The life of the radio galaxy 3C 293:
tracing the radio spectrum over small and large scales

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Introduction

- Radio AGNs go through phases of quiescence and activity and it is crucial to study the time scales of these phases. Properties like steep spectrum core and core prominence have been used to identify a sample of restarted AGNs. However these could also be characteristics of strong interaction with a rich ISM, hence it is crucial to investigate this effect. Jurlin et al. (2020)

- This degeneracy can be broken using resolved spectral studies. However, for very few objects have there been resolved studies of the radio spectrum on both small and large scales.

- Low frequency observations are crucial to trace absorption from the surrounding medium and the injection index.

- LOFAR VLBI opens up the possibility to investigate the spectral properties of such objects on small scales

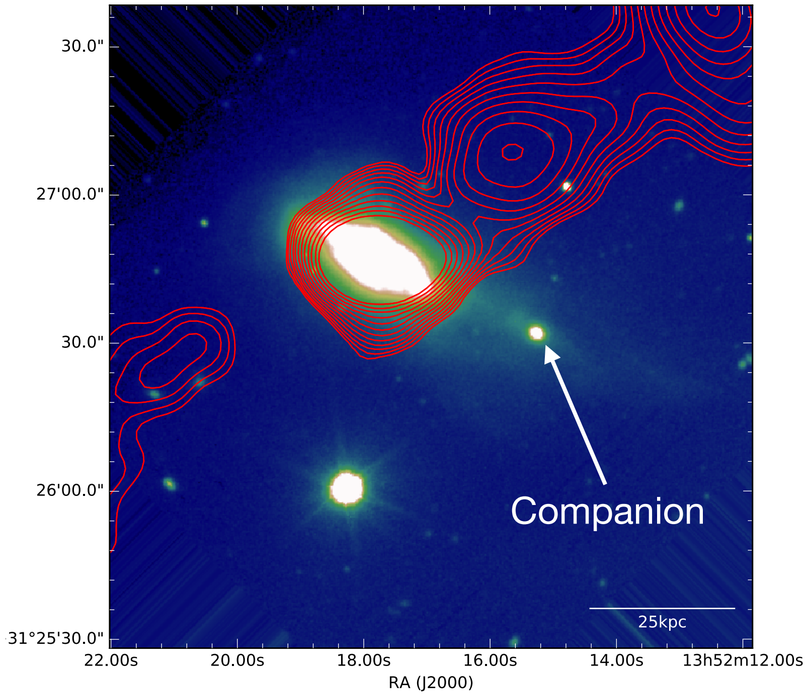
Why 3C293?

- 3C293 is a nearby radio galaxy (z=0.045) with a rich ISM and has been classified as a Double-Double radio galaxy (DDRG). Its core prominence and steep spectrum core make it a good candidate for restarted AGNs Saikia et al.2009, Joshi et al. 2011

- Low frequency analysis with LOFAR VLBI lets us study the central region (4 kpc) of a radio AGN simultaneously with the large scale emission (200 kpc)!

- At ~0.3″resolution - 140 MHz, 1400 MHz, 4800MHz, 8400 MHz with LOFAR,MERLIN and VLA

