The Dynamics & Energetics of Radio-loud AGN

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Credit: NRAO

Radio-loud AGN

- Large scale radio jets
- Kinetic power large fraction of bolometric luminosity (>10^8 L_{Sun})
- Strongly polarised synchrotron radiation
- Elliptical hosts
- FRI---core-brightened
- FRII---edge-brightened

Key Questions

- Environmental Impact
  - Feedback/regulating galaxy growth
  - Shock heating in the intracluster medium
- Duty Cycle
- Fundamental dichotomy
  - Physical parameters governing jet power
  - Why do some RG’s form FRIs and some FRIIs?
  - Is there an evolutionary track (FRI → FRII)?
  - High/Low Excitation Radio Galaxies
- Dynamical Evolution
  - Spherical vs elongated lobes
  - Parsec-scale evolution
- Cosmological Impact
  - Why are more powerful sources found at higher redshift?
- **Jet power (ETOTAL/TAGE)**

  Spectral age/Dynamical age discrepancy

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Spectral vs Dynamical age

- Synchrotron cooling in the lobes of radio galaxies has a steepening effect on the radio spectrum (Spectral ageing).
- Age of electron population in lobes is a function of \`break' frequency and lobe magnetic field
- Dynamical ages given by a model of the lobe advance speed and an estimate of source size.
- Spectral ages always underestimated…
  - Lack of broad-bandwidth radio data?
  - Wrong magnetic field estimates?
  - Substantial mixing of electron population?
  - Dynamical ages are wrong...

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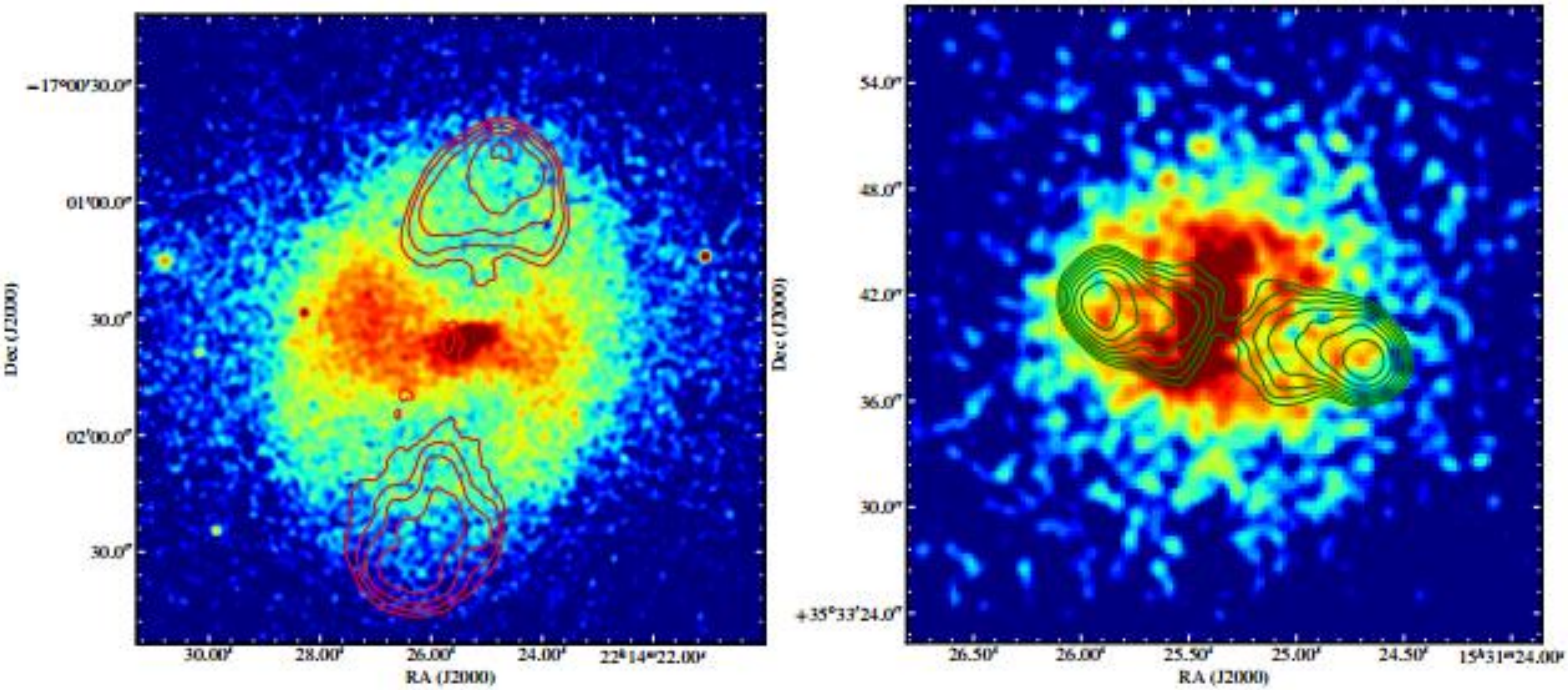
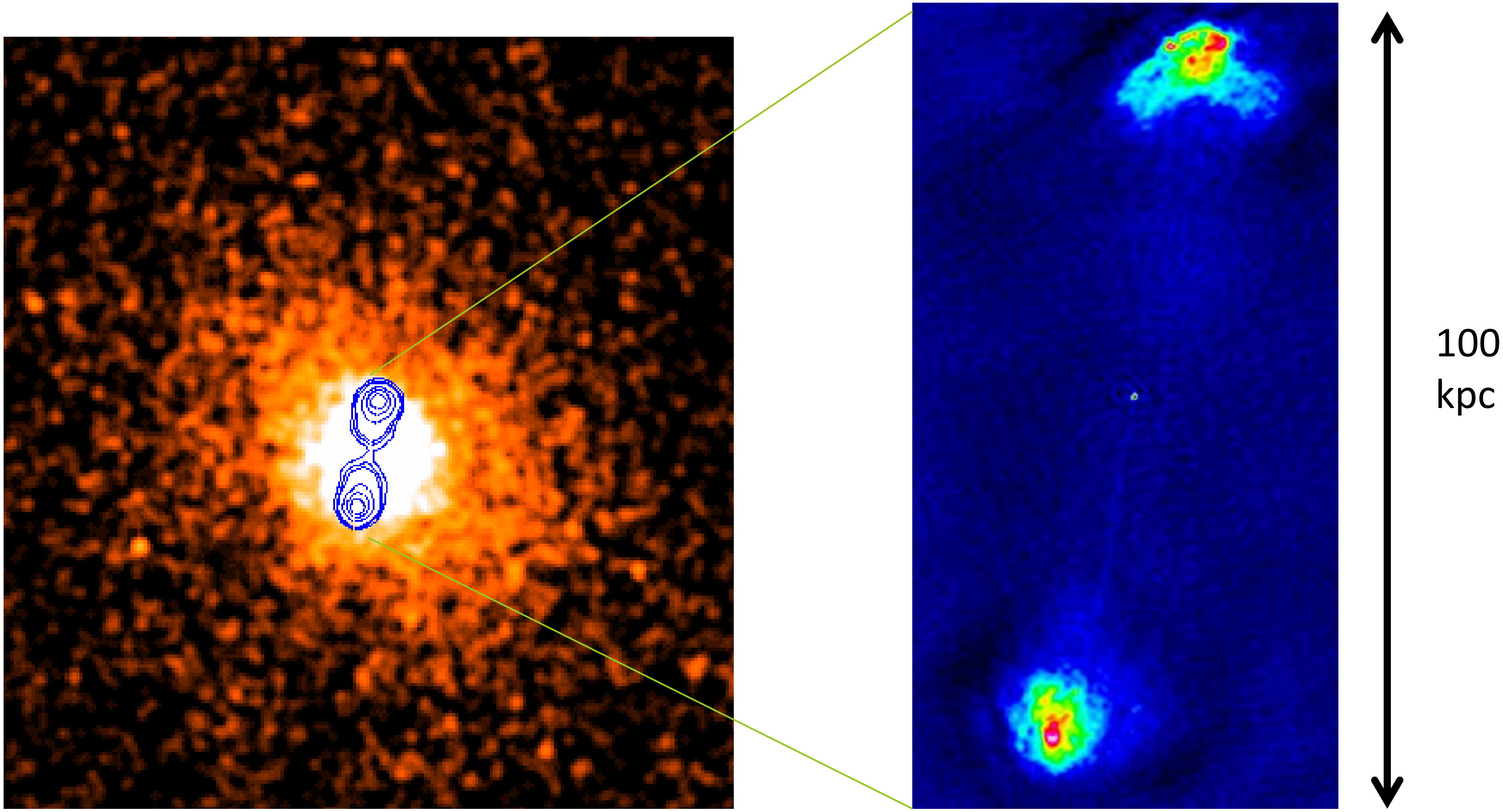
Source	z	Cluster kT (keV)	L_{178} $(W/Hz/sr)$	LAS (arcsec)	Size (kpc)
3C444	0.153	3.5	1×10^{26}	120	320
3C320	0.342	3.3	3×10^{26}	20	100



Croston et al. (2011)

