Kpc-scale radio-jets in NLS1s?

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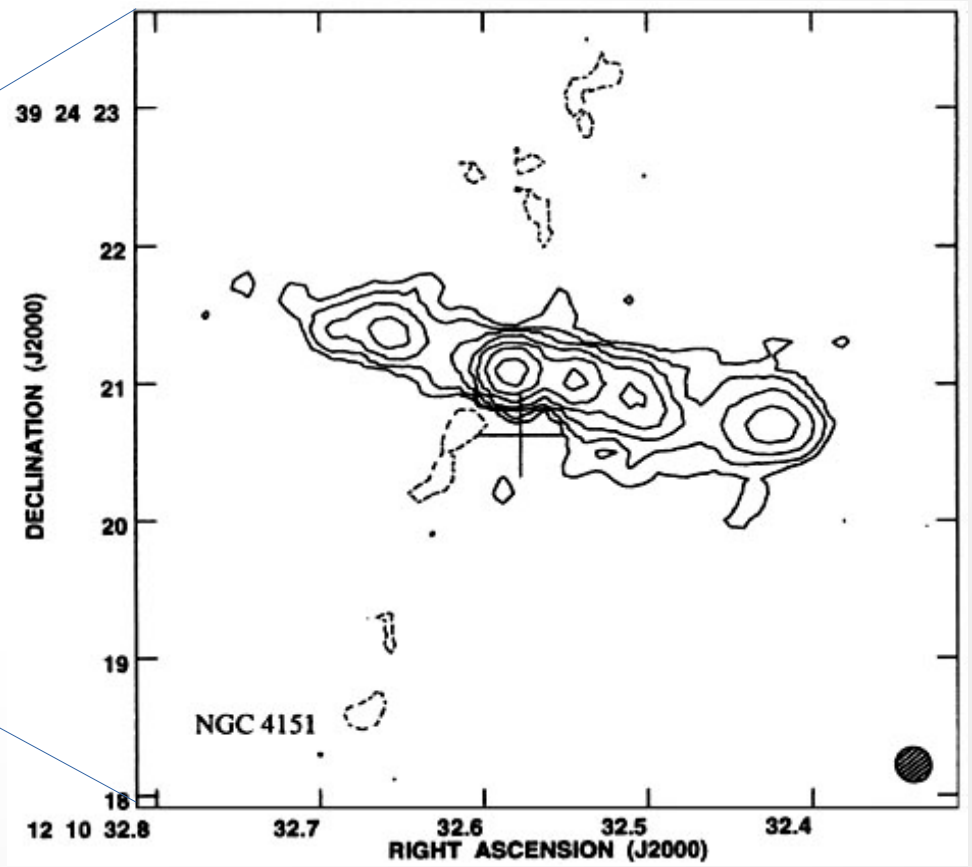
Radio-jets in Seyfert Galaxies

- High resolution radio observations --> parsec-scale radio -jets
- Small-scale, low-power versions of the large-scale jets seen in radio galaxies

