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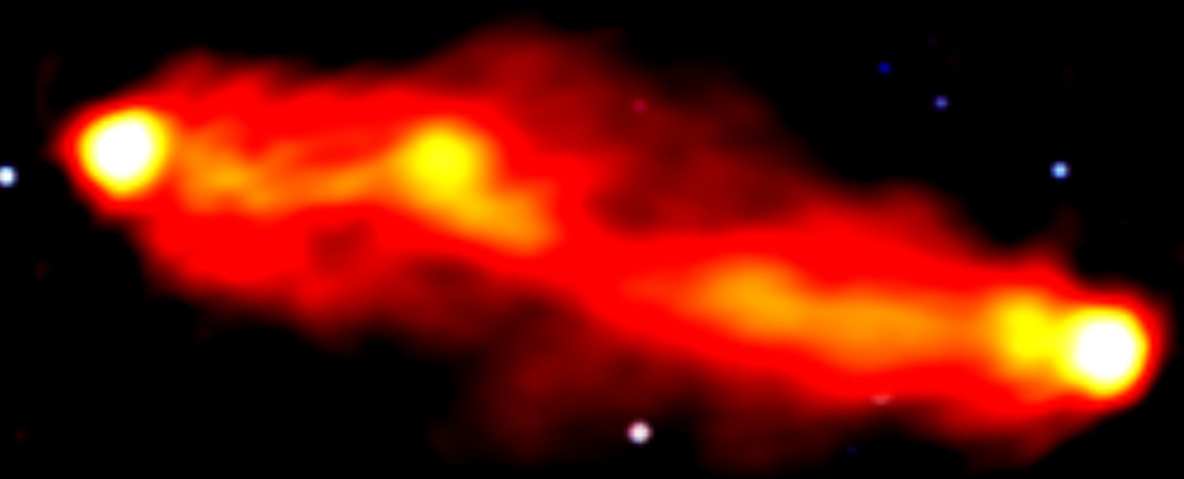
Netherlands Institute for Radio Astronomy

LOFAR

The low-energy electron population in the lobes of FR-II radio galaxies



Jeremy Harwood

LOFAR Status Meeting

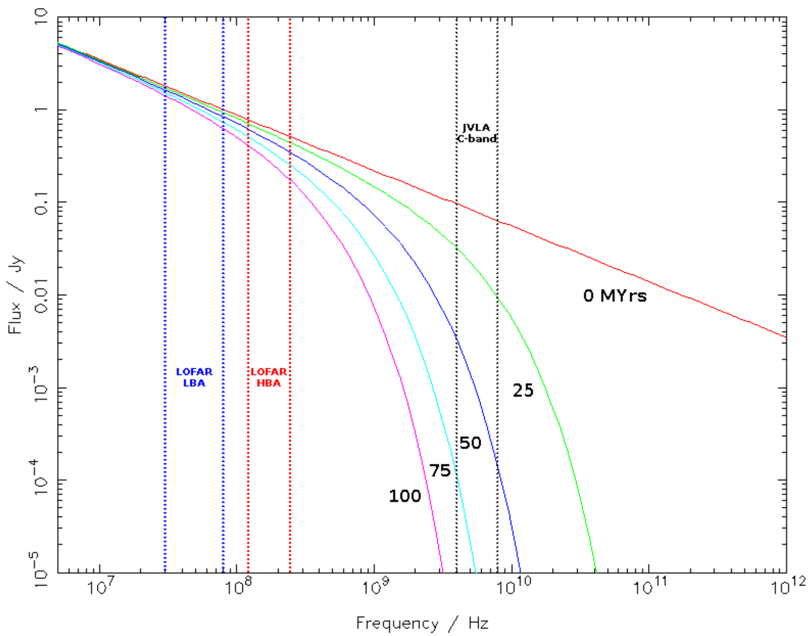
ASTRON, April 2015

Collaborators:

Martin Hardcastle (Hertfordshire)   Judith Croston (Southampton)   Raffaella Morganti (ASTRON)   Huib Intema (NRAO)
Adam Stewart (Oxford)   Marisa Brienza (RUG / ASTRON)   Leith Godfrey (ASTRON)   LOFAR nearby AGN KSP team

Spectral ageing and its parameters

$$I_{\nu}(t) = 4\pi C_3 N_0 sB \int_0^{\pi/2} d\theta \sin^2\theta \int_0^{1/E_T} dEF(x)E^{-\delta}(1-E_T E)^{\delta-2}$$



- The shape of the energy spectrum can give key insights into the underlying physics of a radio source
- Particles undergo shock acceleration (e.g. the hotspots in FR-IIs)
- Preferential cooling of higher energy electrons (spectral ageing)
- This leads to a more strongly curved spectrum in older regions of plasma
- δ (or the observable α_inj) describes the initial electron energy distribution

