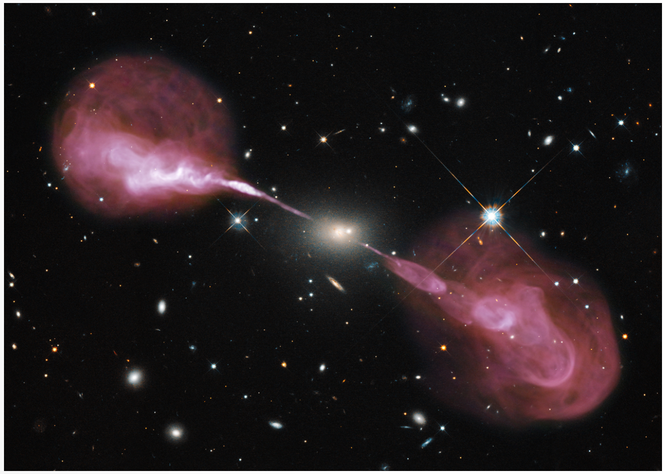
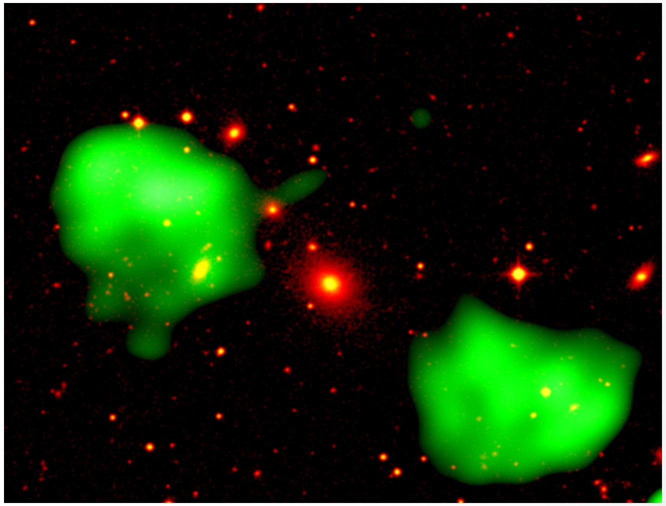
Statistical Studies of Remnant Radio Galaxies

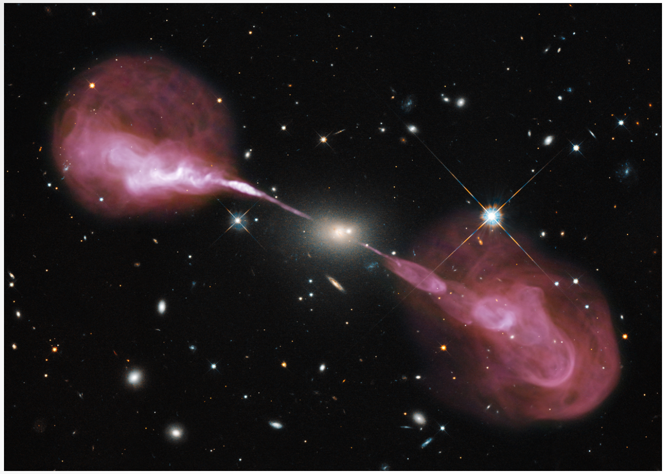
Leith Godfrey (ASTRON)



Herc A: NRAO/NASA



B0924+30: M. Murgia



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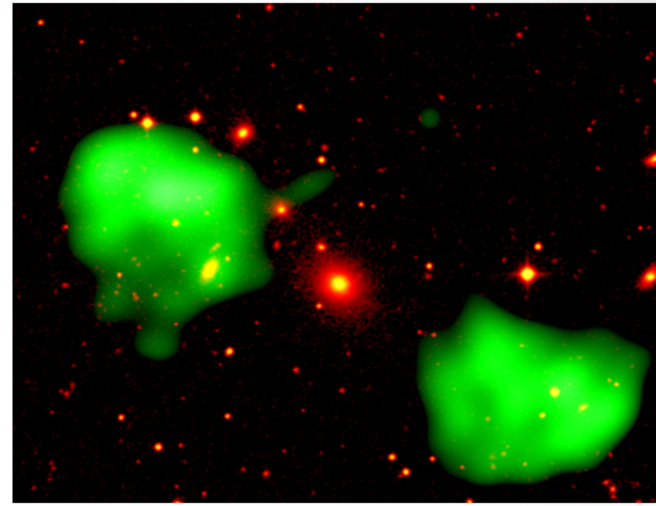

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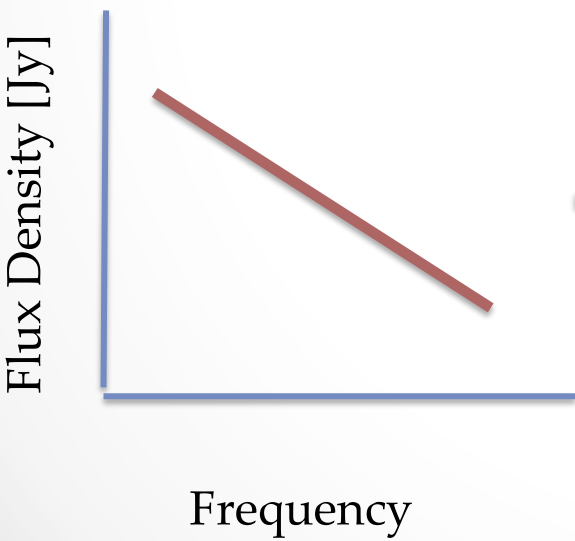
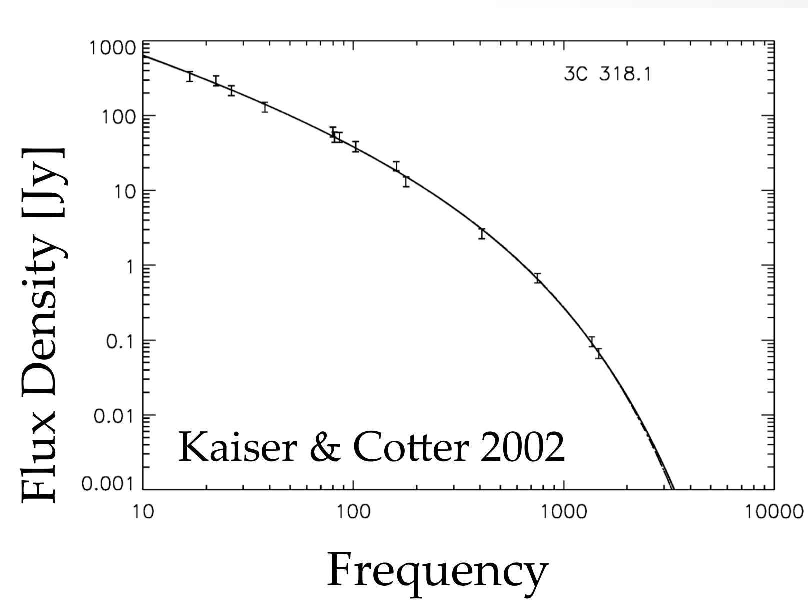
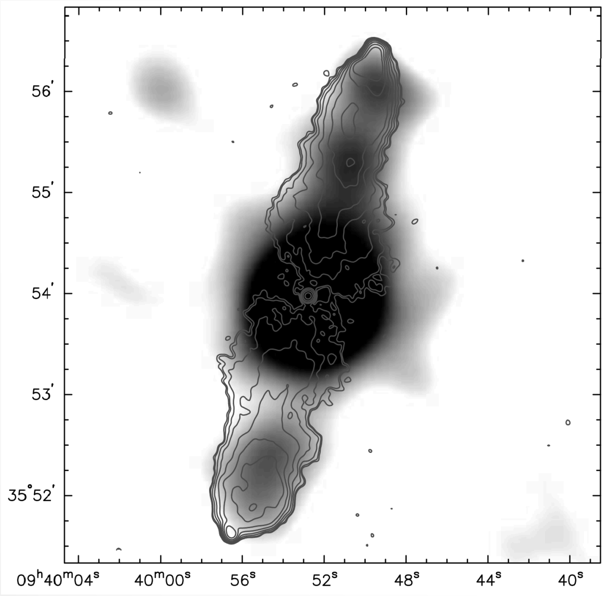




