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Netherlands Institute for Radio Astronomy

kapteyn astronomical institute

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Dying and restarted AGN in the LOFAR sky

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Low frequencies, energetics and life-cycle of radio galaxies

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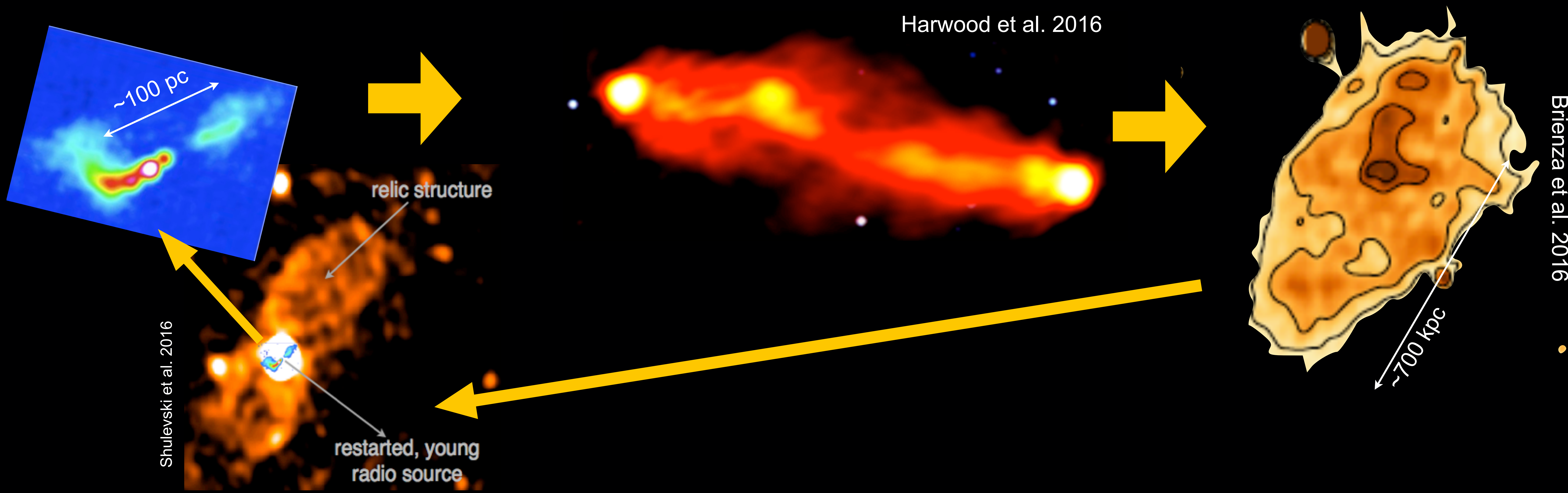
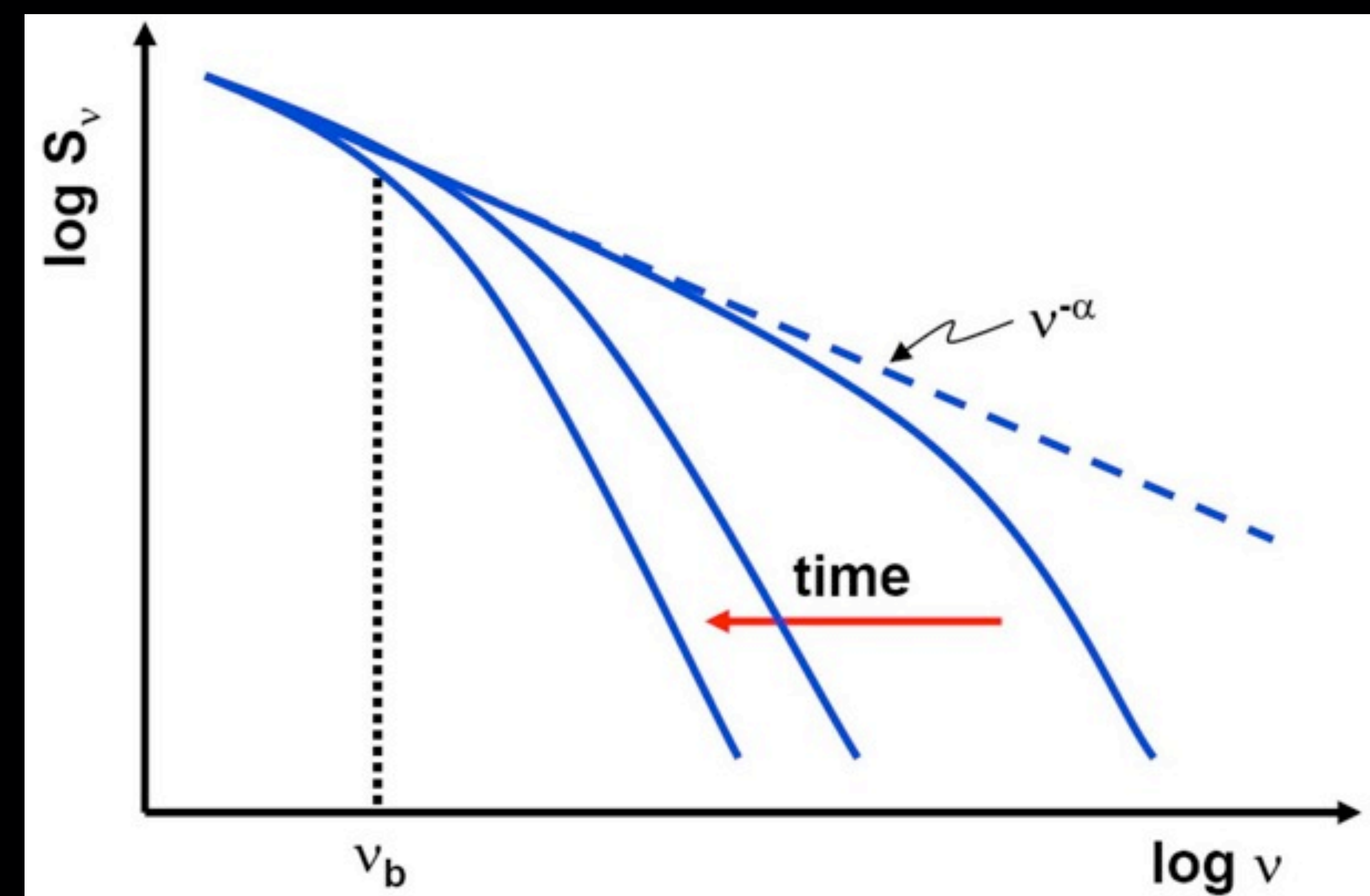


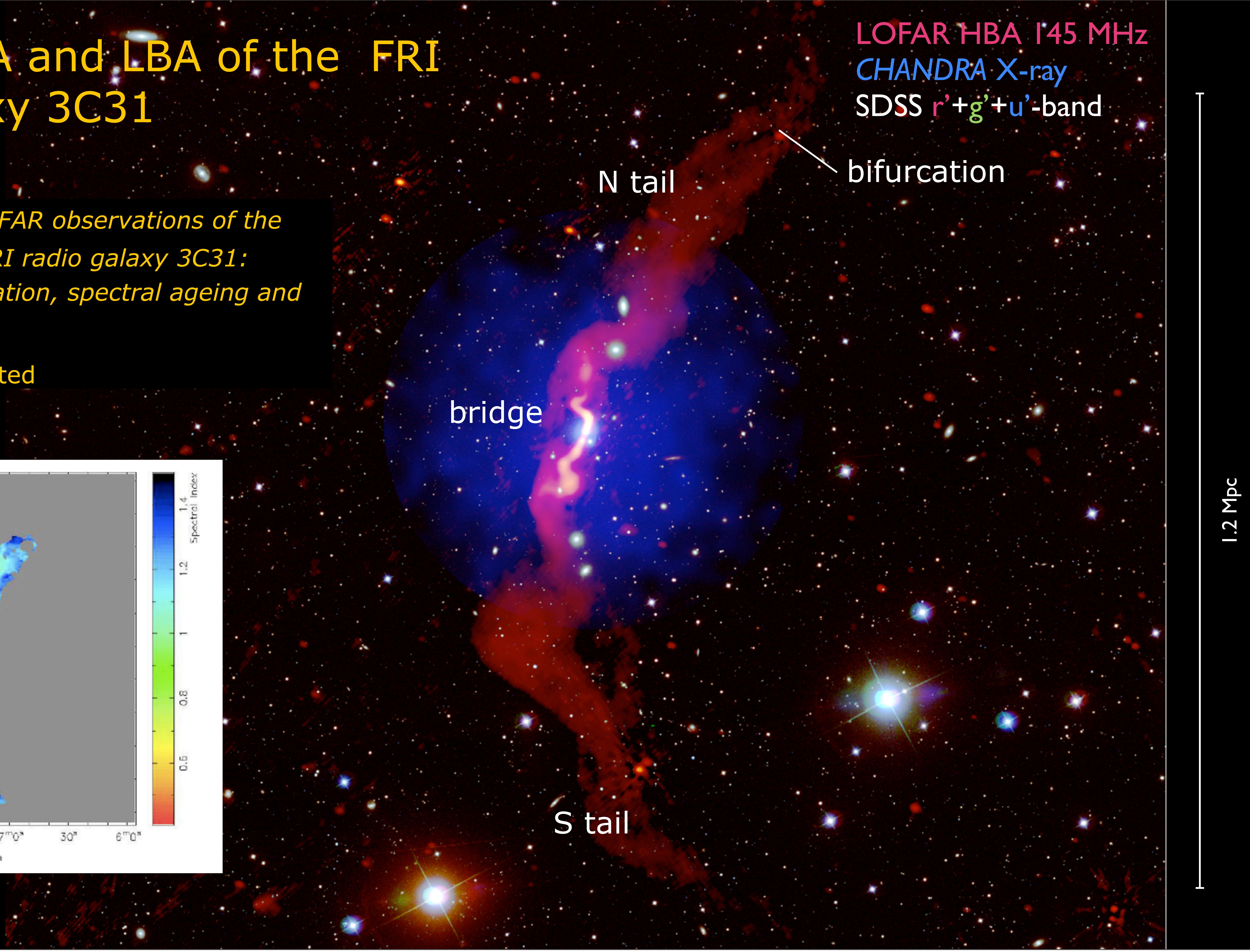
- Key parameters to understand this cycle: injection index, energetics (equipartition? pressure balance?), losses (radiative, expansion), magnetic field etc. => LOFAR Nearby AGN WG
- Selection of dying/remnant radio sources (nuclear engine off!) *rare objects* => need large area, higher resolution with sensitivity to low surface brightness, good frequency coverage for spectral index
- Models of radio galaxy evolution to interpret the results

