GMRT low-frequency study of recently identified DDRGs

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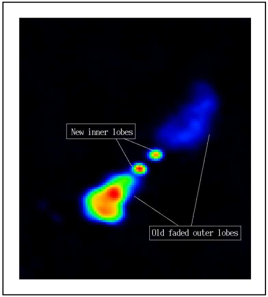
Out line of talk

- Introduction
- Objectives
- Sample selection
- Discussion on 610 MHz GMRT observation time-scale of jet interruption
- Misaligned DDRG J1328+2752 and DDRQ J0746+4526
- Conclusion

Introduction and Objectives

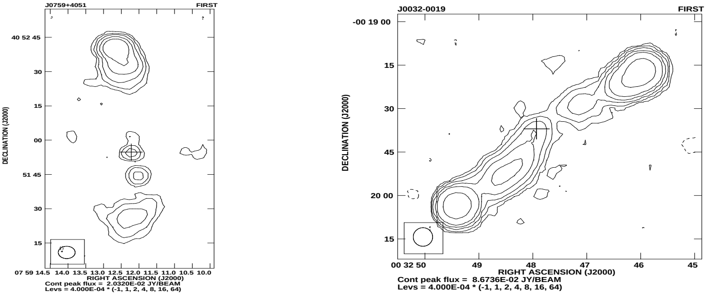
- Double-double radio galaxies (DDRGs) are rare examples of AGNs that undergo multiple cycles of jet activity.
- To understand the nature of these sources and possible reasons for their episodic activity, we need to enlarge the sample of objects.



GMRT 610 MHz image of J0746+4526

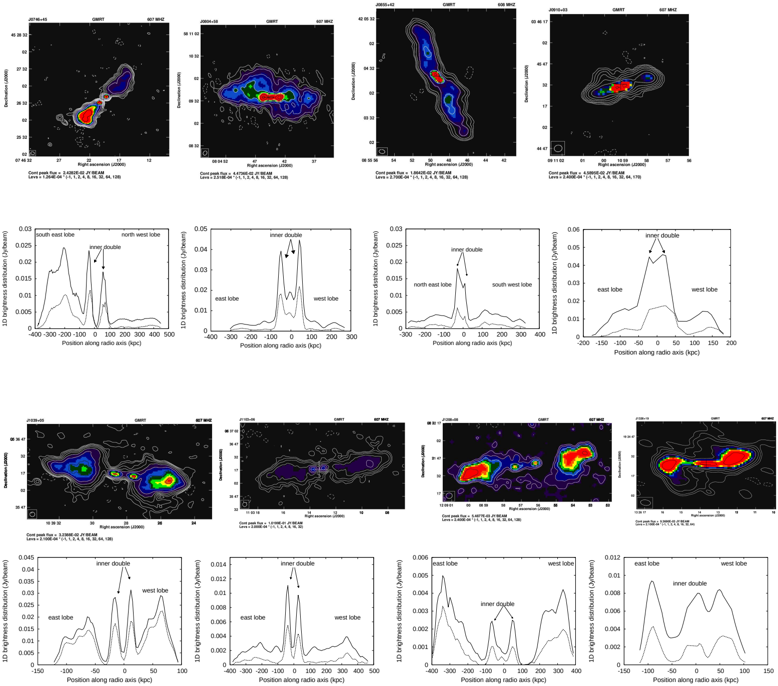
Sample selection and Methodology of classification

Based on only radio structural information Proctor (2011) classified 242 sources as candidate DDRGs. Further detailed investigation of these sources along with optical data from SDSS and DSS catalogues showed only 23 of these sources to be promising examples of DDRGs (Nandi & Saikia 2012).

