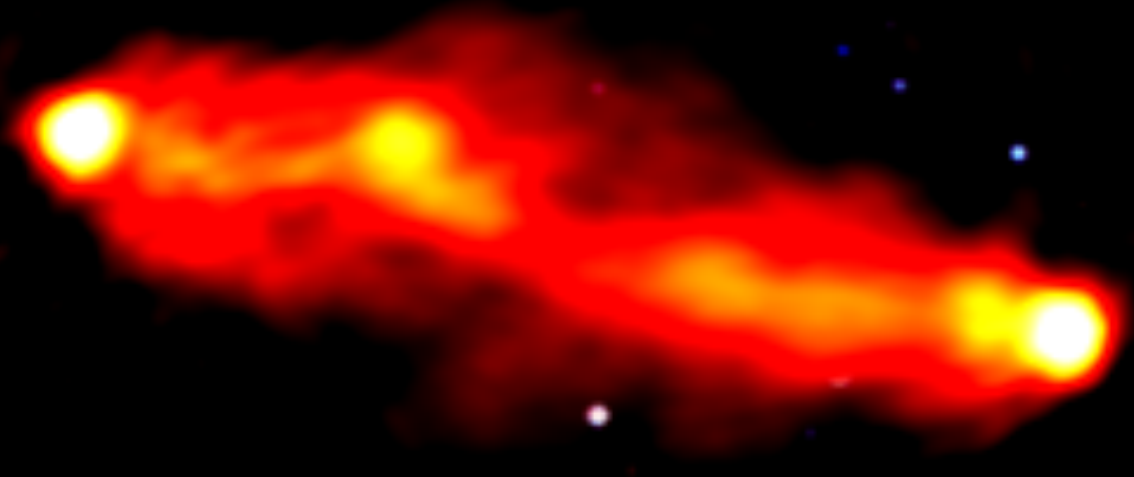# The systematic spectral analysis of radio surveys

Jeremy Harwood
The many facets of extragalactic radio surveys: towards new scientific challenges
Bologna, October 2015

Collaborators:

Raffaella Morganti (ASTRON)   Martin Hardcastle (Hertfordshire)   Judith Croston (Southampton)   Huib Intema (Leiden)
Volker Heesen (Southampton)   Aleksandar Shulevski (ASTRON)   Marisa Brienza (RUG / ASTRON) & the LOFAR nearby AGN KSP team
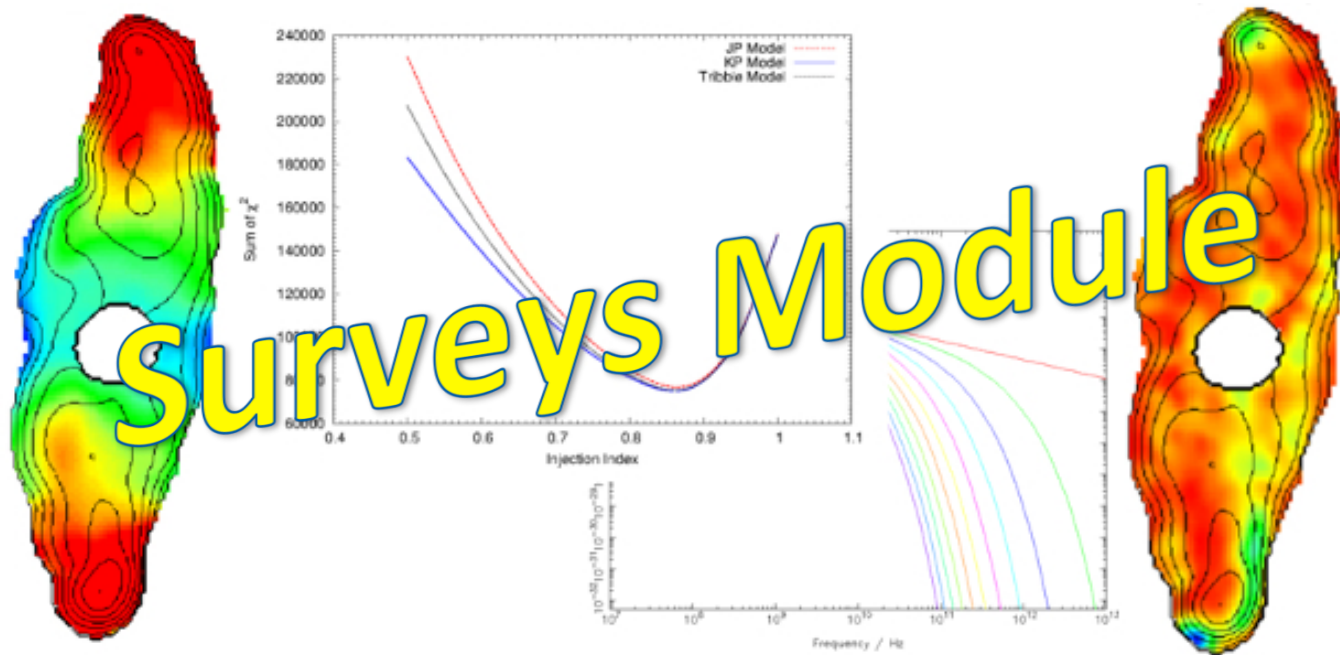
The systematic spectral analysis of radio surveys