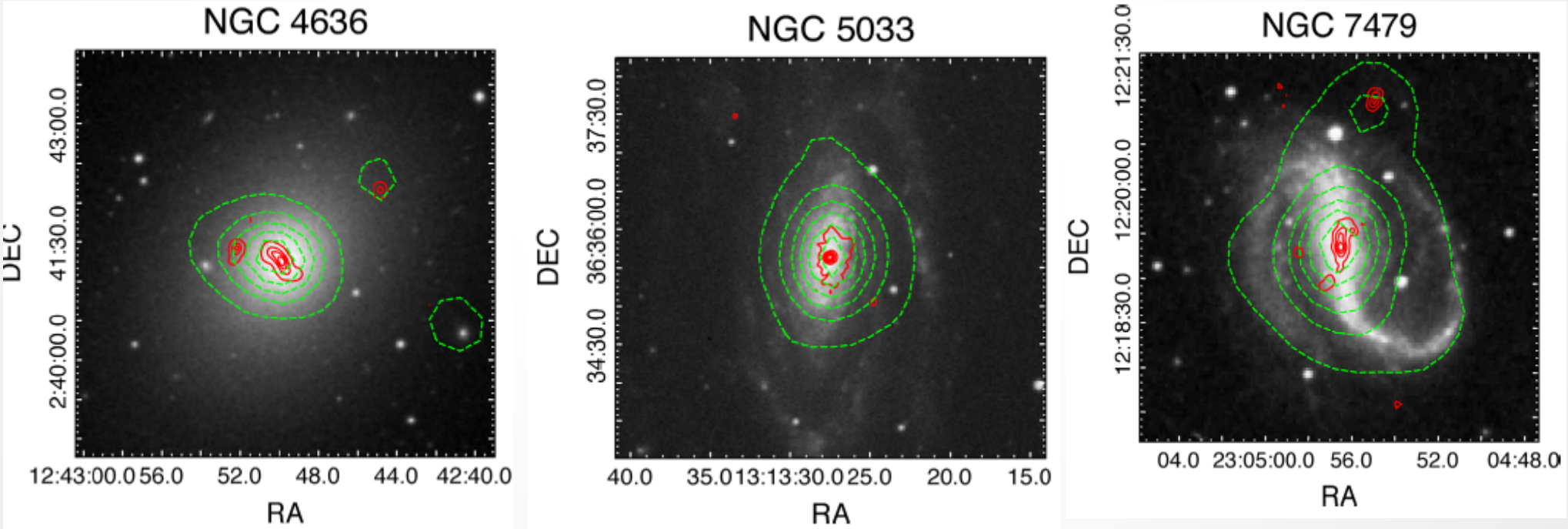
NGC 4151: Seyfert Type 1



8.4 GHz VLA A array observations
(Kukula at al. 1995)

Kpc-Scale Radio structures in Seyferts

- A significant fraction (40%) of Seyferts show kpc-scale radio emission. (Singh et al. 2015)
- Kpc-scale radio-jets appear distorted
  (perhaps by the interaction with the ISM)



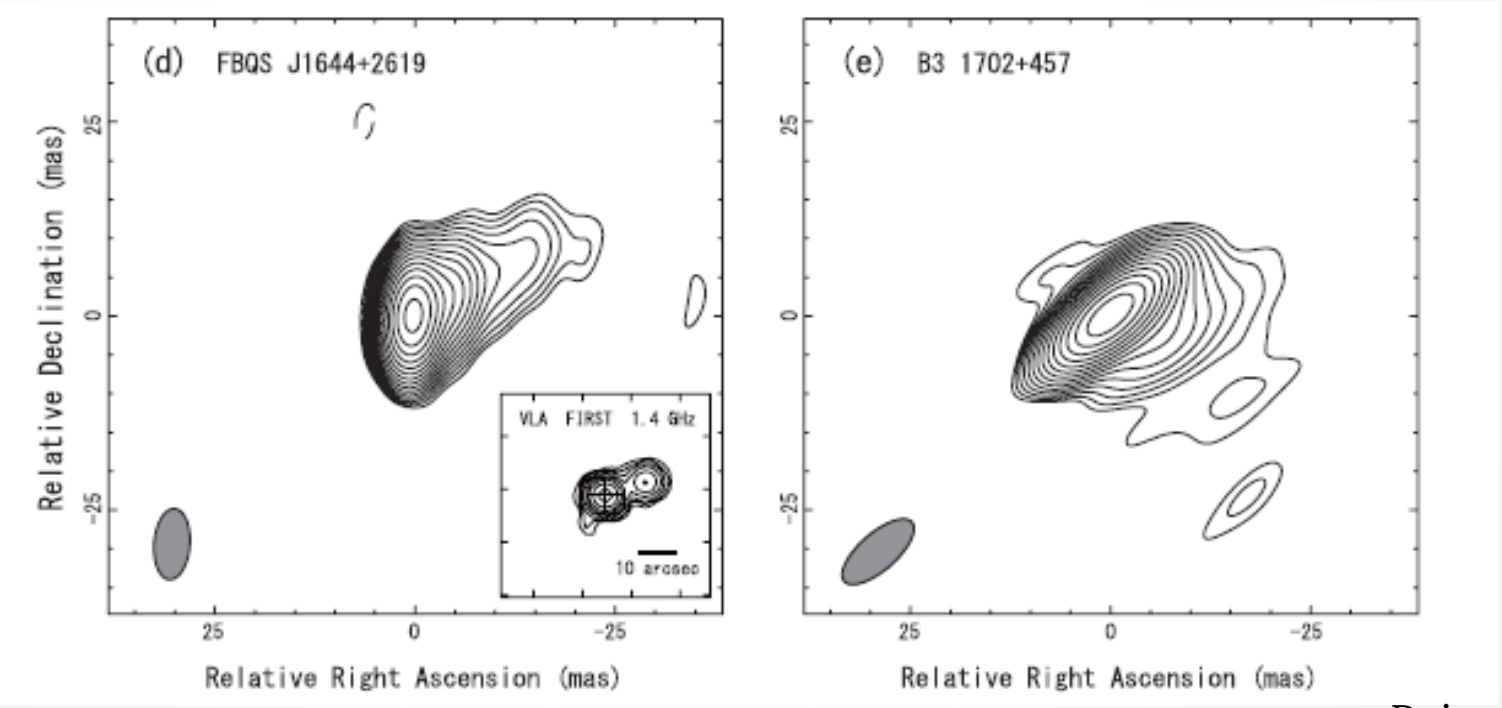
1.4 GHz NVSS (green), FIRST (red) contours overlaid in DSS optical images