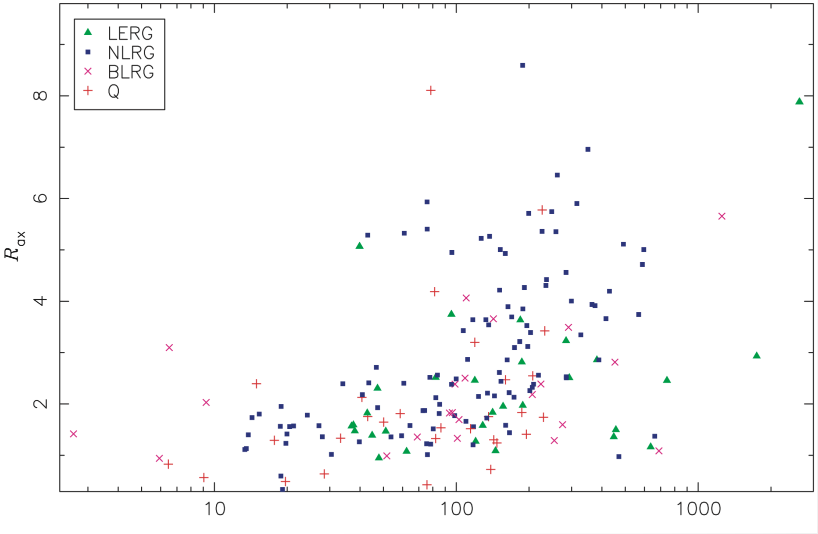
Are FRII radio galaxies supersonic and self-similar?

Lobe pressures comparable to external pressures (Hardcastle +2000/2002; Croston+ 2004)



Axial ratios increase with linear size (Mullin+ 2008).

Axial Ratio



Linear Size [kpc]

The Nature of Radio Loud Quasars

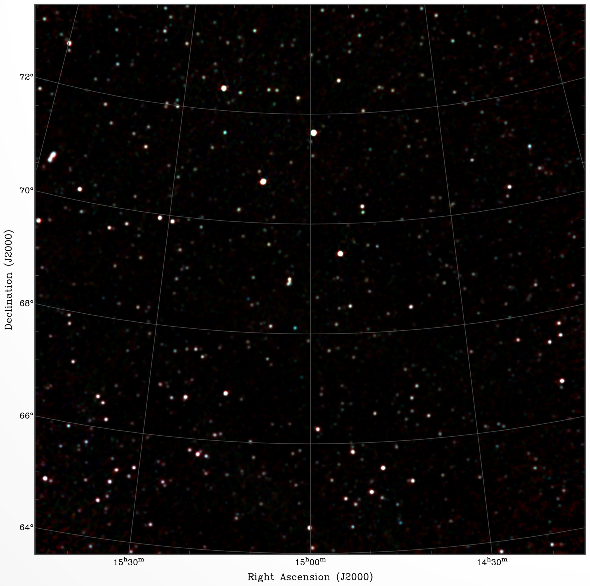
Two proposed models predict quasar transition from radio loud to radio quiet

- Spin-powered jets with Magnetically Arrested Accretion (Tchekhovskoy+ 2010).
- State transitions similar to X-ray binary/microquasars (eg. Nipoti+2005; Kording+ 2006).

These imply the existence of remnant radio lobes associated with radio quiet AGN.

Remnant and restarted radio galaxies represent an effective tool to study:

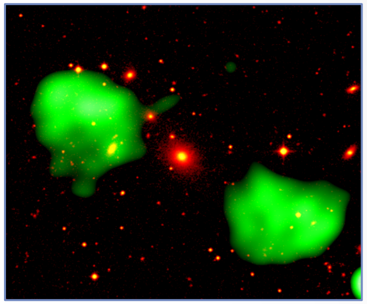
- Duty cycle
- Luminosity evolution
- Radio source dynamics
- Nature of radio loud quasars
- Fate of seed particles for cluster Halos and Relics



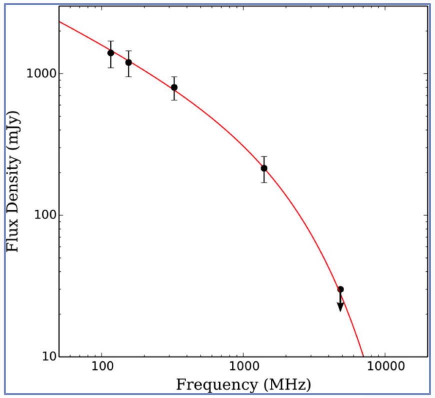
These are also important aspects for interpreting the upcoming continuum surveys

How to spot a remnant radio galaxy

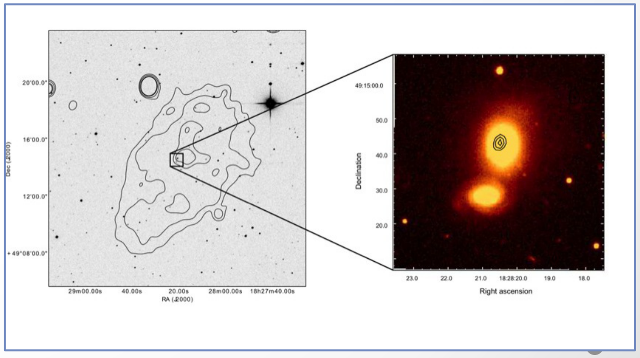
- 1. Low core-to-lobe flux ratio.



