FR II Radio Galaxies at 90 GHz

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ABSTRACT

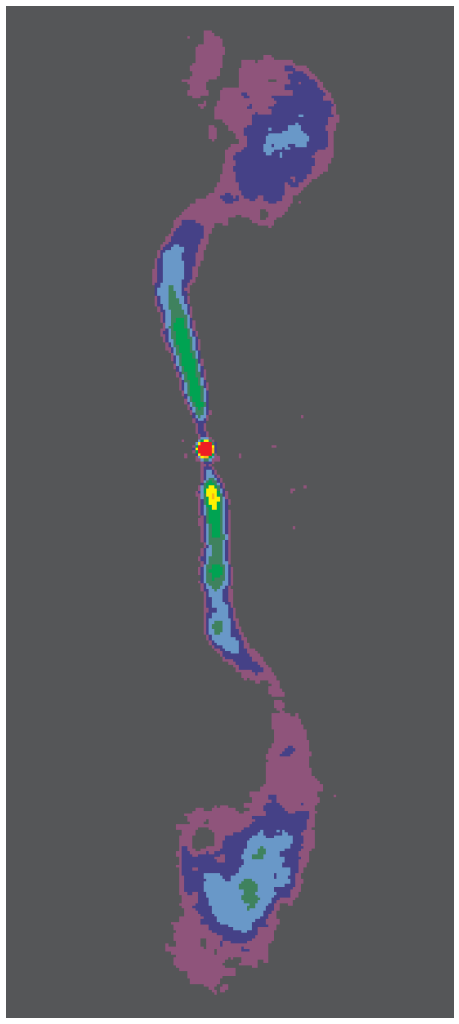
Multi-frequency observations of Fanaroff-Riley (FR) class I and class II radio galaxies demonstrate that their relativistic electron populations have very different energy distributions. In low-power FR Is, low-frequency radio images show morphologies that are dissimilar to the morphologies at high frequencies, consistent with the picture of spectral ageing; but more powerful FR IIs show similar morphologies at low and high frequencies.

We have constructed a sample of well chosen FR II sources to investigate the dependence of electron energy distribution on the nature of these sources. Here, we report the preliminary images of 3C 98 and 3C 390.3 at 90 GHz using the MUSTANG camera on the 100 m GBT. A detailed spectral analysis combining this new data and archival VLA and our GMRT data spanning three orders of magnitude in frequency will detect variations in spectral index and curvature expected from energy losses in the radiating particles.

Motivations

FR I sources show signs of synchrotron cooling in spectral index images (e.g. Lal 2009) made even at sub-GHz frequencies, and often show the presence of diffuse steep-spectrum low-frequency emission, which is not seen at high radio frequencies. By contrast, it is remarkably unusual that any FR II source has a morphology at low radio frequency (less than a few hundred MHz) that is different from its high radio frequency (GHz) morphology. This implies that the particles responsible for the low-frequency emission are entirely co-spatial with those responsible for the high-frequency emission. Or in other words, synchrotron-emitting particles of all energies permeate the lobe magnetic field in the same way, despite the fact that the higher energy particles have shorter radiative lifetimes than the lower energy ones (Blundell 2008).

Background



Fanaroff and Riley (1974) noted that the relative positions of regions of high and low surface brightness in the lobes of extragalactic radio sources are correlated with their radio luminosity. FR Is are low-power sources and have a center-brightened structure and FR IIs are high-power sources and have an edge-darkened structure.