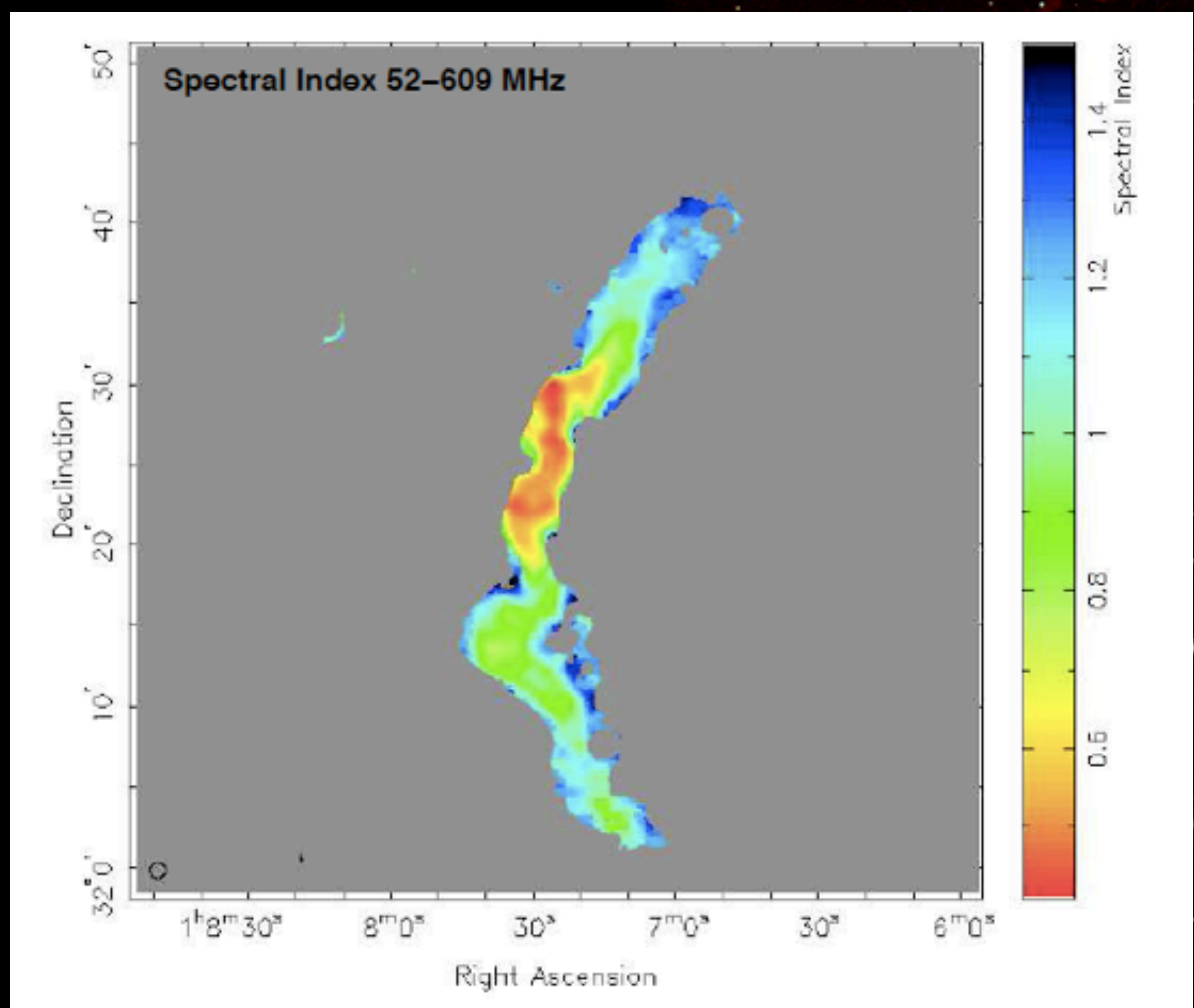


LOFAR HBA and LBA of the FRI radio galaxy 3C31

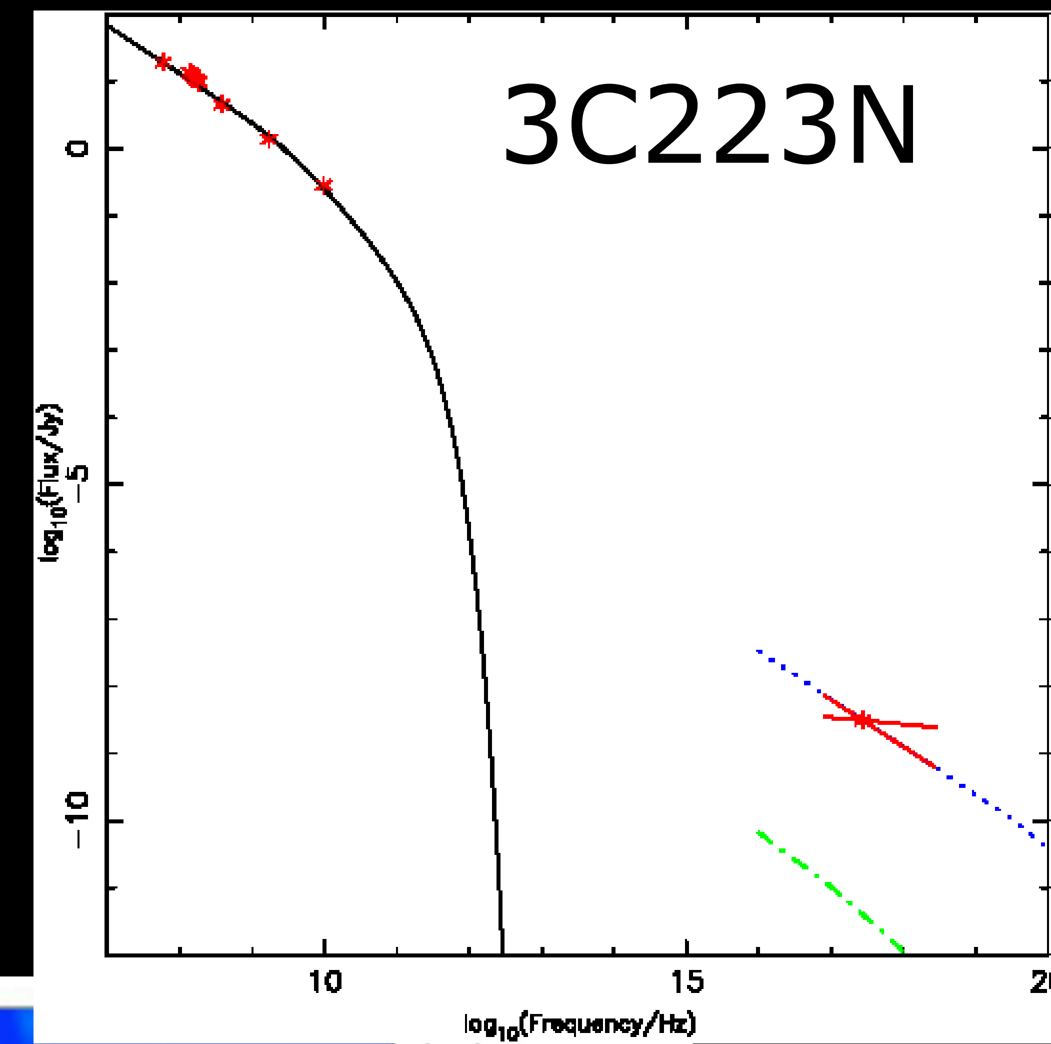
Heesen et al. *"LOFAR observations of the radio tails in the FRI radio galaxy 3C31: cosmic ray acceleration, spectral ageing and magnetic fields"*

about to be submitted



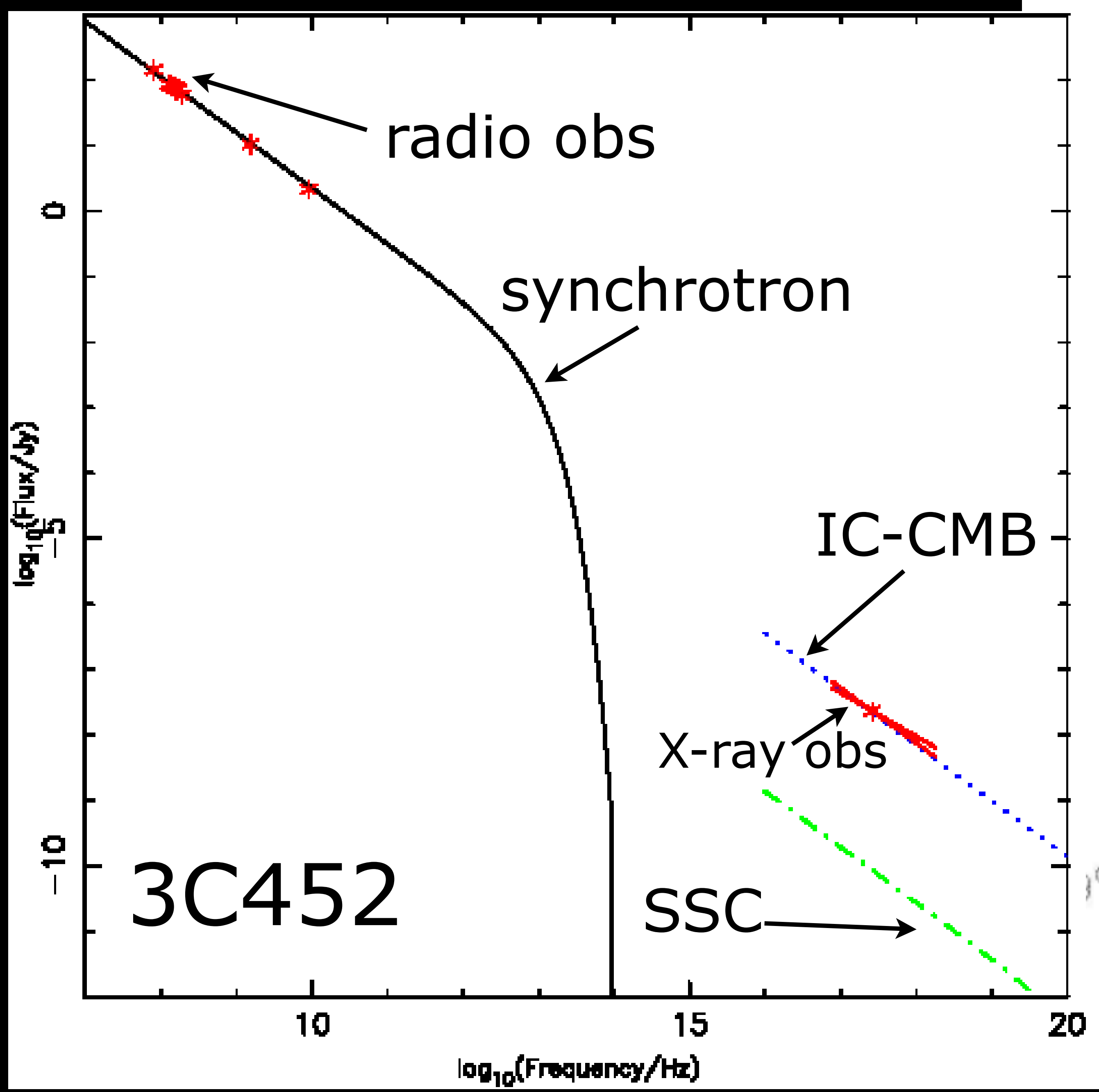


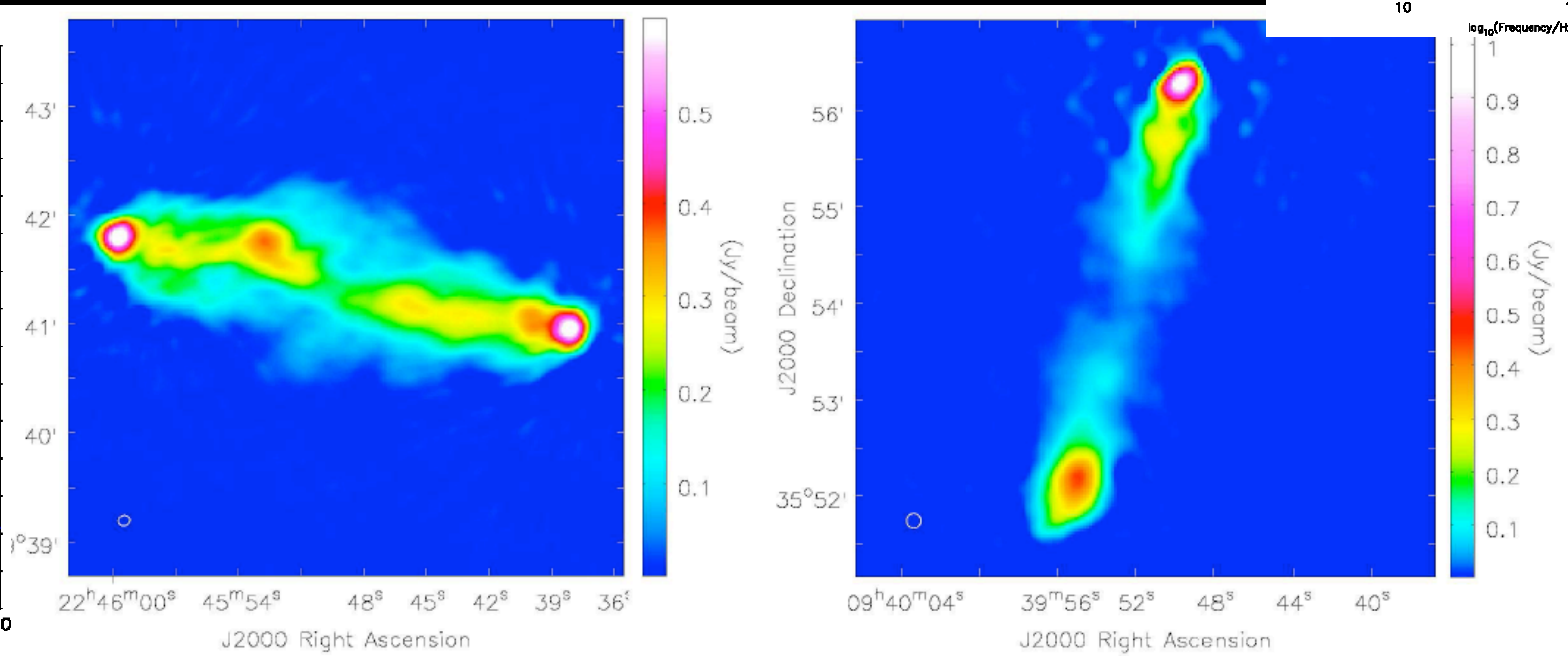
Energetics and morphology of FRII radio galaxies: synchrotron/inverse-Compton model fitting



Better constrained spectrum at low frequencies. Spectral index steeper than expected.

The total lobe energy density is greater than previous estimates by a factor of 5.0 for 3C452 and by ~2.0 for 3C223.