- 2. Steep and/or highly curved spectrum.



- 3. "Relaxed" morphology with no compact features such as jets and hotspots.



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Statistics of remnant radio galaxies in flux limited samples

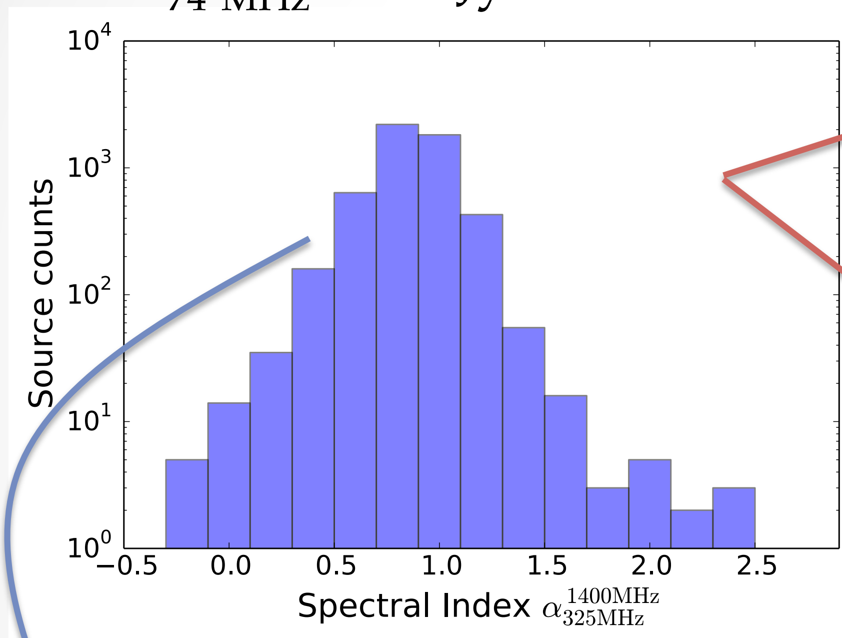
- Approximately 1 - 3 % of B2 and 3C radio galaxies are in "dying" phase (Giovannini+ 1988).
- Remnant fraction ~ $\tau_{remnant}$ / τ_{active}

Active Timescale	Remnant to Active fraction (Giovannini+ 88)	Implied Remnant Timescale	Radiative Cooling Timescale	Light crossing time (300 kpc)
~30 Myr	~ 3%	~ 1 Myr	10 - 100 Myr	~ 1 Myr

- Some effect other than radiative cooling (such as adiabatic expansion losses) contributes significantly to the luminosity evolution in the remnant phase.

Less than 1% of radio galaxies with $S_{74\ MHz} > 1.5$ Jy are ultra-steep spectrum remnants.

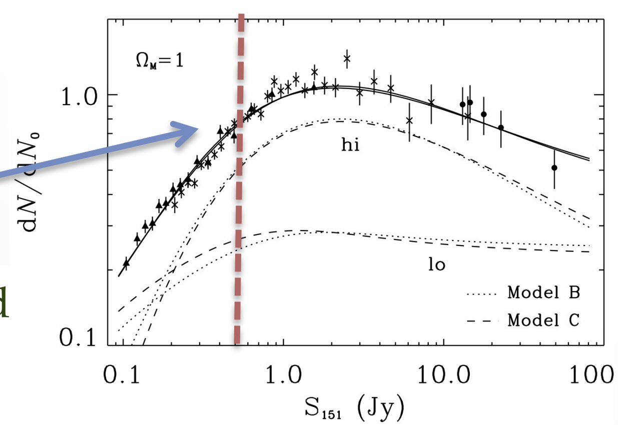
$S_{74\ MHz} > 1.5$ Jy VLSSr Selected Sample



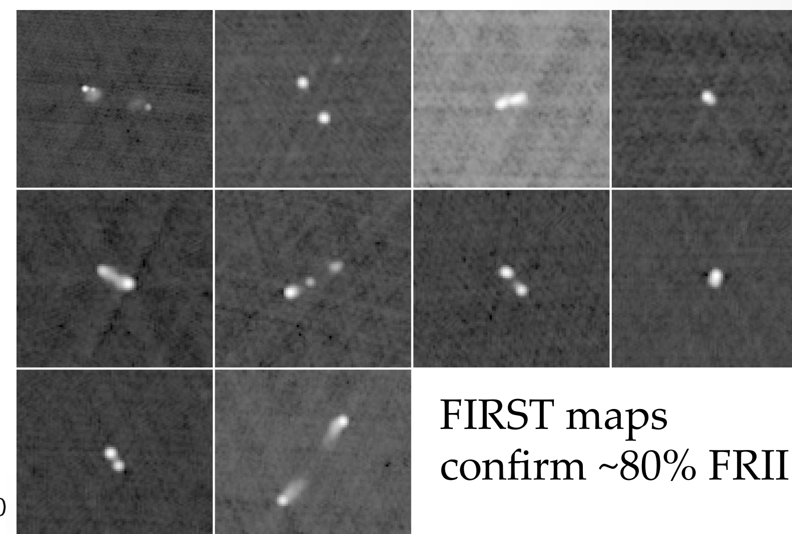
< 1.5% have $\alpha_{0.3-1.4\ GHz} > 1.3$

- Half of the steep spectrum objects are point sources (likely variable).
- Some other USS sources in this sample are likely to be HzRG