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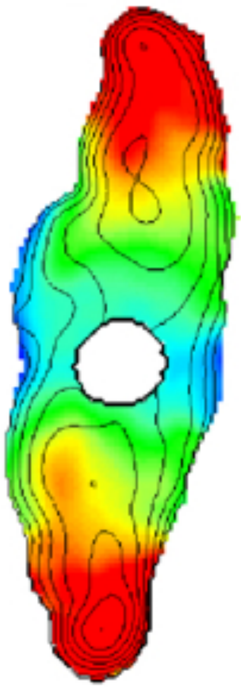
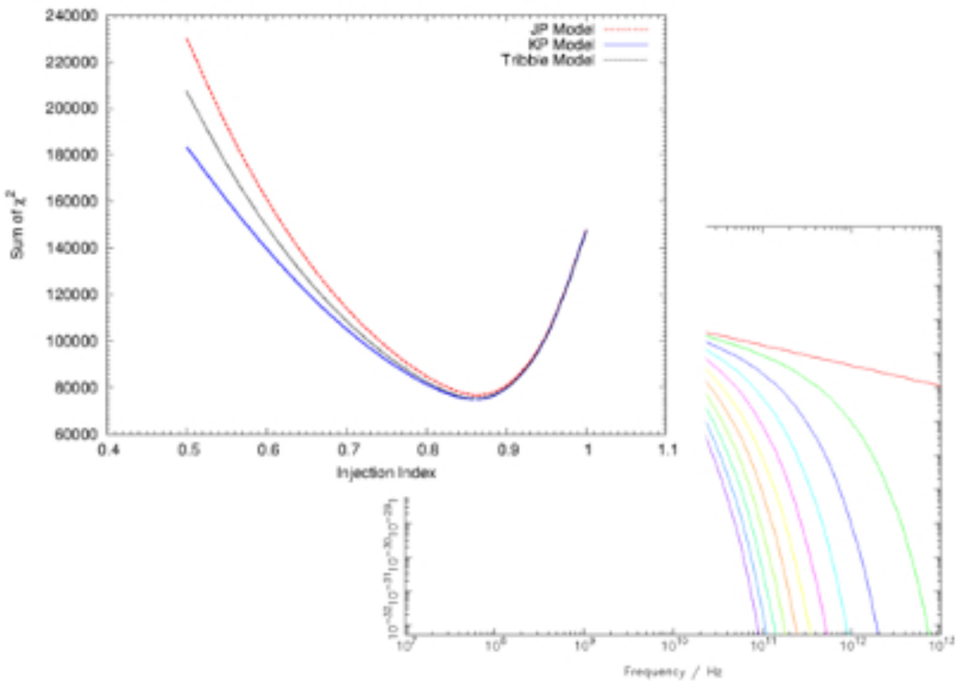
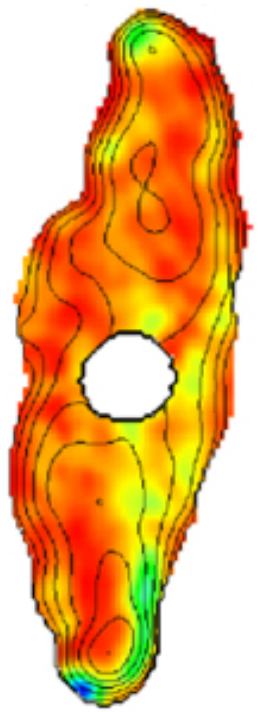
BRATS: Broadband Radio Astronomy ToolS

Spectral analysis software for the new generation of broadband of radio telescope





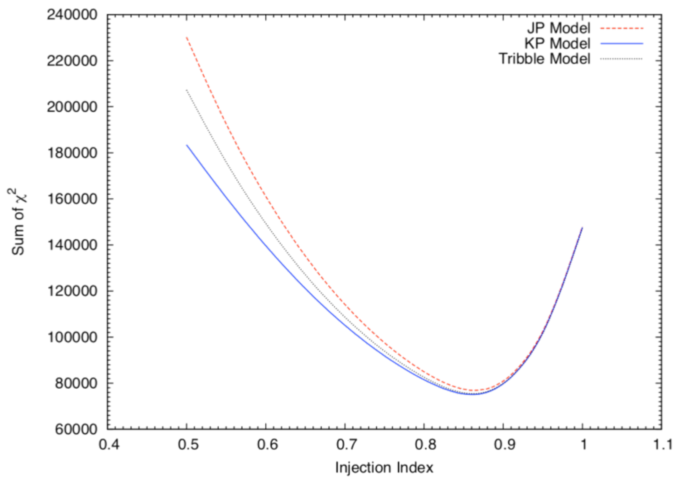


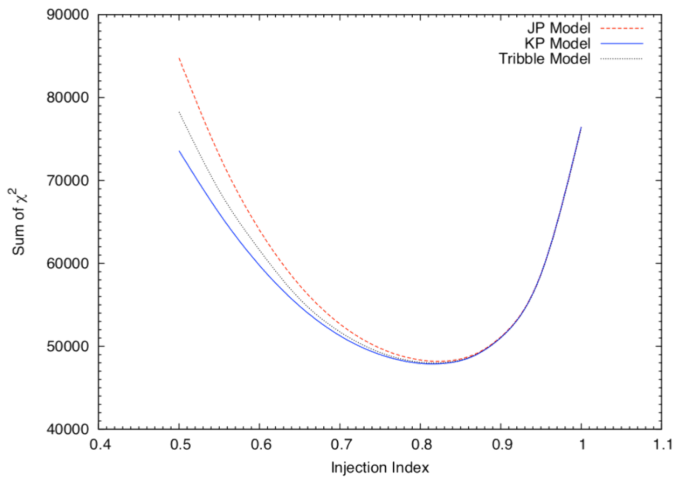
http://www.askanastronomer.co.uk/brats

Injection index minimization

- Standard assumption comes from shock theory and / or obseravation of shock regions
- The spectral index found to sometimes be unreliable measure (Stroe+ 14)
- BRATS sets the injection index as a free variable and minimizes the chi-squared
- Uses all of the source rather than just a small acceleration region
- Tests against simulated data show it can reliably recover the injection index to a high level of accuracy (Stroe+ 14)