- **How do we systematically characterize and investigate sources and populations in these vast volumes of data?**

- **A wide range of previously unexplored and unusual objects, such as giant radio galaxies and relic systems**

- **Analysis of their spectrum remains a largely manual process**

- **Automation is required as detection of these objects becomes more common in surveys and for determining the spectrum of large samples**

- **Currently developing a surveys module for the BRATS software package**

Described in Harwood et al. 2013, 2015

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

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What can BRATS do?

- **Primary purpose was the fitting of spectral ageing models to sources on small spatial scales but has now expanded to do much more...**

- **Spectral index, polynomial fitting, colour-colour plots, parameter determination**

- **Combining maps in the image plane, resizing images, difference maps, plus much more**

- **Self contained with a user interface. No need to write or modify any code**

- **Versions for Mac and Linux (incl. cluster environments)**

- **Available to download from the website, including cookbook, tutorial etc.**

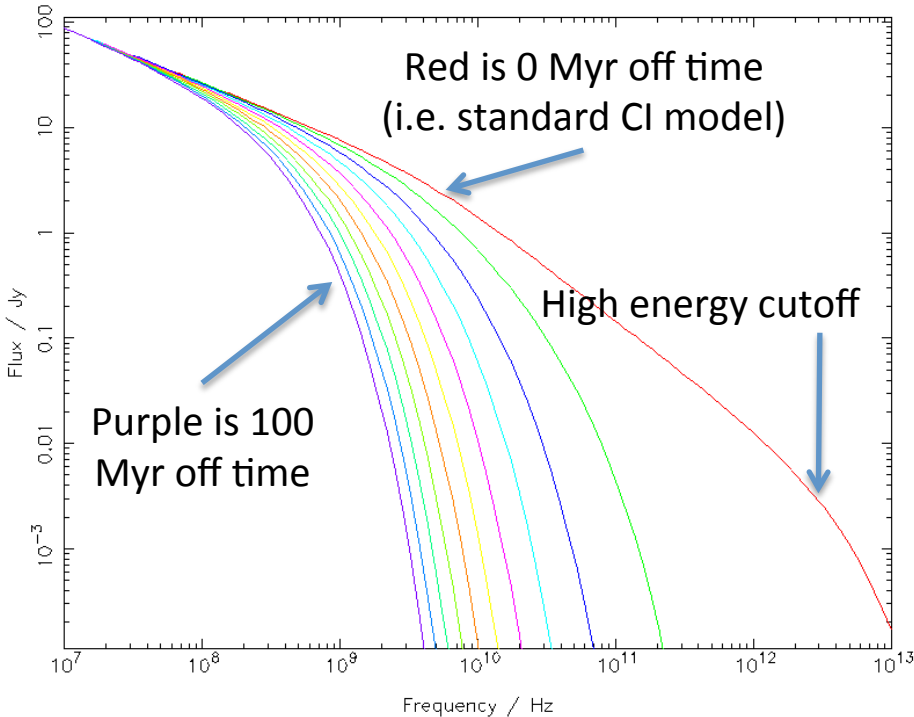- **http://www.askanastronomer.co.uk/brats**