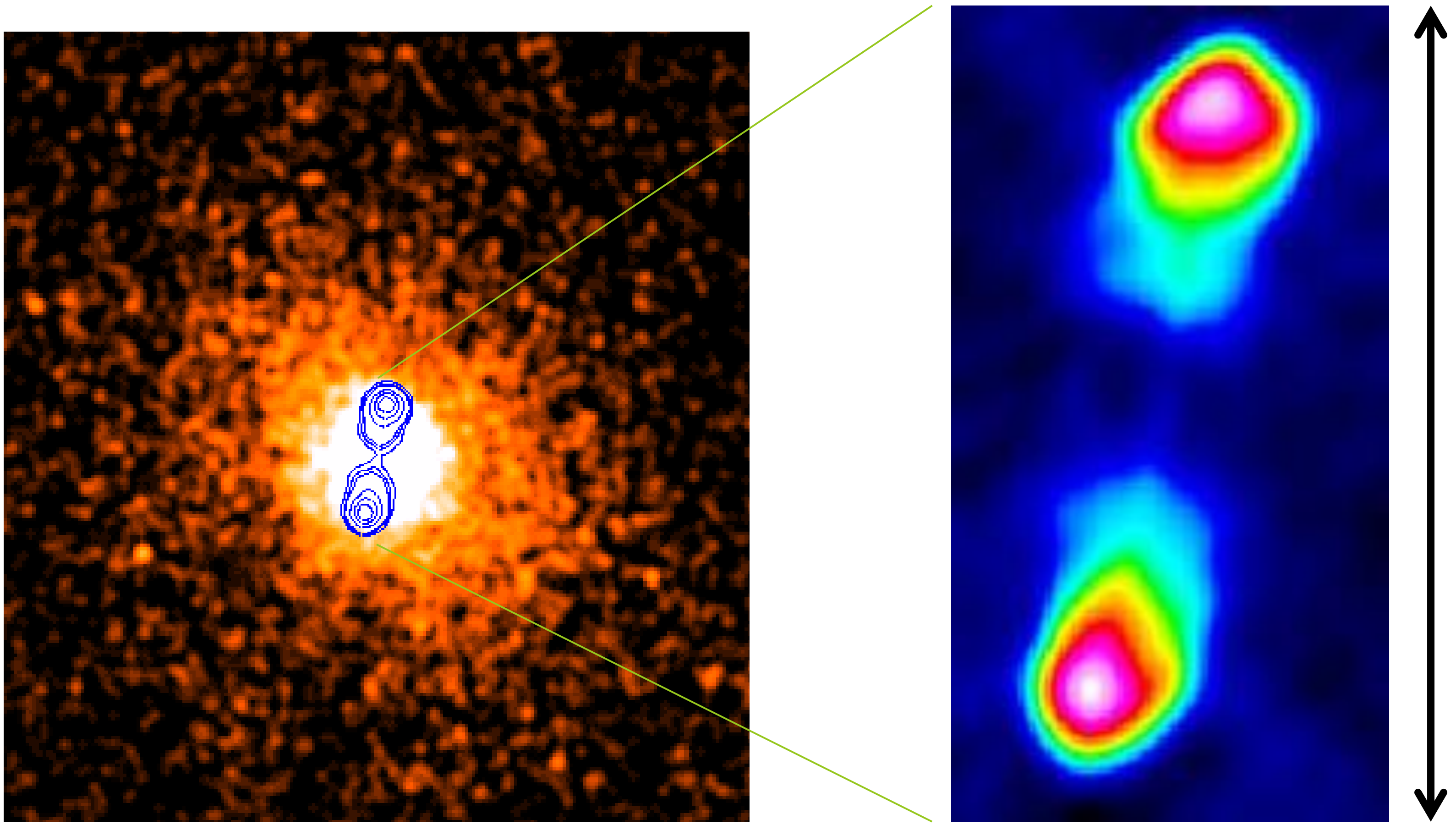
Chandra 0.5-5 keV

E-MERLIN 1.4 GHz



T_{dyn}~25 Myrs

Mahatma et al. (in prep)



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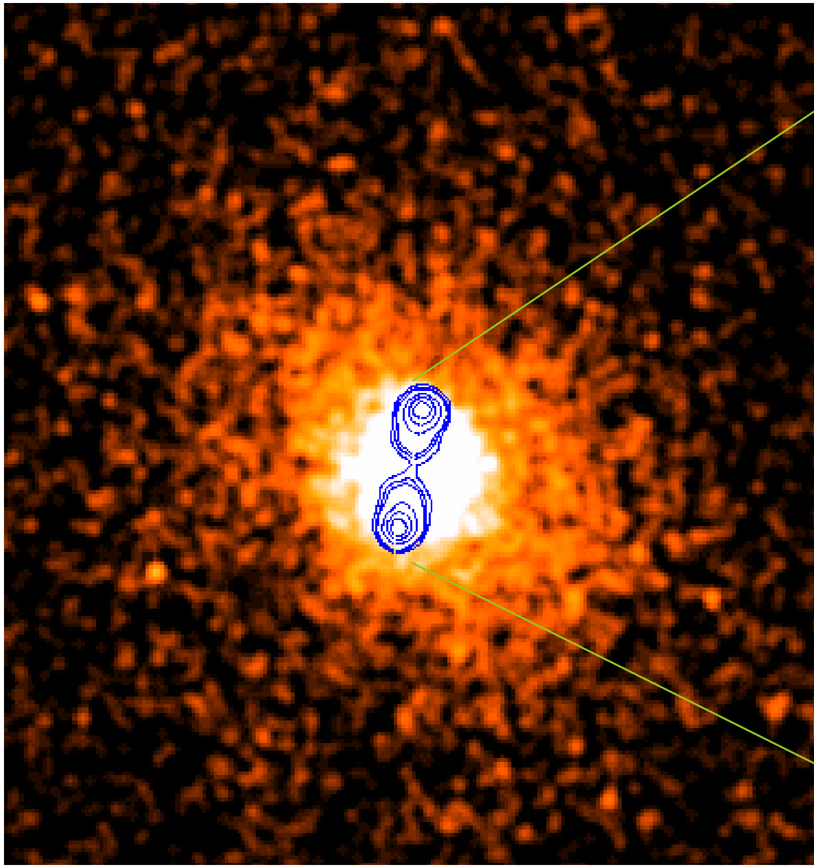
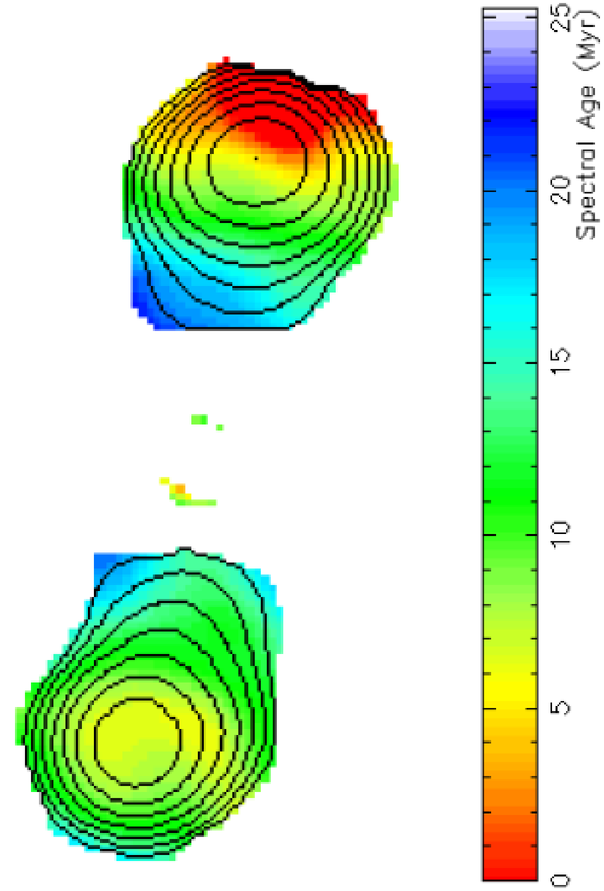


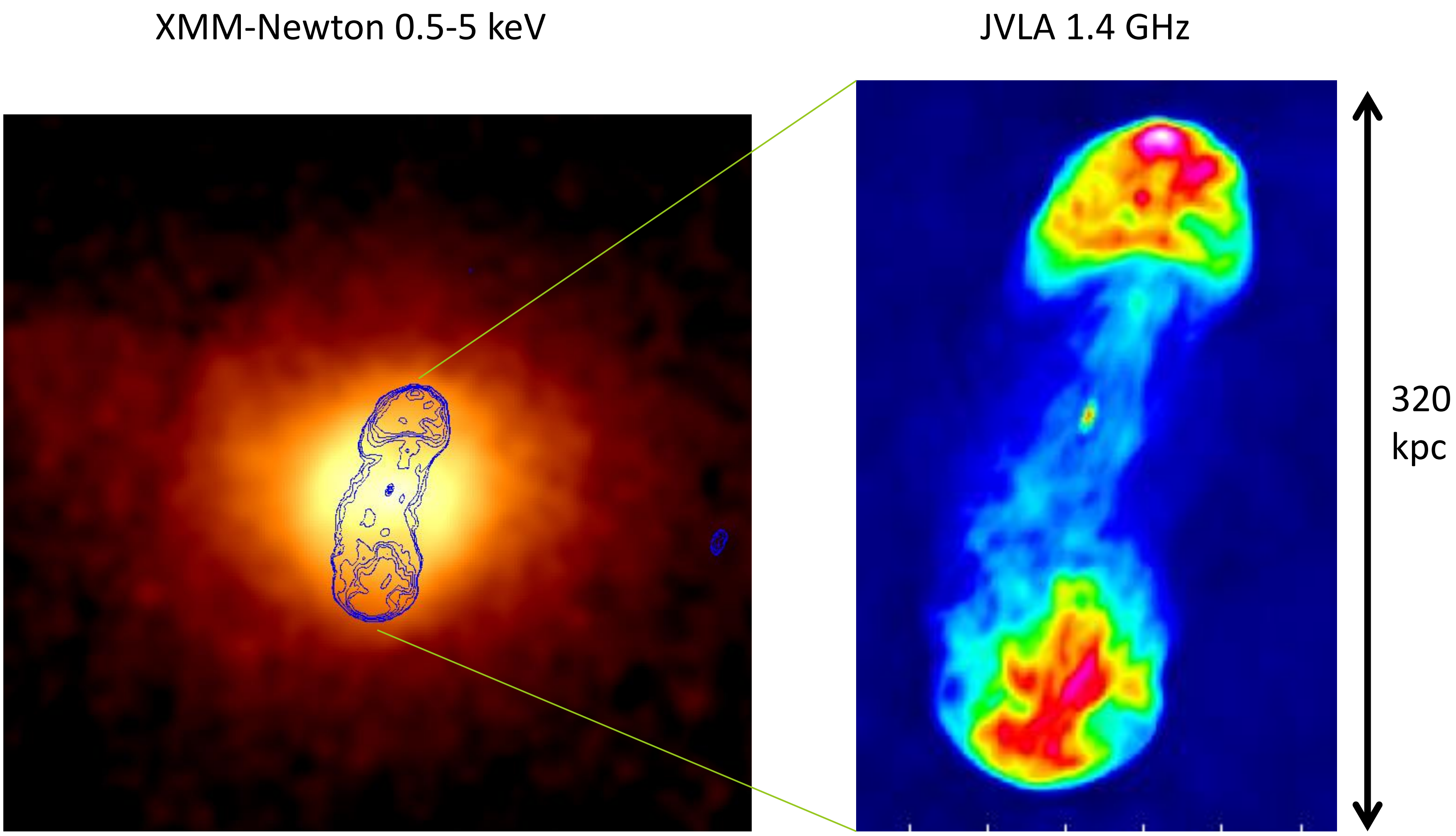


T_{dyn}~25 Myrs

T_{spec}~25 Myrs

BRATS (Harwood et al. 2013)