What do we know so far? (Harwood et al. 2013)





- **First spectral ageing analysis on small spatial scales using broad bandwidth data**
- **Intermediate stage of the JVLA upgrade**
- **Many assumptions which go in to these models may be wrong**
- **Injection index found to be higher than assumed (~0.8 vs. 0.6)**

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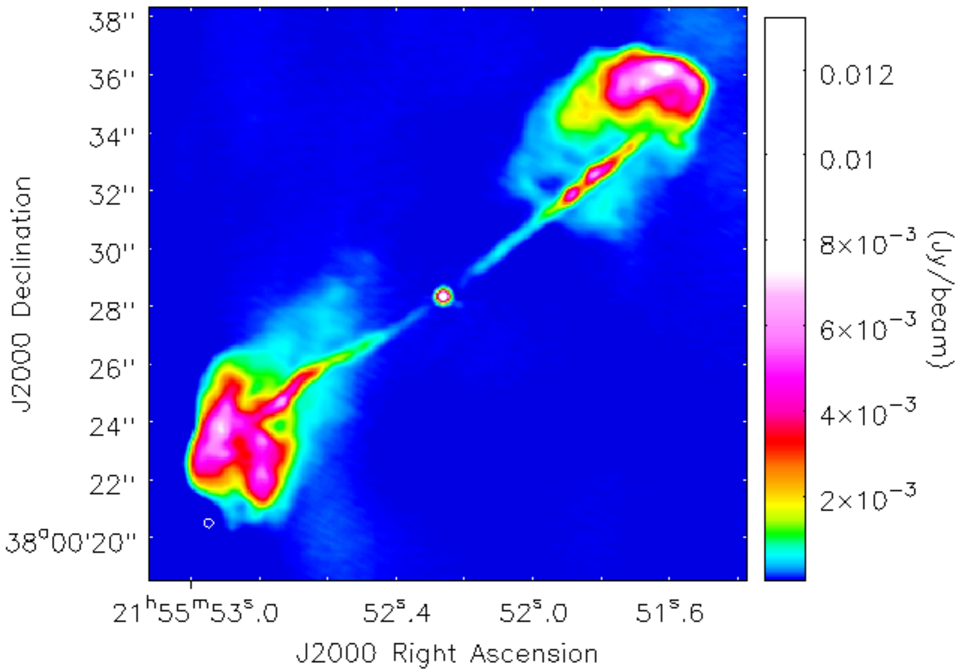
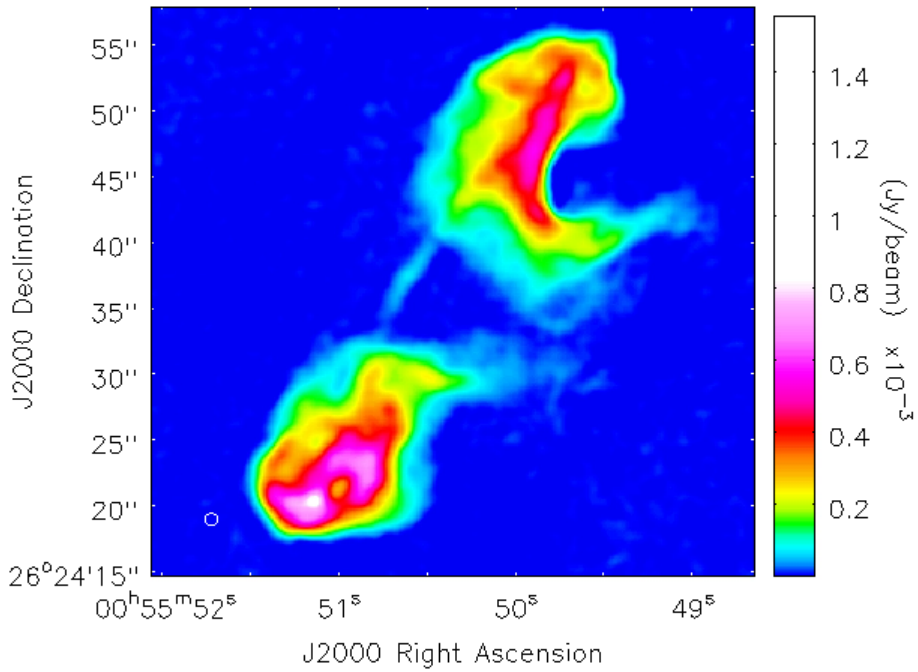
3C438 and 3C28 with the JVLA



3C438 – 0.3” beam
4 GHz bandwidth at 6 GHz



3C28 – 1” beam
4 GHz bandwidth at 6 GHz

Injection index (3C438 and 3C28, in prep)