What is spectral ageing?
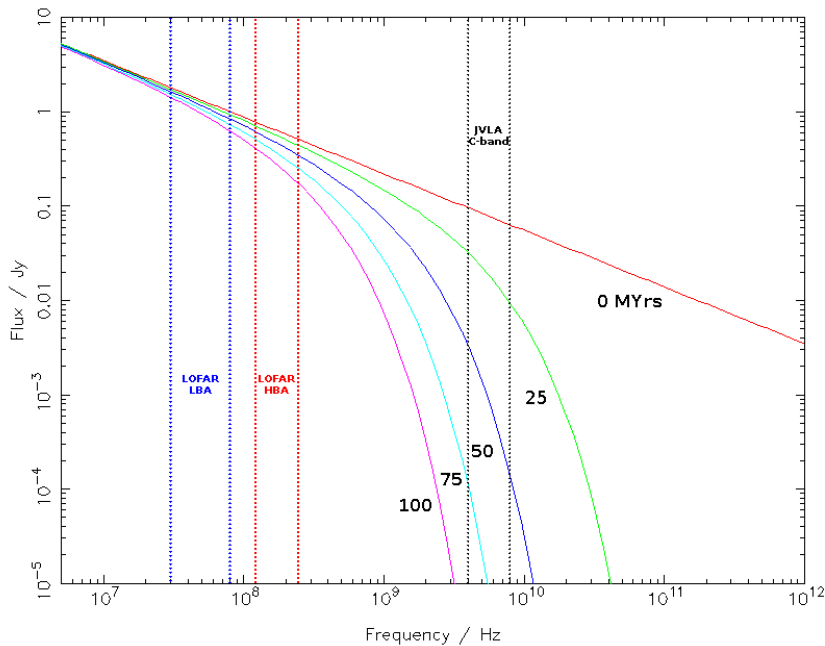
Example JP model between 0 and 100 Myr with various frequency bands noted

- 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

Fitting to the integrated flux

Red is 0 Myr off time
(i.e. standard CI model)

High energy cutoff

Purple is 100
Myr off time

Flux / Jy

Frequency / Hz

CI off (Komissarov-Gubanov, KGJP) model with an off time
of between 0 and 100 Myr (active phase of 30 Myr)

- **May be necessary due to:**
  - **Unresolved in the survey**
  - **Unresolved in the complementary data**
  - **Non-detections at higher frequencies**
  - **Unable (or too time intensive) to obtain images matched in beam size etc.**

- **These sources will form a large fraction of any survey**

- **Continuous injection (CI) models are the most common method of fitting to the integrated flux**