Mahatma et al. (in prep)



T_{dyn}~90 Myrs

Croston et al. (2011)

Mahatma et al. (in prep)

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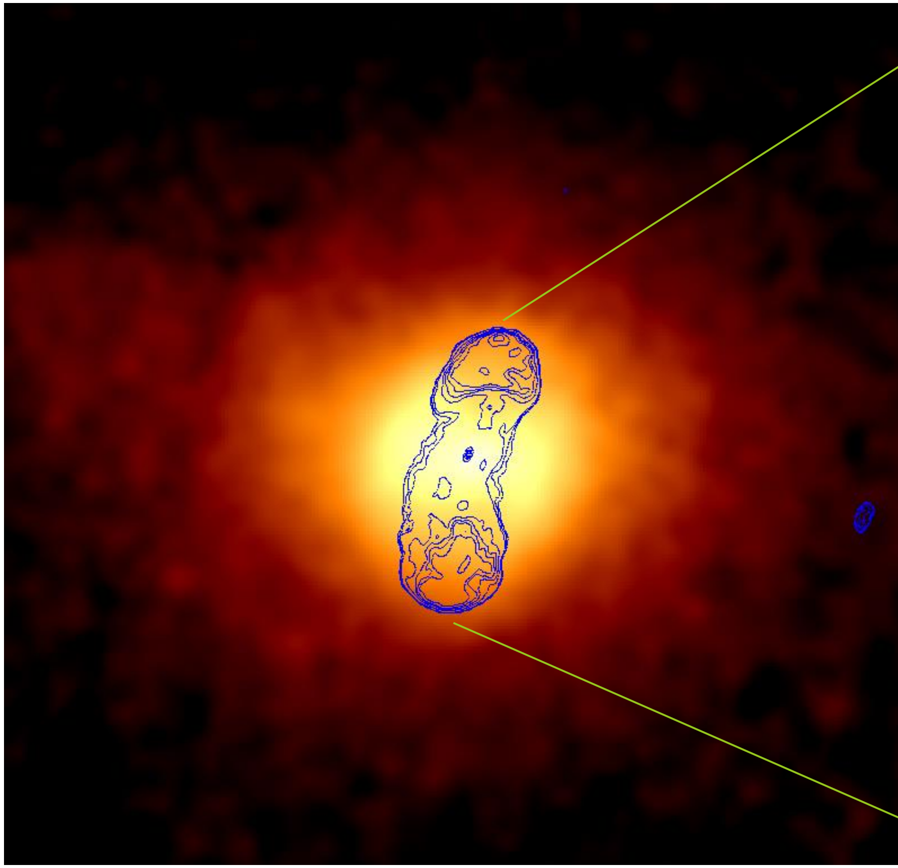
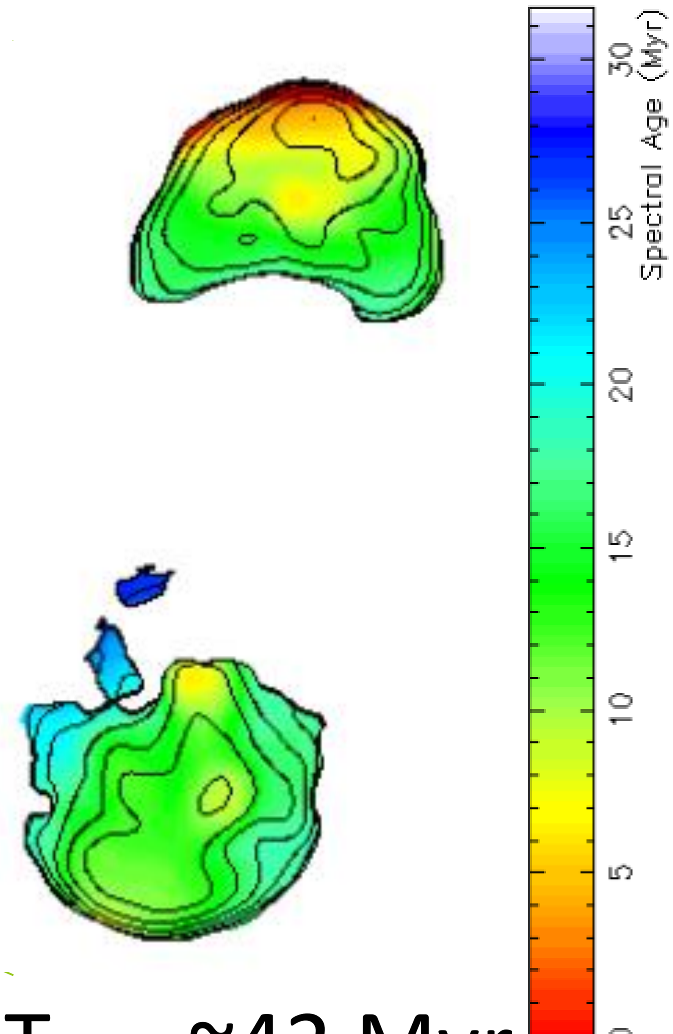
XMM-Newton 0.5-5 keV





T_{dyn}~90 Myr

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Tspec~42 Myr

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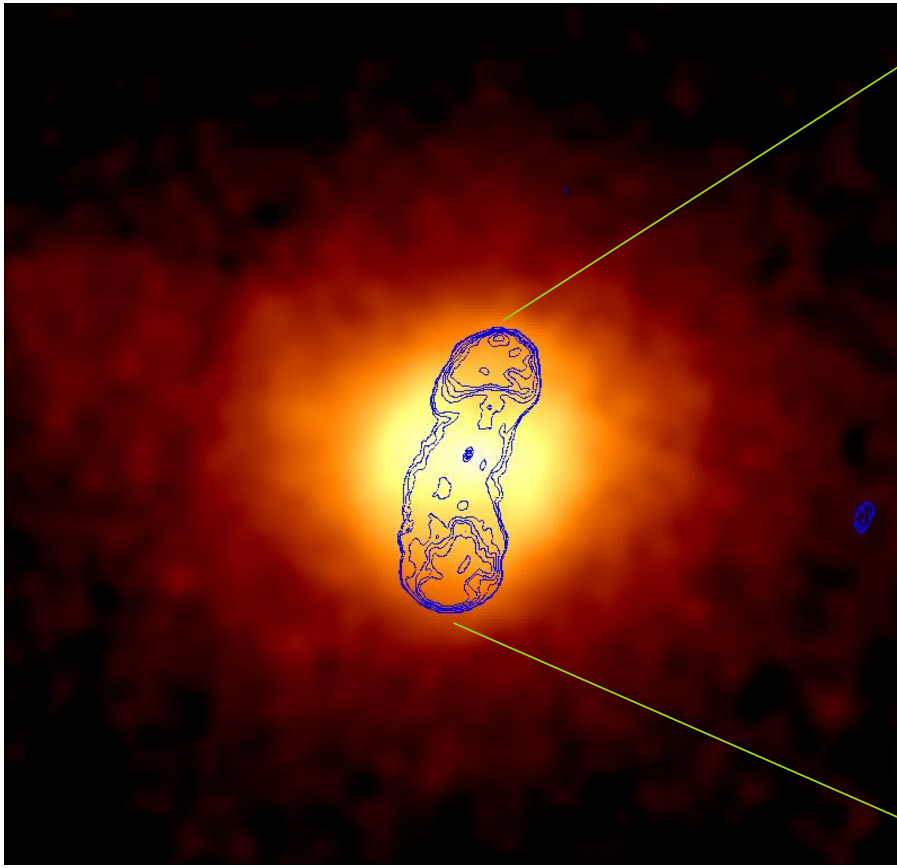
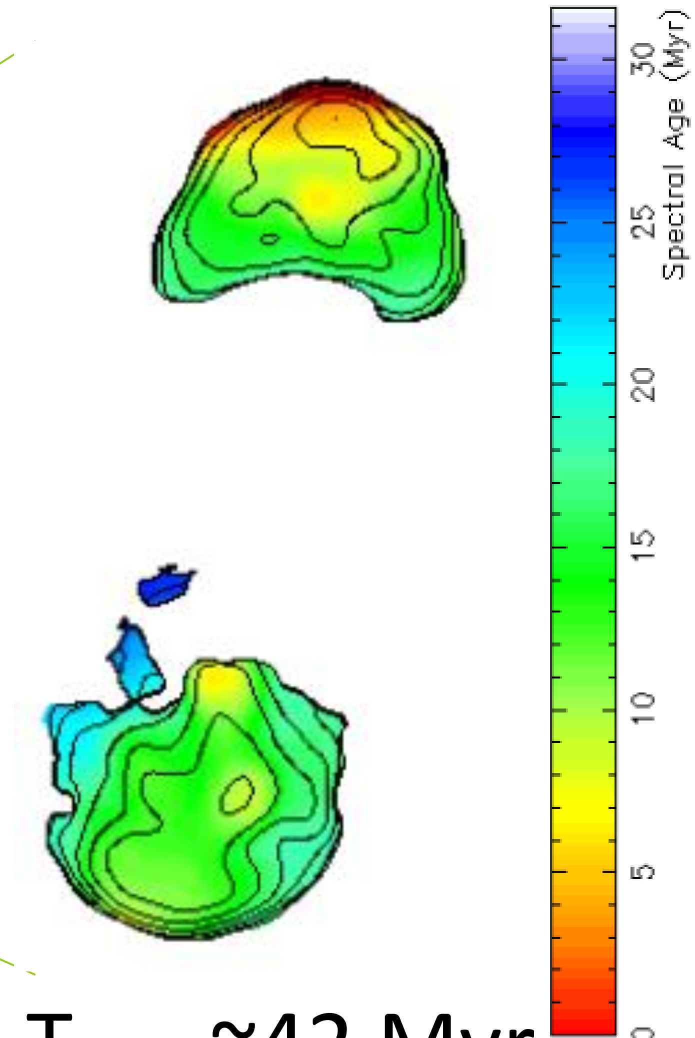
XMM-Newton 0.5-5 keV





T_{dyn}~45 Myr

Croston et al. (2011)