Table 5. Best fitting injection indices and magnetic field strengths

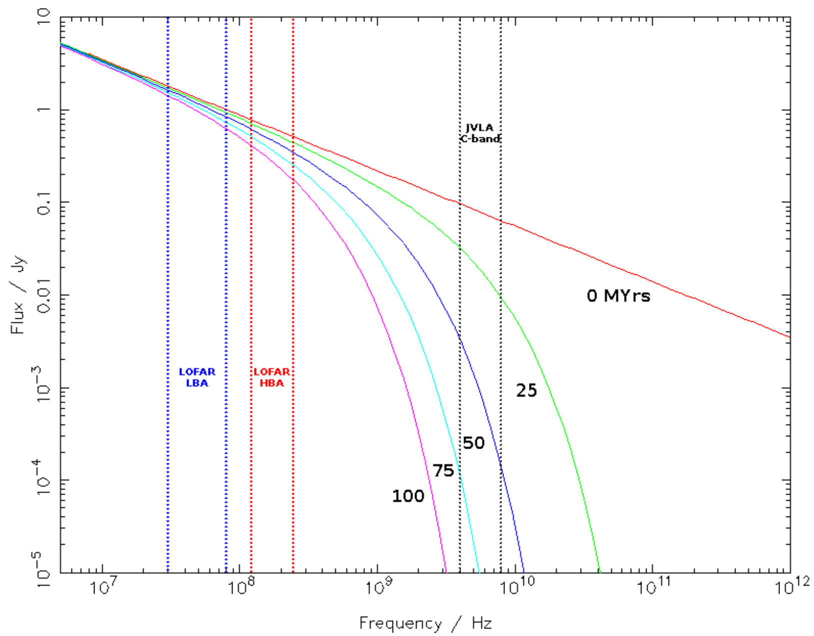
Source	Model	Injection Index	Error +	Error -	Magnetic Field Strength (nT)
3C438	JP	0.84	0.01	0.01	4.02
	KP	0.78	0.01	0.01	3.65
	Tribble	0.82	0.01	0.01	3.89
3C438	JP	0.80	0.01	0.01	3.77
(No Jet)	KP	0.72	0.01	0.02	3.34
	Tribble	0.77	0.01	0.01	3.60
3C28	JP	1.21	0.01	0.01	1.35
	KP	1.12	0.02	0.02	1.12
	Tribble	1.17	0.02	0.01	1.22

Best fitting injection indices for 3C438 and 3C28 and magnetic field strengths. 'No Jet' indicates the best fitting injection index values where emission coincident with the assumed location of the jet is excluded (Section 2.4.1 and 3.1). Errors are determined using the methods of Avni (1976) detailed in Section 2.4.3.

- **Remain higher than previously assumed**
- **3C438 in the range of Harwood+ 13**
- **3C28 has a very high injection index**
- **Integrated spectral index known to be high (> 1)**
- **Most likely a relic source**

Powerful radio galaxies and LOFAR

- **Excellent for determining the injection index due to low curvature**
- **Constrain the low-energy electron population (synchrotron / IC fitting)**
- **Low frequency observations are able to probe previously unseen emission**



	3C223	3C452
Redshift	0.137	0.081
LAS	306 arcsec	280 arcsec
Physics size	740 kpc	428 kpc