~80% FRII



Euclidean normalised source counts from Willott+ 2001



FIRST maps confirm ~80% FRII

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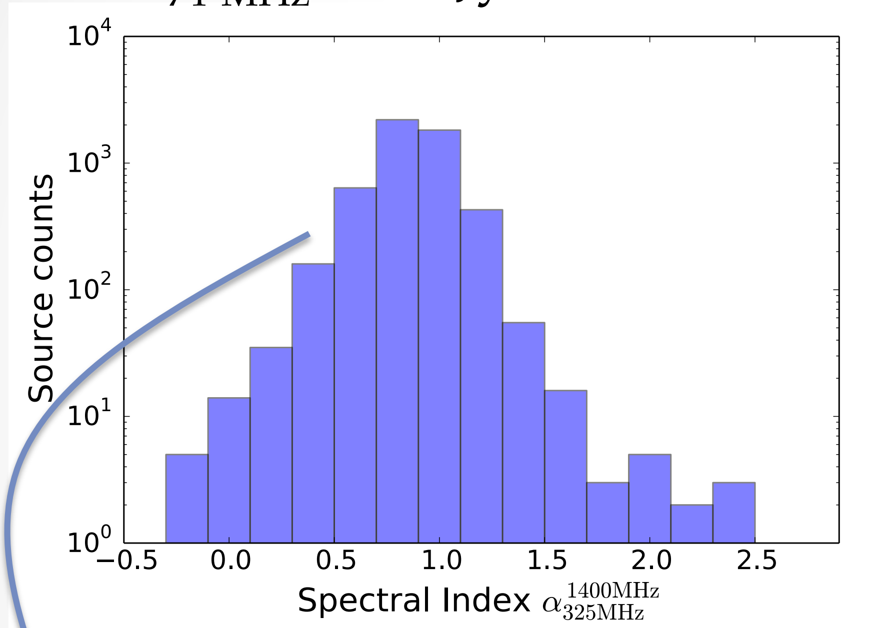
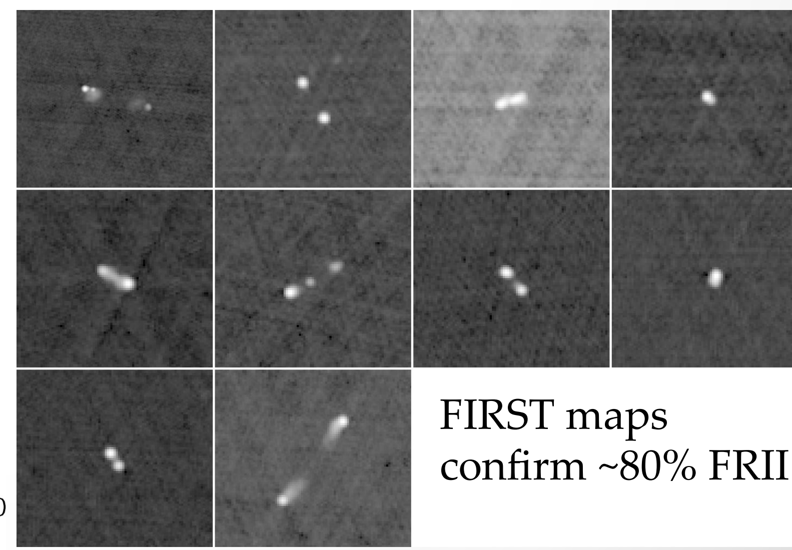
$S_{74\,\mathrm{MHz}} > 1.5$ Jy VLSSr Selected Sample



➔ < 0.5 % of the sample are ultra steep spectrum remnants.

➔ **Implied remnant fading timescale ~ 0.1 Myr !?**



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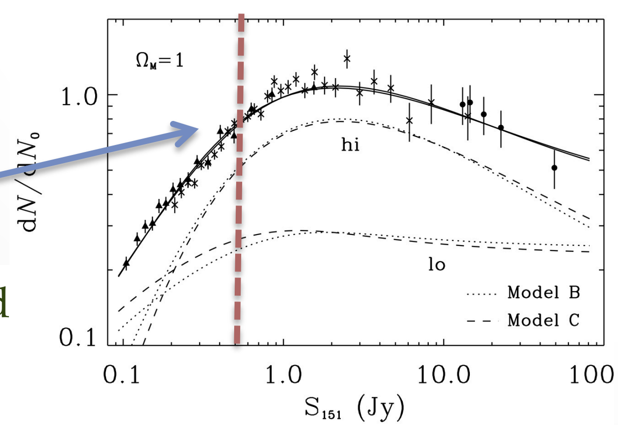

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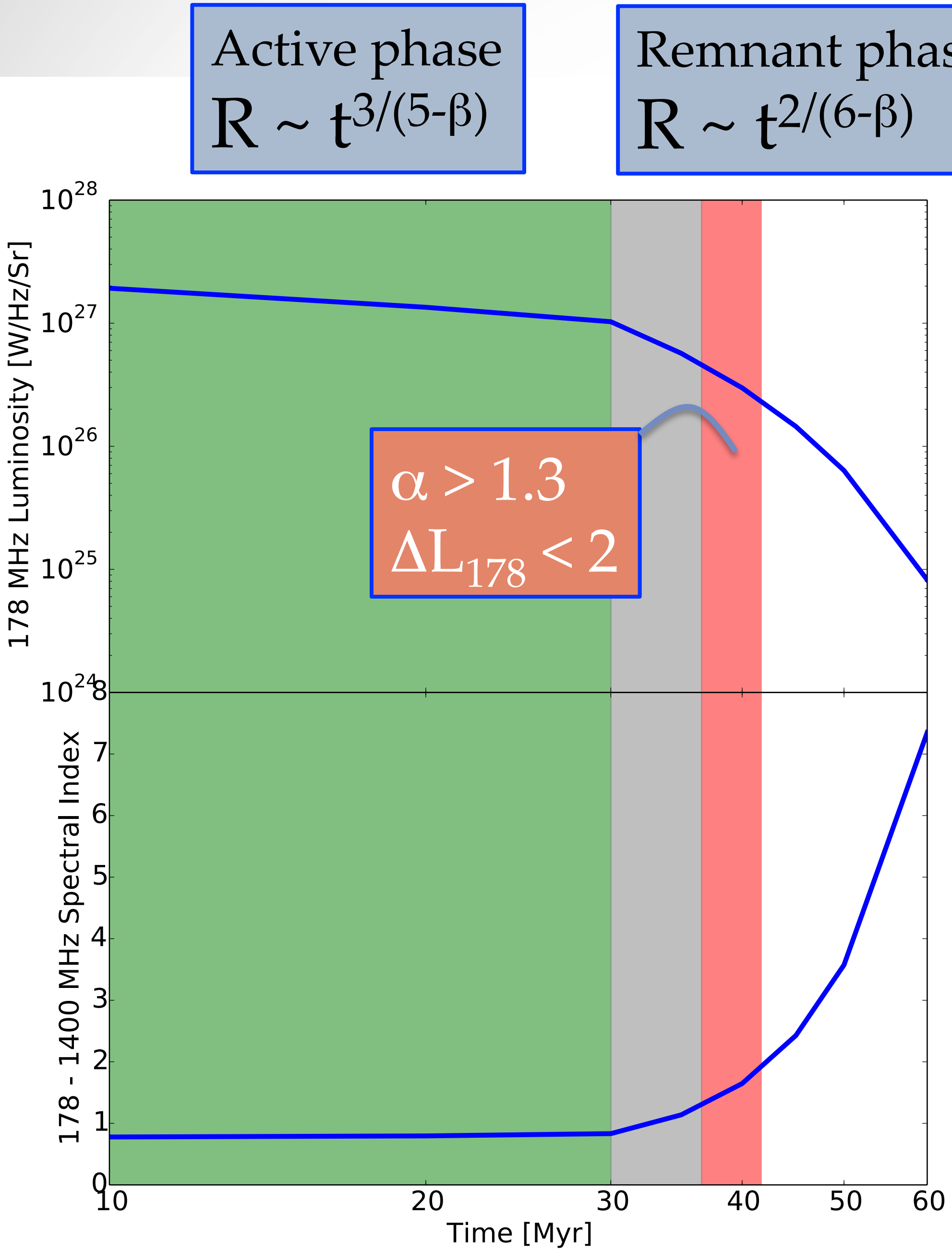


Spectral evolution for a "typical" FRII radio galaxy.