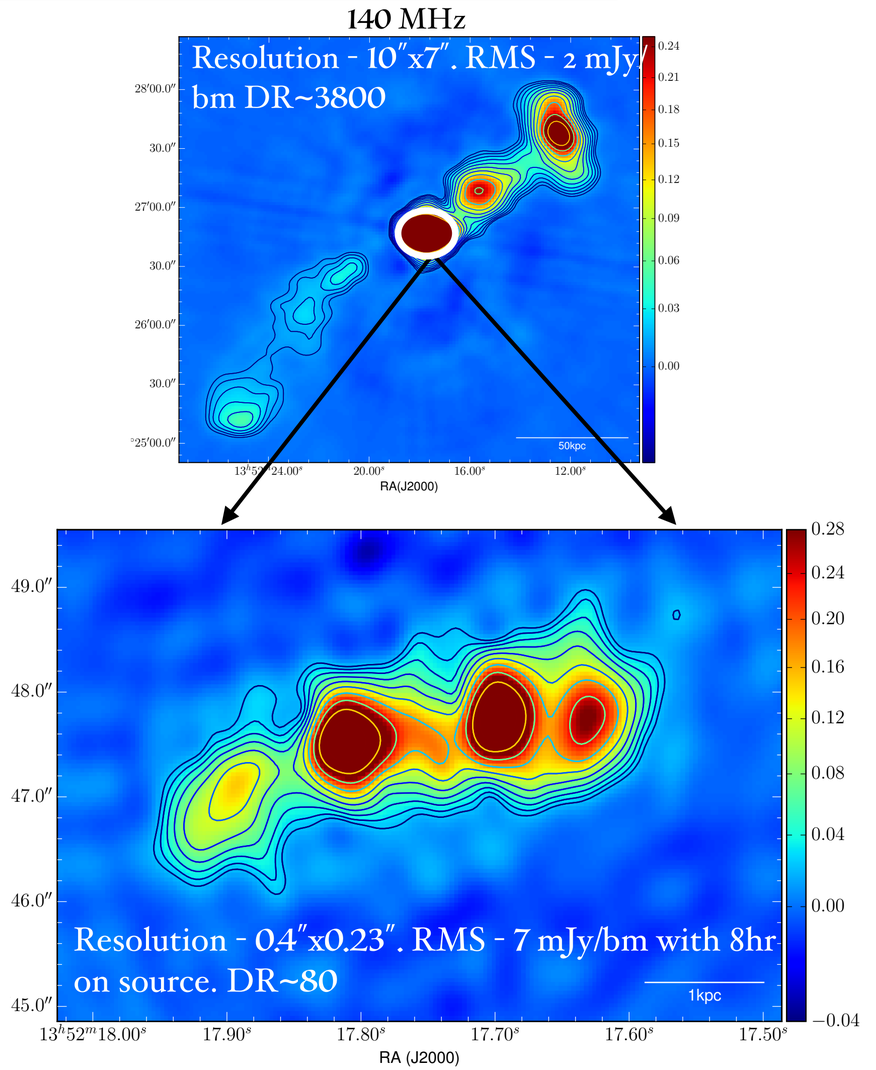
- At 6-15″ resolution - 57 MHz, 140MHz, 612 MHz, 1400MHz, 4800MHz with LOFAR, GMRT and VLA.



Optical continuum - B.Emonts (GTC)

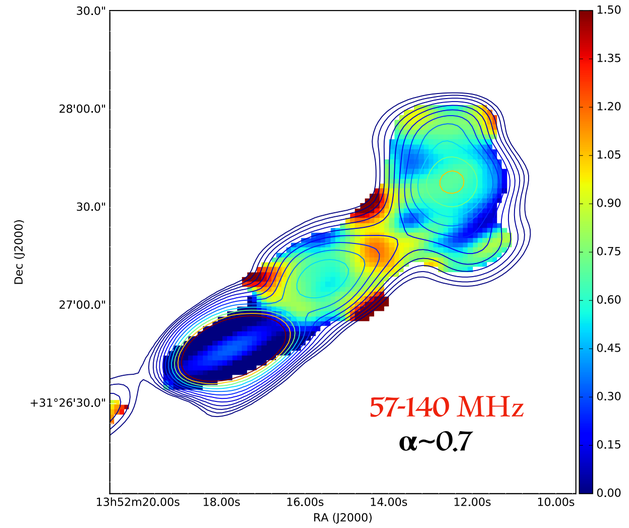
Data

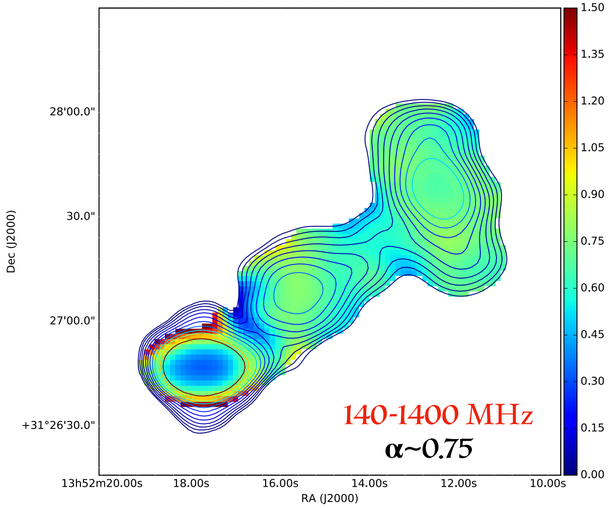
- 3C293 covered by LoTSS - 1.2° away from the phase centre in the pointing.
- 10″ image of outer lobes made after extracting target from the dataset and then self-cal and imaging on the target Shimwell et al. 2017,2019
- Long baseline pipeline used to image the centre. Morabito et al. (in prep), van Weeren, Sweijen
- LBA image made by Francesco de Gasperin and MERLIN high resolution image from Beswick et al.2004