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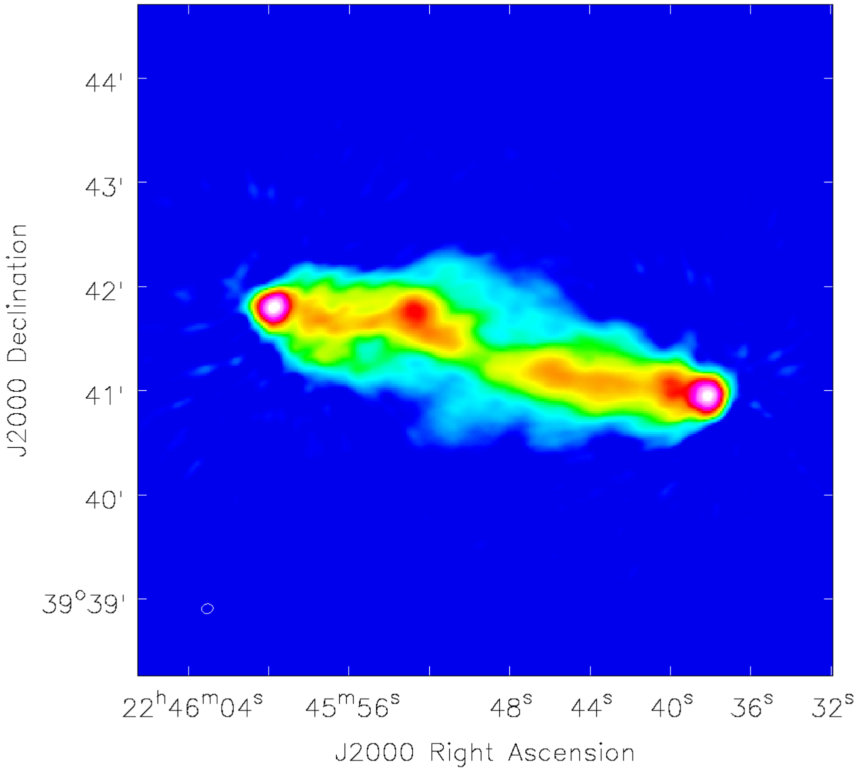
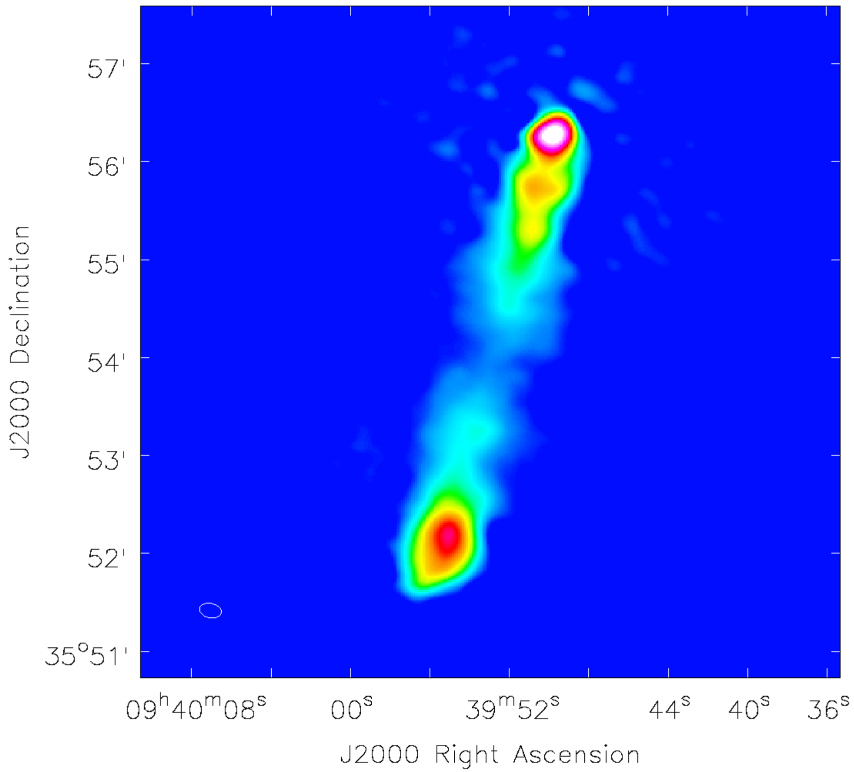
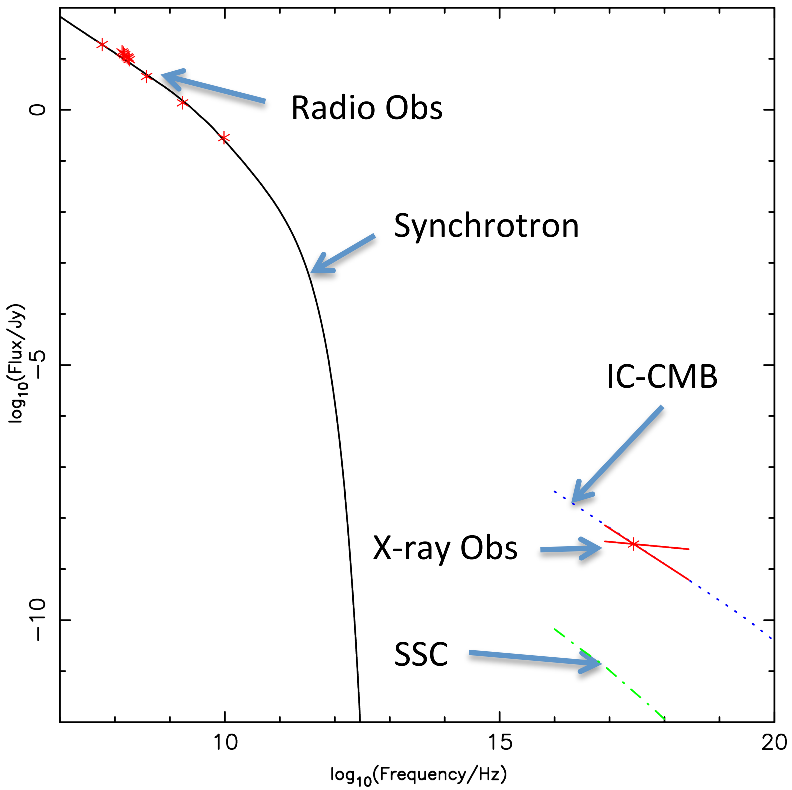


3C452 – 6” beam
48 MHz bandwidth at 138 MHz



3C223 – 10” beam
7 MHz bandwidth at 147 MHz

Synchrotron / IC modelling



- **Spectral / injection index ~0.8 for both sources**
- **Synchrotron / IC CMB modelling can determine the total energy content of the lobes (e.g. Croston et al. 2004, 2005)**
- **3C223 is a factor of 2 larger than previously thought (Croston et al., 2004)**
- **3C452 is a factor of 5 larger than previously though (Croston et al., 2005)**

What does this mean for FR-IIs?

Table 7. Summary of lobe pressures

Source	Lobe	P_{lobe} (J m^{-3})	P_{ext} (J m^{-3})	*Ratio*
3C452	Total	4.3×10^{-13}	1.11×10^{-13}	3.94
3C223	Northern	9.3×10^{-14}	9.6×10^{-14}	0.97
	Southern	1.1×10^{-13}	9.6×10^{-14}	1.15

- **The lobes of 3C223 are brought back into pressure balance (vs. Croston 2004)**
- **The lobes of 3C452 are highly over pressured**
- **Double the estimate from X-ray measurement (Shelton et al. 2011)**
- **The same assumption of flattening has been applied to larger samples**

Summary

- The injection index is higher than previously assumed (~0.8 vs. 0.6)
- The total energy is higher that previously found by a factor of 2 – 5
- 3C223 brought back in to pressure balance
- 3C452 significantly over pressured
- BRATS software package http://www.askanastronomer.co.uk/brats
- Many other interesting results from these 2 new papers! Come and talk to me if you're interested

