A deep search for High-Redshift Radio Galaxies (HzRGs) with GMRT

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Radio Galaxies

- Radio galaxies refer to otherwise normal galaxies (usually elliptical), hosting AGN which emits powerful radio emission through jets/lobes.
- The standard components are compact nuclei and powerful radio emission on either side, extending up to a few Mpc!
- About 10% of the galaxies with AGN produce powerful radio emission.
Two broad class

From the 3C Survey, Fanaroff and Riley (1974) have found a morphology – luminosity relation – type I (or FRI, left) of lower luminosity and type II (or FRII, right), higher.
Optical identification of RGs

It has been first noticed in early 80's that the fraction of 3C radio sources that can be optically identified are 3 times less for those with radio spectral index steeper than 1 (stronger at lower radio frequencies).
Radio Spectral Index between 178 MHz and 5 GHz
(The dashed line is the chance coincidence rate)

Blumenthal and Miley, 1979, Tielens, Miley and Willis, 1979
Optical identification of RGs

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This finding that the steep spectrum sources are more distant as compared to the sources with normal spectra, has been exploited since then to find more high-redshift radio galaxies.
Exploiting the spectral-index – redshift correlation is the most efficient method to find HzRGs.

Method: Shortlist USS --- discard nearby objects using known optical surveys, --- get accurate radio positions, --- get K-band imaging (K-z relation) and last, spectroscopy (the major limitation).. (or the reverse)

Most of the High-z radio galaxies known today (~ 45) are discovered using this correlation.

Till date, there is only one (two?) radio galaxy known with z > 5 (discovered in 1999).

Known HzRGs: - Tip of the iceberg?

- GMRT detection from deep, full synthesis, 150 MHz observation.

Median: 1.33 Jy!

Population remains to be discovered – 10 to 100 times deeper observations needed.

GMRT detection from deep, full synthesis, 150 MHz observation.

FRI/FRII luminosity
Why high-redshift radio galaxies?

- Evolution of Radio Galaxies

How does the radio source population evolve as a function of redshift and luminosity?

Does the radio galaxy population decrease beyond redshift of 3 or 4? (Evidence for redshift cutoff (1990) not valid anymore (2001, 2009)?

Why high-redshift radio galaxies?

- **Environmental effects - protoclusters?**
  A majority of HzRGs reside in cluster like environments, suggesting HzRGs can be used as tracers of (proto) clusters.

- **Energetics and survival of radio sources (due to high I/C loss)**
  The inverse Compton loss w.r.t. \( z \) is \((1+z)^4\) - at \( z=5 \), this loss is \( 1300 \) times more dominant as compared to \( z=0 \).

- **(Supermassive) BH formation at these epochs**
  The radio galaxy require supermassive BH at the center – therefore, study of HzRGs trace the formation of SMBHs.

- **Why \( z \) – alpha correlation?**
  The reason for this correlation is not well understood.

  *Hill and Lilly 1991; Venemans (thesis, 2005)*
The GMRT Programme....
Giant Metrewave Radio Telescope (GMRT)

GMRT consists of 30 antennas, each of 45 metre diameter, spread over 30 km area, at Khodad, 90 km off Pune, India.

It is the world’s largest radio telescope at metre-waves. Frequency of operation 150 MHz to 1430 MHz.

Designed and fabricated in India.

GMRT is run by National Center for Radio Astrophysics of the Tata Institute of Fundamental Research.
The GMRT Programme....

- To optimize the search, 'well known deep fields' are chosen, most of which don't have deep radio data below 1.4 GHz *(partly in 'reverse' direction)*
- DEEP-II-1,2,3 (~2 deg X 0.5 deg/field & 50,000 spectra).
- VIRMOS-VLT – (~ 4 degree$^2$ and 10,000 spectra)
- VLA-COSMOS - (~ 2 degree$^2$ and 40,000 spectra)
- LBDS – Deep radio data by R. Windhorst, Oort and others.
- HDF/GOODS-N – small field of view, but wealth of data ..
- TAU-BOOTES field, (with Gregg Hallinan)