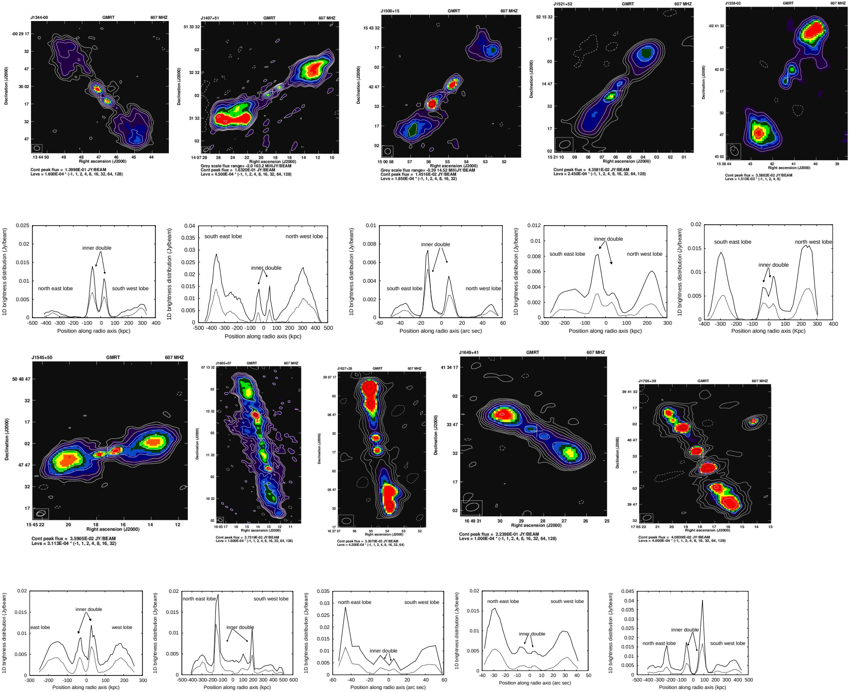


Non DDRG candidates (Nandi & Saikia 2012)

- Early studies indicated that large linear sizes are characteristic of most of the known DDRGs (Schoenmakers et al. 2001).
- Median sizes of the inner and outer doubles are $\sim$75 and $\sim$530 kpc respectively.
- Improved statistics on large and small-sized DDRGs will be helpful to understand their evolution process.
- In order to confirm their episodic nature we started GMRT observation for this sample.



GMRT 607 MHz images and one-dimensional brightness distributions (Nandi et al. 2019; submitted).



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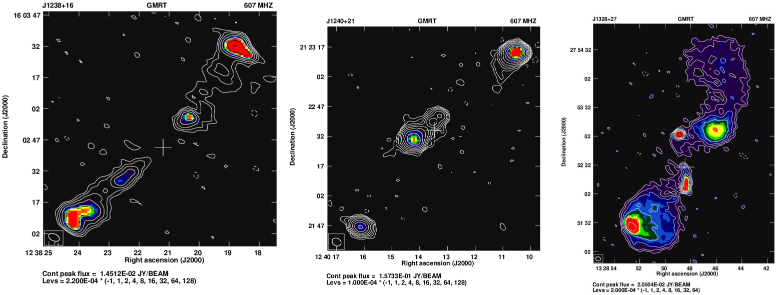
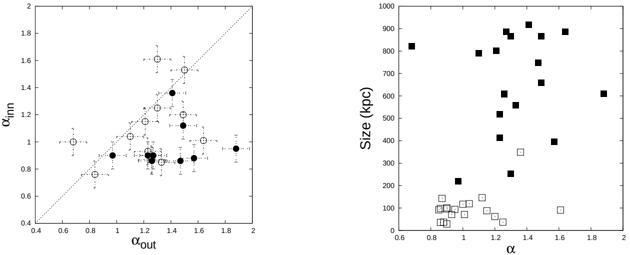
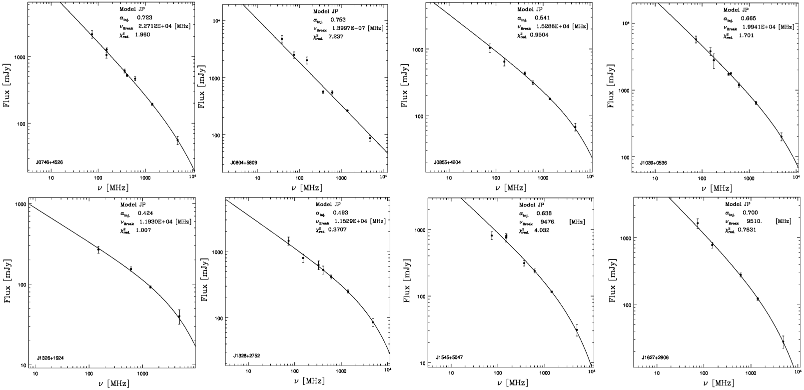