BLOB1 (Brienza et al. 2014)
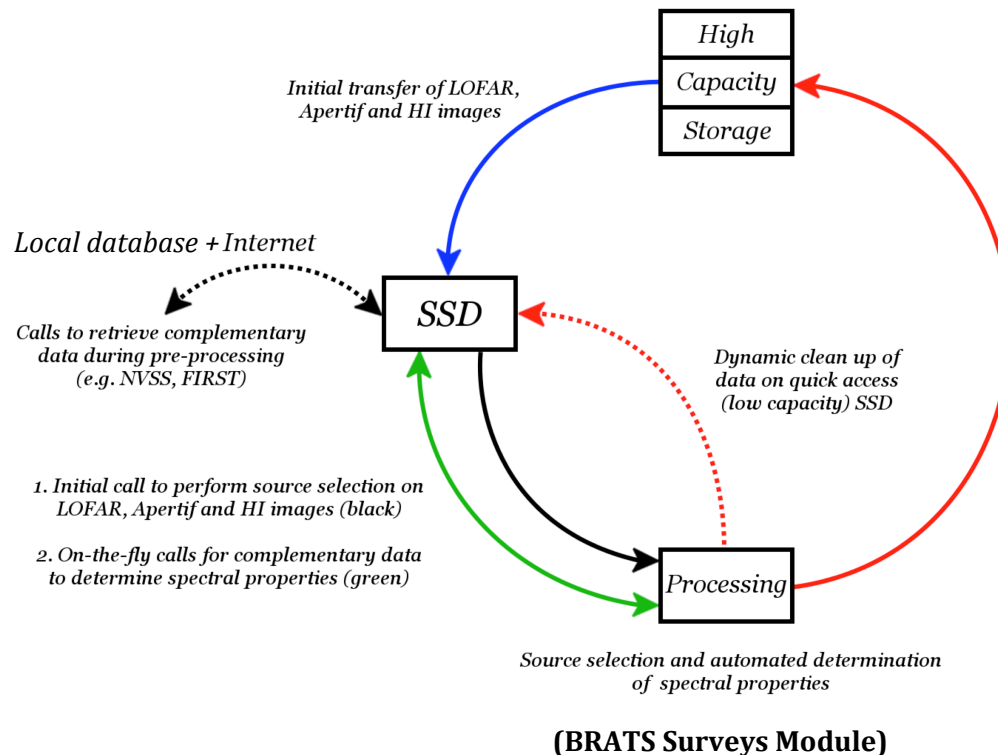
LOFAR HBA at 137 MHz, 22" beam
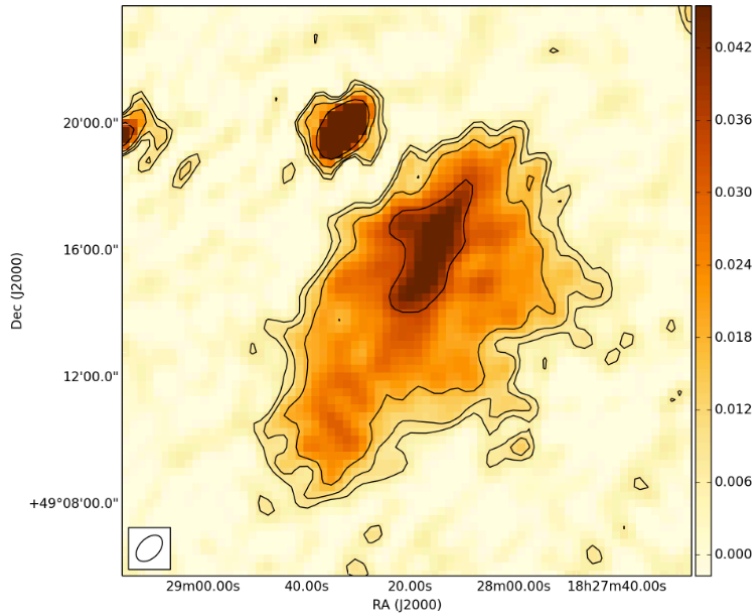
Best fitting age: 16 Myrs (on) 60 Myrs (off)
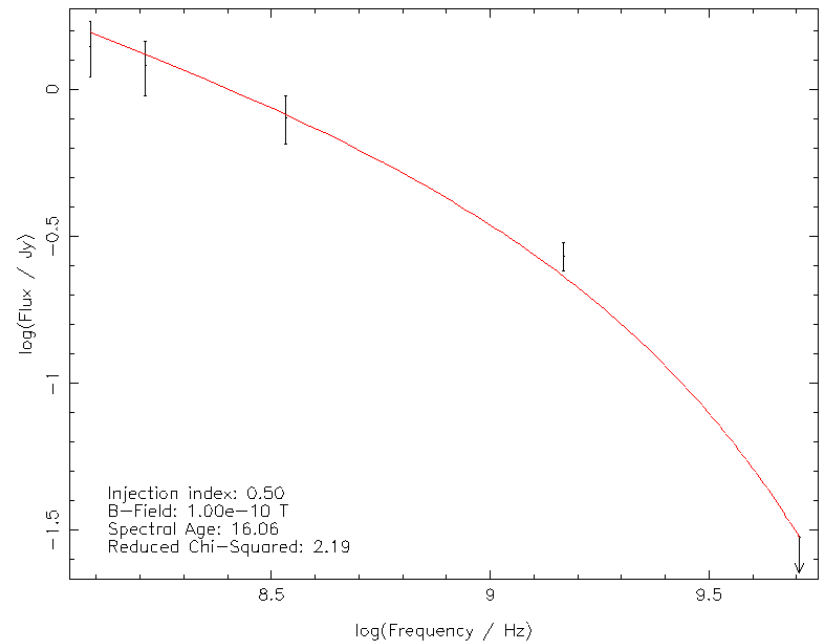
- **Current (beta) version currently has 2 CI models, standard CI and CI off (KGJP)**

- **Determine whether a source is likely to be active or not, upper limits are not a problem**

Surveys Processing Flow Diagram

Initial transfer of LOFAR, Apertif and HI images

Local database + Internet

Calls to retrieve complementary data during pre-processing (e.g. NVSS, FIRST)

High Capacity Storage

SSD

Dynamic clean up of data on quick access (low capacity) SSD

1. *Initial call to perform source selection on LOFAR, Apertif and HI images (black)*
2. *On-the-fly calls for complementary data to determine spectral properties (green)*

Processing

Source selection and automated determination of spectral properties

(BRATS Surveys Module)

- **Provides a way to systematically analyse a large number of sources**

- **Selecting candidates for a more detailed analysis**

- **Population studies e.g. determining if a source is likely to a relic**

- **Release timeline:**
  - **Phase 1: Fitting to individual sources, available in the beta version**
  - **Phase 2: Survey fitting from a local database, available in next full release (early 2016)**
  - **Phase 3: Fully automated complementary data retrieval, release date TBC**