Spectral Index Maps

- Spectral index maps were made with 5σ emission cut after aligning images
- No ultra-steep spectrum, no frequency break in spectrum from 57-4800 MHz. The spectral index shows remarkable homogeneous spatial distribution.
- Certainly not a remnant of an older phase of activity. Spectral age ~7.3 Myr
- Particle mixing and re-acceleration could flatten the spectra at higher frequencies and erase spectral curvature. Need dynamical age!

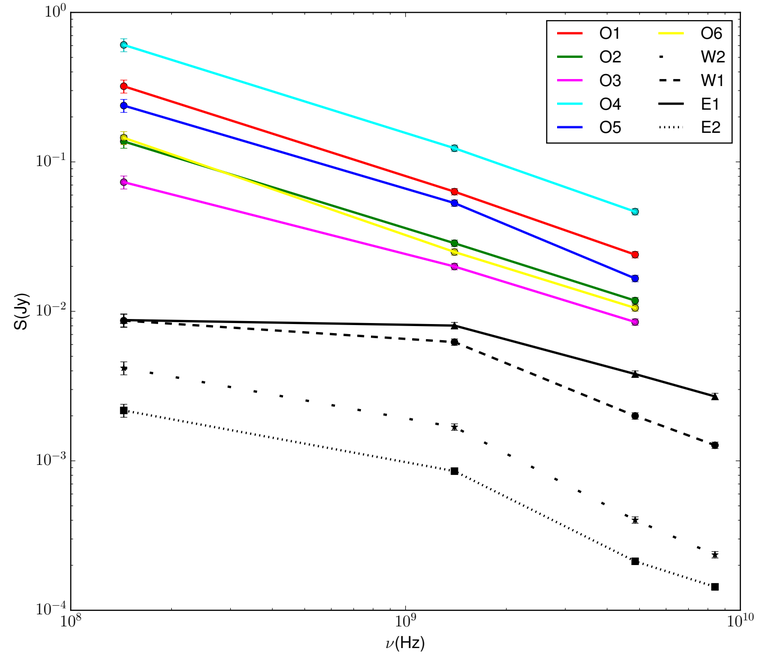




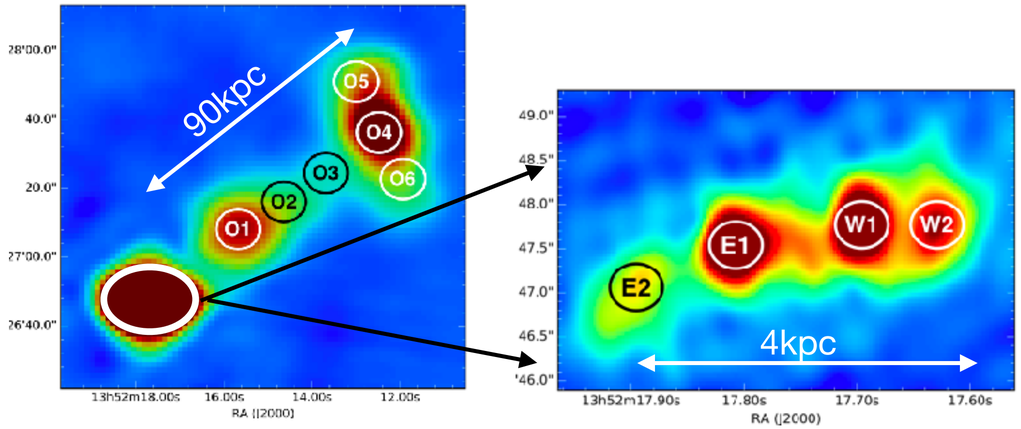
Either outer lobe still powered by the centre, maybe jet disrupted by interaction with ISM, or the AGN restarted after a very short time.