Singh et al. (2015) MNRAS

Radio-jets in NLS1s?

very long baseline interferometry (VLBI) pc-scale radio properties

- A few NLS1 shows a prominent one-sided linear structure
- Doppler beaming with an intrinsic jet speed of 0.7c – 0.9c
- Mildly or highly relativistic jets
- High brightness temperature (10^8 – 10^{10} K)
- Inverted radio spectrum
- Rapid flux variability

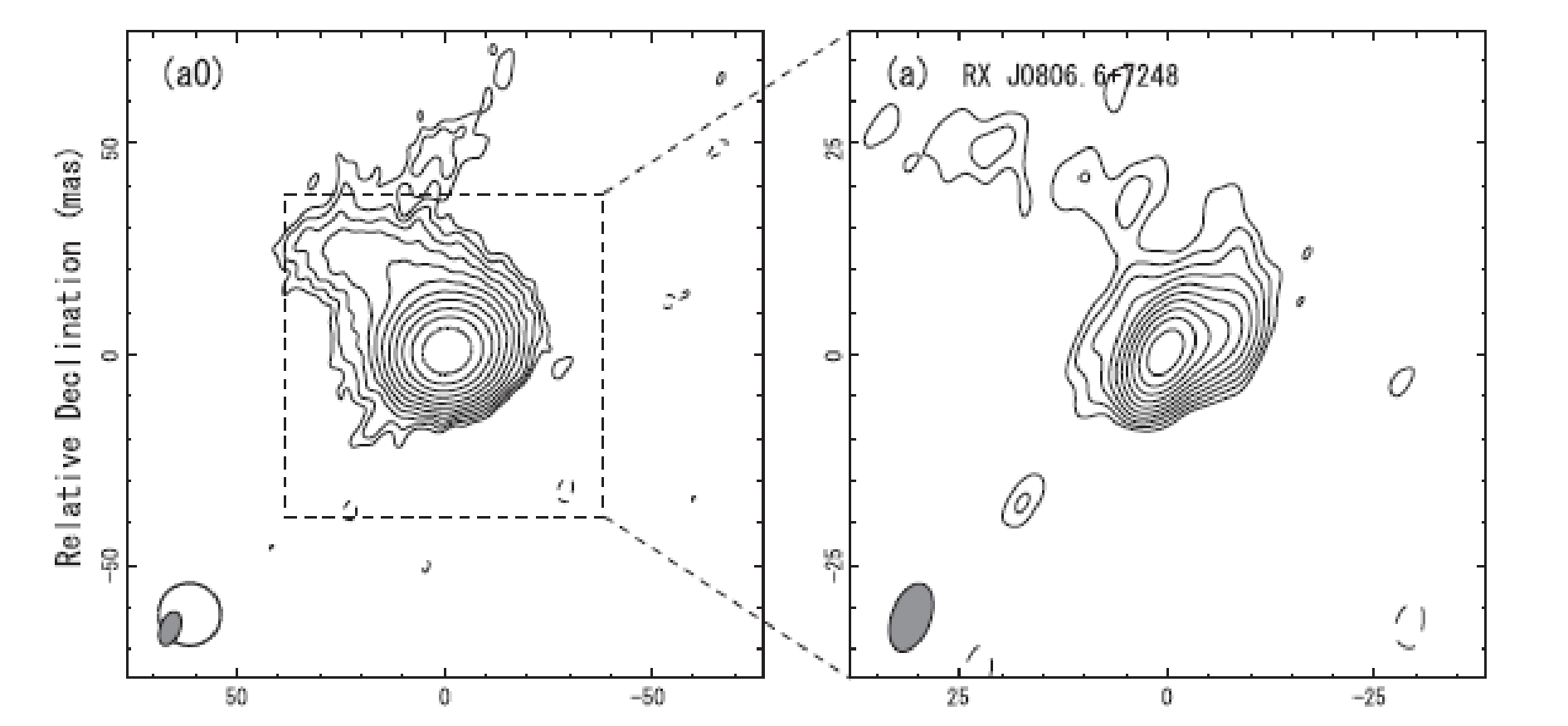


Doi et al. (2011)

Radio-jets in NLS1s?

very long baseline interferometry (VLBI) pc-scale radio properties

- Not all radio-bright NLS1s are blazar like
- Some NLS1s show steep spectra with diffuse pc-scale structures
- Unlikely to be strongly beamed



Doi et al. (2011)

Motivation

- Are relativistic jets in NLS1s common?
- What is the radio-loudness of NLS1s?
- Which factors determine the radio-loudness (mass and spin of SMBH, accretion rate, host galaxy properties etc.)
- How radio-jets in NLS1s compare with BL-AGN?