- **If you would like to use it prior to public release (i.e. the non-user friendly version) get in touch**

Pros and cons of integrated fitting


60 – 150 MHz
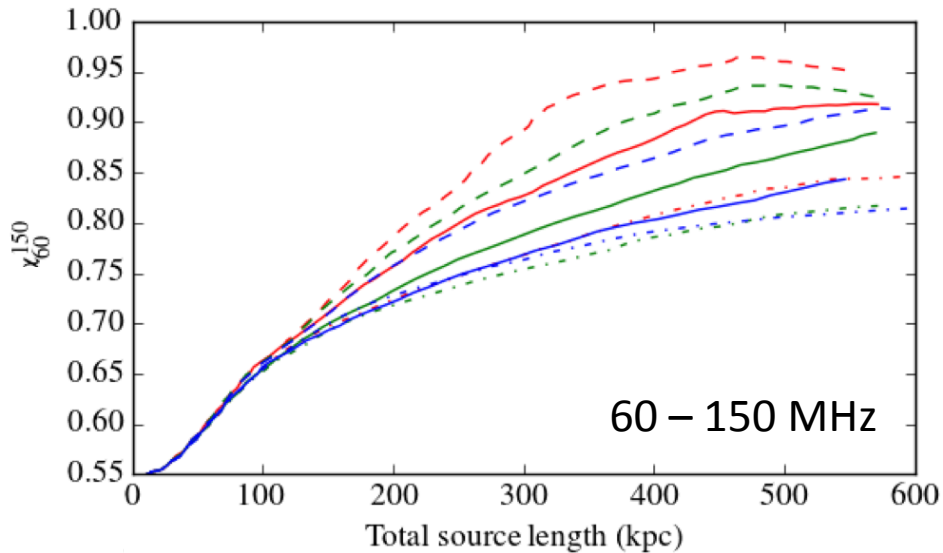
Integrated spectral index as a function source length (from simulations)

Hardcastle et al. (in prep)

- **Advantages:**
  - **Very fast (< a few seconds per source)**
  - **Only requires integrated flux values**
  - **Doesn't require the original maps**
  - **Can handle upper limits**
  - **Can be useful for source selection**

- **Disadvantages:**
  - **Unable to determine age variations as a function of position**
  - **For large samples, generic assumptions must be made**
  - **Reliability of CI type models is not clear**
  - **Unable to reliably recover model parameters**

# Moving to higher resolutions
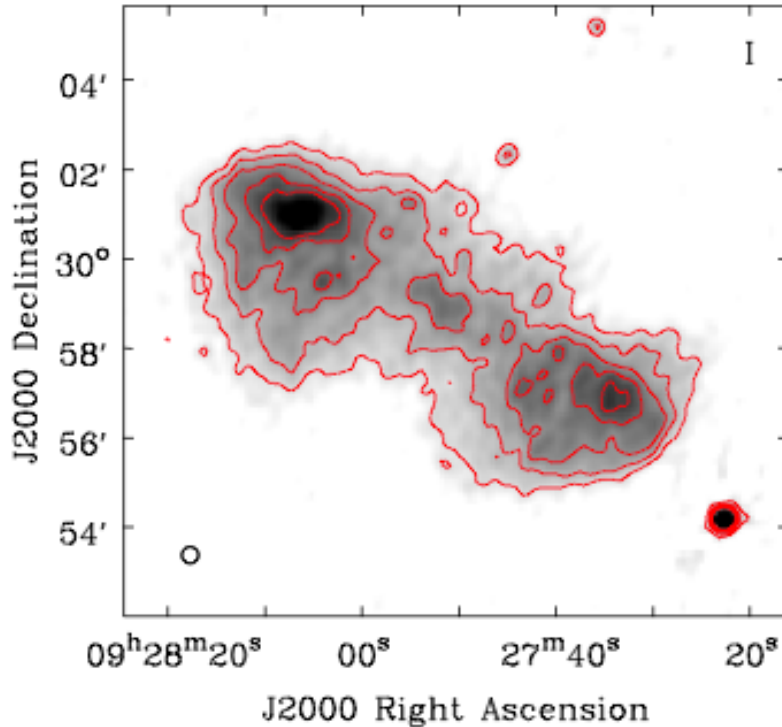
B2 0924+30 (Shulevski et al, in prep)
LOFAR HBA at 140 MHz, 22" beam