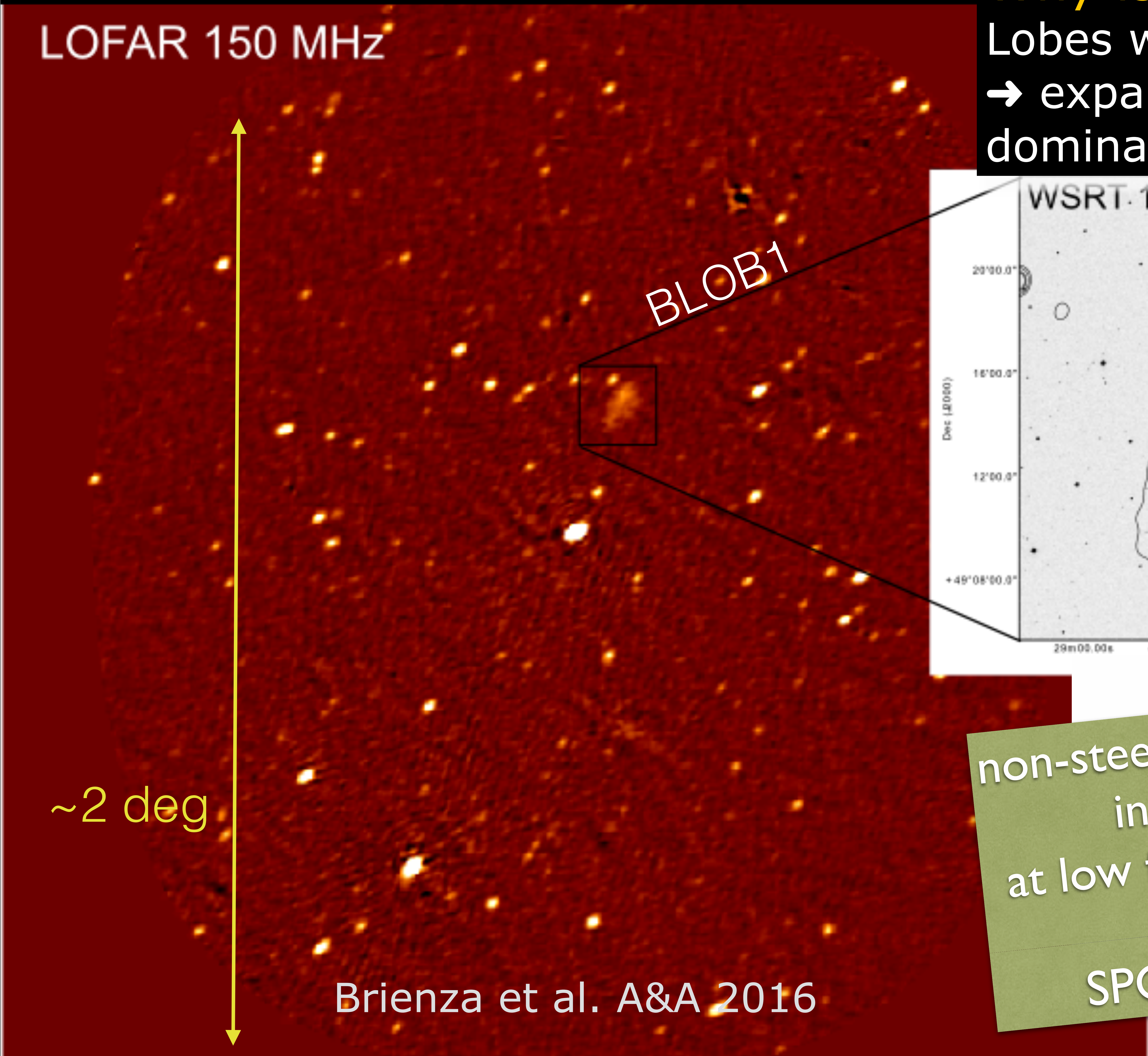
The magnetic field strength of both sources is greater compared previous estimates **but still below equipartition**.
The observed departure from equipartition may in some cases provide a solution to the spectral versus dynamical age disparity problem.

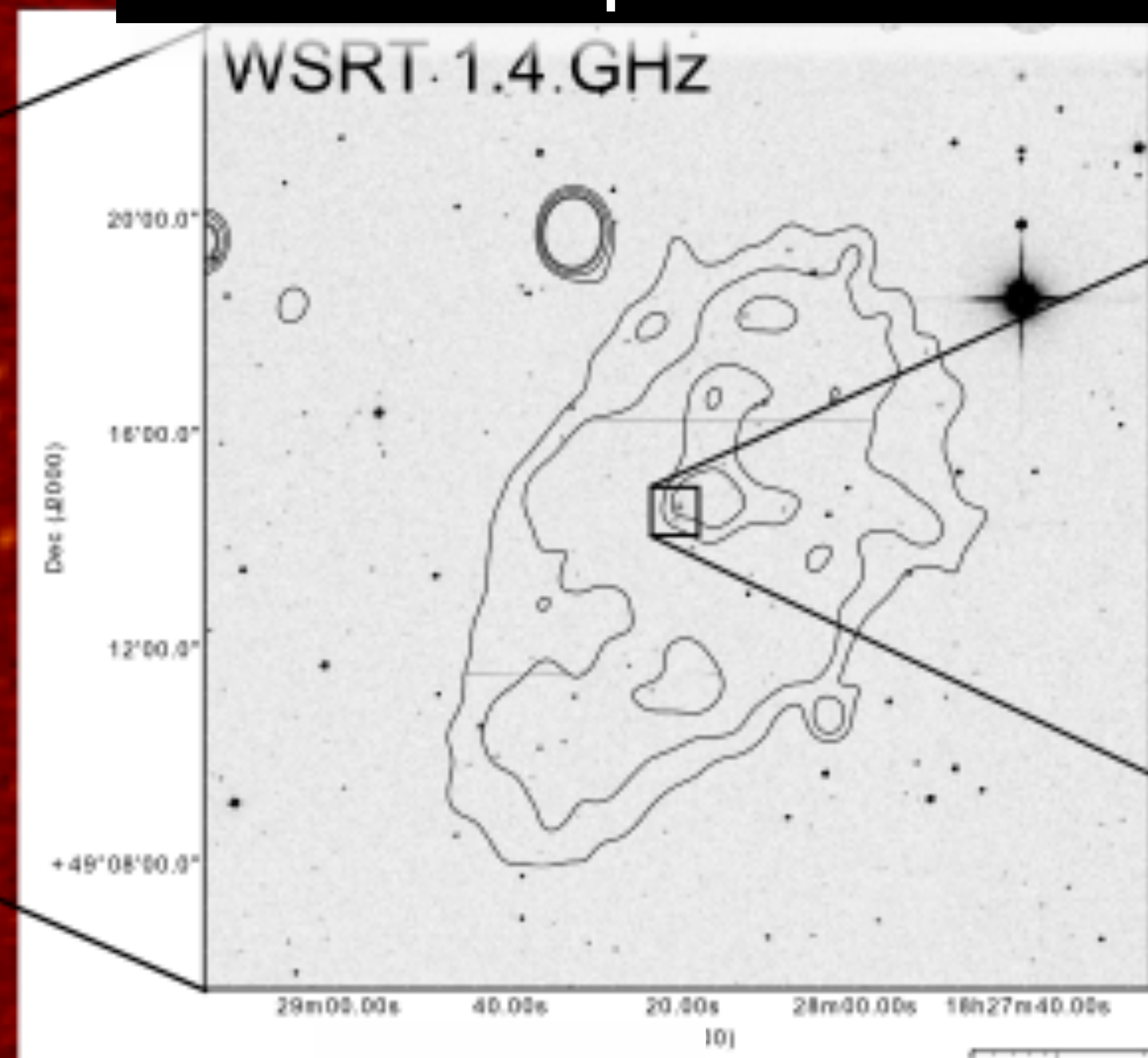
Harwood et al. "*FRII radio galaxies at low frequencies I: energetics and morphology*" 2016 MNRAS arXiv:1603.04438

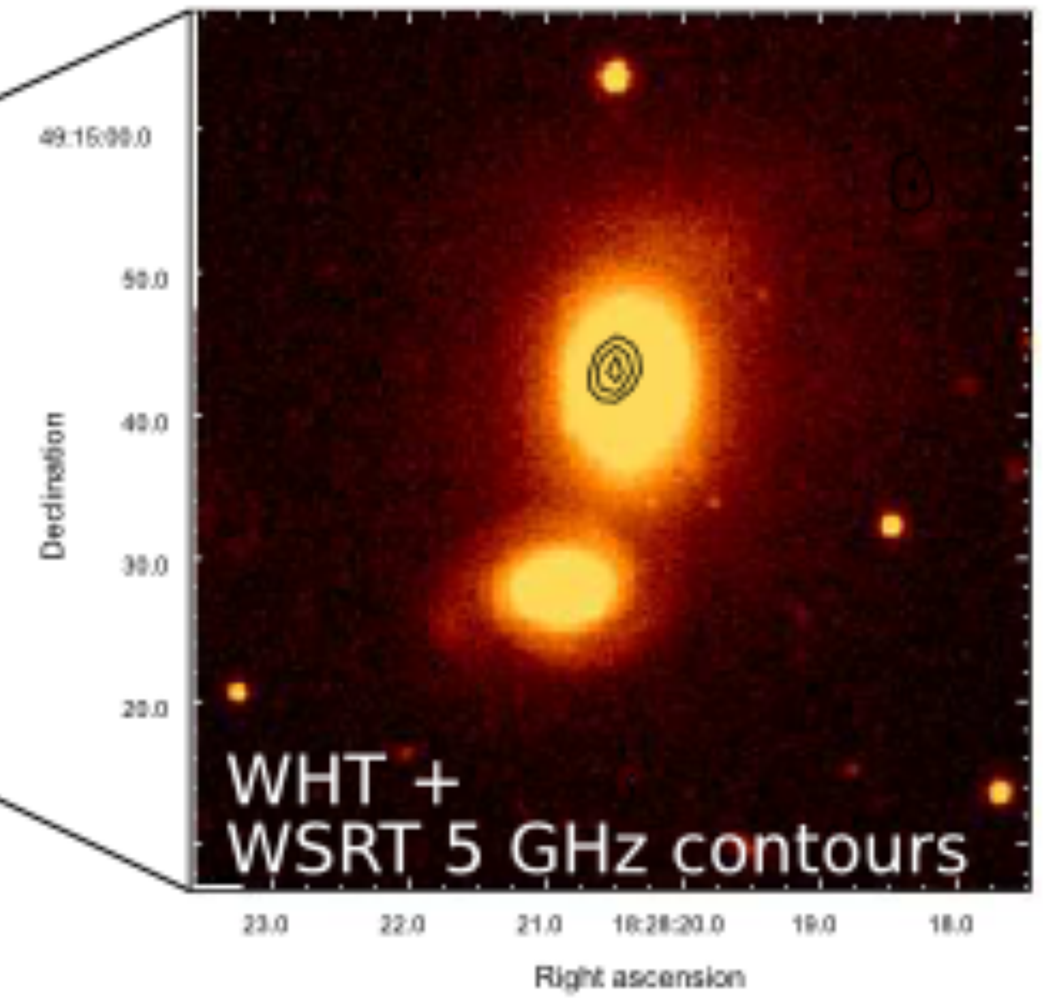
Serendipitous LOFAR discovery of a 700-kpc remnant radio galaxy at low redshift

Why is the radio plasma in BLOB1 still visible?

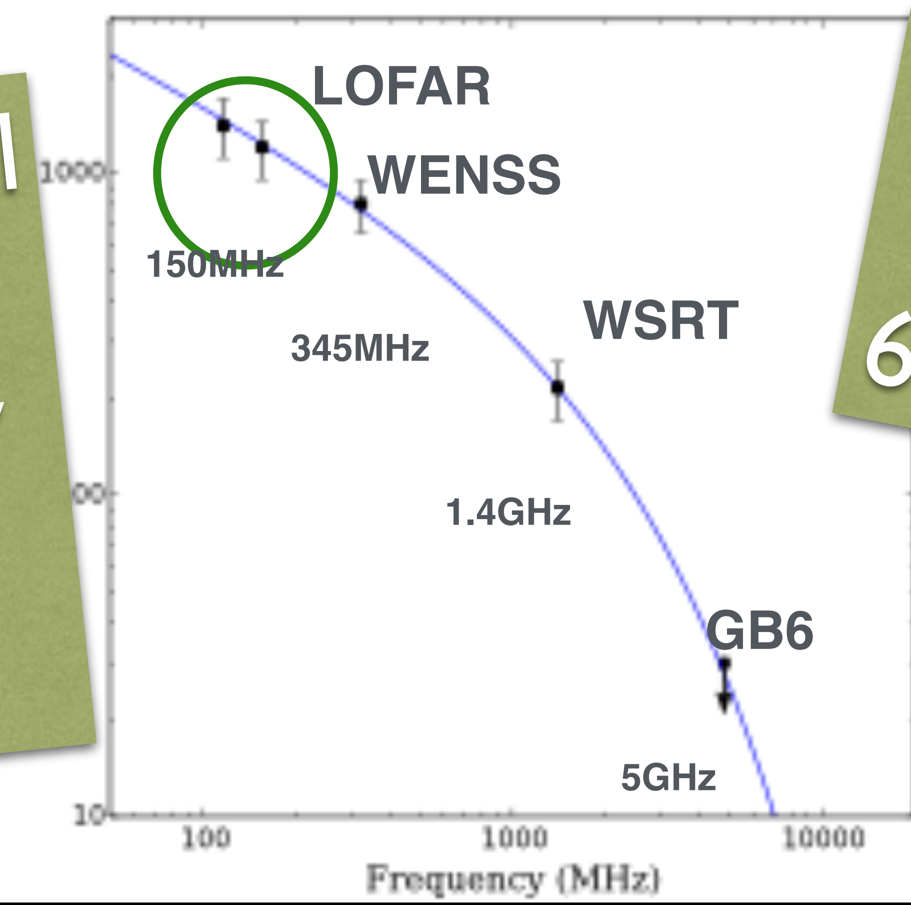
Lobes with low internal energy densities and pressures ➜ expansion rate is low ➜ radiative cooling is the dominant process in the evolution of the source.