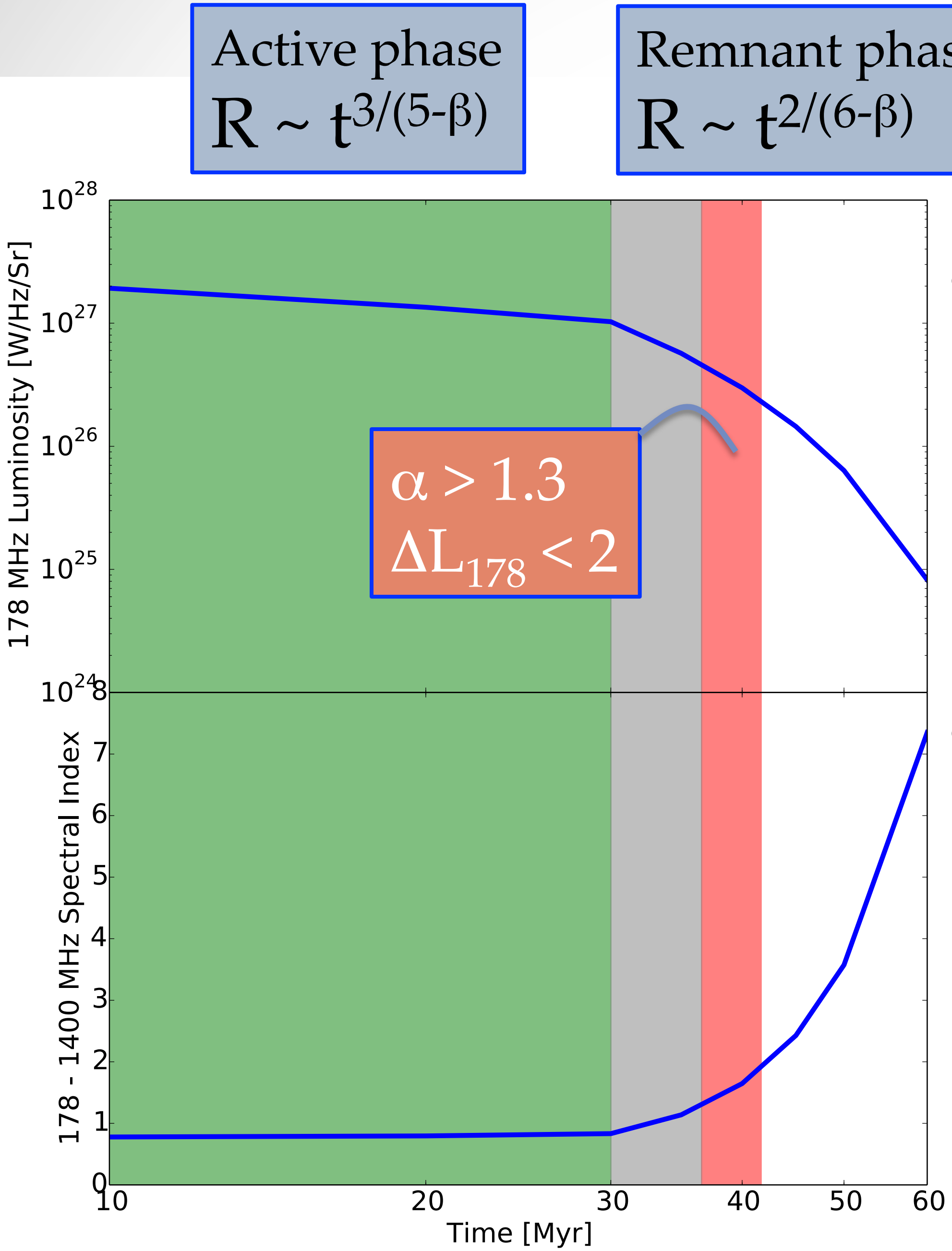
$$\frac{\partial N(\gamma,t)}{\partial t} + \frac{\partial}{\partial \gamma}\left(N(\gamma,t)\frac{\partial \gamma}{\partial t}\right) = \sigma(\gamma,t)$$

$$\frac{d\gamma}{dt} = -\frac{4\sigma_T}{3m_e c}\gamma^2\beta^2 U(t) - \frac{1}{3}\gamma\frac{1}{V}\frac{dV}{dt}$$

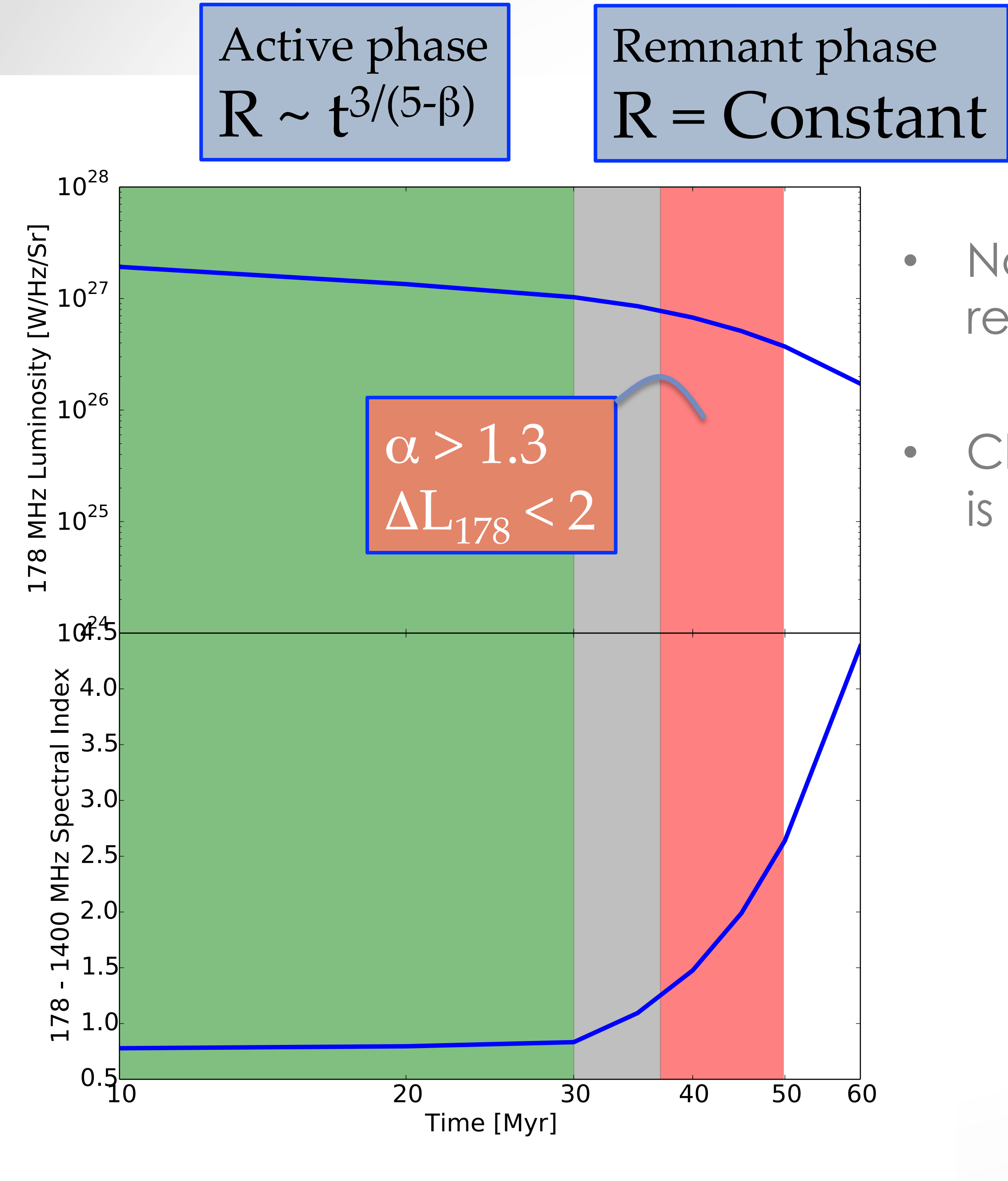
- $z=1$
- $Q_{jet} = 10^{46}$ erg/s
- $\rho \sim R^{-\beta}$ with $\beta = 1.9$
- $\alpha_{inj} = 0.6$