GMRT images misaligned DDRGs J1238+1602, J1240+2122 and J1328+2752 (Nandi et al. 2019; submitted)



Left panel: Spectral index variation of new sample of DDRGs. Right panel: Sizes of the inner and outer doubles vs spectral index for this sample of DDRGs.

Spectral ageing analysis



Spectra for the 8 sources and the fits using the JP model.

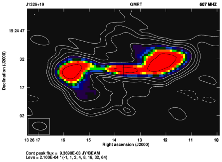
The break frequency above which the radio spectrum steepens, $\nu_{\rm br}$, is related to the radiative synchrotron age, $\tau_{\rm syn}$, and the magnetic field strength, B, through the following relation.

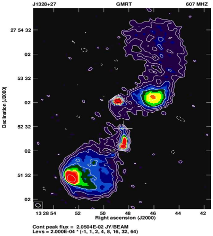
$$\tau_{\rm syn}[{\rm Myr}] = 50.3 \frac{B^{1/2}}{B^2 + B_{\rm iC}^2} [\nu_{\rm br}(1+z)]^{-1/2}, \quad (1)$$

where $B_{\rm iC}$=0.318(1+z)^2 is the magnetic field strength equivalent to the inverse-Compton microwave background radiation. The obtained age limits vary from $\sim$ 11 Myr to 52 Myr.

Time-scale of jet interruption and optical host properties

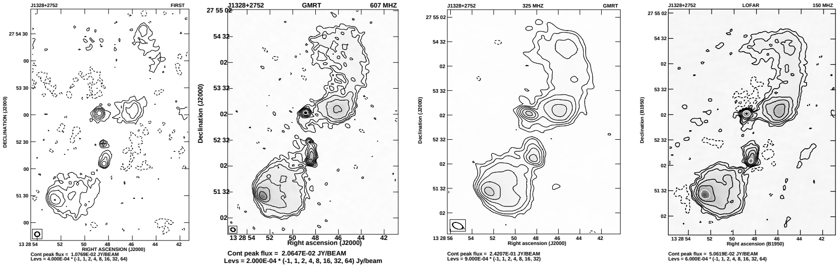
- The jet interruption time-scale is smaller than a few Myr.
- We have calculated the CI (R90/R50) values of the host galaxies in our sample.
- CI $<2.8 \rightarrow$ late type galaxies CI $>2.8 \rightarrow$ early type galaxies (Nakamura et al. 2003)
- CI value is higher than 2.86 for the sources J1326+1924 and J1328+2752.





Left panel: S-shaped DDRG J1326+1924 Right panel: Misaligned DDRG J1328+2752

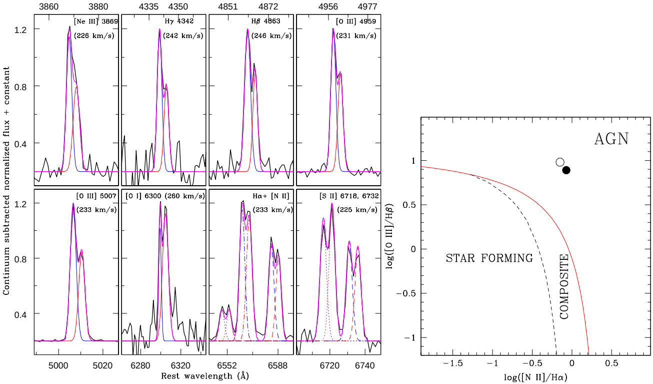
Misaligned DDRG J1328+2752



FIRST, GMRT and LOFAR image J1328+2752. (Thanks Timothy Shimwell for LOFAR image)

AGN not only gives irregular jet outflow but also there is irregularity in direction of its ejection axis. A nearby galaxy or the coalescence of massive black holes may trigger a new jet with sufficient axis rotation.

