The central component has a peak flux of $\sim 80 \, \text{mJy beam}^{-1}$ and an integrated flux density of $\sim 120 \, \text{mJy}$, which appears to be partially extended and could be compact FRII radio source. There is a galaxy like object seen in the Digitized Sky Survey some $7''$ away from the core. Investigation of radio sources with similar morphology in the past has revealed a compact double at the centre with diffuse lobes on either side. This indicates multiple epochs of AGN activity where the diffuse outer lobes belong to the previous epoch of AGN activity and the inner compact double corresponds to the most recent epoch of activity (e.g. Jamrozy et al. 2007). Further observations with GMRT at 610 MHz indeed revealed the possibility of a compact double at the centre (see Fig. 1). However, when the source was observed with VLA at higher radio frequencies with higher resolution, the central compact double morphology was resolved to a core and one sided detached jet. Further observations, including determining the redshift of this object are necessary.

**GMRT J0138+4057**: The morphology of this source is typical of head-tail radio sources (Lal & Rao 2004), that are usually found in dense environments (see Fig. 2). At 150 MHz the central component of this source has a peak flux of $\approx 90 \, \text{mJy beam}^{-1}$.

**GMRT J0140+4053**: This source is very similar to GMRT J0137+4121, though it is much more diffuse lacking a strong central component (see Fig. 2). From the morphology, this resembles a low luminous radio galaxy with diffuse lobe on either
Deep 150 MHz observations

Figure 2. Three of the background sources discovered from the 150 MHz map of the field of Ups And. Top: Giant radio source 4C39.04. This image at 150 MHz is the highest sensitivity and also highest resolution image at this frequency. The angular size is about 7 arcmin. Lower left: GMRT J0140+4053, from the morphology, this resembles a low luminous radio galaxy with diffuse lobe on either side. The central component does not look compact. Lower right: GMRT J0138+4057, this is a candidate for a head–tail source.
side. An optical galaxy appears to be located at the position of the core. At 610 MHz we are able to partially resolve a compact core with a peak flux of 13 mJy beam$^{-1}$.

**GMRT J0139+3956 (4C39.04):** This is the well know Giant Radio Source (GRS) 4C39.04. The 150 MHz map (Fig. 2) is the highest resolution and highest sensitivity map at this frequency. The angular size of this source is about 7 arcmin. The central component has a peak flux of $\approx 680$ mJy beam$^{-1}$ at 150 MHz. It is important to study the spectral index variation across the source at low radio frequencies (i.e. $< 1$ GHz), which will preferentially probe old populations of electrons. Archive data at the GMRT exists for this source at L-band and at VLA up to 5 GHz. Our 610 MHz observations with GMRT revealed a bright central core $\approx 32$ mJy beam$^{-1}$. The large-scale structure of this source, showing relaxed lobes has been reported by a number of authors (e.g. Hine 1979; Vigotti et al. 1989). Our results enable us to further interpret the spectral shape of this object. The core spectral index between 150 MHz and 4.8 GHz is 0.8, which suggests the existence of a Steep Spectrum Core (SSC).

### 4. Concluding Remarks

Multifrequency GMRT and VLA observations have been presented and have helped clarified the nature of 4C39.04 as a SSC. For these sources (apart from 4C39.04), high resolution optical data is required to determine the source redshift and galaxy type, thus allowing for a global picture of the source. In the case of GMRT J0138+4057, GMRT J0140+4053 higher resolution radio data is required to resolve the possible core and like with GMRT J0137+4121 (using the VLA at 4 GHz) allow the radio source nature to be determined. In summary we have been able to determine a detailed picture of a number of extended sources detected at 150 MHz, quantifying their nature up to 4 GHz. This is just a small number of extended sources from single pointing, but should be typically found in the low frequency sky with a many of them of previously undetected. The GMRT archive should be exploited before and used in conjunction with future low frequency radio arrays.

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