- USS remnant phase begins several Myr after the active phase, by which time the remnant has faded by a large factor.

Spectral evolution for a “typical” FRII radio galaxy.



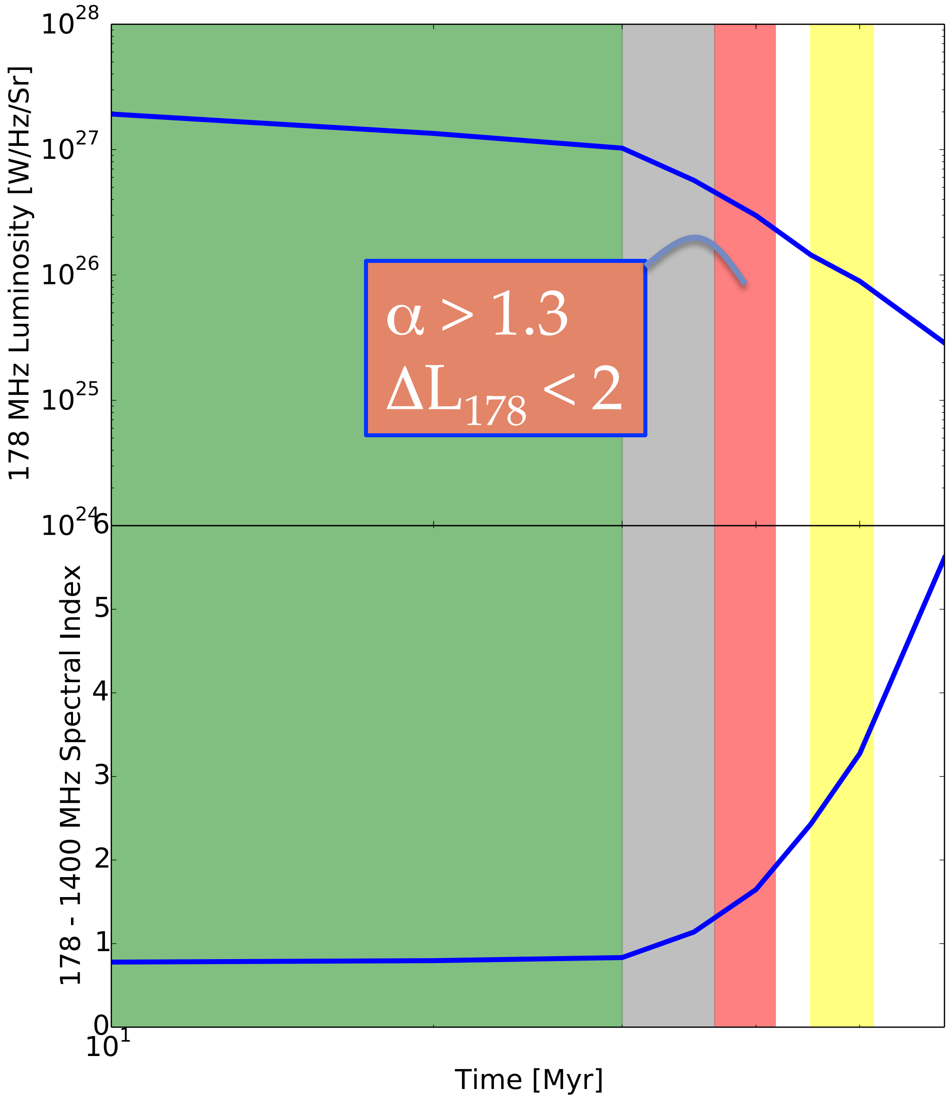
- This behaviour can explain the very low detection rate of USS remnants, but requires rapid expansion losses for 10’s of Myr in the remnant phase.
- This implies the lobes remain strongly over-pressured relative to the external medium up to the end of the radio galaxy’s life.
  - c.f. Hardcastle+ 2013.



- No adiabatic losses in remnant phase.
- Clearly the fading timescale is too long.

Active phase
$R \sim t^{3/(5-\beta)}$

Remnant phase
(Sedov + buoyant rise)



- Sedov-like expansion + buoyant rise after lobes reach pressure equilibrium with the external medium.
- Buoyant remnants continue to fade rapidly because of steep spectrum and continued magnetic field evolution.

A search for remnant radio galaxies associated with optically selected quasars

- I have performed a search for remnant radio lobes associated with SDSS Quasars:
  - Selection at low frequency (74 MHz VLSSr) to increase probability of detecting steep spectrum remnants
  - VLSSr x SDSS Quasars: 768 sources with $\alpha > 0.5$

- Candidate remnants are selected based on integrated radio spectral properties:
  - VLSSr 74 MHz → WENSS 325 MHz → NVSS 1400 MHz
  - Criterion 1: $\alpha(325 \rightarrow 1400\ \mathrm{MHz}) > 1.3$
  - Criterion 2: $\alpha(74 \rightarrow 325\ \mathrm{MHz}) - \alpha(325 \rightarrow 1400\ \mathrm{MHz}) > 0.4$

0/768 (< 0.3 %) of VLSSr x SDSS QSO sample are remnants.

WEAVE-LOFAR survey will greatly improve sample size and enable robust conclusions.