non-steep spectral index
at low frequency
&
SPC > 0.5



15 Myr ON
+
60 Myr OFF

Low magnetic field ~1μG

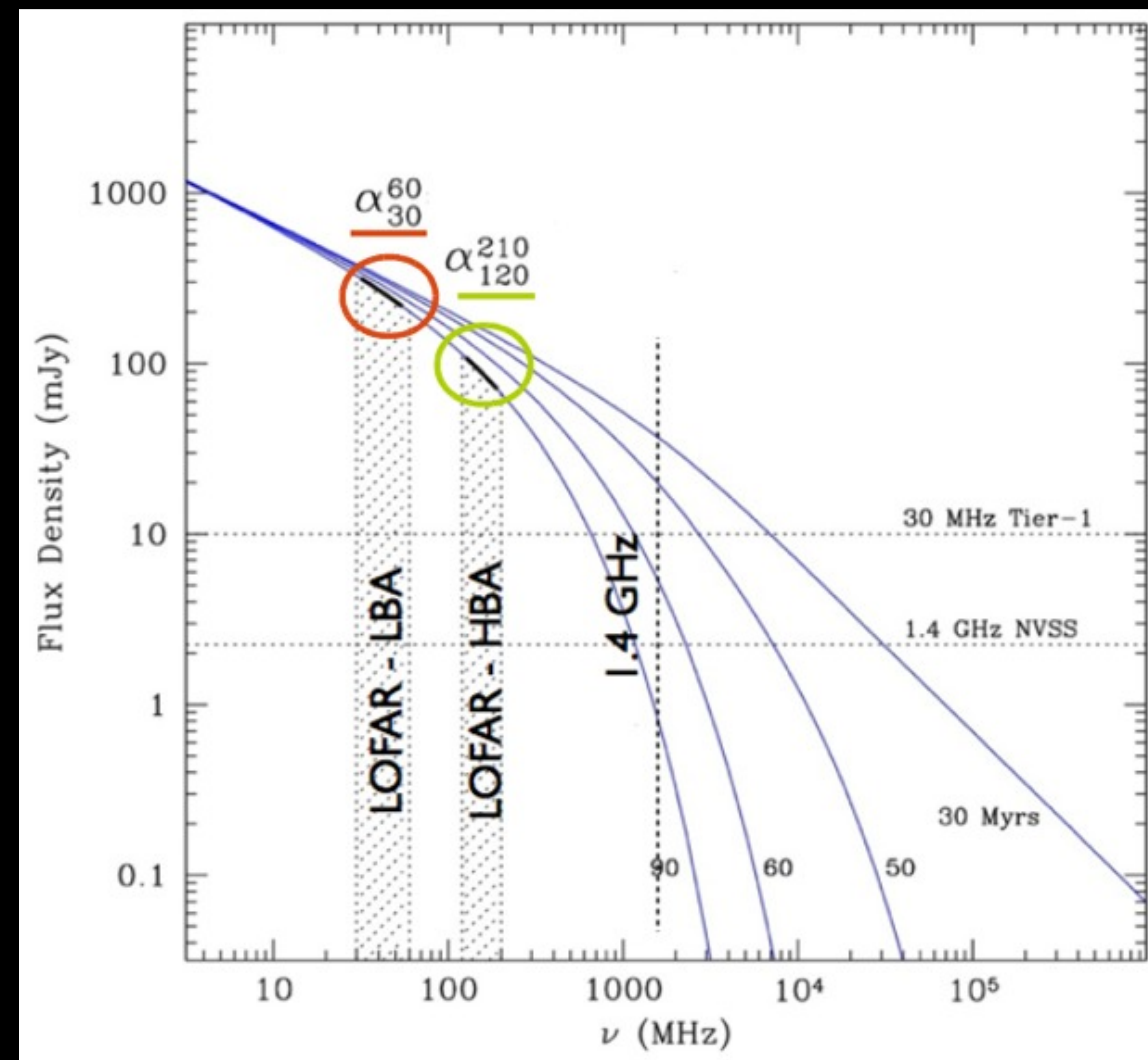
SELECTING REMNANT/DYING RADIO GALAXIES

PhD Marisa Brienza

So far mostly using steep spectral index sources
Importance of low frequencies

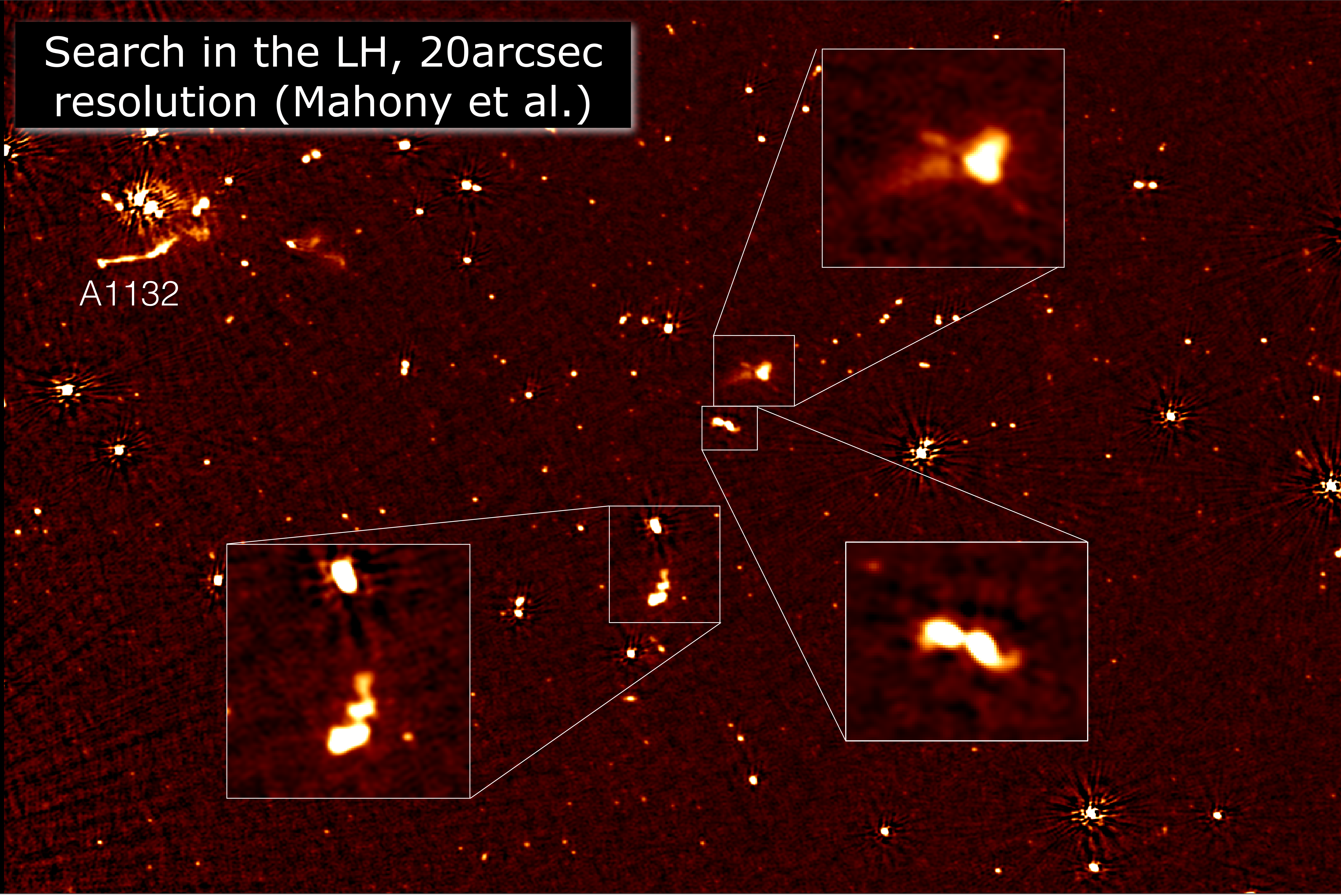
SELECTION

- STEEP SPECTRAL INDEX
  (e.g. Parma+2007, Dwarakanath+2009, Sirothia+2009, VanWeeren+2009)
- SPECTRAL CURVATURE
  (Murgia+2011)
- MORPHOLOGY
  (e.g. Saripalli+2009)



...we want to use all these criteria together!

Search in the LH, 20arcsec resolution (Mahony et al.)