VLBI/VLBA observations are limited to small samples of few dozens of NLS1s.

Investigation of Radio properties of NLS1s

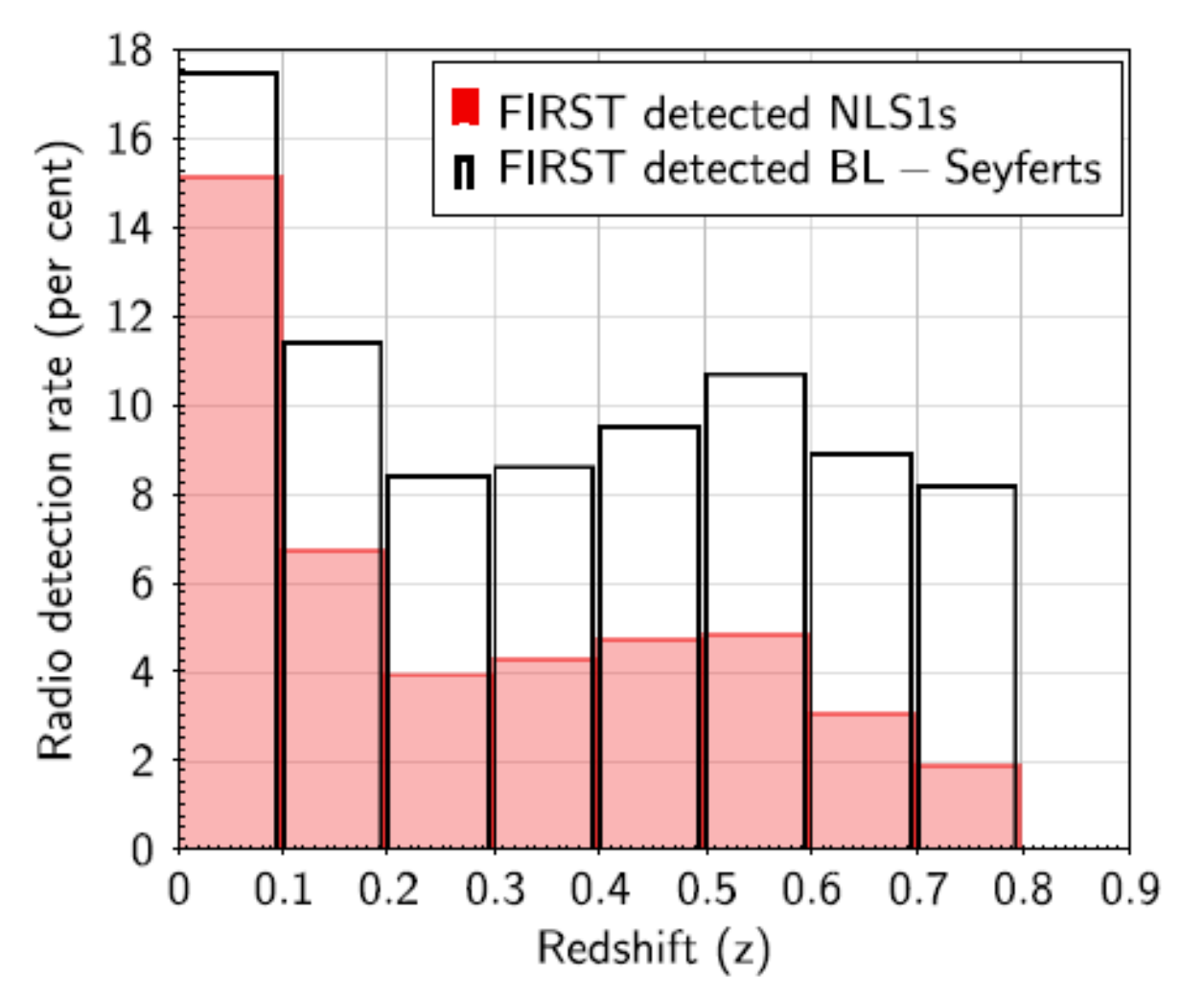
- 11101 optically-selected NLS1s ($z < 0.8$)

  (Rakshit et al. 2017)
- Derived from SDSS DR 12
- Search for Radio-counterparts in 1.4 GHz FIRST, 1.4 GHz NVSS, 327 MHz WENSS and 150 MHz TGSS
- 498/11101 (4.5%) radio-detected NLS1s
- 95.5% NLS1s remain undetected

Singh and Hum Chand 2018, MNRAS (submitted)