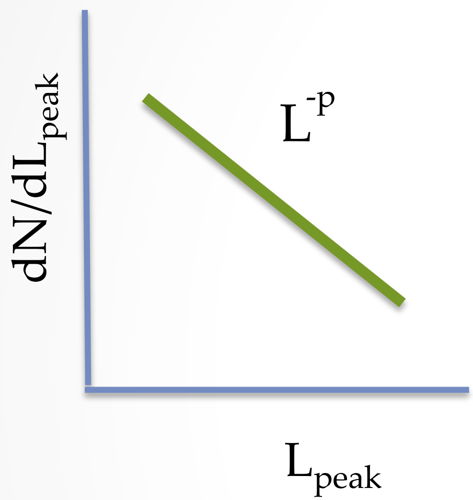
Summary

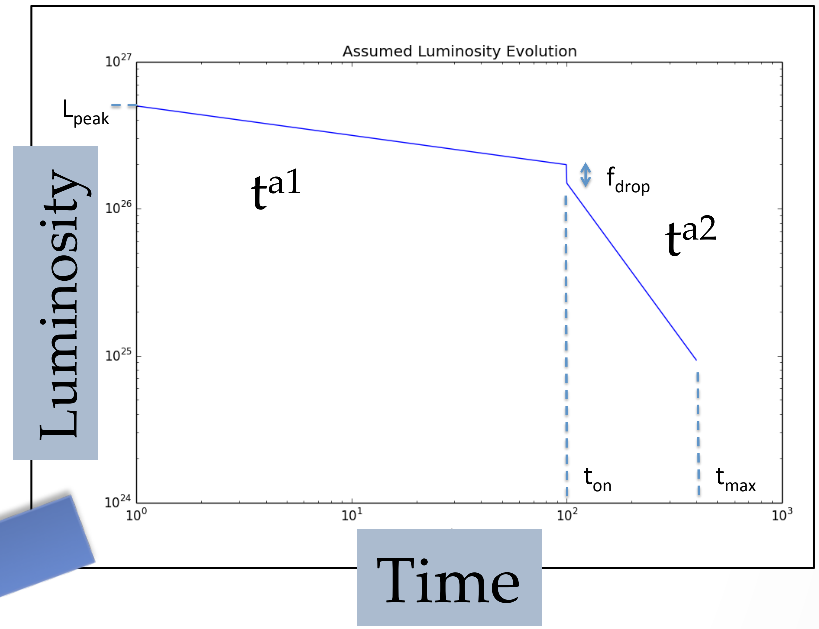
- Remnant radio galaxies are very rare, but have the potential to make significant contribution to several areas of radio galaxy physics
  - Duty cycle, source dynamics, luminosity evolution, nature of RLQ, seed particles for cluster relics/halos.

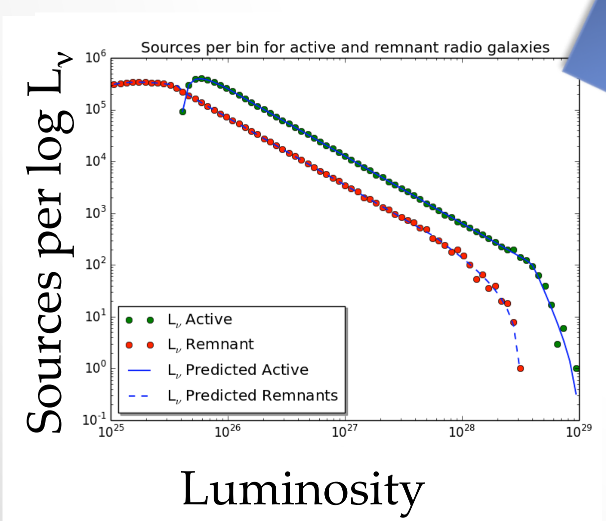
- The very low fraction of FRII radio galaxies that are ultra-steep spectrum remnants suggests rapid adiabatic losses after the jets switch off
  - Suggests lobes remain over-pressured until the end of life.
  - Implies that the many sources in the sample are young remnants that are not yet ultra-steep spectrum.

- We find no evidence for an evolutionary connection between radio loud and radio quiet quasars, but a larger sample size required to enable robust conclusions.