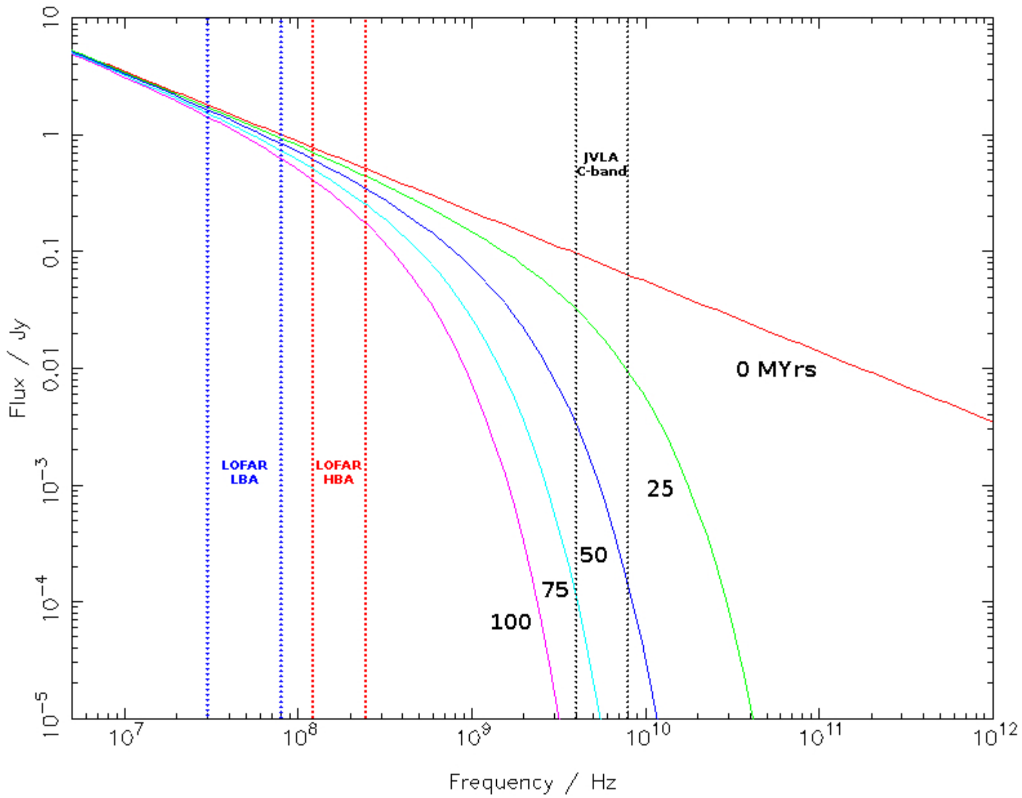
What can BRATS do?

- Fitting of spectral ageing models to sources on small spatial scales
- Injection index determination (spectral index is often not the best way!)
- Spectral index / polynomial fitting, combining maps in the image plane, resizing images, difference maps… plus much more
- If you plan on doing a spectral ageing analysis, come and talk to me
- Available to download from the website, including cookbook, tutorial etc.
- http://www.askanastronomer.co.uk/brats

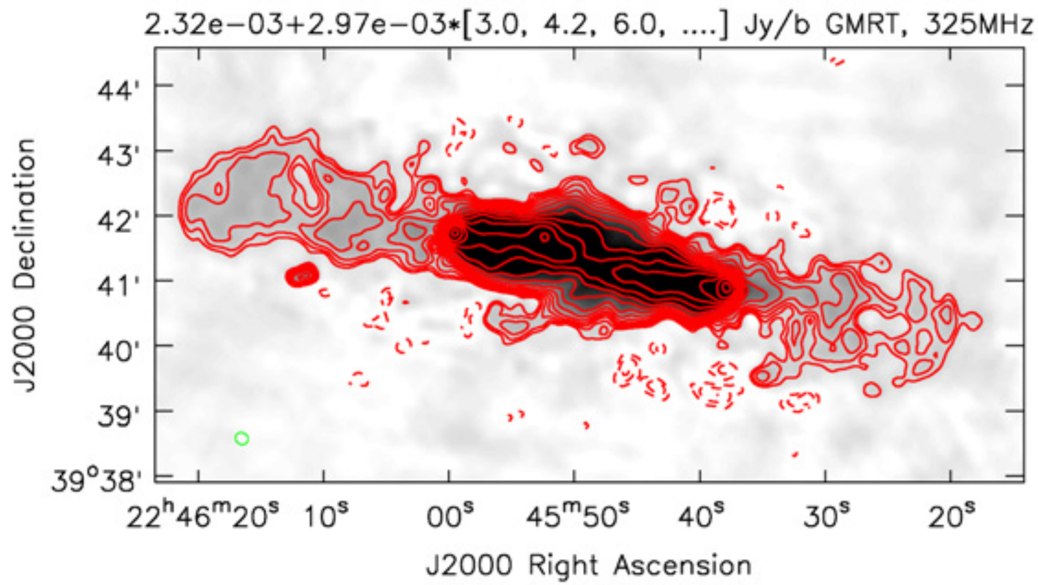
Powerful radio galaxies and LOFAR

- **Excellent for determining the injection index due to low curvature**
- **Constrain the low-energy electron population (synchrotron / IC fitting)**
- **Low frequency observations are able to probe previously unseen emission**
- **Test the claim that 3C452 is a DDRG**