Central region

- Central region spectra show break at 1400 MHz, no ultra-steep spectrum from in any region
- 140-1400 MHz spectrum strongly affected by absorption (α~0.1), especially in inner lobes.
- Inner lobes a young CSS source with B_{eq}~116 microG, typical of CSS.
- Diffuse emission in W2 and E2 shows high frequency spectrum similar to the outer lobe. Open channel?

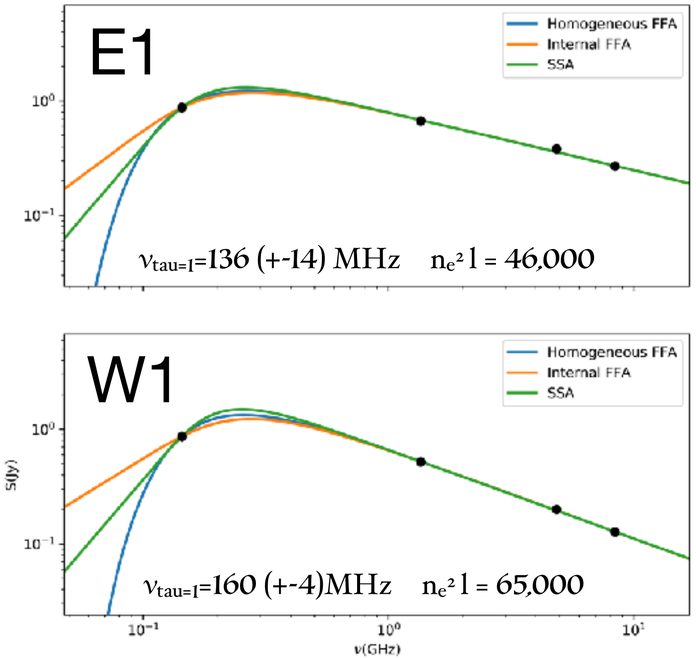


Inner lobes a young CSS source. Diffuse emission could be an open channel

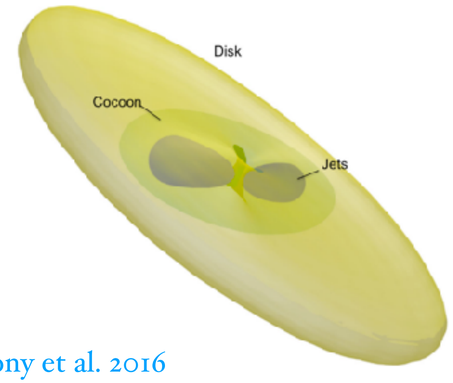


Absorption in inner lobes

- Free-free absorption and Synchrotron self absorption absorption models give a $\nu_{turnover} \sim 270$ MHz, CSS source.
- $\nu_{turnover}$ = 236 (+-40) MHz using size-frequency correlation for CSS/GPS sources.
- FFA gives higher $\nu_{tau=1}$ and emission measure for western region.
- Consistent with jet-ISM interaction traced by HI and ionised outflows
- SSA gives absurdly high magnetic field of B = 800G!



Our data suggests FFA is the dominant absorption mechanism and that western jet is receding! (work in progress)



Mahony et al. 2016

Summary

- Our analysis shows that the inner lobes are a young CSS source, with absorption likely due to FFA. The eastern jet is approaching and western receding. Diffuse emission on either side of inner lobes suggests that they could be an open channel for electrons from inner to outer lobes.

- 3C293 is not a typical restarted galaxy, as the core prominence and steep spectrum core would suggest.

- Either the AGN activity has either never stopped and the outer lobes are still powered by the centre.

- or AGN has stopped and restarted after a very short amount of time. Not enough time for the outer lobes to show curvature in our frequency range. Higher frequency observations of outer lobe are tough! (work in progress)

- LOFAR VLBI can let us investigate a young CSS source (4 kpc) with the large scale emission (200 kpc) simultaneously (even for a source 1.2° away from the phase centre)