In AGN jets and extended radio lobes, the radiative lifetimes of the synchrotron emitting electrons can be shorter than the time to transport them from the nucleus to the location along the jets where they are observed (Cotton et al. 2009). This requires some resupply or re-acceleration of the radiating particles well outside of the nucleus. The effects of the electron energy losses are more pronounced at high radio frequencies enabling evaluation of the relative effects of particle losses against any re-acceleration or resupply. *We propose to investigate the dependence of electron energy distribution, using radio data spanning almost three orders of magnitude in frequency, on the nature of FR I and FR II classes.*

Our Sample

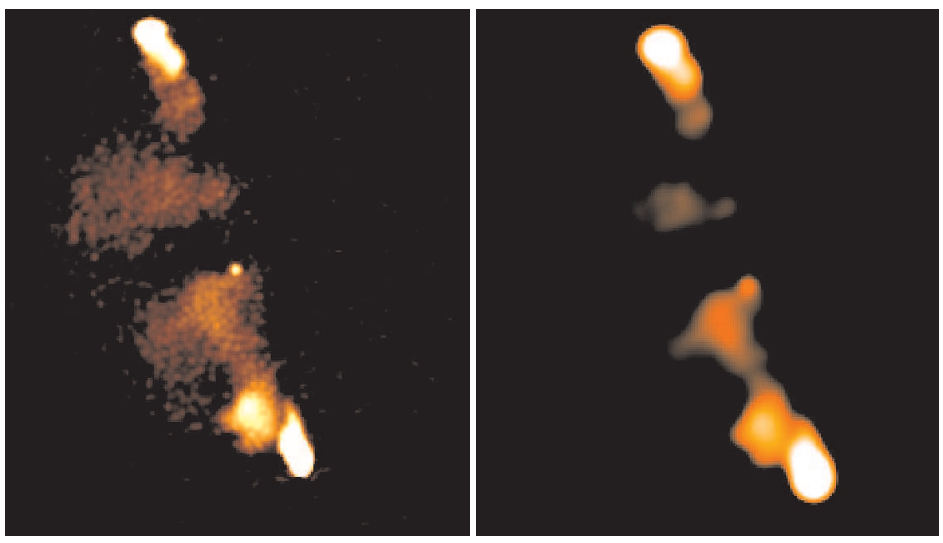
We have selected FR II radio galaxies from the 3CRR sample of Laing et al. (1983) that have angular size greater than 150″ and less than 750″. We also impose a requirement that sources should be at least three beams across in the direction perpendicular to the lobes. These criteria provide us with 14 sources which are representative of the low-redshift Atlas[†] subsample of 3CRR radio galaxies in the sense that they have identical redshift range, integrated spectral properties and radio power. Additionally, all sample sources have VLA data at GHz frequencies and GMRT data at MHz frequencies at (nearly) identical resolution spanning almost three orders of magnitude in frequency; and all have *Chandra* and/or *XMM-Newton* data as well. The X-ray data will allow detailed modelling of the interplay of jets and lobes with the hot ambient gas environment (Forman et al. 2005).

Image: VLA map of 3C 449, a FR I radio galaxy at 8.4 GHz (source: VLA archive data).