	3C223	3C452
Redshift	0.137	0.081
LAS	306 arcsec	280 arcsec
Physics size	740 kpc	428 kpc

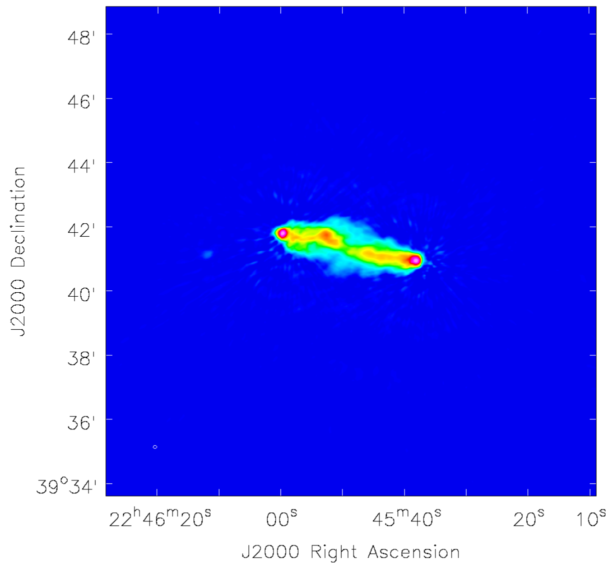


Example JP model between 0 and 100 MYrs
with various frequency bands noted

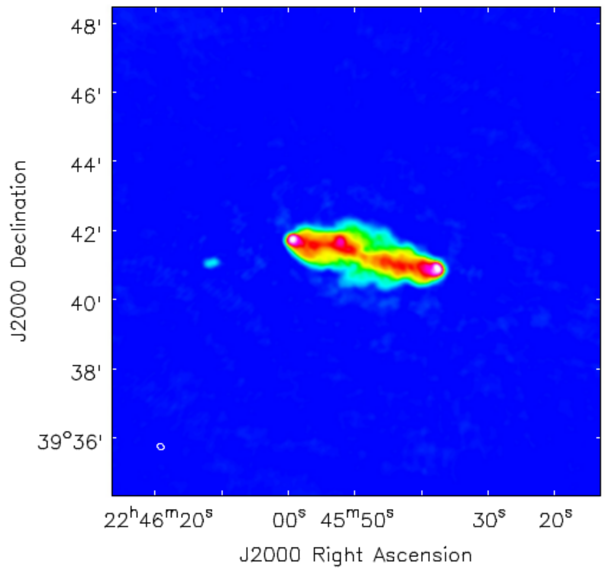


GMRT - 11" beam
32 MHz bandwidth at 325MHz (Sirothia, 2013)

- **Paper published in 2013 claiming 3C452 was a DDRG (Sirothia et al.)**
- **Using a (very) conservative estimate of alpha = 0.5 and extrapolating the 3 sigma contour of Sirothia et al. the relic emission should have a surface brightness of 17 mJy / beam at 116 MHz**
- **If we assume Sirothia's spectral index of 2.3, this increases to 107 mJy / beam!**