- Region selection based on user parameters

- Fitting of JP, KP and Tribble models

- Can determine how the age (or other model fit) varies as a function of position

- The number of assumptions required is reduced e.g. constant parameters over its history

- Model parameters can be investigated in greater detail

Radio Relic B2 0924+30 (Shulevski et al, in prep)
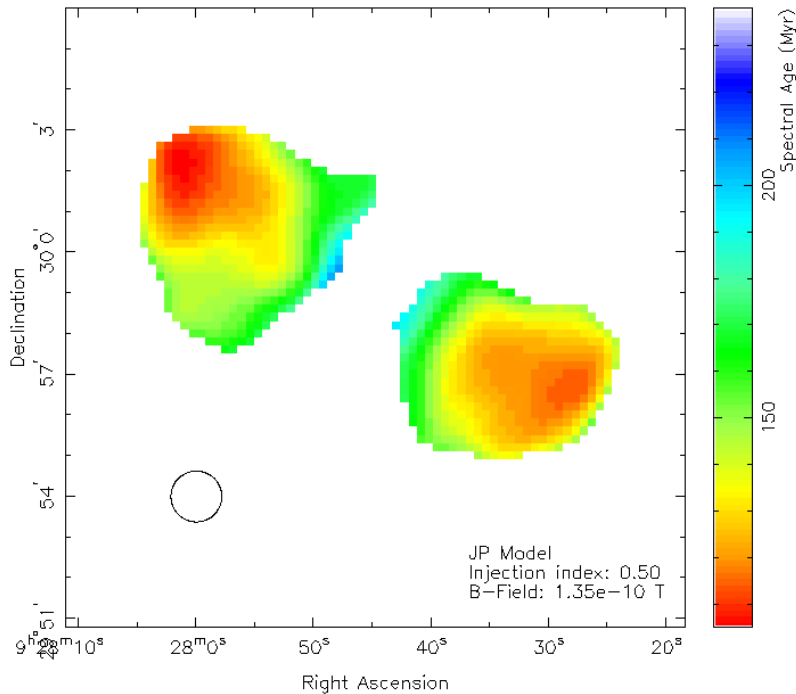
BRATS spectral ageing map
(LOFAR + WSRT + NVSS)