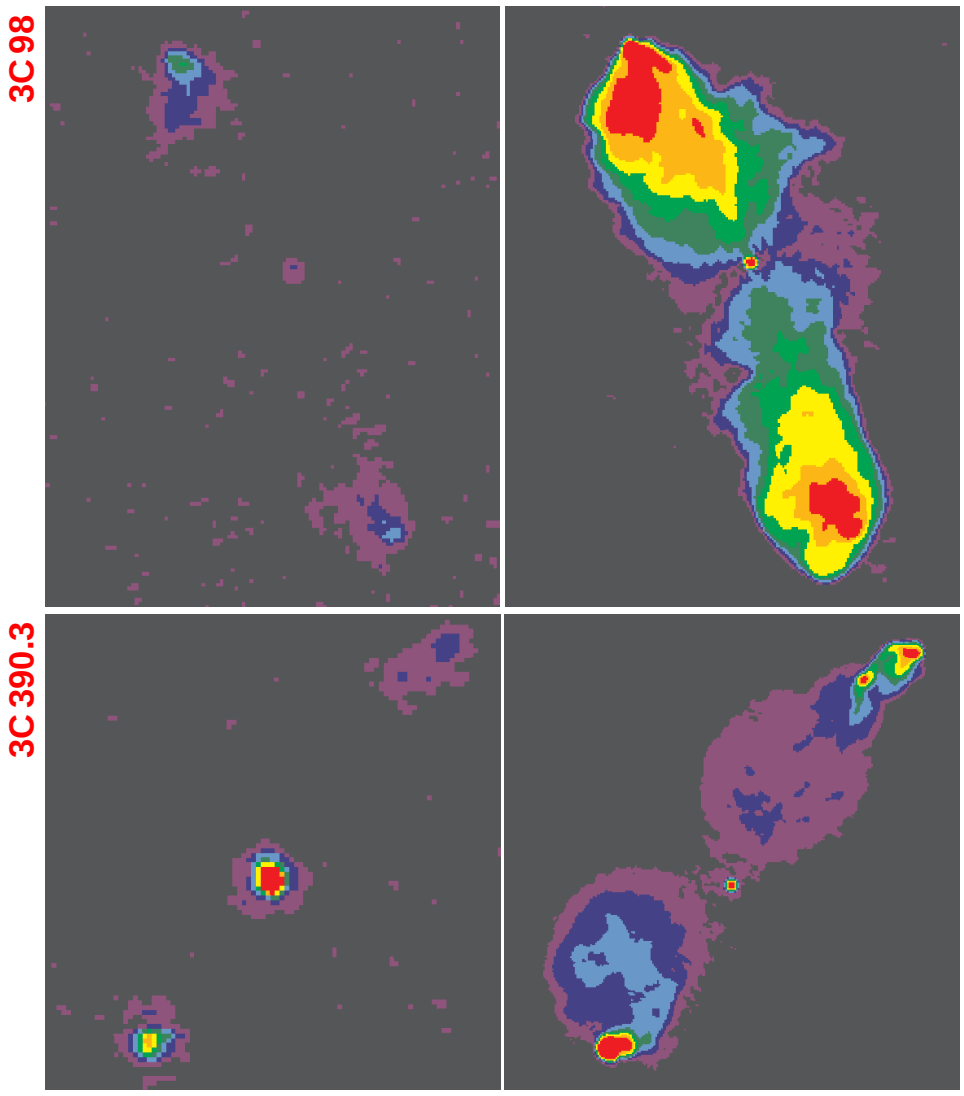
Observations

Our goal is to measure the structure on 9″ scales at 90 GHz and derive spatially resolved spectra of FR II radio galaxies using MUSTANG 3 mm bolometer camera on the GBT.

Image: Synthetic 90 GHz map (right image) and 1.5 GHz map (left image, source: Atlas catalog) of 3C 33. Our proposed new Green Bank Telescope (GBT) observations will show deviations, if any in the radio morphology from this synthetic image.



New/Preliminary Images of FR II Radio Galaxies at 90 GHz



Top row images: 90 GHz MUSTANG-GBT map (left image) and 4.9 GHz map (right image, source: Atlas catalog) of 3C 98. Bottom row images: 90 GHz MUSTANG-GBT map (left image) and 1.5 GHz map (right image, source: Atlas catalog) of 3C 390.3. The left column images will be compared with their corresponding synthetic images and the deviations, if any from it will provide hints of synchrotron cooling. *In our preliminary images, the radio cores and the hotspots (known to be sites of particle acceleration) are clearly detected.*

Ongoing Efforts and Future Plans

The acquired 90 GHz MUSTANG array observations on the GBT is being analyzed for 4 (3C 33, 3C 66.1, 3C 98 and 3C 390.3) of the 9 (approved) sample sources and the spectral analysis will be performed

- to look for evidence of particle ageing or re-acceleration, and
- to look for evidence of a depletion of higher energy electrons, if any, i.e., test if the loss mechanisms are winning over the resupply mechanisms (Cotton et al. 2009).

Although our goals and our sample selection are primarily aimed at characterizing the electron population in the large-scale lobes, our results complement the small amount of existing information on the hotspots and the cores of powerful radio galaxies at 90 GHz and demonstrate the role of ALMA in exploring several unknowns.

Important References

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7. Rudnick, L. 1999, New Astr. Rev., 46,95.
8. [†]Atlas cataog: `http://www.jb.man.ac.uk/atlas/`.