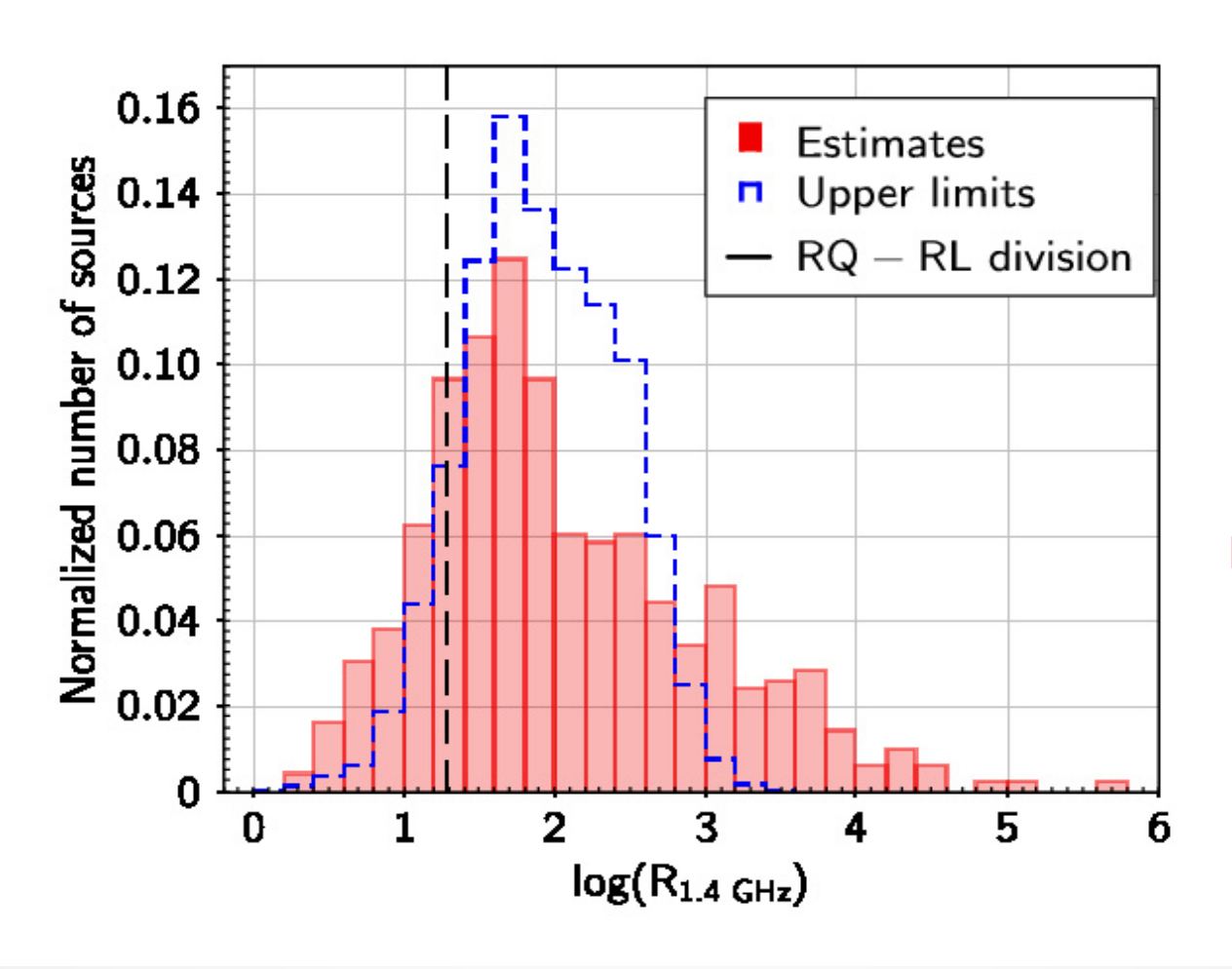
Radio detection rate is lower for NLS1

- In compared to BL-Seyferts the radio-detection rate of NLS1s is lower
- Jet production efficiency is lower in NLS1s and/or
- Jets are of low power



Fraction radio-loud NLS1s?