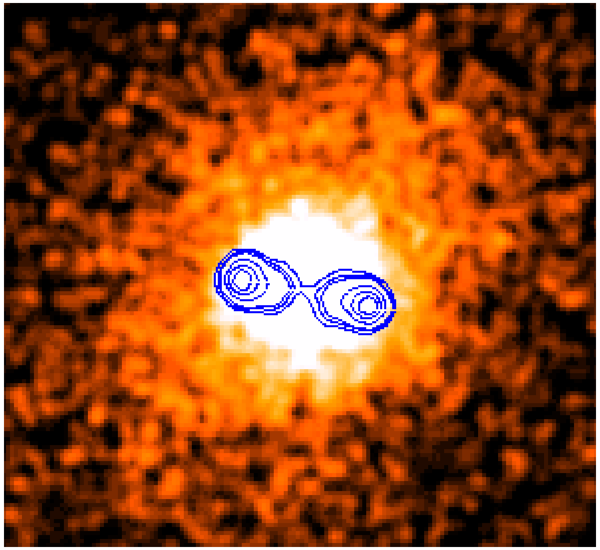
Tspec~42 Myr

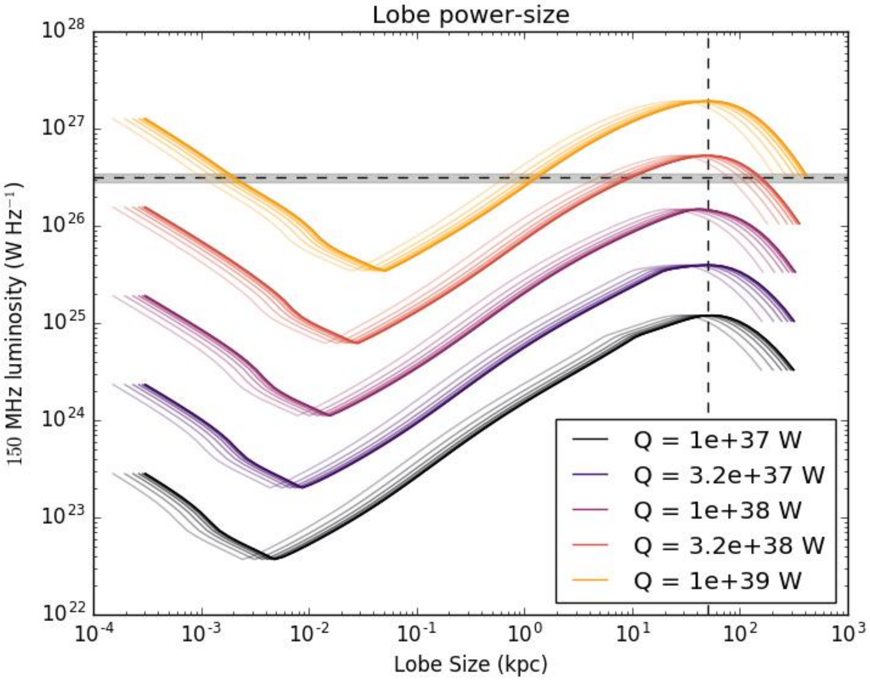
BRATS (Harwood et al. 2013)

Mahatma et al. (in prep)

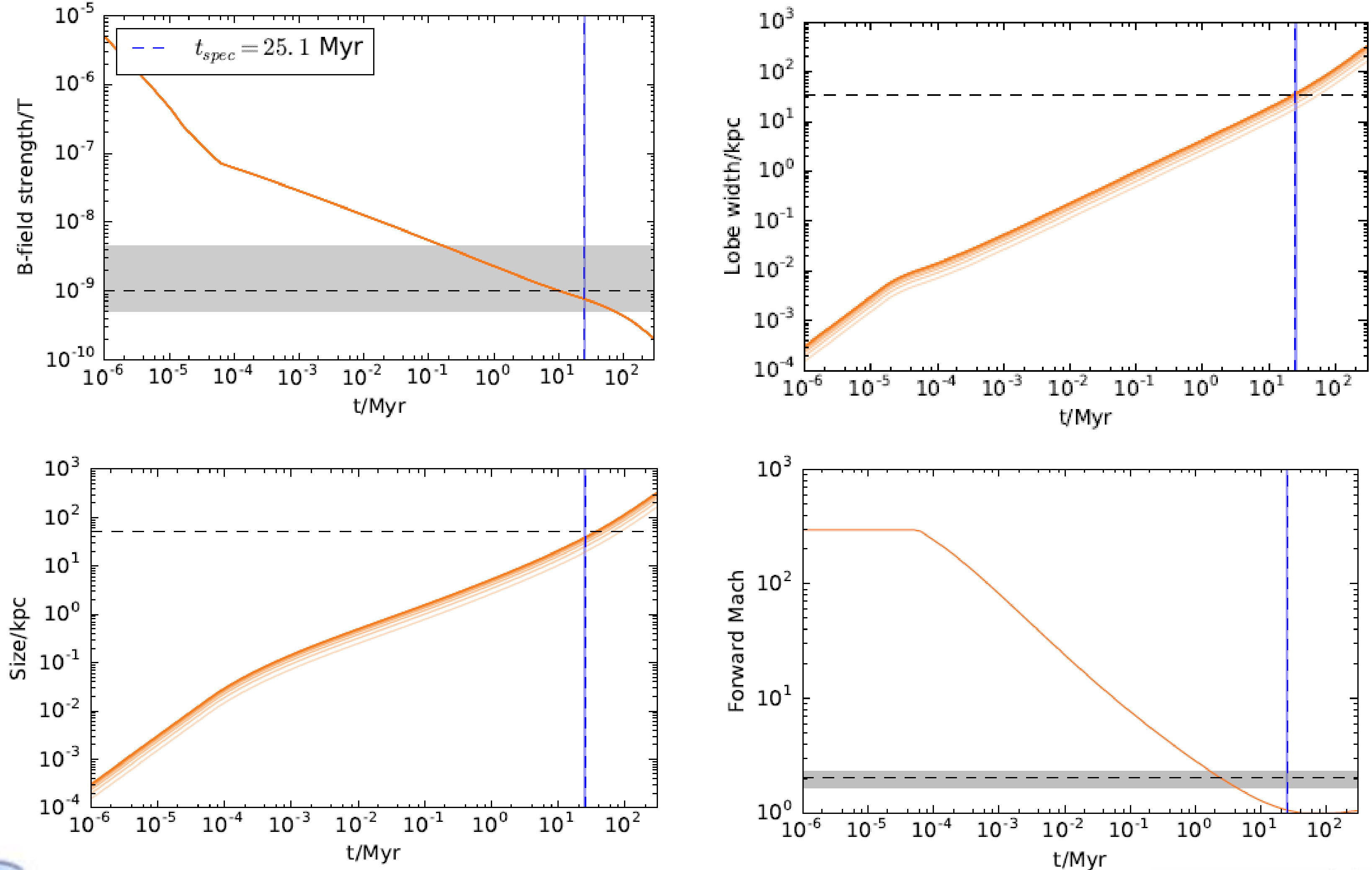
Analytic modelling

- Semi-analytic model of Hardcastle (2018)
- Describes the dynamics of the 'shocked shell' around radio galaxy based on environment and jet power
- Assumptions based on insights of numerical simulations (Hardcastle & Krause 2013; English et al. 2016)
- Describes radio lobe luminosity evolution and lobe dynamics





Lobe properties vs dynamical age



Mahatma et al. (in prep)

Results

- 3C320
  - Observational spectral age: **25 Myr** (B – dependent!)
  - Observational jet power: **1.2×10^{38} W**
  - Model dynamical age **33 Myr**
  - Model jet power: **1.4×10^{38} W**

- 3C444
  - Spectral age: **42 Myr** (B – dependent!)
  - Observational jet power: **5×10^{38} W**
  - Model dynamical age?
  - Model jet power?

Mahatma et al. (in prep)

Results and Conclusions

- Agreement between spectral and dynamical ages for 3C320, not for 3C444 (yet)
- Broad-bandwidth radio data are a <u>requirement</u> for spectral ages
- Instantaneous dynamical ages are unreliable – shock speed changes with time
- Radio lobes are not in equipartition between B-field and electron energies.
- Lobe plasma of cluster-centre FR-II radio galaxies do not require a significant population of protons for dynamical evolution – (Croston et al. 2018)
- Apply to larger samples of radio-loud AGN

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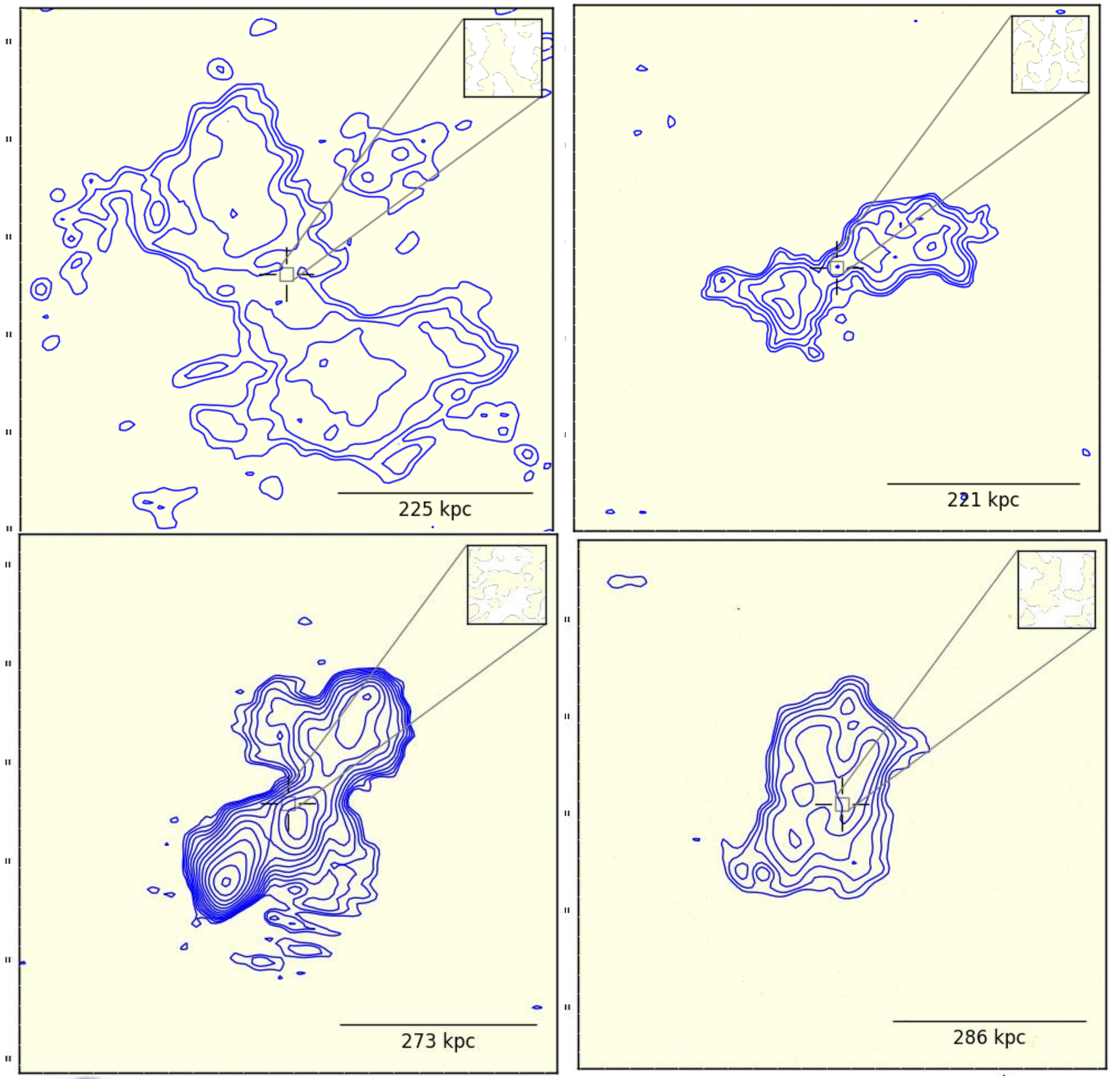
  - Spectral age/Dynamical age discrepancy