- **Example of being limited by complementary data**

- **~1000 regions, 7 frequencies, < 30 minute run time with 2 cores**

- **Can infer galaxy type during its active phase e.g. 'ghost hotspots'**

- **Integrated flux (new observations + literature), $\alpha_{inj} > 0.85$**

- **From resolve study $\alpha_{inj} < 0.72$**

Spectral ageing in the lobes of cluster-centre FR-II radio galaxies

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22 September 2015

ABSTRACT

Recent investigations have shown that many parameters and assumptions made in the application of spectral ageing models to FR-II radio galaxies (e.g. injection index, uniform magnetic field, non-negligible cross-lobe age variations) may not be as reliable as previously thought. In this paper we use new VLA observations, which allow spectral curvature at GHz frequencies to be determined in much greater detail than has previously been possible, to investigate two cluster-centre radio galaxies, 3C438 and 3C28. We find that for both sources the injection index is much steeper than the values traditionally assumed, consistent with our previous findings. We suggest that the Tribble model of spectral ageing provides the most convincing description when both goodness-of-fit and physically plausibility are considered, but show that even with greatly improved coverage at GHz frequencies, a disparity exists in cluster-centre FR-IIs when spectral ages are compared to those determined from a dynamical viewpoint. We find for 3C438 that although the observations indicate the lobes are expanding, its energetics suggest that the radiating particles and magnetic field at equipartition cannot provide the necessary pressure to support the lobes, similar to other cluster-centre source such as Cygnus A. We confirm that small scale, cross-lobe age variations are likely to be common in FR-II sources and should be properly accounted for when undertaking spectral ageing studies. Contrary to the assumption of some previous studies, we also show that 3C28 is an FR-II (rather than FR-I) source, and suggest that it is most likely a relic system with the central engine being turned off between 6 and 9 Myrs ago.