- Most of radio-detected (407/498 ~ 82%) are radio-loud in our sample.
- Overall fraction of RL-NLS1s in optically-selected sample is merely 3.5%
- A fraction of NLS1s with no detection can also be radio-loud



No RL-RQ dichotomy

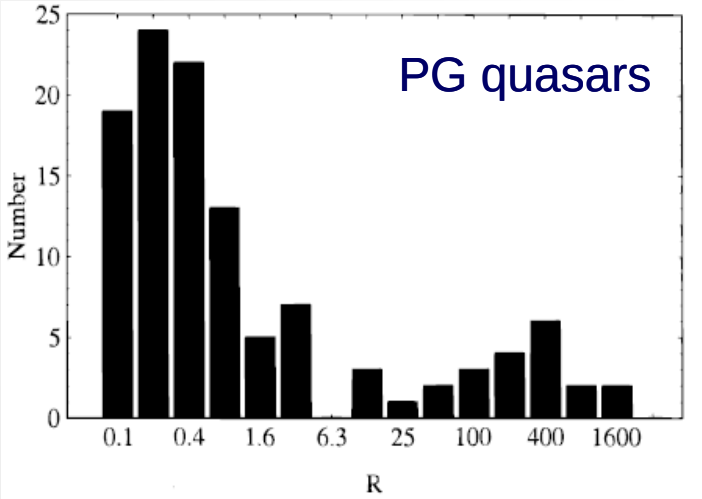
Radio-loud Radio-quiet dichotomy does not exist !

A change in paradigm

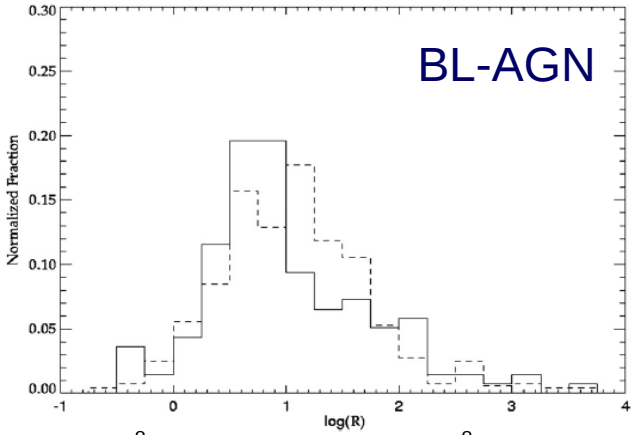
- Presence of dichotomy in early samples can be explained due to sample selection effects
- But basic question still exist - What makes AGN radio-loud?

(SMBH mass, accretion rate, Host galaxy, combination of more than one factor)

Dichotomy (Falcke+96)

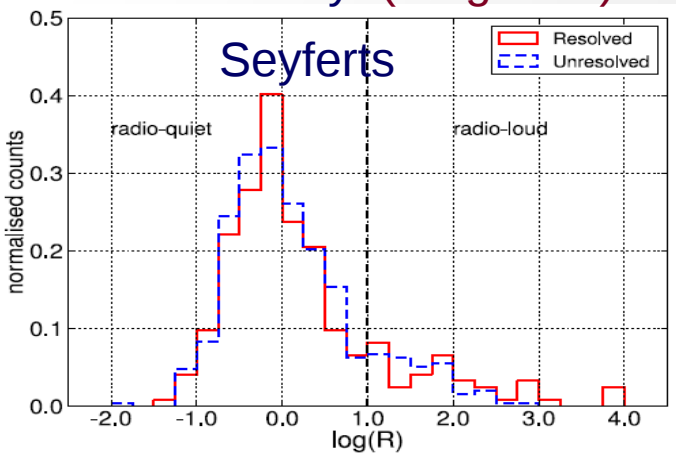


No Dichotomy (Rafter+09)