Candidate remnant radio galaxies (LOFAR H-ATLAS – Hardcastle et al. 2016)



Mahatma et al. (2018)

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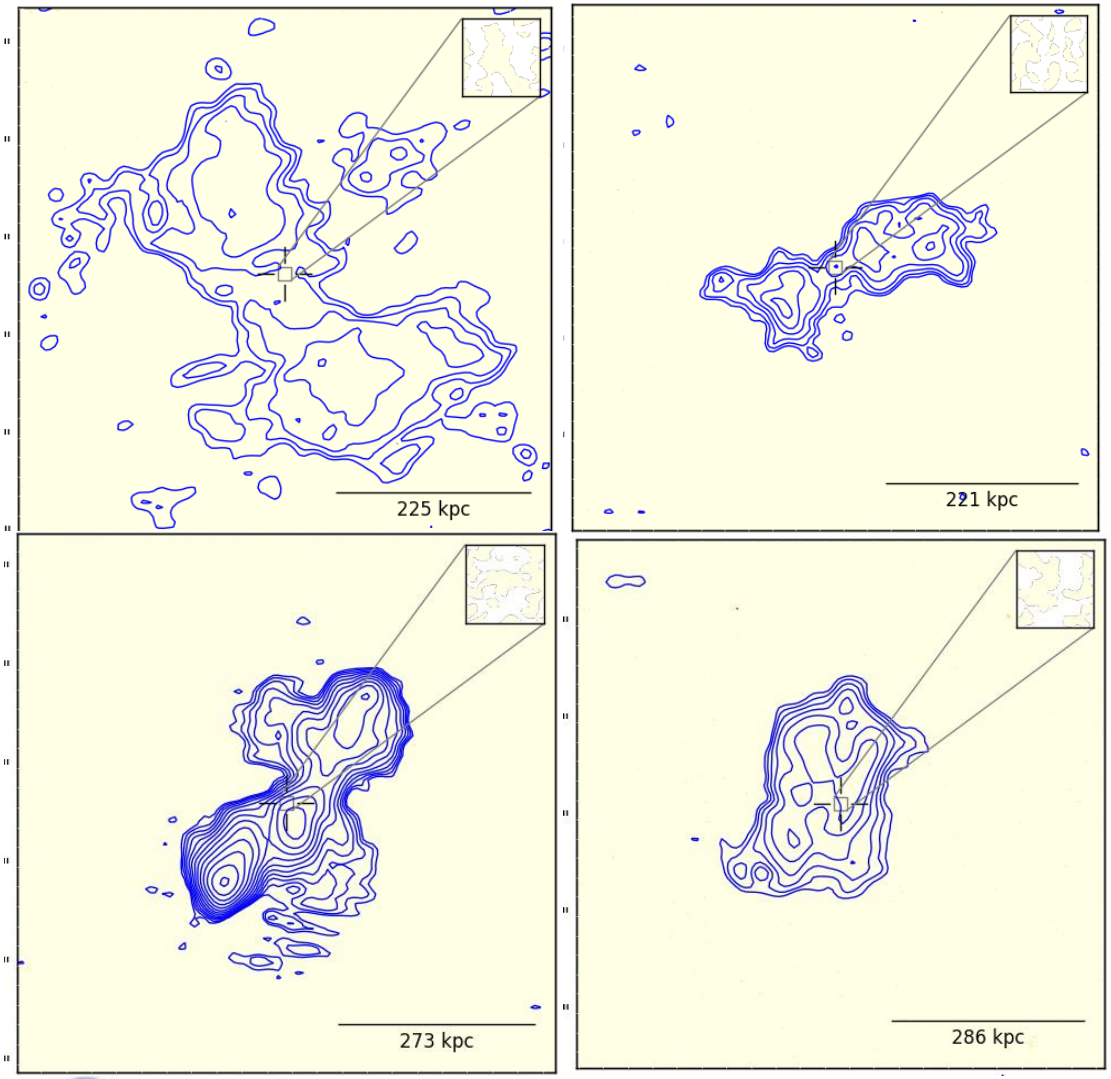
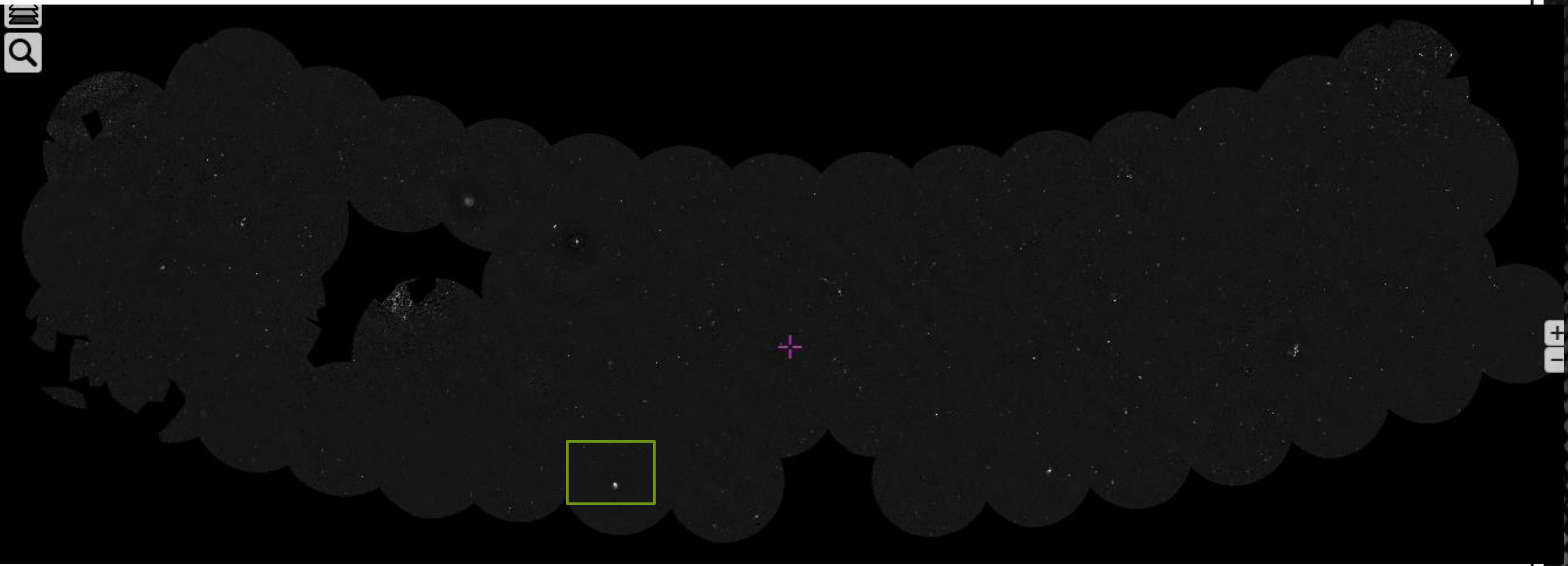


- Systematic sample of candidate remnants
- Remnant fraction: 10%
- Rapid fading of remnant plasma before jets switch on
- Restarting jets?

Mahatma et al. (2018)

LOFAR Two-Meter Sky Survey (LoTTS) DR1

Shimwell et al. (in prep), Williams et al. (in prep), Duncan et al. (in prep)