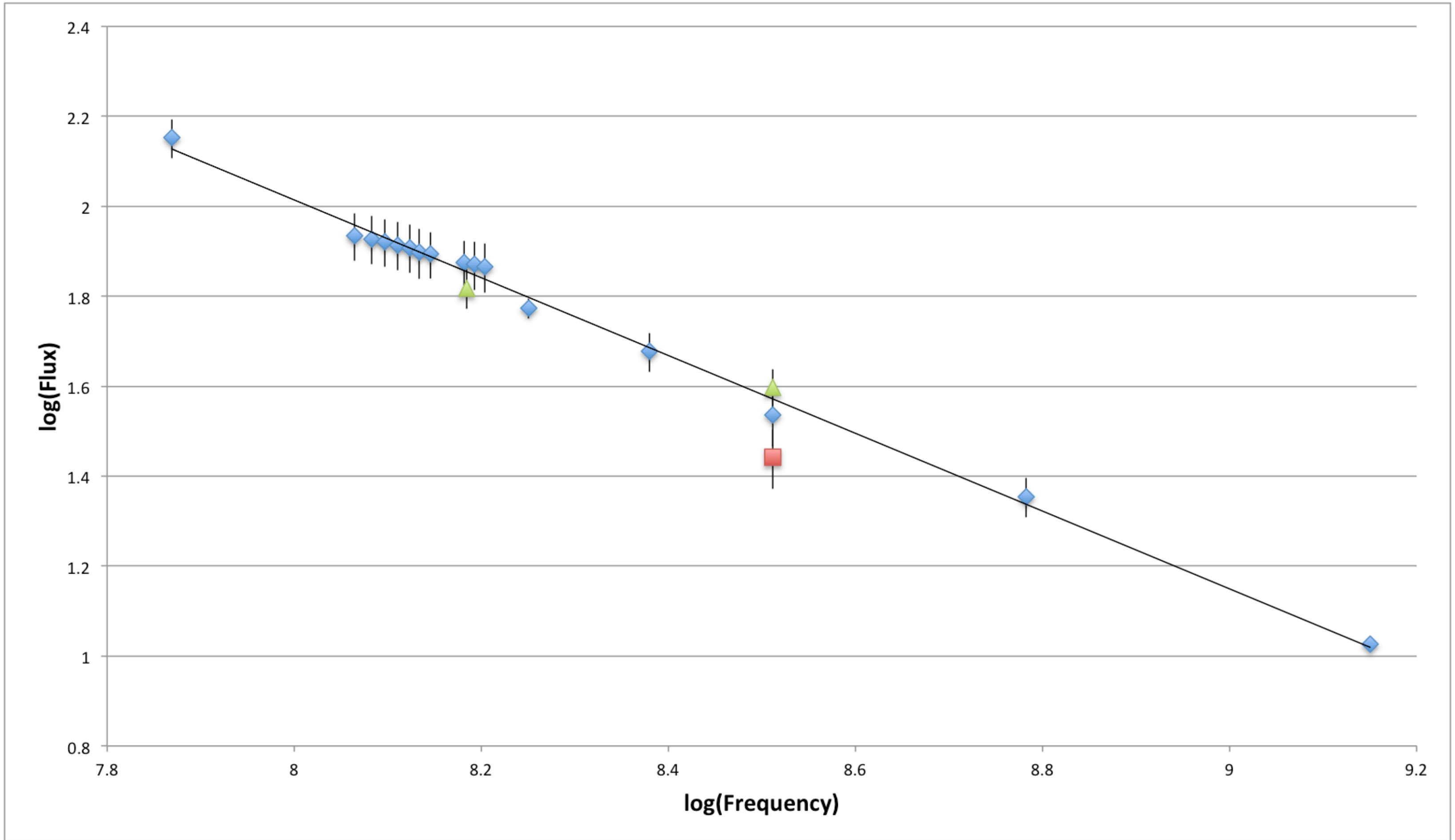


LOFAR - 6” beam
48 MHz bandwidth at 138 MHz



Reprocessed GMRT - 11” beam
32 MHz bandwidth at 325MHz

- **No sign of the relic lobes at LOFAR HBA frequencies**
- **We have reprocessed the GMRT data and it is not observed at either 325 or 150 MHz**
- **Not seen at low-frequencies with the JVLA (Rick Perley)**



3C452 74 MHz to 1.4GHz spectrum

Imaging results (3C452 / 3C223)

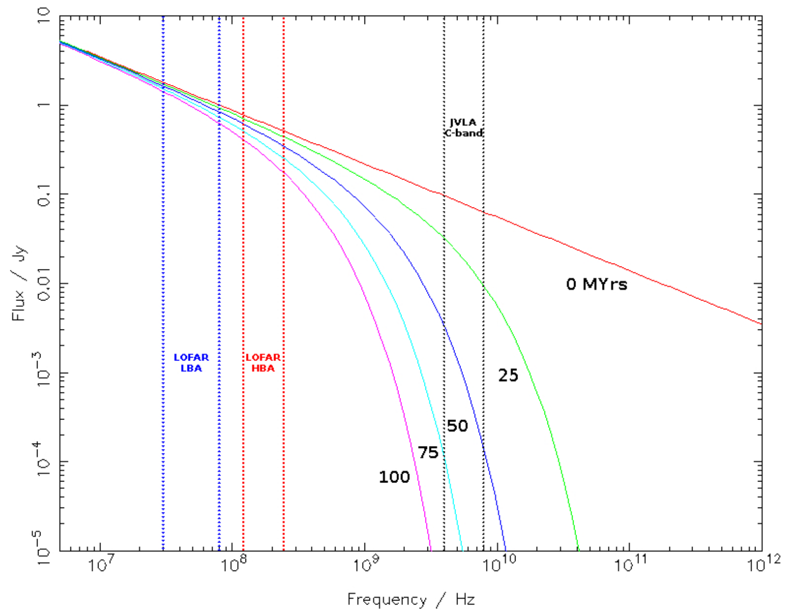
	Freq. (MHz)	Flux (Jy)	RMS (mJy/beam)
3C452	116	85.0	2.0
3C452	160	73.5	1.2
3C452 (Full BW)	138	79.28	0.45
3C223	119	24.9	1.9
3C223	160	18.2	1.1
3C223 (Full BW)	147	19.97	0.48

- **Integrated fluxes are in good agreement with the literature**
- **Injection index is again higher (~0.8 for both sources)**
- **Synchrotron / IC CMB modelling can determine the total energy content of the lobes (e.g. Croston et al. 2004, 2005)**

Other results for 3C438 / 3C28

- Dynamical and spectral ages of 3C438 agree well
  - Most likely due to its young age (~3-4 Myrs)
- 3C28 is an FR-II, not an FR-I as has sometimes been assumed…
- … although it is most likely in a off phase
- Cross-lobe variations are important to spectral age fitting
- Tribble model again provides the best balance between goodness-of-fit and physical plausibility
- Matched resolution, broad bandwidth observations at L, C and K bands will provide a conclusive answer to the physical plausibility problem

What is spectral ageing?



Example JP model between 0 and 100 Myrs with various frequency bands noted

- **The shape of the energy spectrum can give key insights into the underlying physics of a radio source**
- **Particles undergo shock acceleration (e.g. the hotspots in FR-IIs)**
- **Preferential cooling of higher energy electrons (spectral ageing)**
- **This leads to a more strongly curved spectrum in older regions of plasma**
- **If we can determine an accurate model we can determine the age, hence total power, of a source**