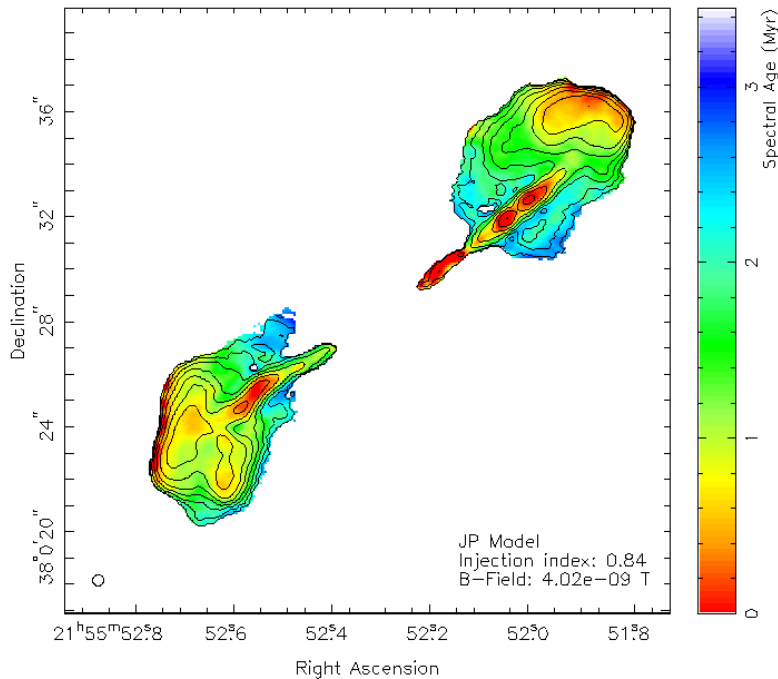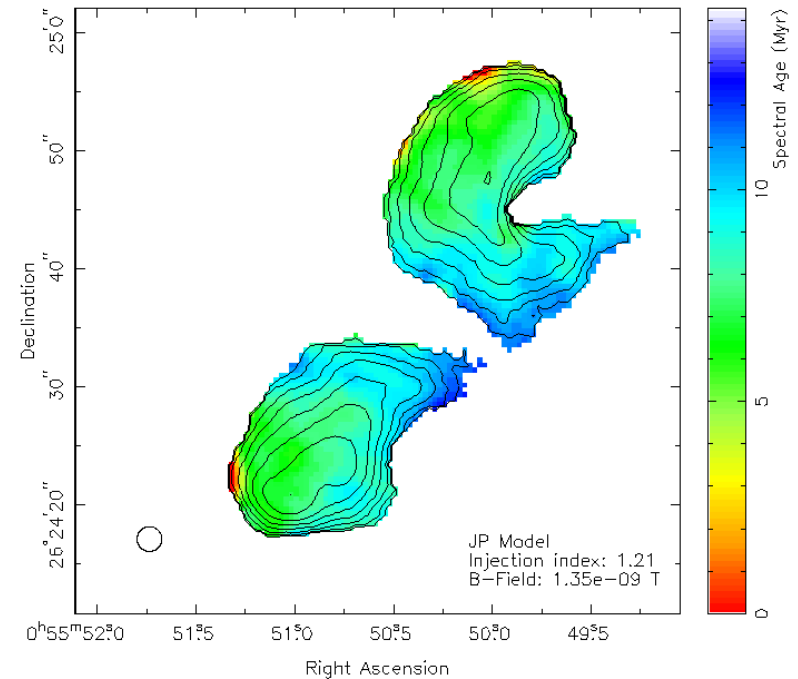
MNRAS 2015, 454, 3403
http://arxiv.org/abs/1509.06757
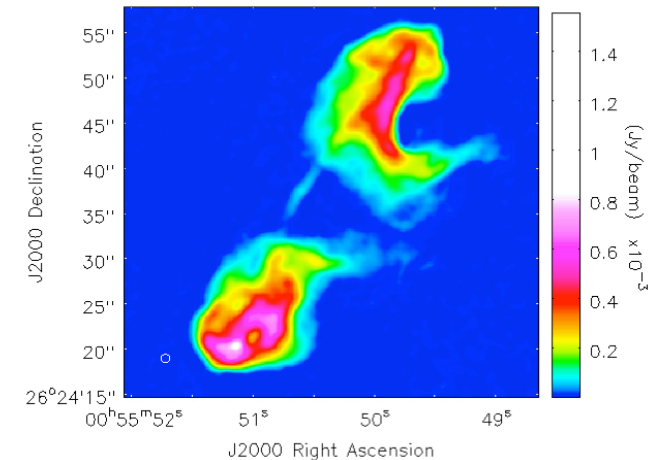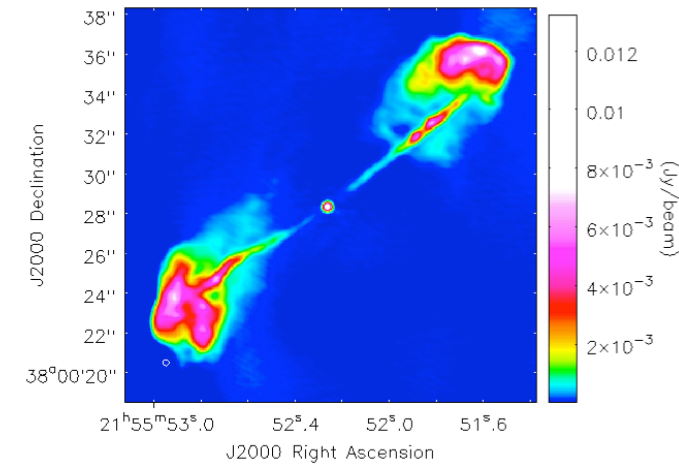
Well resolved fitting
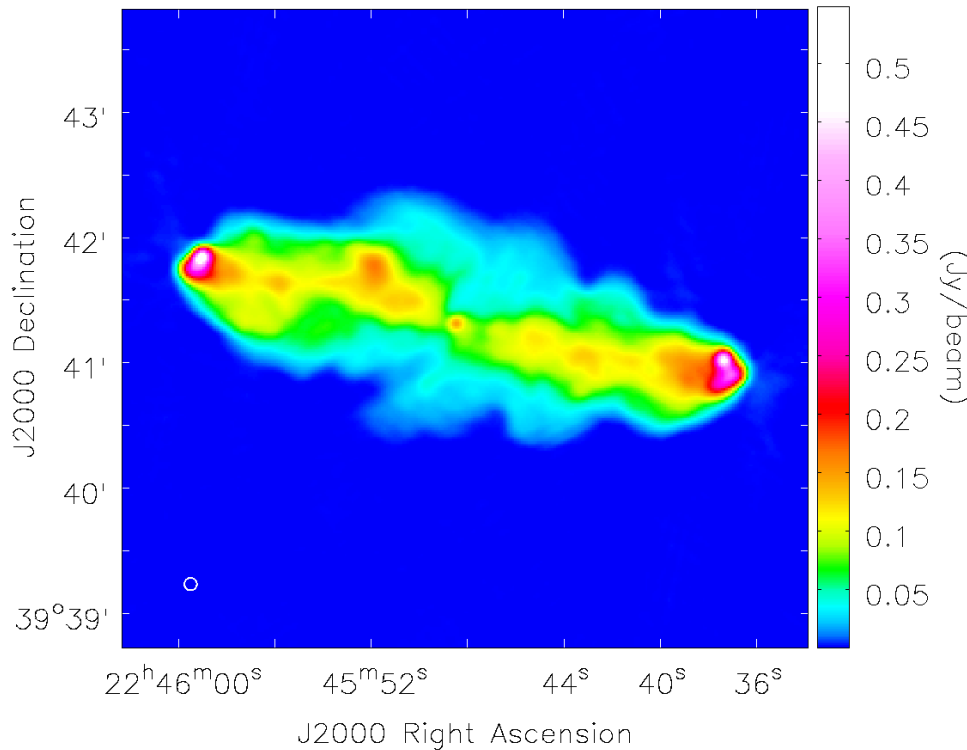

3C438 – 0.3" beam
4 GHz bandwidth at 6 GHz

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

3C452: VLA P-band, A, B and C-configurations
368 MHz, ~160MHz bandwidth, ~6" resolution

Pros and cons of resolved fitting

Advantages:

- Can determine variations as a function of position
- Reduction in the detrimental effects of superposition
- Can more easily spot unusual features which may affect fitting
- Is able to find sources which have recently become inactive

Disadvantages:

- Requires complementary data at a similar resolution
- Requires the radio maps must be available
- Must be well matched, aligned and have good image fidelity
- Can be computationally expensive (especially for large, well-resolved sources)

Conclusions

- **Getting the most out of survey data is likely to require a multi-stage approach**

- **The large number of potentially interesting sources found in current and future surveys requires an (semi-)automated approach to analysis**

- **BRATS and the upcoming surveys module will provide the tools for analysing a large number of sources on relatively short timescales**

- **Survey fitting from a local database, available in next full release (early 2016)**

- **Designed to allow new models to be added relatively easily. If this is something you are interested in, come and talk to me**

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