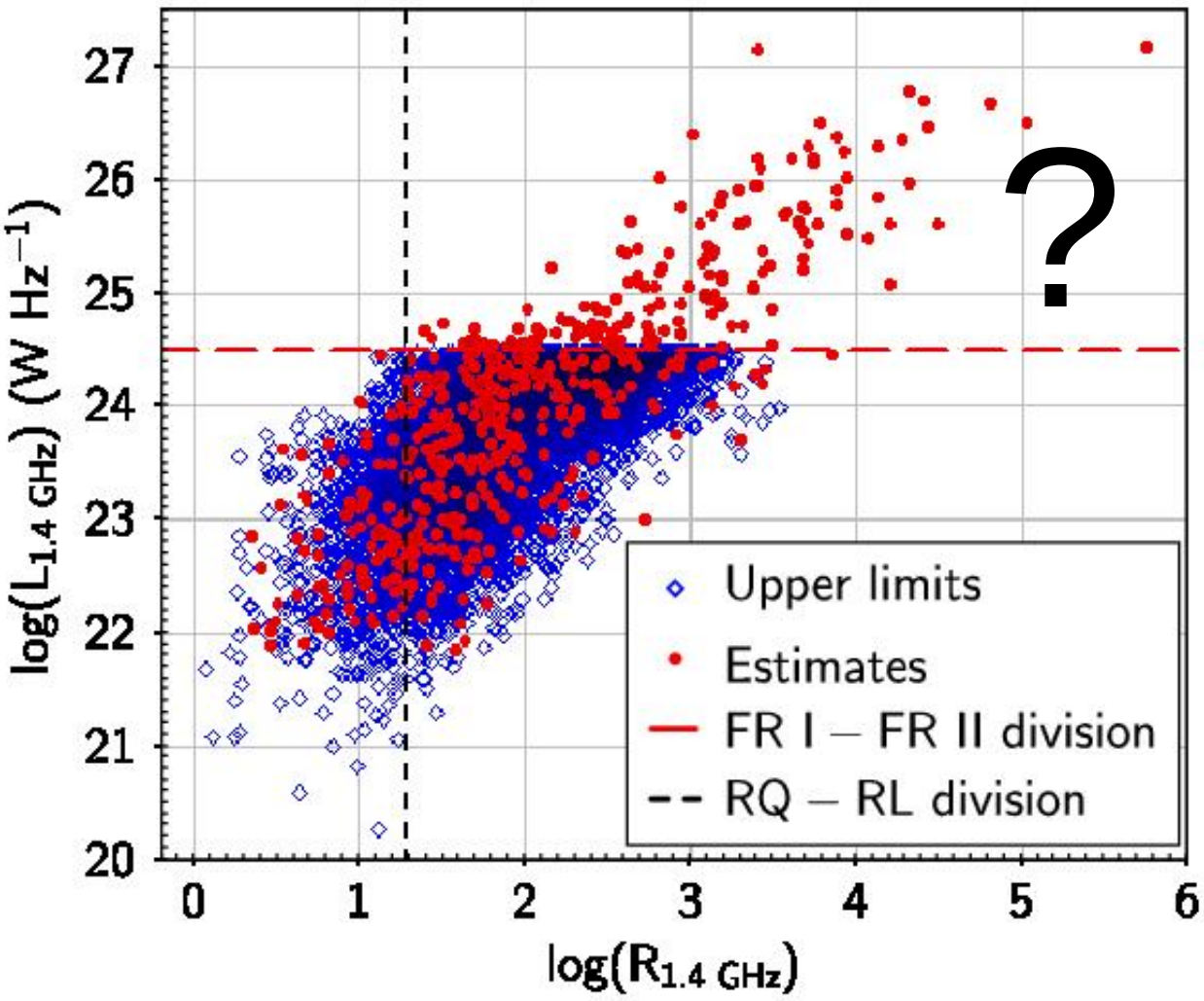
$M_{BH}>10^8 M_{sun}$ (Solid), $M_{BH}<10^8 M_{sun}$ (dashed)

No Dichotomy (Singh+15)