First Results: LBDS field

- Full synthesis observations at 150 MHz, 16 MHz BW.
- Analysed in AIPS++, rms noise ~ 0.7 mJy/beam
- About 770 sources down to ~20% of the beam. Faintest reliable source ~ 5 mJy
- Deep observations exists at 327, 610, 1412, 1465 and 4860 MHz (less than 150 MHz area) and WENSS, NVSS, FIRST.
- About 85% of the sources have counterparts at 610 MHz or higher freq. The median spectral index of 0.78 (92% of the sources have spectral index in the range median+/- 0.5)
- About 90 sources below 10 mJy have counterparts in NVSS and FIRST and this subset has median spectral index of 0.53
A few examples of Steep Spectrum Sources

- GMRT084627+0453128: \( \alpha = 1.15 \)
- GMRT083349+0432020: \( \alpha = 1.37 \)
- GMRT084528+0440732: \( \alpha = 1.48 \)
- GMRT084901+0445049: \( \alpha = 1.88 \)
Results

- Spectral index cut-off of 1 or 1.3? We choose a cut-off of 1 in the spectral index – this sample has 157 sources. Among this 149 has counterpart in FIRST and FIRST position is taken for searching for counterparts in SDSS.

- 98 sources don't have counterparts in SDSS, majority of them unresolved and are strong candidates for HzRGs.

- Further deep K-band imaging and spectroscopy is needed to get redshift.

- *Couple of objects objects have clear FR-II morphology, based on FRI/FRII luminosity break, its redshift should be > 2*
TIFR GMRT Sky Survey (TGSS)

Reference: http://tgss.ncra.tifr.res.in/

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Overview of the TGSS

- TGSS is designed to carry out a GMRT 150 MHz survey of the sky in the declination range -55° to 90° (37000 deg², 90% of sky).
- In sky coverage and depth, this will be the only metre-wavelength counterpart to the VLA 1400 MHz survey (NVSS), which is currently the most used radio survey.
- The sky is imaged with a resolution of 20″. Thus, in beam area our survey will be about 5 times superior to NVSS.
- The survey is made by observing 5 snapshots of 3 min each for a total of 5040 fields. This requires 210 sessions of 11 hour each including calibration.
- We were granted 1820 hours in the GTAC cycle 18, 19 and 20 for which the observations are underway. Remaining about 200 hrs of time may be allotted in GTAC cycle 21.
- We have set up a dedicated computational facility for processing the survey data at the rate comparable to that of taking the observation.
- The details of TGSS and its data products are made available to user community from our website http://tgss.ncra.tifr.res.in
- In our first and second data releases images and catalogue of sources in about 2100 sq. deg. are available. Subsequent data releases at about 4 month intervals are planned to make full survey data available to astronomical community.
- About a million source will be catalogued and imaged in the complete survey, with already about 50,000 presented in first data release.
Comparison of the major low-frequency surveys

5-σ flux-density (left panel) and resolution (right panel)
What next?

– First two steps are done, now the third step

*Deep K-Band imaging, for* $K - z$ *relation to estimate redshift or spectroscopy to look for HzRGs.*

Jarvis et al 2001
Summary

- The known HzRGs till date represents the tip of the iceberg. The population of HzRGs 10 to 100 times fainter are yet to be discovered.

- GMRT @ 150 MHz will fill this gap.

- In near future, TGSS will produce several tens of thousands of HzRG candidates, which needs to further followed up with deep K-band imaging or spectroscopy.

- Observing such large sample, is best suited for ROBO-AO telescopes.
A new Giant Radio Source at $z = 0.6$

At 150 MHz image, this was found beyond HPBW.
A new Giant Radio Source at $z = 0.6$
A new Giant Radio Source at $z = 0.6$

Figure 1: The images of the new Giant Radio Source discovered with GMRT at 150 MHz (top...
Optical Spectroscopy at IGO

$r$ band magnitude of 21.3, \textit{photometric redshift of 0.62}; this object has linear size $> 2$ Mpc, with $z > 0.5$, about 15\% of giant radio sources are at $z > 0.5$, but none larger than 2 Mpc

Spectroscopic redshift of 0.57