A fiducial model for the population of remnant radio galaxies

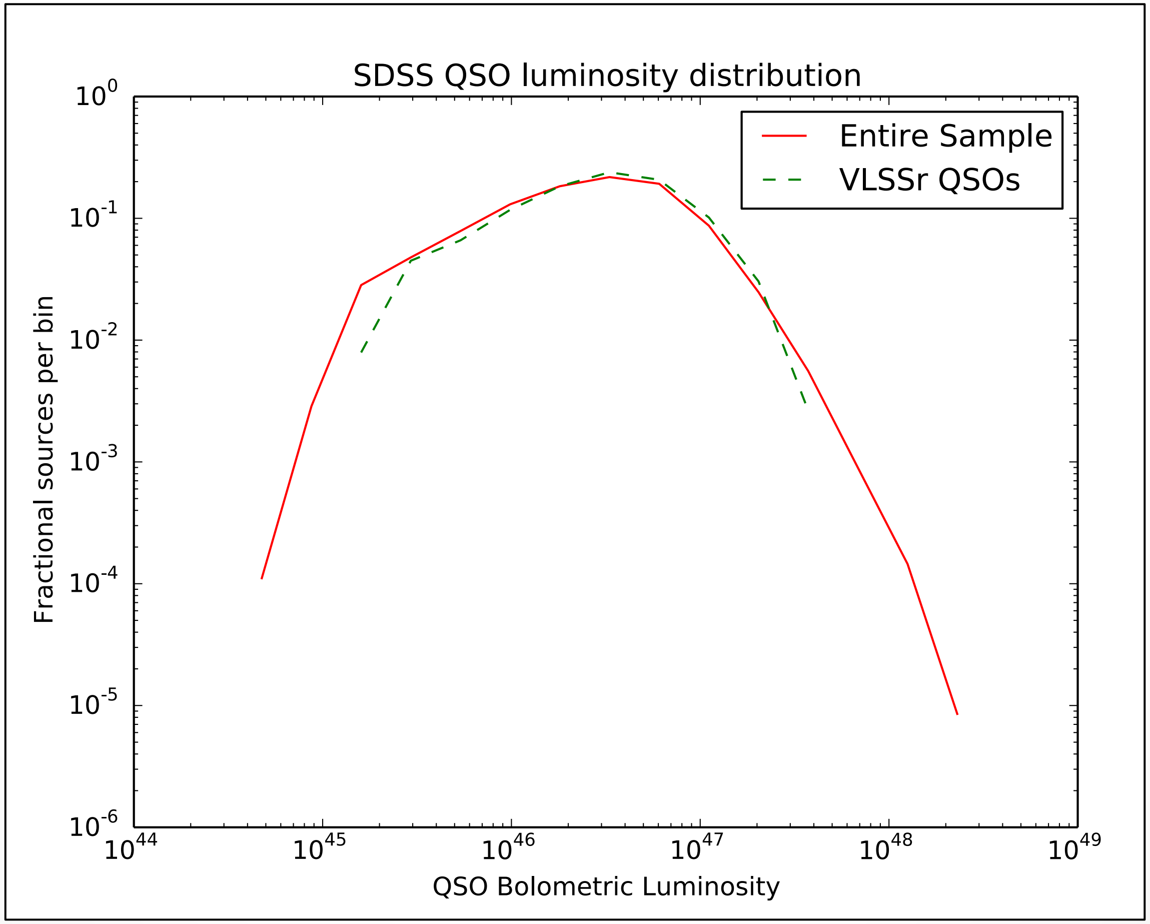




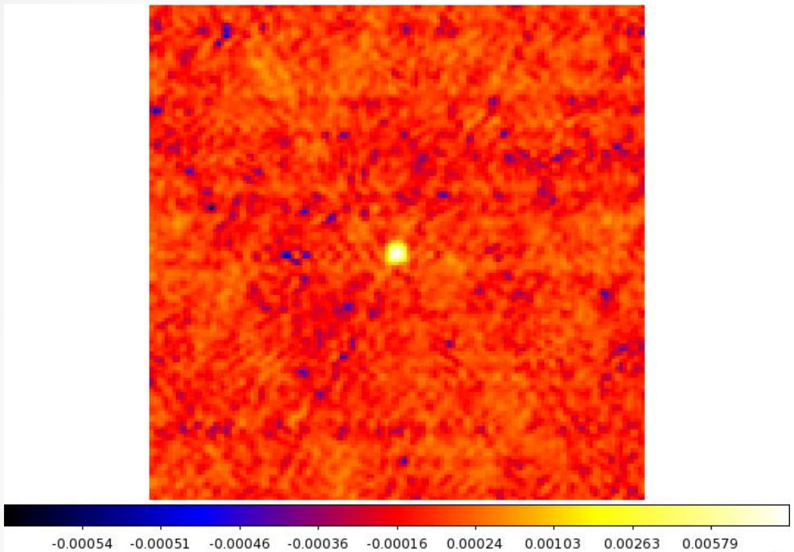


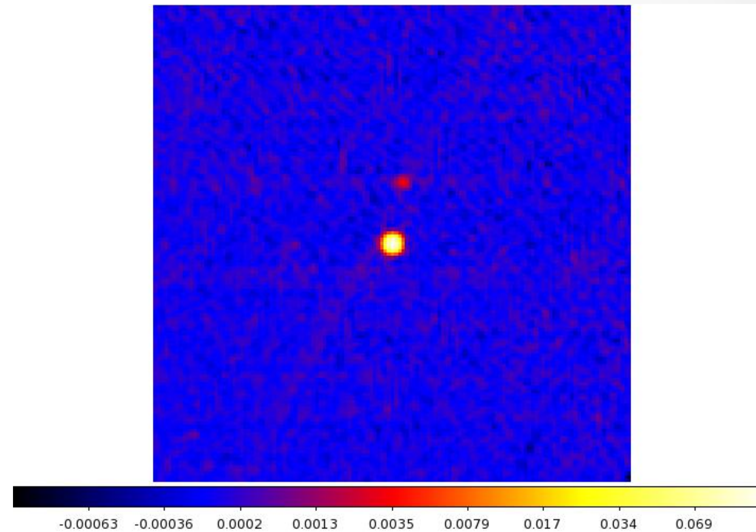
$$\frac{remnants}{actives} \approx \left(\frac{a_1(1-p)+1}{a_2(1-p)+1} \right) f_{drop}^{p-1} \approx 10\%$$

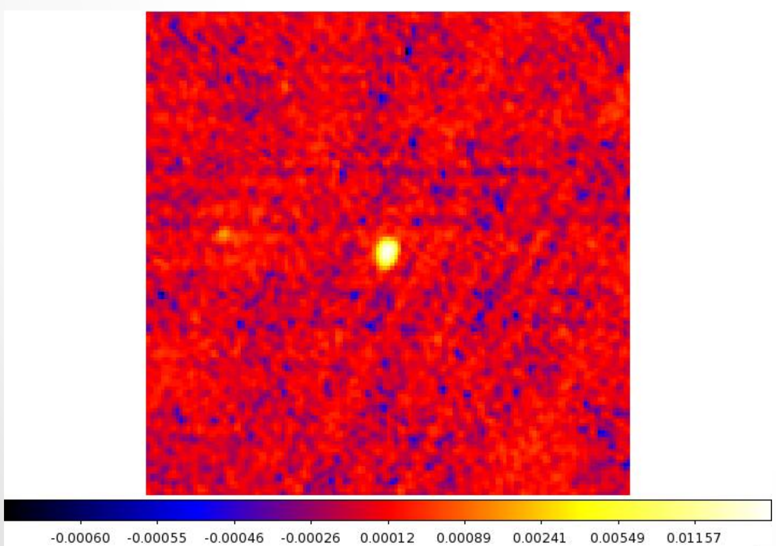
A drop in QSO luminosity cannot explain lack of remnants in this sample, because the radio selected QSOs have the same luminosity distribution as the parent population.

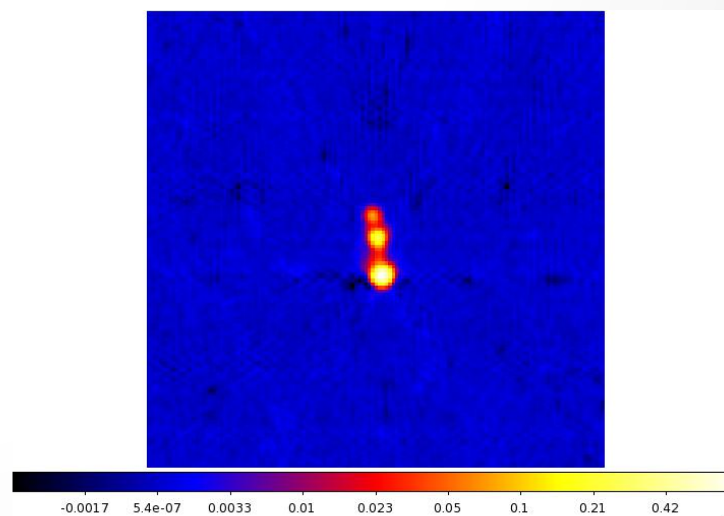


Only 4 candidates meet criterion 1 or 2.
However, the FIRST maps of these remnant candidates clearly show emission at the position of the quasar (they are not remnants!).









0/768 (< 0.3 %) of VLSSr x SDSS QSO sample are remnants. But how many do we expect to find?

- Dynamical models → source evolution (eg. Kaiser+ 2002).