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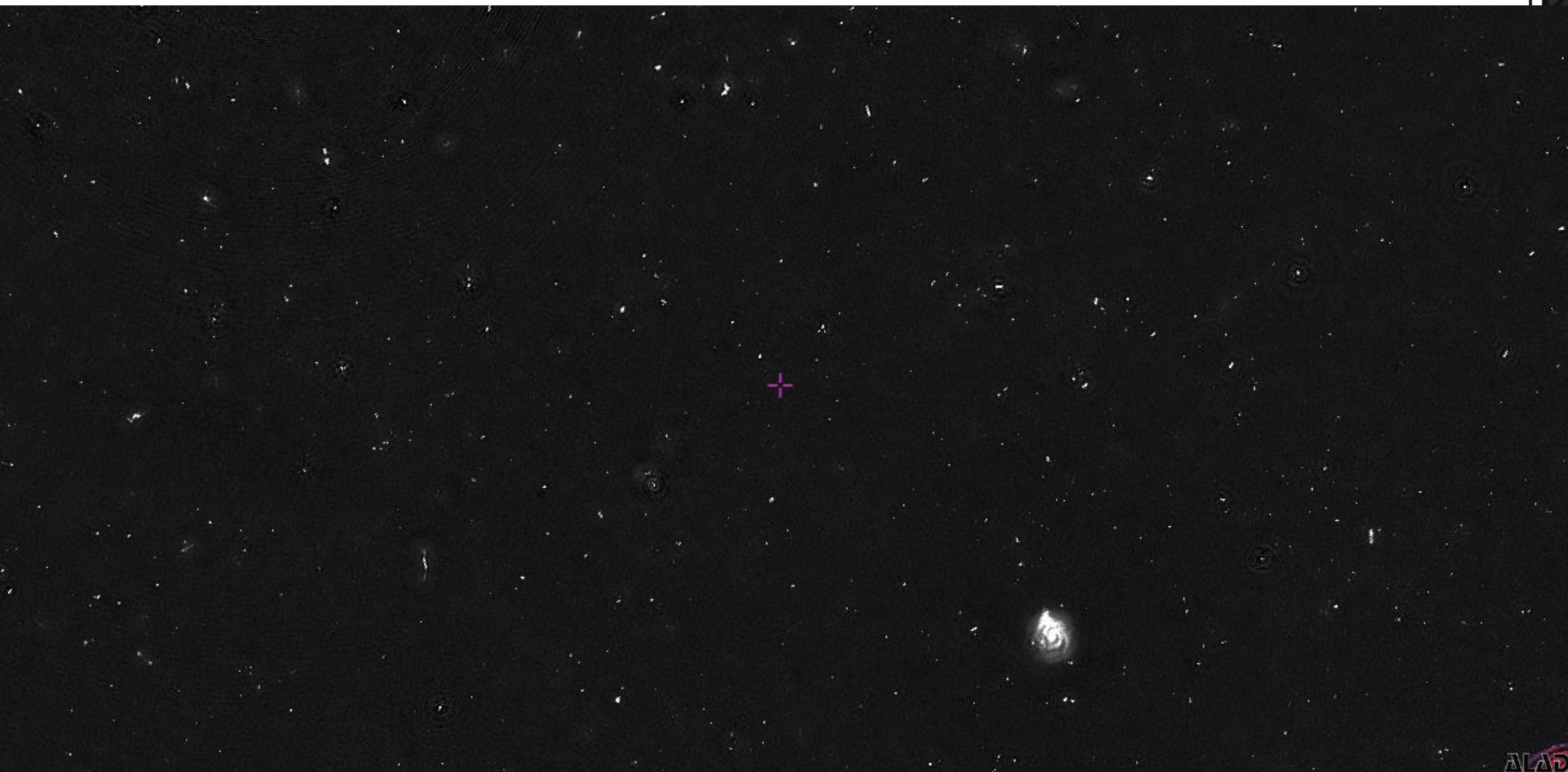

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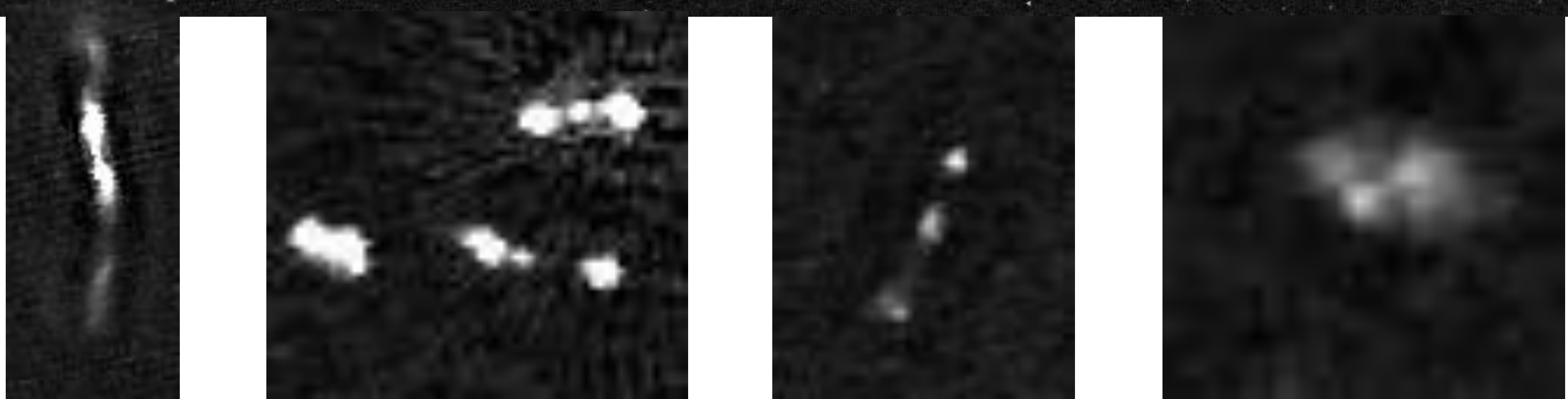
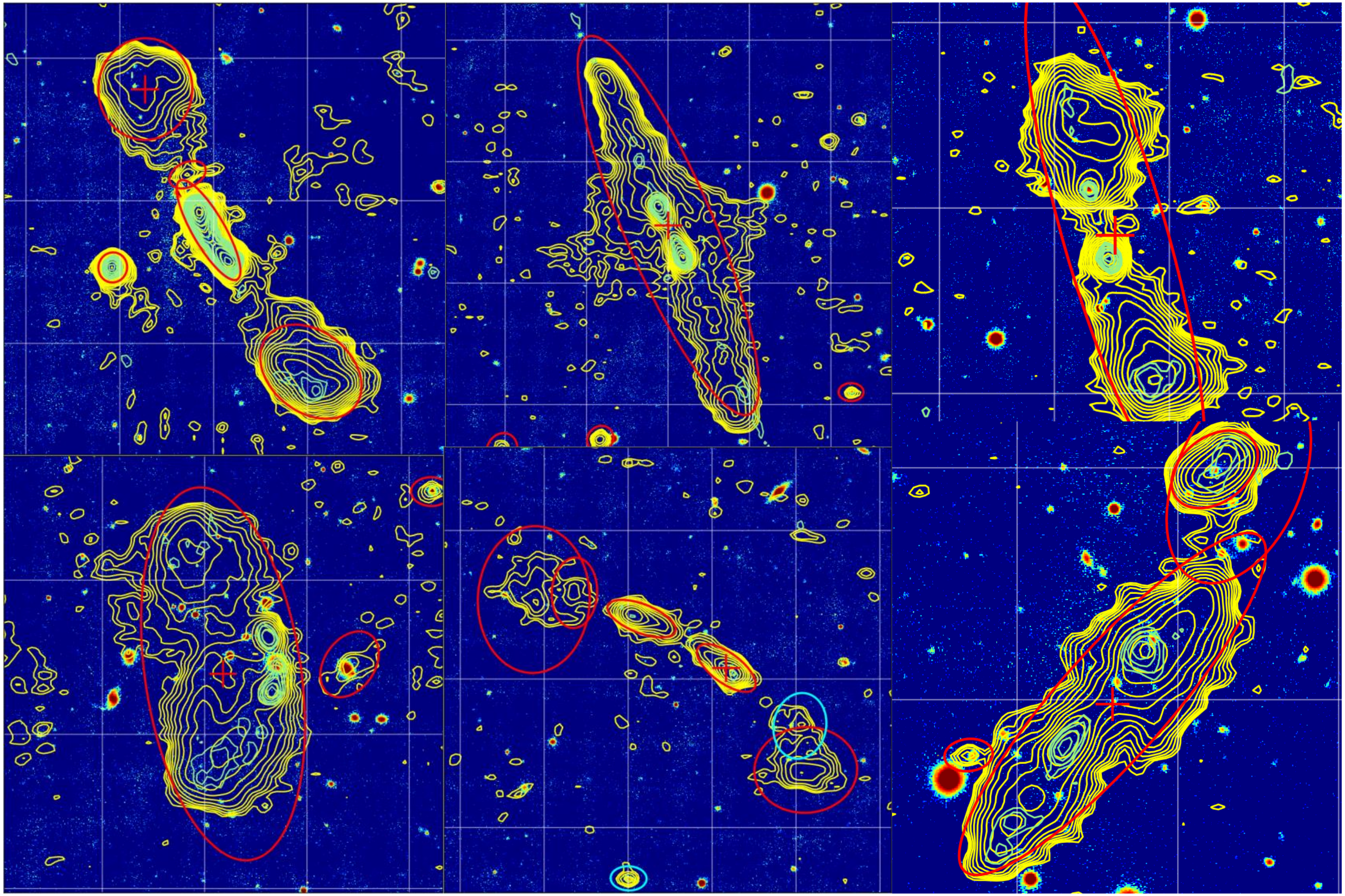


Restarting radio galaxies (LoTSS DR1 HETDEX)

LoTSS DR1 – Shimwell et al. (in prep), Williams et al. (in prep), Duncan et al. (in prep)



Mahatma et al. (in prep)