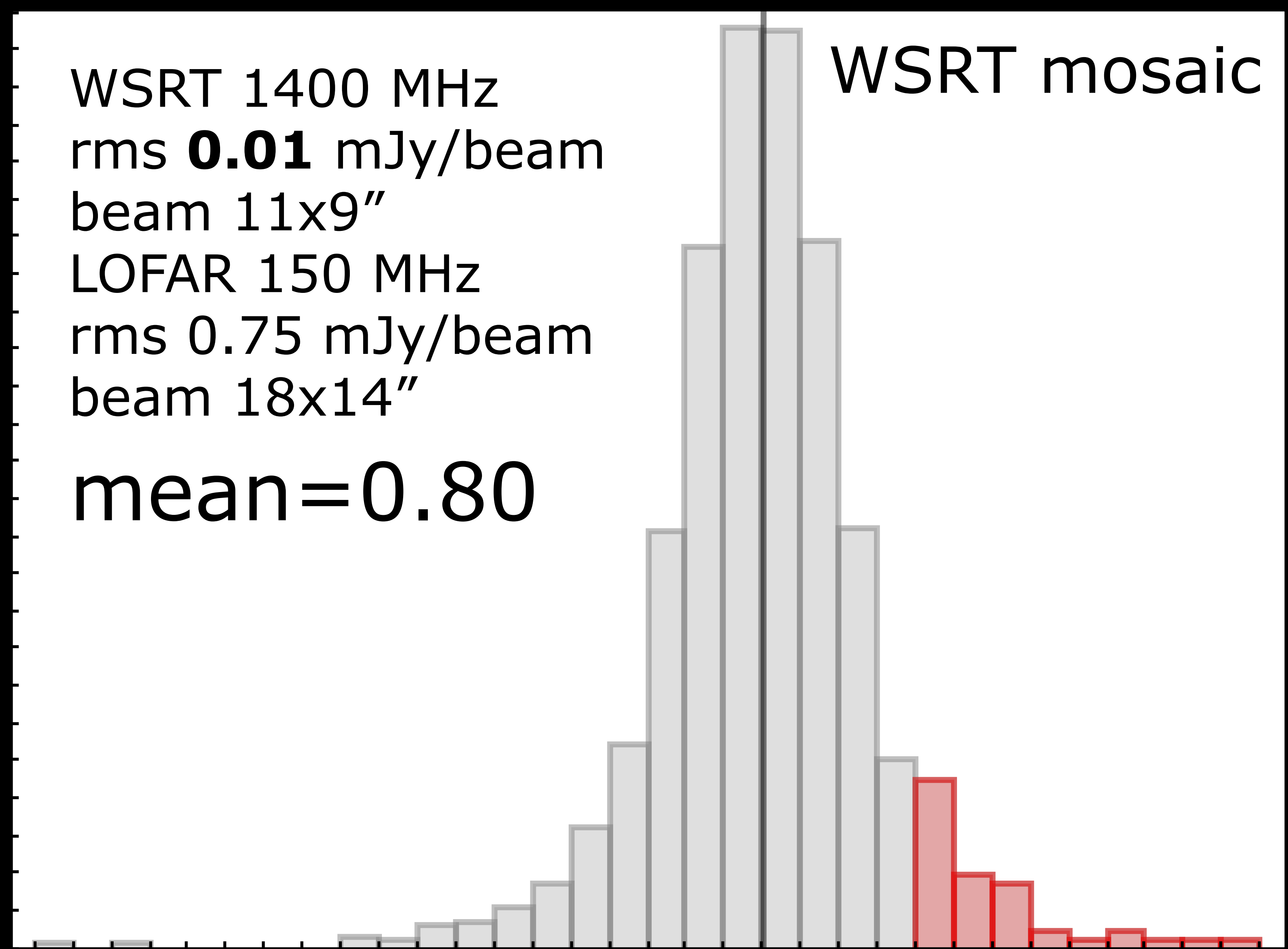


Brienza et al. in prep

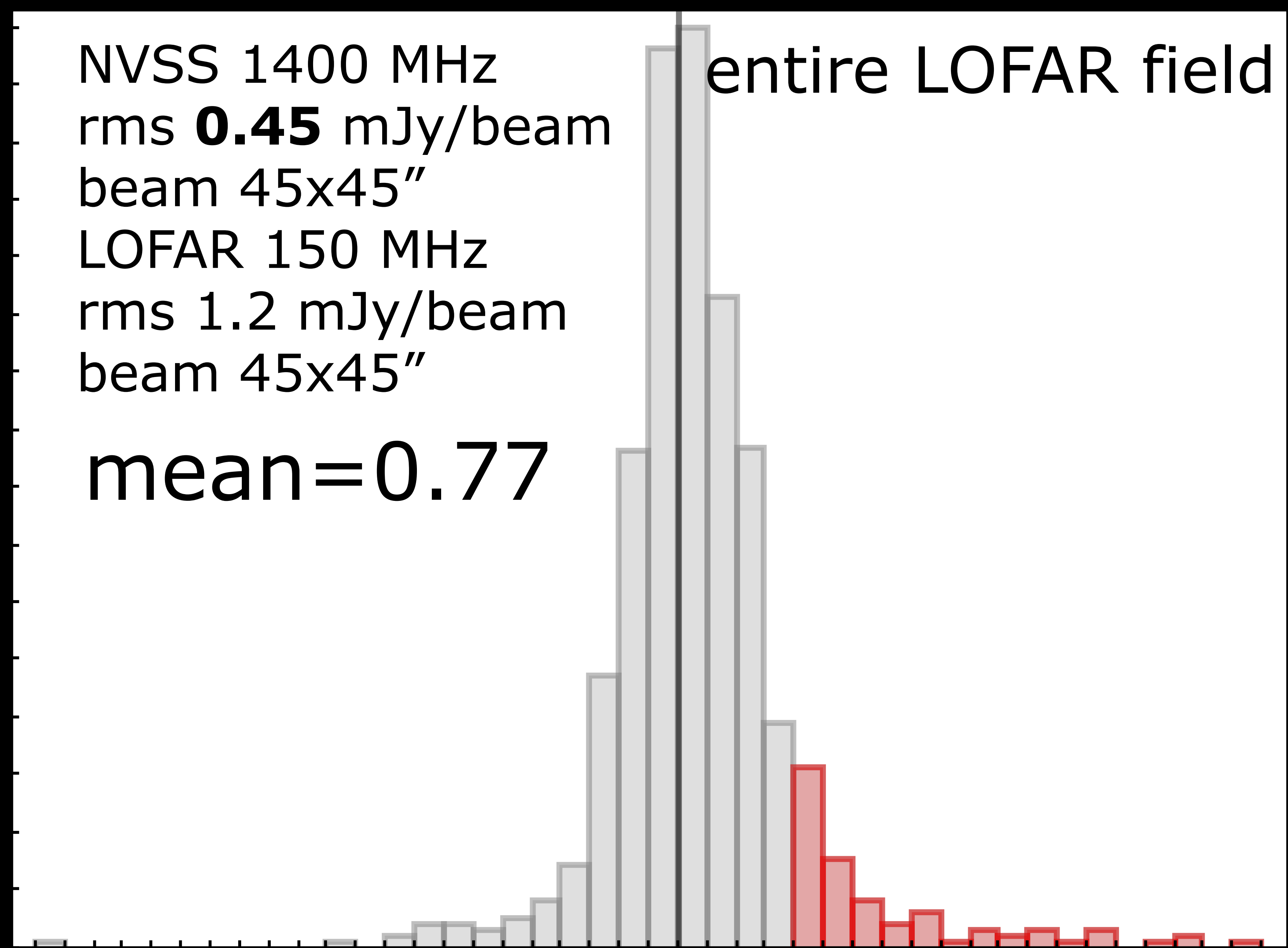
SPECTRAL INDEX >1.2

$S \sim \nu^{-\alpha}$

Why this value?



alpha(LOFAR-WSRT)



alpha(LOFAR-NVSS)

1379 sources

7% steep

25% of resolved sources (>26”) are steep

743 sources

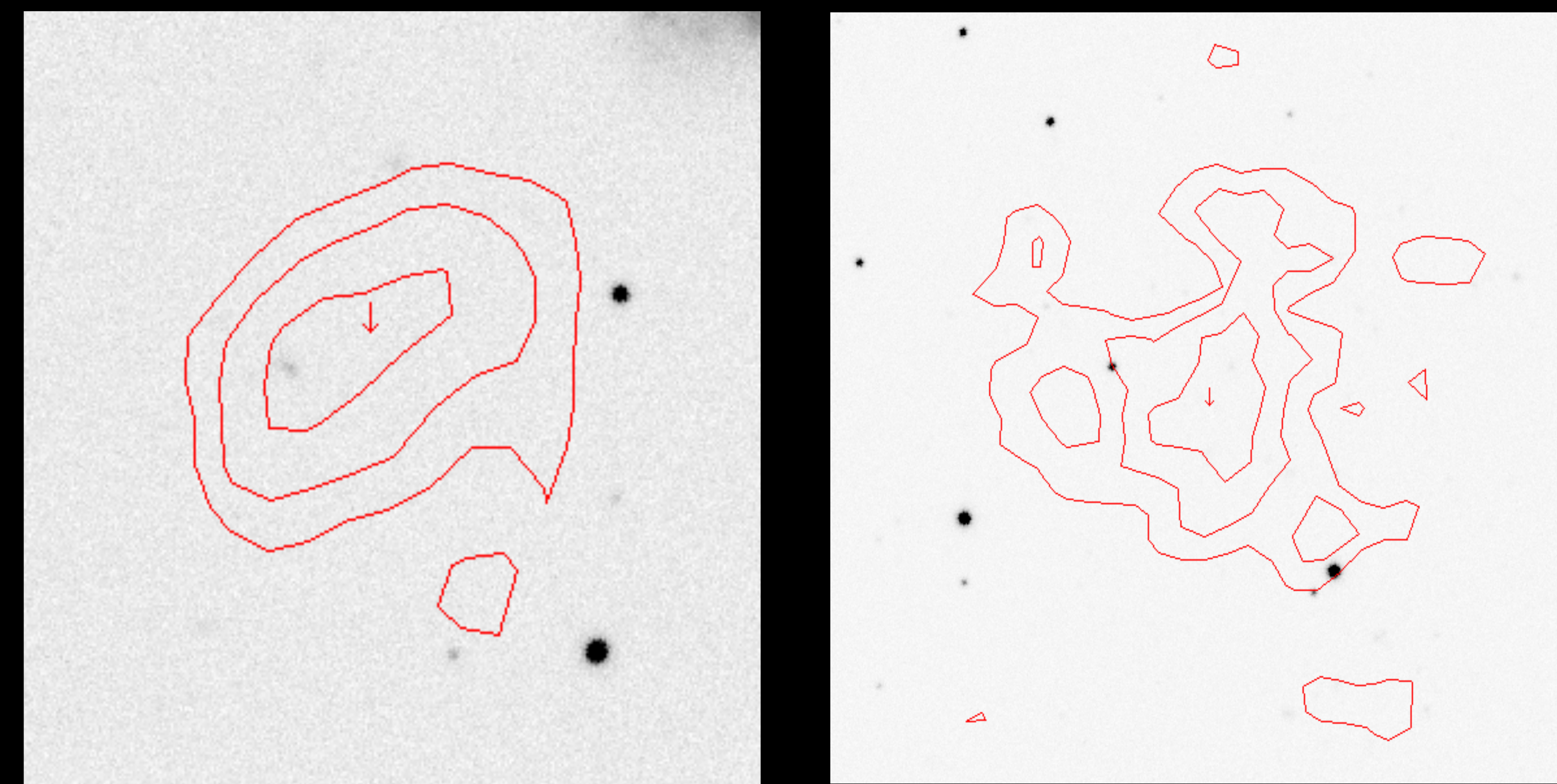
with spectral index cut applied (36.5mJy)

5.8% steep

35% of resolved sources (>64”) are steep

Brienza et al. in prep

MORPHOLOGY SELECTION



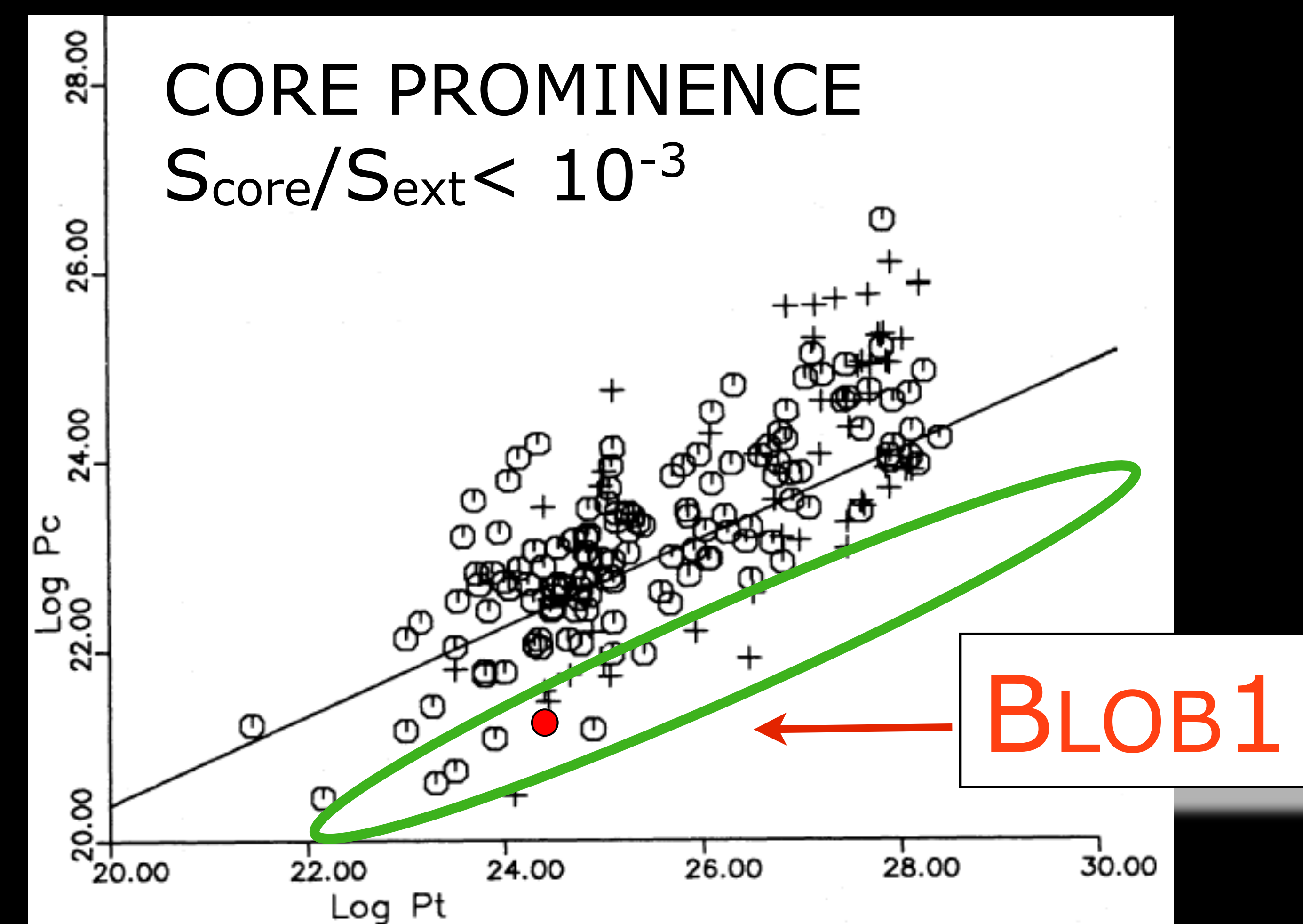
LOFAR CONTOURS + SDSS

- ★ EXTENDED
- ★ RELAXED MORPHOLOGIES
- ★ LOW SURFACE BRIGHTNESS
- ★ WITHOUT COMPACT COMPONENTS (UNDETECTED IN FIRST)

optical ID important to confirm
the nature/redshift of the sources!

~ 10 CANDIDATES

among the extended, i.e. a few %
How many of them are also among the steep spectrum?



