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High-Redshift Radio Galaxies from Deep Fields

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Abstract. Most of the radio galaxies with $z > 3$ have been found using the red-shift spectral index correlation. We have started a programme with the Giant Metrewave Radio Telescope (GMRT) to exploit this correlation at flux density levels about 100 times deeper than the known high-redshift radio galaxies, with an aim to detect candidate high-redshift radio galaxies. Here we present results from the deep 150 MHz observations of LBDS-Lynx field, which has been imaged at 327, 610 and 1412 MHz with the Westerbork Synthesis Radio Telescope (WSRT) and at 1400 and 4860 MHz with the Very Large Array (VLA). We find about 150 radio sources with spectra steeper than 1. About two-thirds of these are not detected in Sloan Digital Sky Survey (SDSS), hence are strong candidate high-redshift radio galaxies, which need to be further explored with deep infra-red imaging and spectroscopy to estimate the red-shift.

Key words. Radio source—high-redshift—galaxies.

1. Introduction

The empirical correlation that the high-redshift radio galaxies tend to exhibit steep radio spectra has been successfully applied to search for radio sources at high red-shifts and today, about 45 radio galaxies are known beyond red-shift of 3 (see Miley & de Breuck 2008 and reference therein). In order to understand whether the known HzRGs represent typical FRII radio sources at high-redshifts, or the highest luminosity sources in that category, we plot the extrapolated flux densities at 150 MHz of all known HzRGs ($z > 3$; Figure 1). It is clear from the figure that nearly all of the known HzRGs are two to three orders of magnitude more luminous than the FRI/FRII break luminosity. This is largely due to the selection effects because nearly all the searches for steep spectrum radio sources use sky surveys such as WENSS and SUMSS at low radio frequencies and NVSS at higher radio frequencies. The median flux density of all known HzRGs at $z > 3$ at 150 MHz is ~1.3 Jy, whereas the FRI/FRII break luminosity is more than two orders of magnitude fainter, indicating that the known HzRGs represent the tip of the ice-berg in luminosity. There are, potentially, a large number of HzRGs yet to be discovered which are expected to be 10 to 100 times less luminous than the known HzRGs. The 150 MHz band of

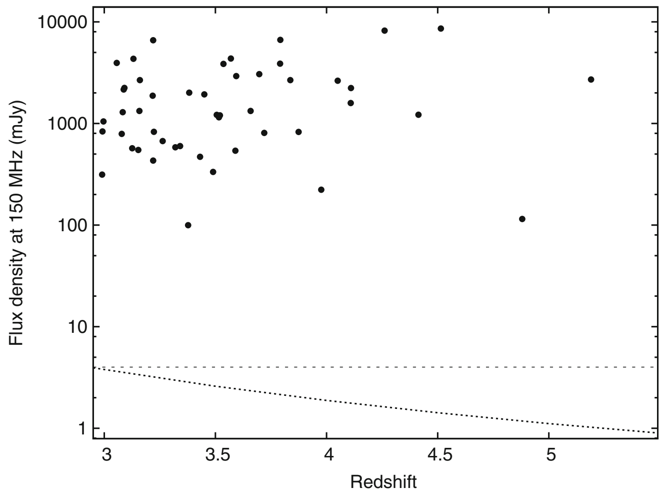

Figure 1. The 150 MHz flux densities of known HzRGs. The dotted line is the rest-frame FRI/FRII break luminosity. The dashed horizontal line is the GMRT detection limit from this work. It is clear that a large number HzRGs, that are 10 to 100 times less luminous than the known HzRGs are yet to be discovered.

GMRT (Giant Metrewave Radio Telescope, India, http://www.ncra.tifr.res.in) with its large field of view (3 degrees), high angular resolution (∼20″) and better sensitivity (∼1 mJy from a full synthesis observation) is well-suited to fill this large gap, by searching for steep spectrum sources using deep radio observations at low frequencies like 150 MHz. We have started a programme to observe several carefully chosen deep fields at 150 MHz with GMRT with an aim to detect steep spectrum radio sources to flux density levels much fainter than that of known high-redshift radio sources. In this paper we present deep 150 MHz radio observations of the LBDS-Lynx field (Windhorst *et al.* 1984) with the GMRT with the primary aim of detecting steep spectrum radio sources which are candidate HzRGs (Ishwara-Chandra *et al.* 2010).