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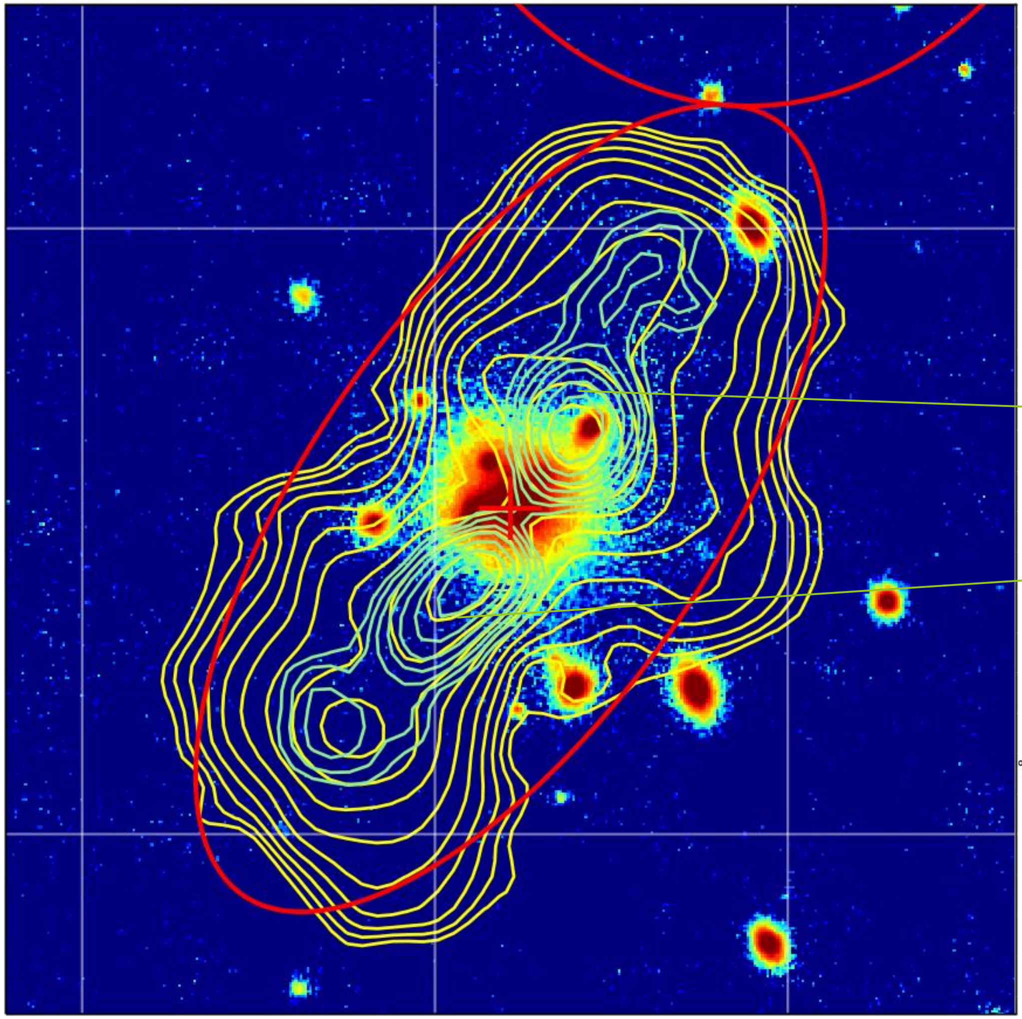
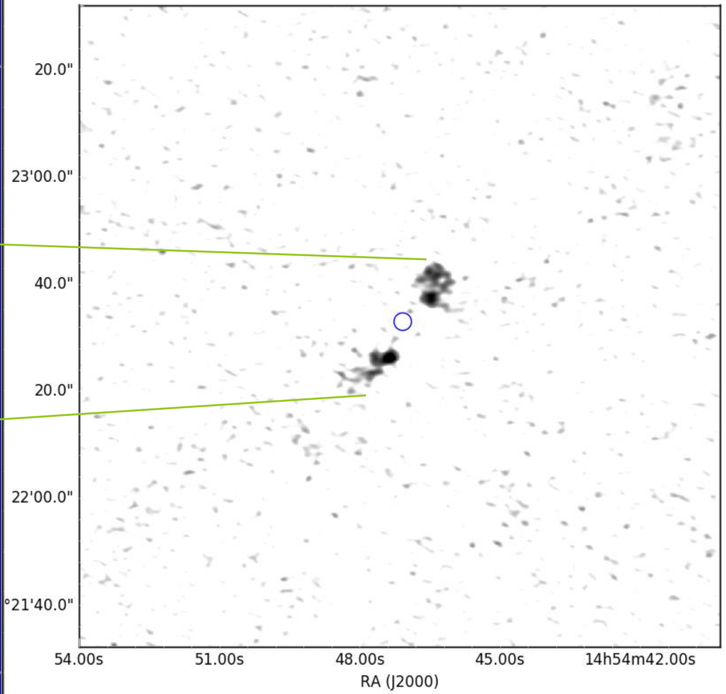


JVLA A-array 1.4 GHz



Pan-STARRS + LOFAR 150 MHz (yellow) + FIRST 1.4 GHz (green)

Mahatma et al. (in prep)

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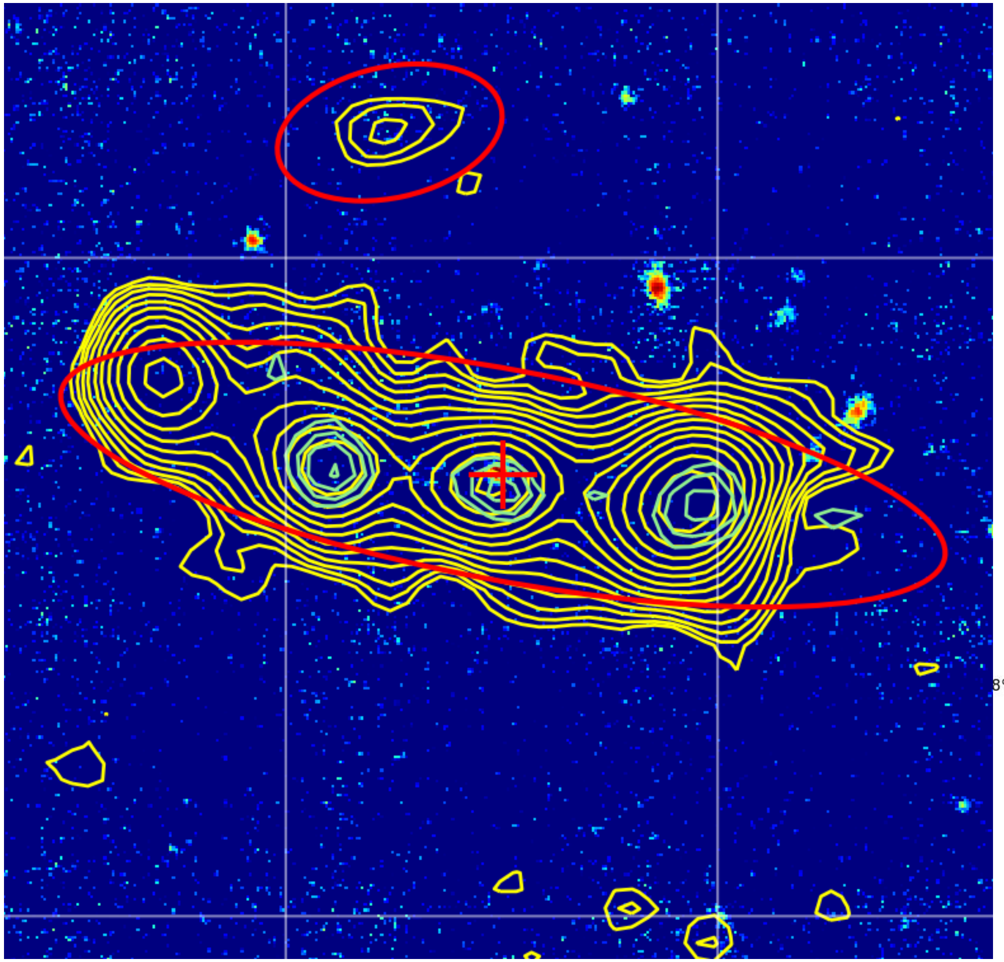

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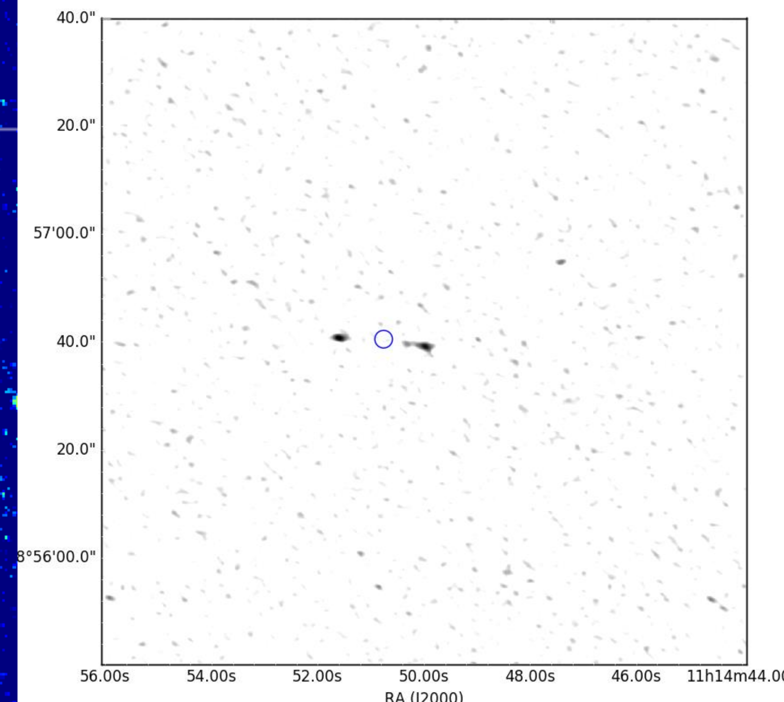

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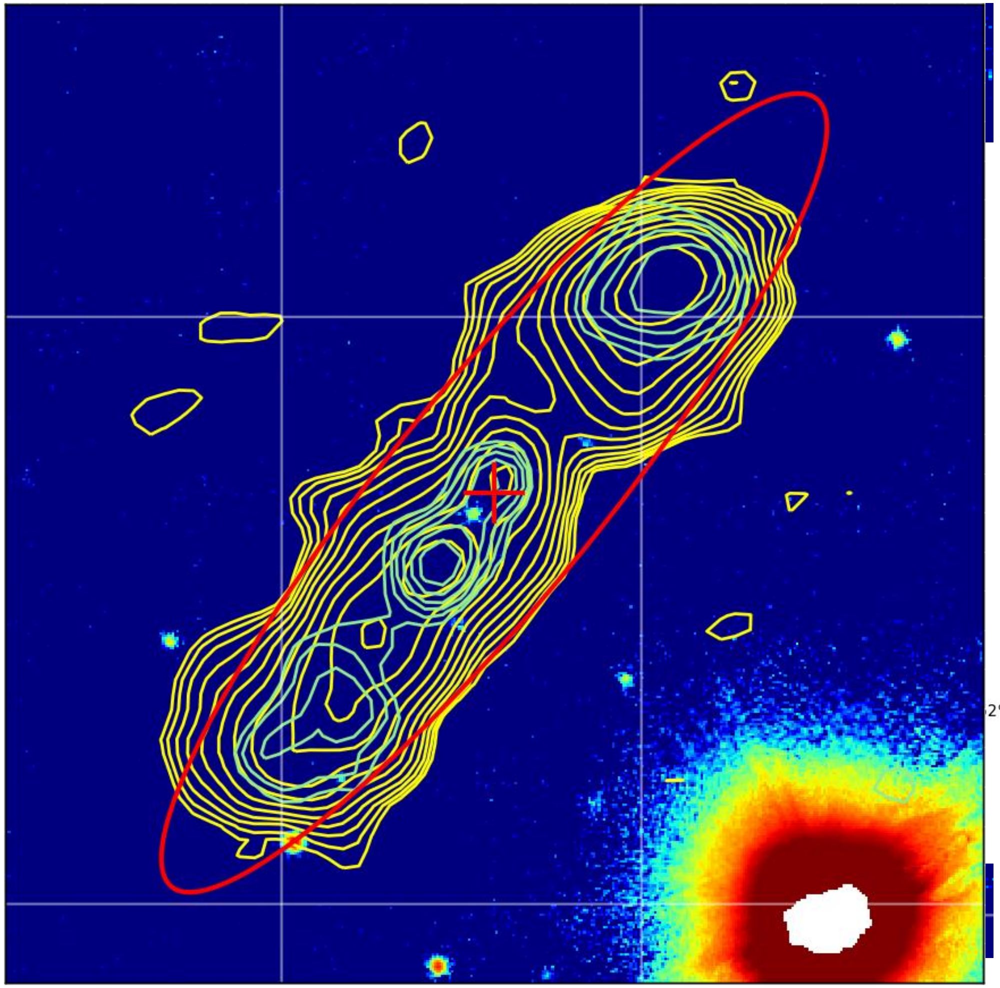