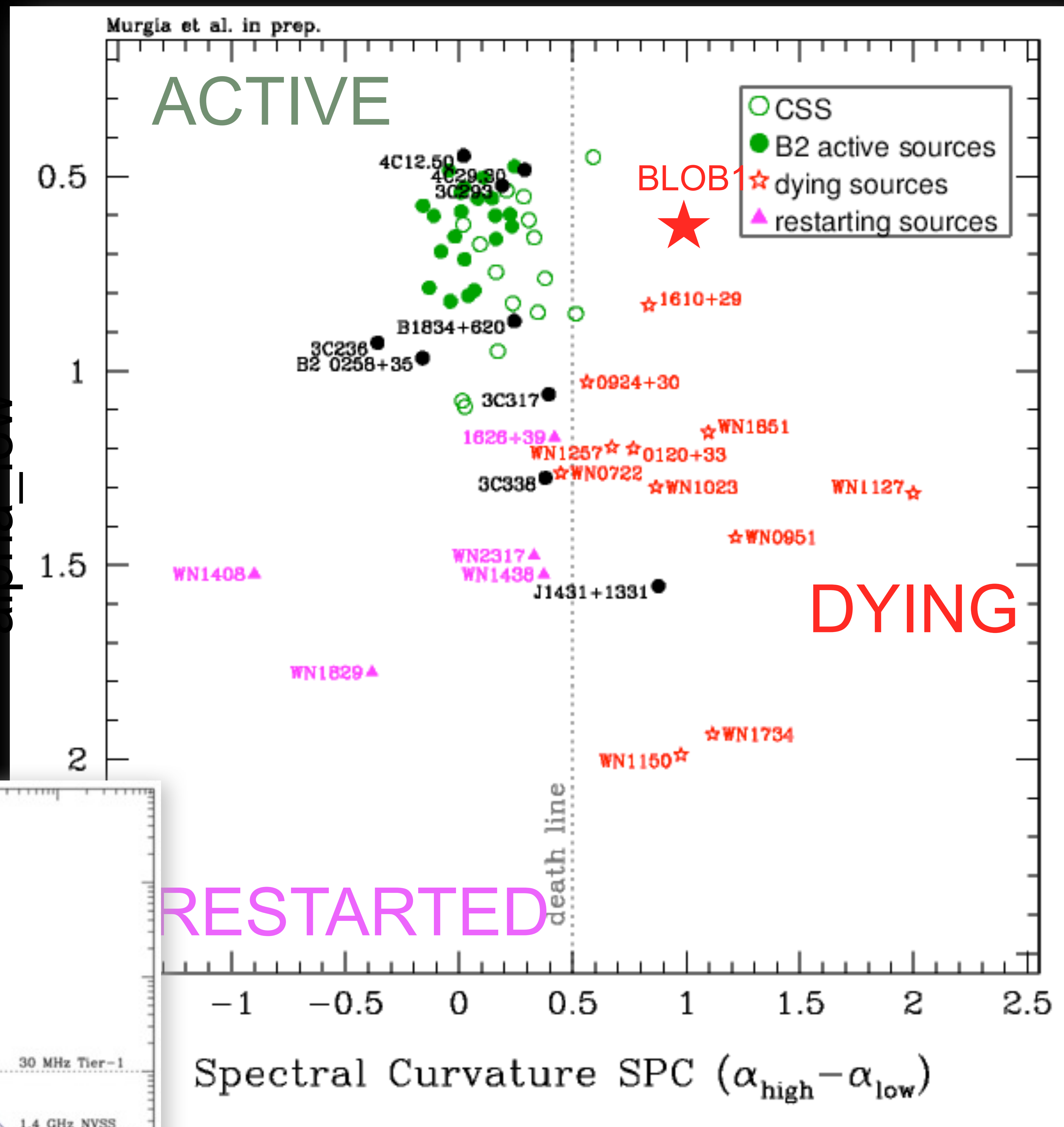
Giovannini et al.

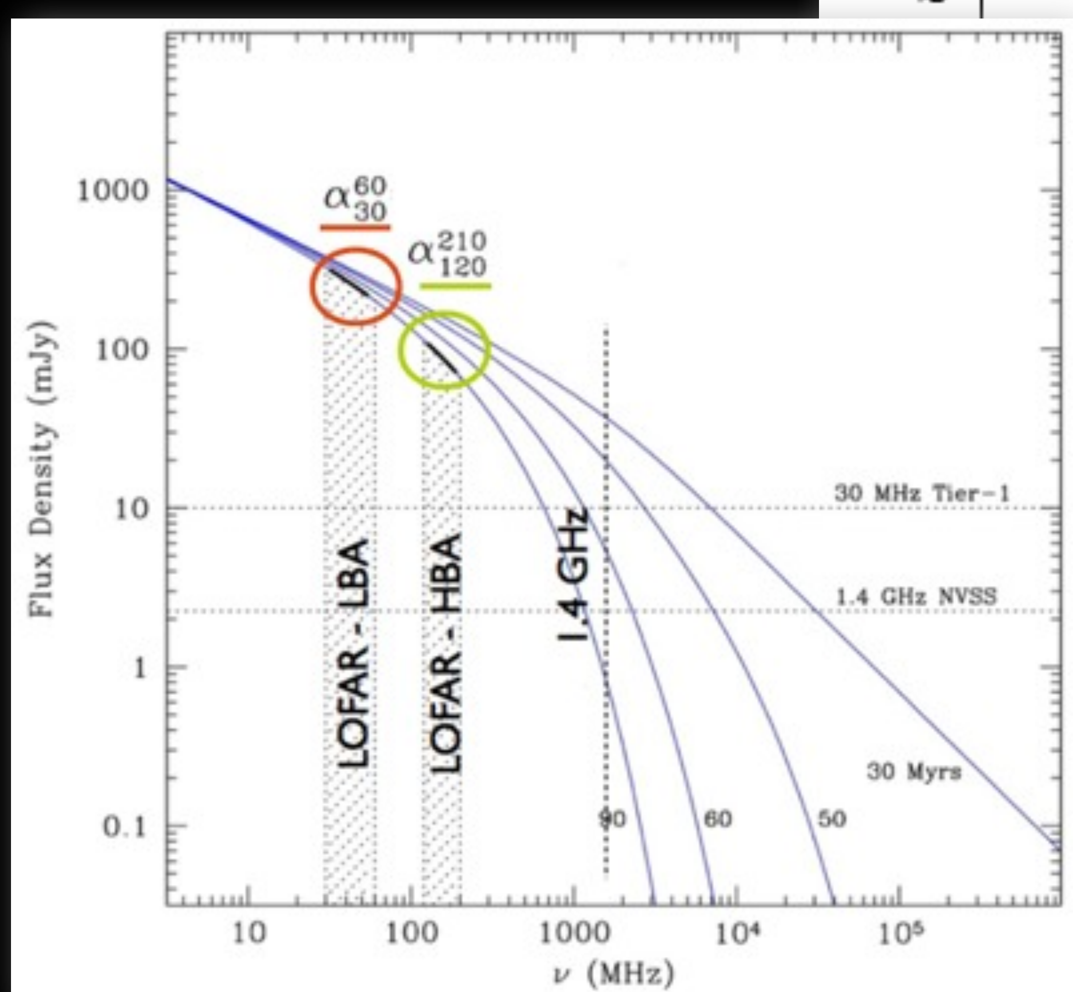
SPECTRAL CURVATURE = $\alpha_{high}-\alpha_{low}$

Brienza et al. in prep

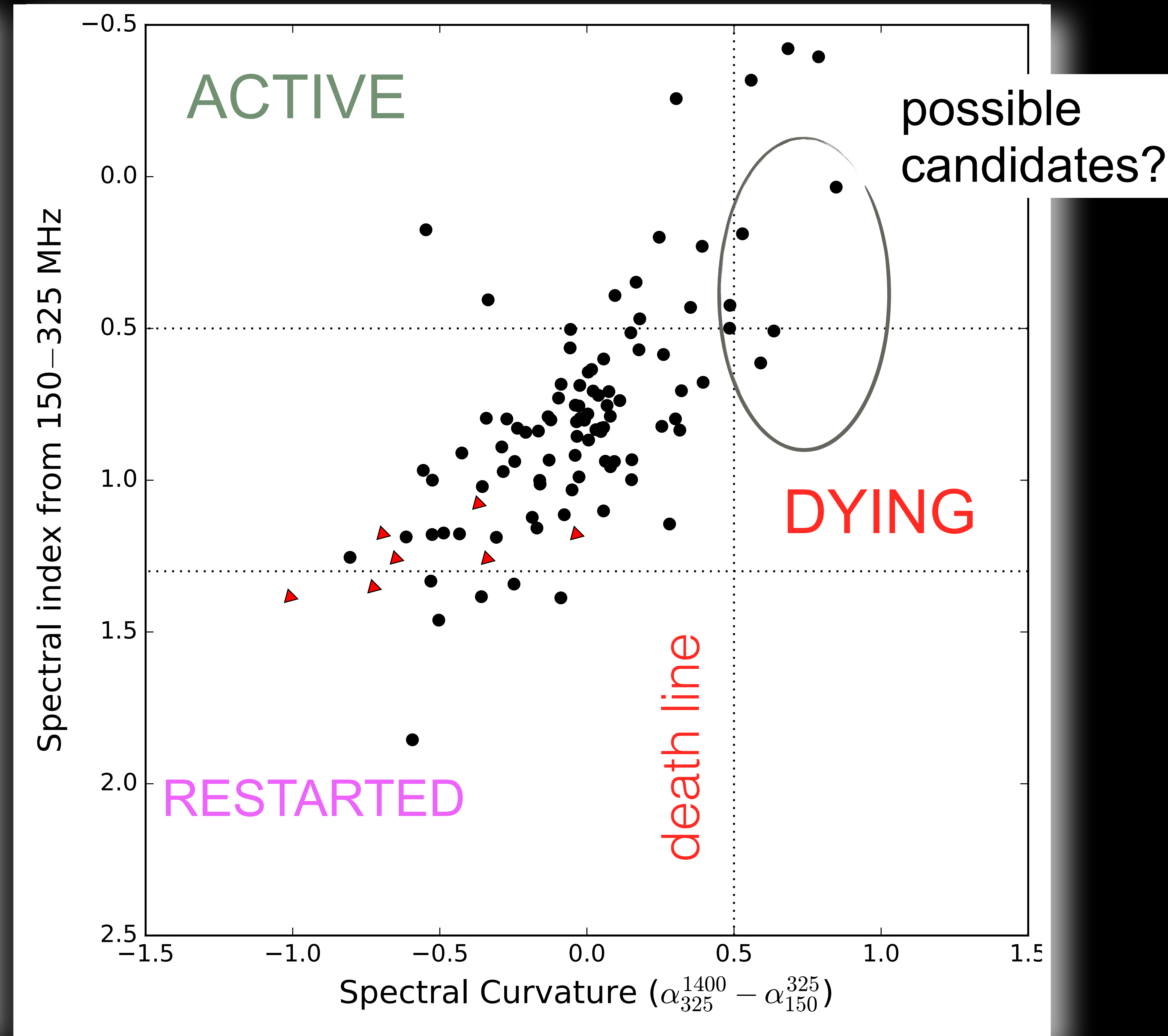
S~nu$^{-\alpha}$

Literature data from Murgia et al. in prep





LOFAR-WENSS-NVSS



Limited in sensitivity and frequency range: need for LBA data!

MODELING THE INTEGRATED SPECTRA OF RADIO GALAXIES

→ Radiogalaxy.py (Godfrey et al. in prep)

→ Generalised Continuous Injection Model

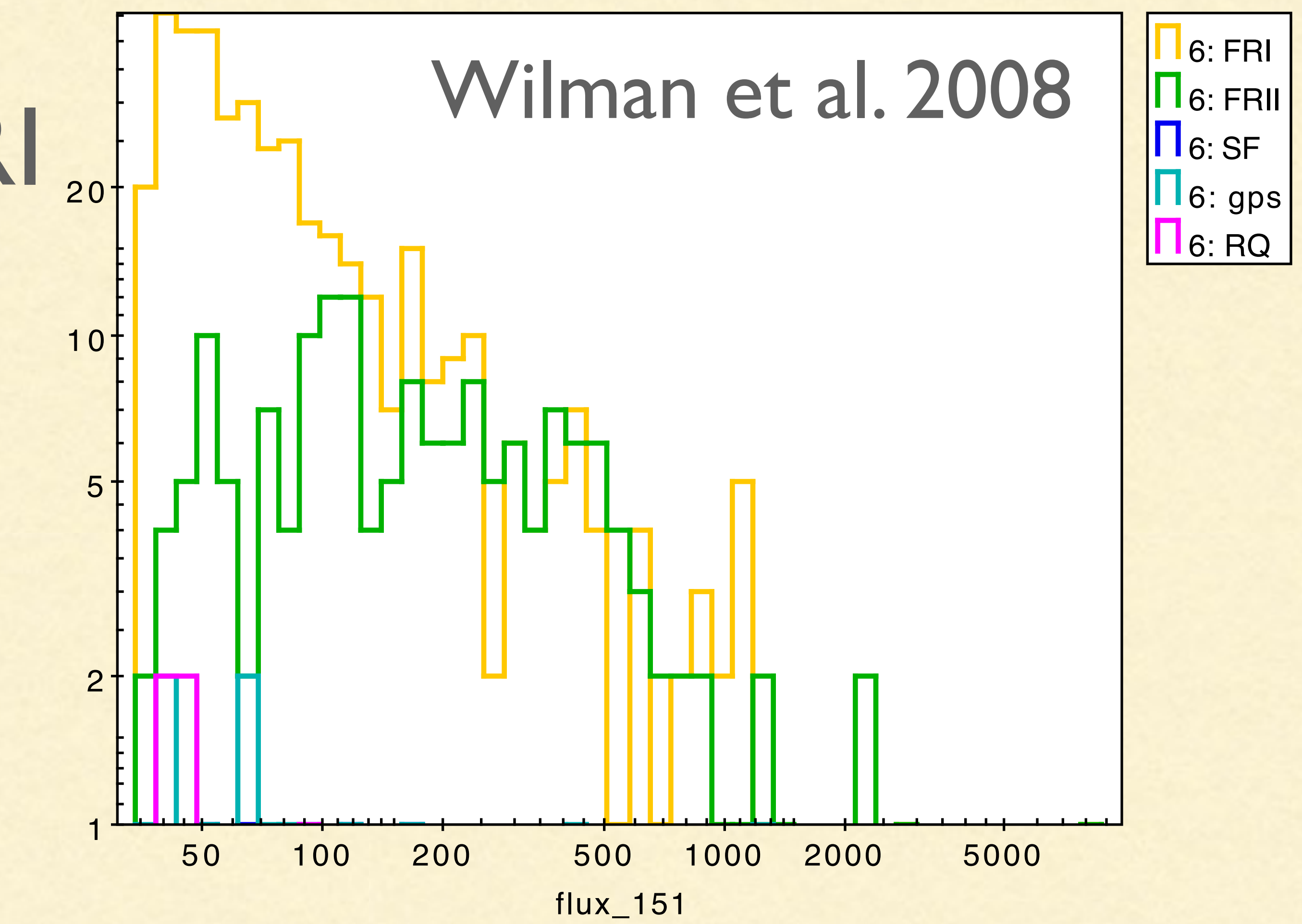
- Distribution of magnetic field strengths (within each ΔV).=> within each volume element, Gaussian distribution of the field (i.e. non-uniform distribution of the field)
- Adiabatic and radiative cooling.
- Arbitrary evolution of Volume and B-field.
- Relevant to multiple phases (eg. active + remnant)
- Arbitrary, time-dependent particle injection.
- Fast enough for spectrum fitting & producing mock- catalogues.