Double-peaked emission lines J1328+2752

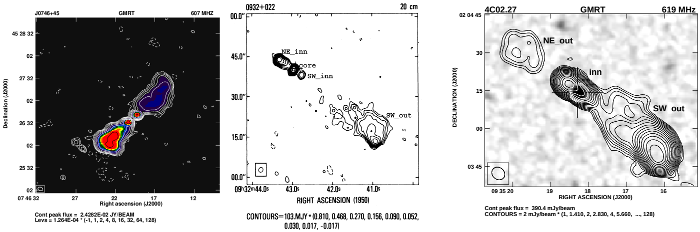


Left panel: The double-peaked emission lines obtained from the de-reddened SDSS spectrum of J1328+2752.

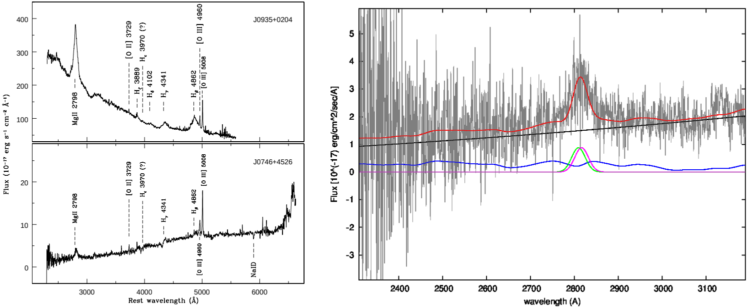
Right panel: BPT diagram of J1328+2752 (Nandi et al. 2017).

The continuum-subtracted normalized flux of eight major emission lines are shown together with the normalized model. The left (blue) and right (red) Gaussian may correspond to two merging components. The total model flux (magenta) of each spectral line is also shown in the figure. The two components are separated by a velocity of 235 $\pm$ 10.5 km/s (Nandi et al. 2017).

A red quasar J0746+4526



Left panel: DDRQ J0746+4526 (Nandi et al. 2014). Middle and Right panel: VLA and GMRT image of DDRQ 4C02.27 (Hintzen et al. 1983 and Jamrozy et al. 2009).



Left panel:

The SDSS spectra of J0935+0204 (upper panel) and J0746+4526 (lower panel). Right panel: The best fit to the Mg II emission line of the SDSS spectrum of J0746+4526 (Nandi et al. 2014).

The FWHM of the emission line of a quasar spectrum is related to its black hole mass by the following relation:

$$M_{\rm BH} = 7.24 \times 10^6 \left[\frac{\lambda L_\lambda\,(3000\,\text{Å})}{10^{44}\ \text{erg s}^{-1}}\right]^{0.5} \left[\frac{\text{FWHM}}{1000\ \text{km s}^{-1}}\right]^2 M_\odot$$

where L_λ (3000 Å) is the monochromatic luminosity at 3000 Å.
$M_{\rm BH} \sim 8\times10^7 M_\odot$ from its observed MgII emission line. The reddening of the host is $\sim$ 0.70 mag.

Discussion and conclusions

- For majority of sources, the spectral index of the outer lobes is significantly steeper.
- Age limit is relatively lower lifetime value in comparison to remnant radio sources (Jamrozy et al. 2004; Murgia et al.2011; Brienza et al. 2016) as well as large sized DDRGs (Saikia Jamrozy 2009).
- The time-scale of jet interruption is smaller than the large-sized DDRGs (Konar et al. 2012)
- To probe the exact mechanism of the formation of DDRGs, it is important to investigate the optical spectra for a large sample of DDRGs.
- In future we plan to make multi frequency high resolution radio observations of these sources.

Thanks