2. Results and discussion

The 150 MHz observations of the LBDS-Lynx field centered at RA of $08^h41^m46^s$ and DEC of $+44^d46'50''$ (J2000) were carried out with the GMRT (Swarup *et al.* 1991) on December 11, 2006 using a bandwidth of 16 MHz. The data were analysed using `AIPS++` (v1.9; build #1556; Sirothia *et al.* 2009). The final image was made after several rounds of phase self-calibration, and one round of amplitude-and-phase self-calibration. The final rms noise achieved was ∼0.7 mJy/beam with a resolution of $\sim 19'' \times 15''$ at a position angle of 27°. The final catalogue contains about 765 sources above a flux density limit of ∼4 mJy. In addition to the published deep observations of the LBDS field at 327, 610, 1412, 1462 and 4860 MHz, we used the WENSS catalog at 325 MHz and the NVSS and FIRST catalogs at 1400 MHz to obtain the spectral index of sources found at 150 MHz. A total of 639 sources out of

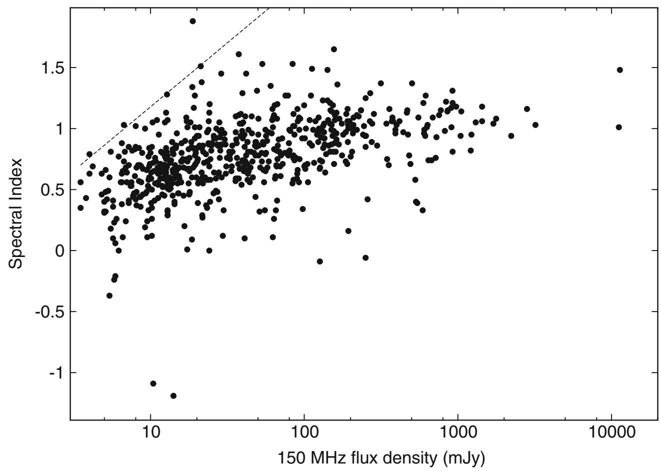

Figure 2. The spectral index distribution of sources detected at 150 MHz ($S_\nu \propto \nu^{-\alpha}$). The dashed line shows the spectral index limit corresponding to five sigma limit of FIRST.

765 (83%) have spectral index determined. The median spectral index of the sample is 0.78. The spectral index distribution is presented in Fig. 2.

2.1 *Sample of steep spectrum sources*

We have cross-matched the sample of 157 sources, with spectral index steeper than 1 with VLA FIRST survey. If the counterpart is seen in FIRST, we have taken the position from FIRST survey to obtain better accuracy. Among the 157 sources, 8 sources did not have counterparts in FIRST and hence the 150 MHz position was used to cross-match with SDSS.

We positionally matched each steep spectrum source position with the photometric object catalog (PhotoObjAll) from the DR7 release of the Sloan Digital Sky Survey (SDSS; Abazajian *et al.* 2009). 59 radio sources from this sample had at least one SDSS primary object within 6 arcsec (38% identification). The remaining 98 sources had no optical counterpart in SDSS within 6″ radius. The median 150 MHz flux density for the sources not having counterpart in SDSS is ∼110 mJy, which is more than an order of magnitude fainter than the median flux density at 150 MHz for known HzRGs (see Fig. 1). One of the steep spectrum source without SDSS counterpart (GMRTJ084533+455835), is unresolved at 150 MHz, but resolves into a clear compact FRII source of about 8 arcsec size in VLA FIRST. Using the 150 MHz flux density and FRI/FRII break luminosity, we estimate that this source should be at a red-shift of ∼2 or higher (for its luminosity to be above the FRI/FRII break).

3. Concluding remarks

We have initiated a major programme to search for steep spectrum radio sources with the GMRT with the aim to detect high-redshift radio galaxies of moderate luminosity. The fields for this programme are carefully chosen such that extensive data exists at higher radio frequencies and deep optical imaging and/or spectroscopy is also available for most of the fields. Here we have presented the results from deep 150 MHz low-frequency radio observations of the LBDS-Lynx field with the GMRT, India reaching an rms noise of of $\sim$0.7 mJy/beam and a resolution of $\sim 20''$. We have demonstrated that this GMRT programme can search for high-redshift radio galaxies more than an order of magnitude fainter in luminosity compared to most of the known HzRGs. We provide a sample of about 100 candidate HzRGs with spectral index steeper than 1 and no optical counterpart to the SDSS sensitivity limits. A significant fraction of the sources are compact, and are strong candidates for high-redshift radio galaxies. These sources will need to be followed up at optical and near-infrared bands to estimate their red-shifts.

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