→ Evolution of the radio galaxy different for FRII ➜ self-similar model and FRI ➜ jet driven, pressure limited model (Luo & Sadler 2010) followed by adiabatically expanding (bubble phase)

→ Create mock catalogues

STATISTICAL MODELS OF THE REMNANT RADIO GALAXY POPULATION

For the sources in the Lockman-Hole field (Brienza et al. in prep)



→ SKADS Simulated Skies (S3), most (~70%)of the sources FRI

→ Create mock catalogues of the radio galaxies by assuming appropriate **distributions** for the model parameters:

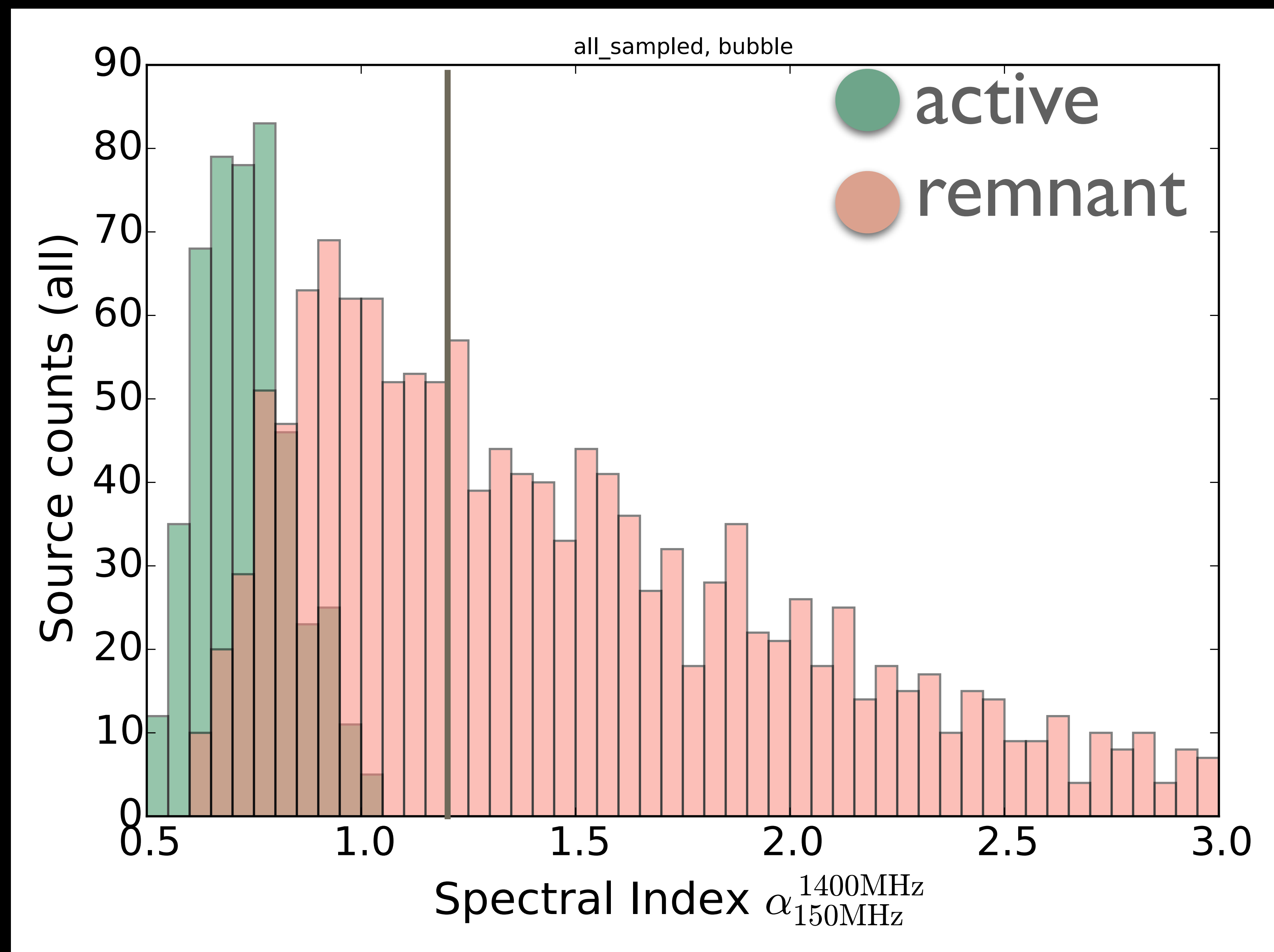
- jet power
- redshift
- active time
- observation time
- magnetic field evolution
- volume evolution
- injection index

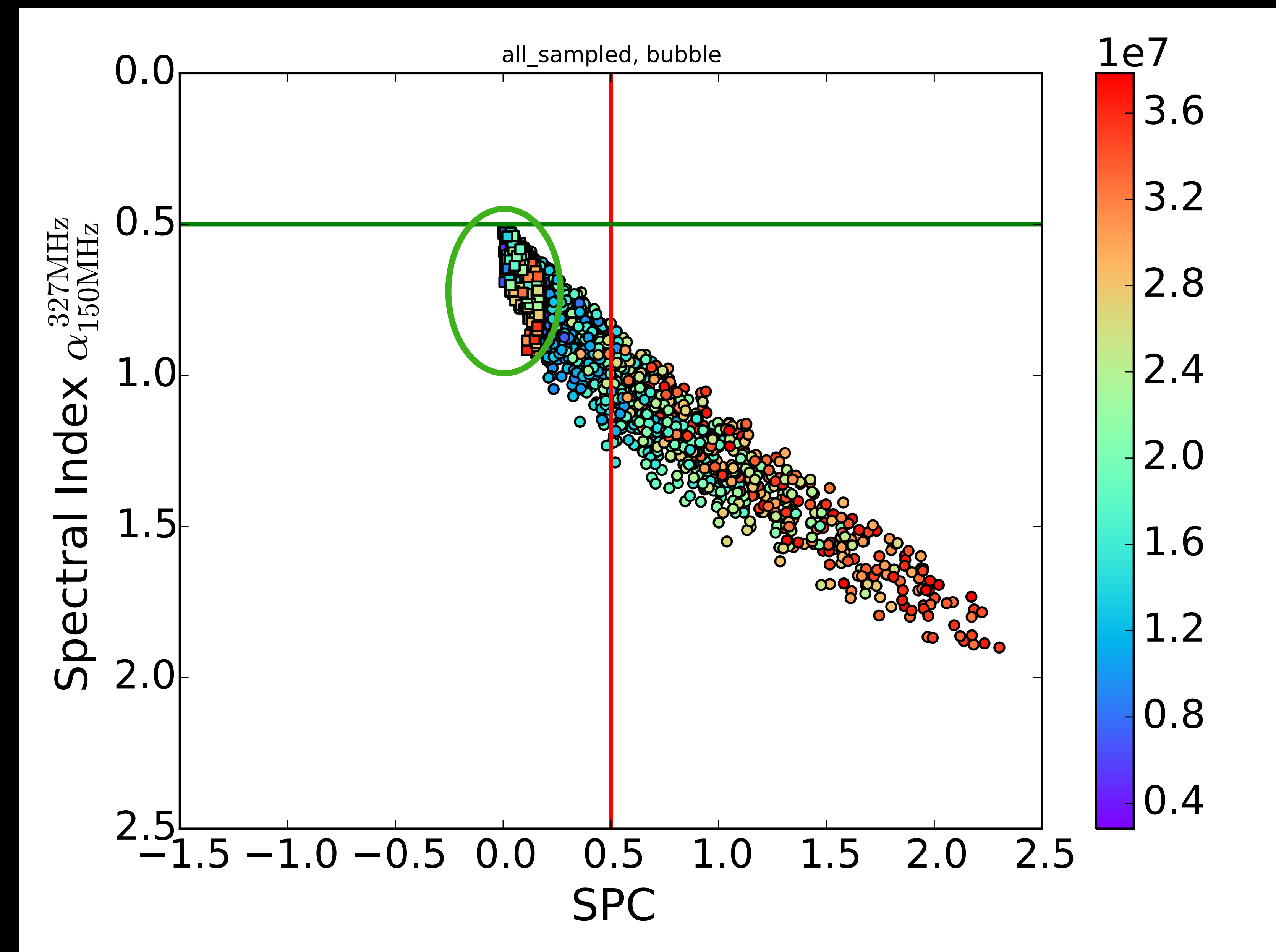
→ Comparison with observations

STATISTICAL MODELS OF THE REMNANT RADIO GALAXY POPULATION

Godfrey et al. in prep
Brienza et al. in prep

Evolution of active phase following Luo & Sadler 2010 (pressure-limiting approximation)