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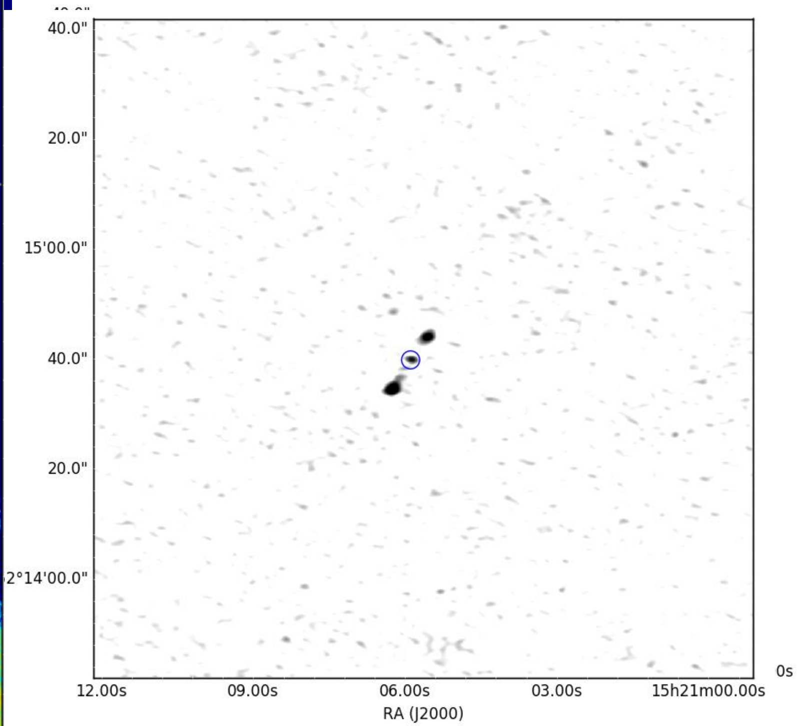

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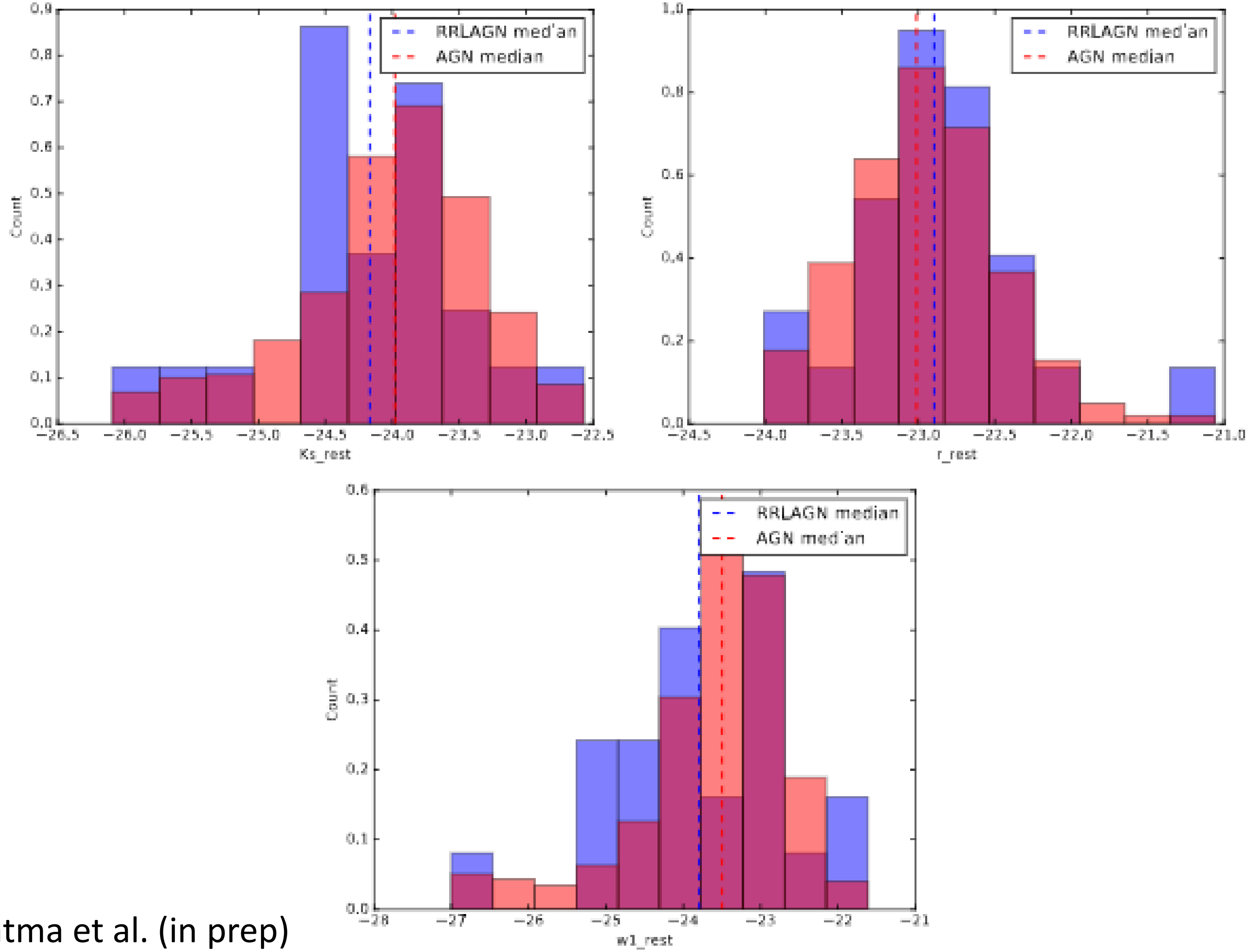
Host galaxy properties compared to normal RLAGN



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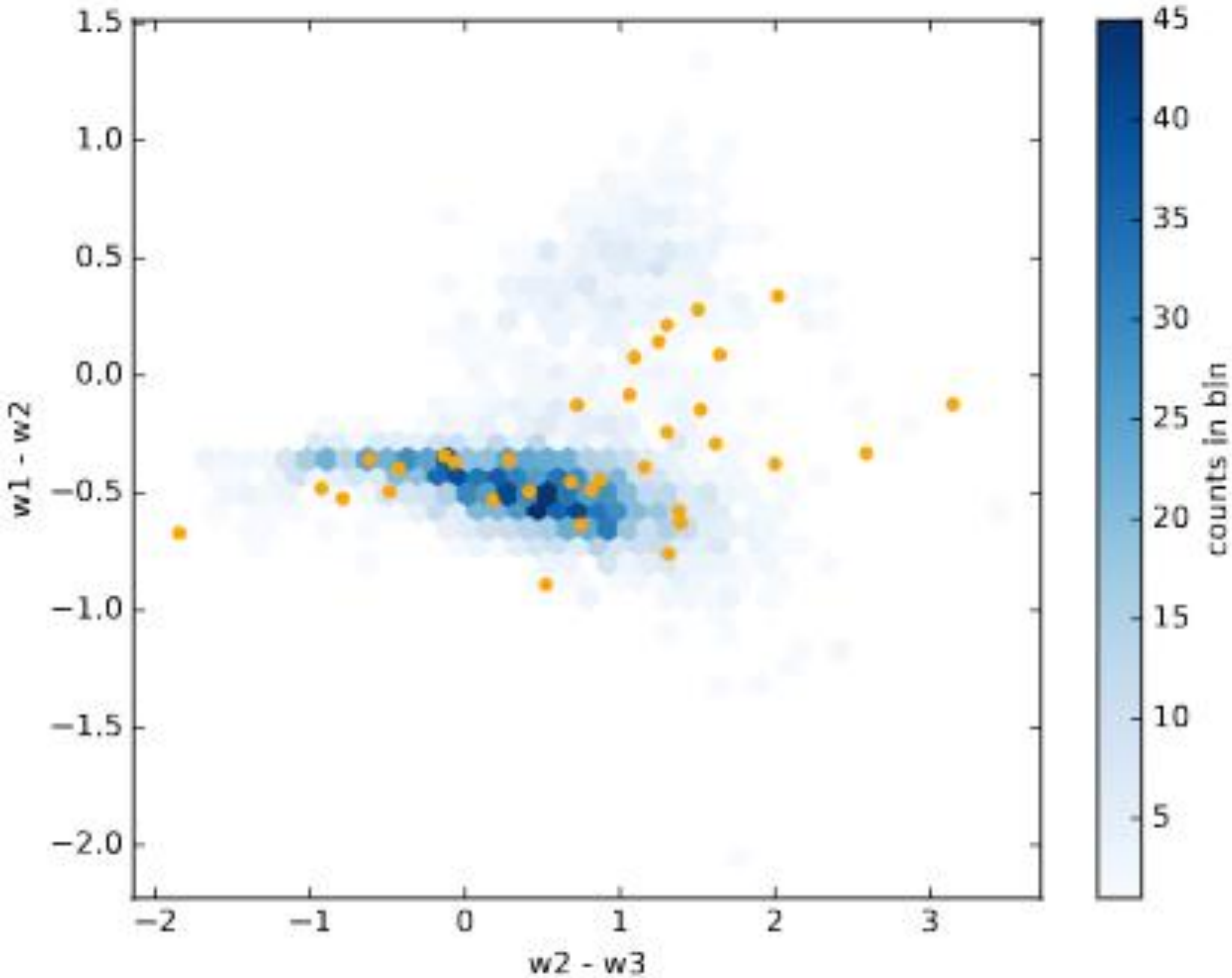

Mahatma et al. (in prep)

Results and Conclusions

- Now have a robust, systematic sample of candidate remnant radio-loud AGN (around 11 sources)
- Remnant fraction of 10% implies very rapid fading of synchrotron plasma
- Spectral index of switched off sources varies substantially
- Samples of restarting radio galaxies are now starting to be made with LOFAR (LOFAR Two-Metre Sky Survey – Shimwell (2017, and in prep)
- Global star-formation may not change significantly between AGN episodes.
- Radio-AGN episodes work independently to changes in the host galaxy.
- Some evidence of dustier host galaxies than normal radio galaxies

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