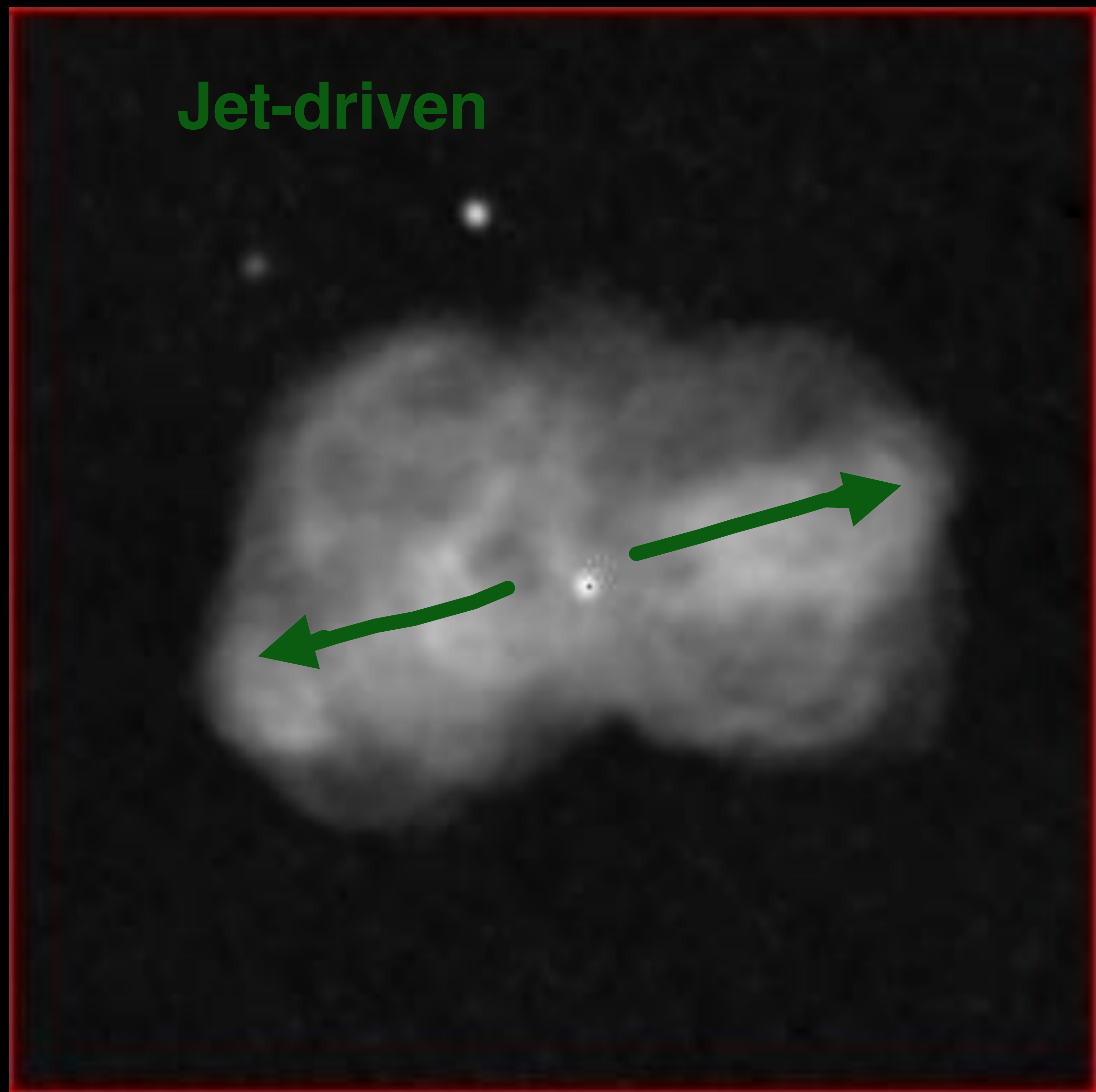


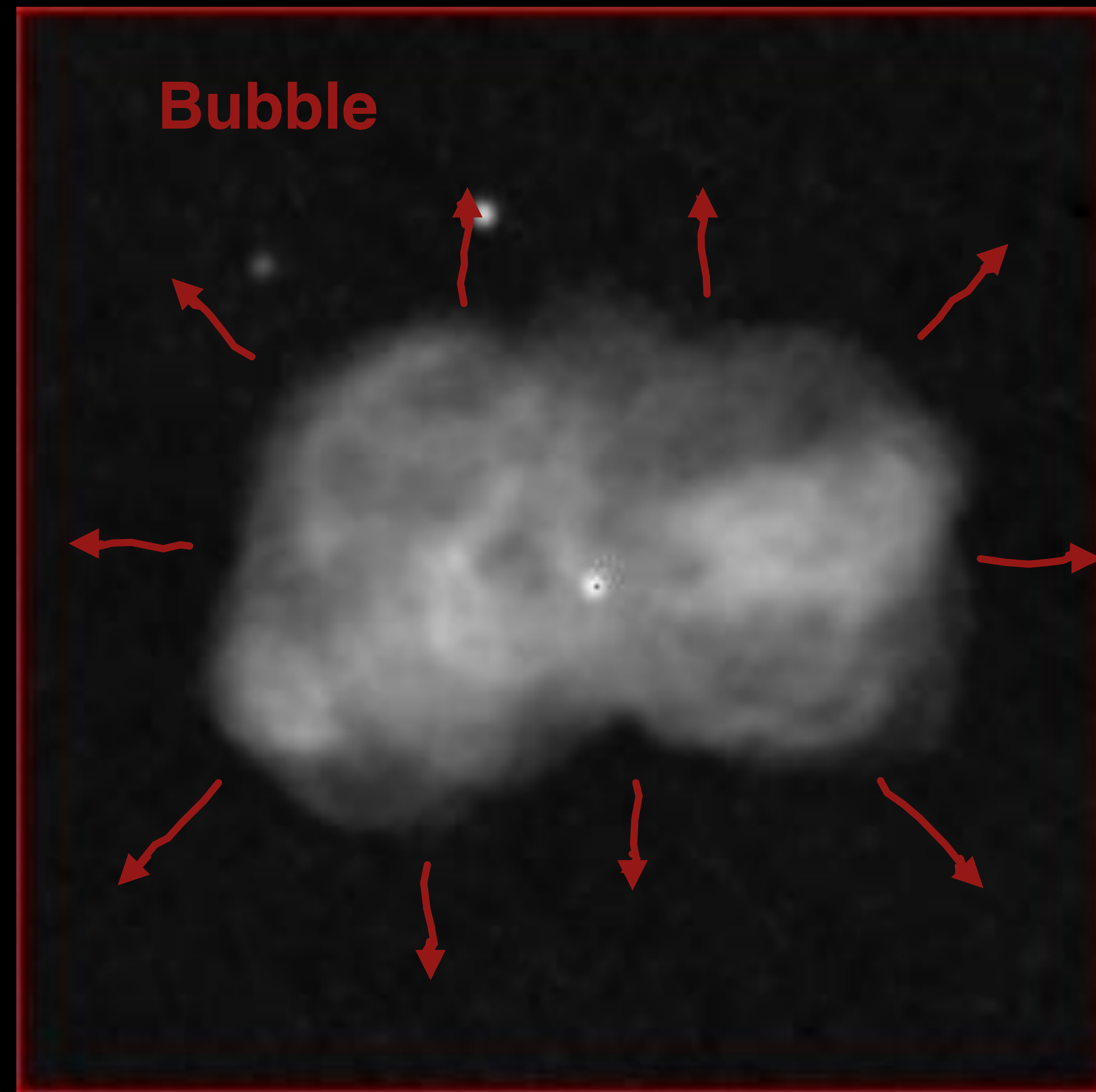


ONLY radiative losses included

↓

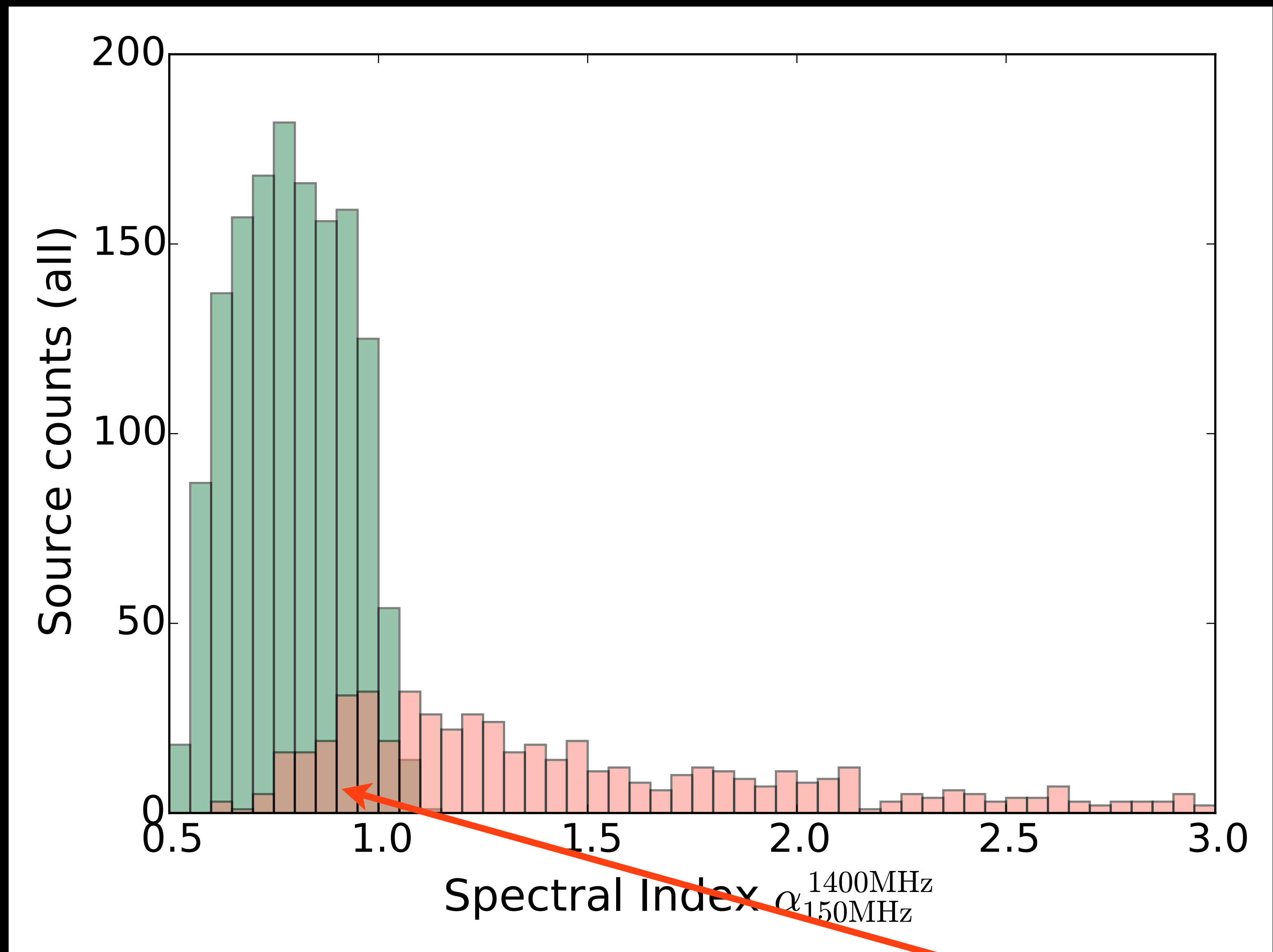
NEED FOR ADIABATIC EXPANSION! (to reproduce observation)

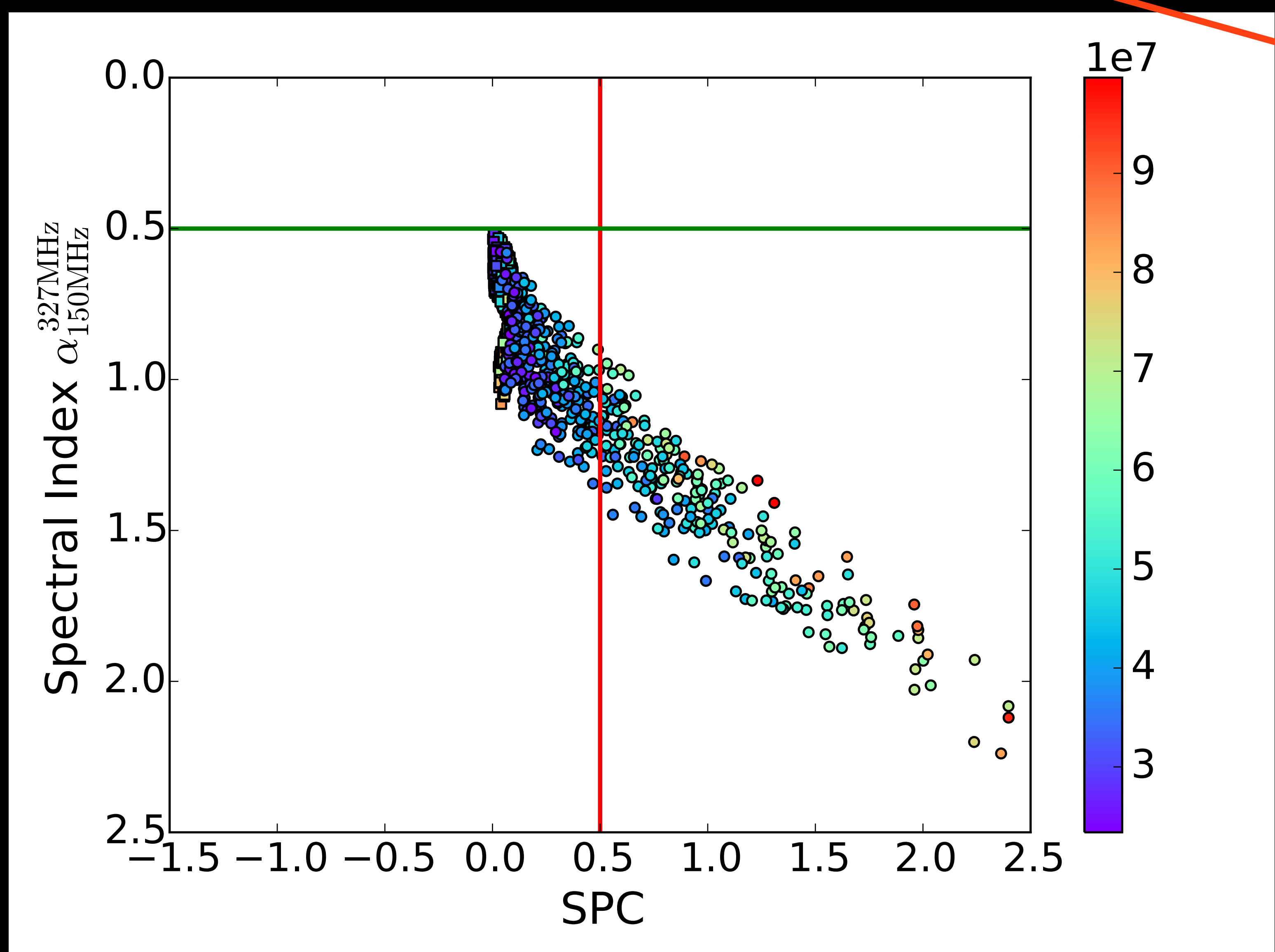




Tracing the adiabatic expansion in FRI: follow Luo & Sadler 2010

Preliminary modelling/statistics with adiabatic expansion





Sources in the "remnant phase" ~35% of the whole population

Those with α>1.2 are 16% ➜ about twice what we detect

Note: a large fraction of the "remnants" for the model definition cannot be recognised by our selection based on spectral index and/or spectral curvature

Brienza et al. in prep.

Conclusions

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- Inventory of dying/remnant radio sources in the Lockman Hole field in progress ➜ using three different criteria
- Preliminary results: relatively small numbers also at low frequencies (<10%)
- Modelling the evolution of FRI including remnant phase (in progress)
- Preliminary results: Losses due to adiabatic expansion important
- Cases like Blob1 (long *off* phase) are rare?
- Also on-going: look for *young* radio galaxies and *restarted*

All to be extended to the Tier-1 survey fields to expand the statistics!