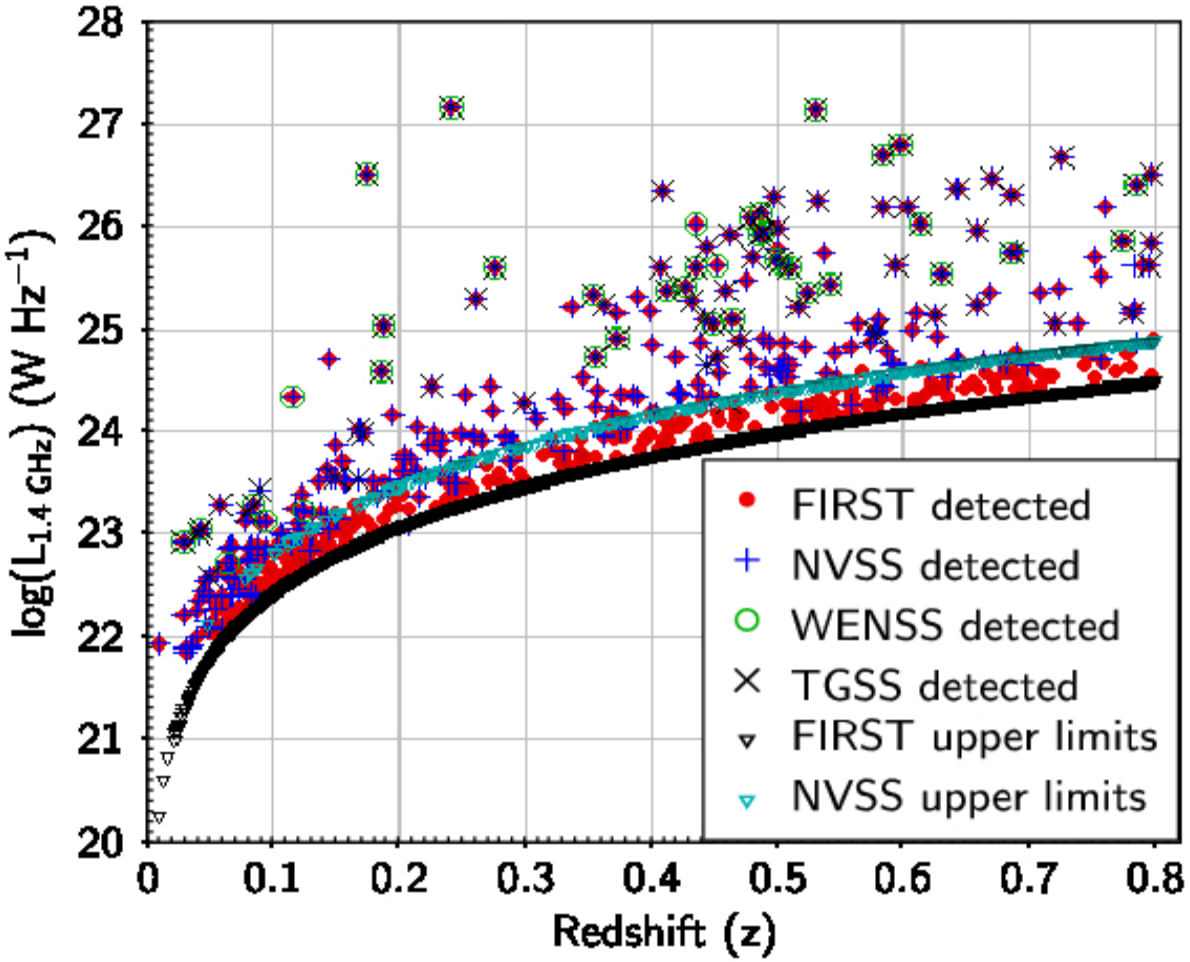
Radio properties of NLS1s

- Wide range of distributions in radio-loudness and radio luminosity
- Unexpected radio-luminous NLS1s (similar to powerful radio galaxies)



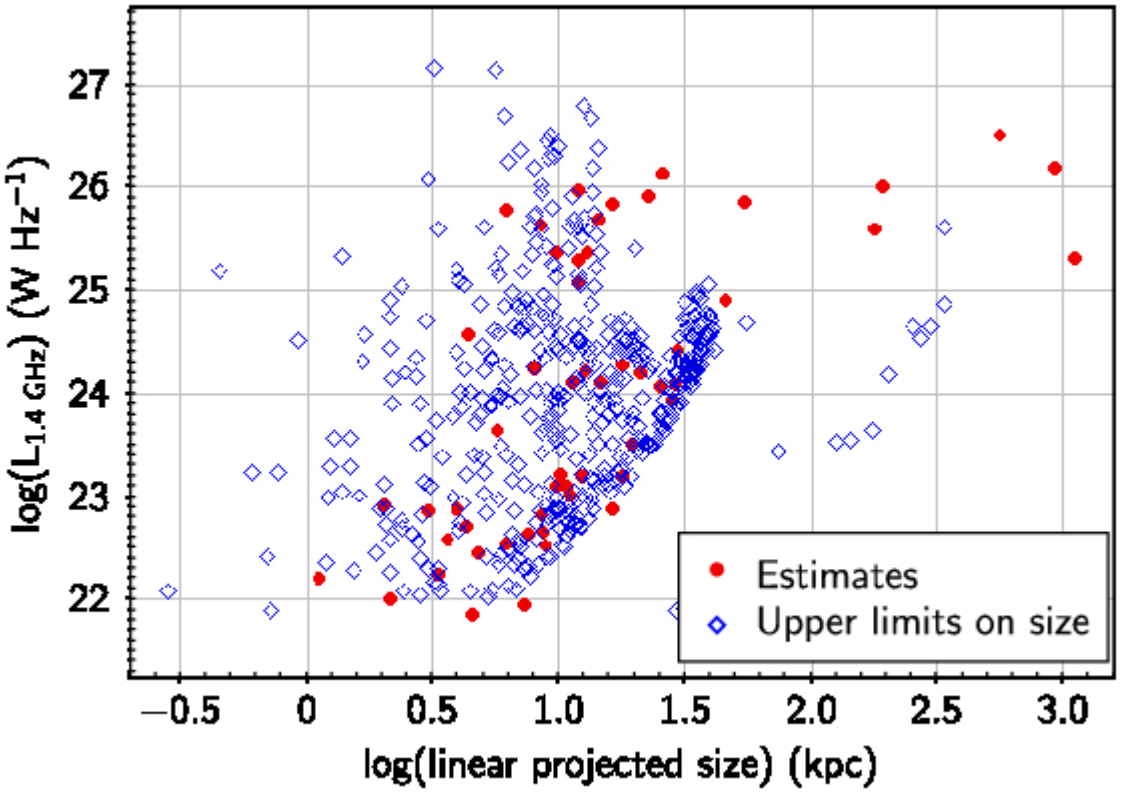
Radio properties of NLS1s

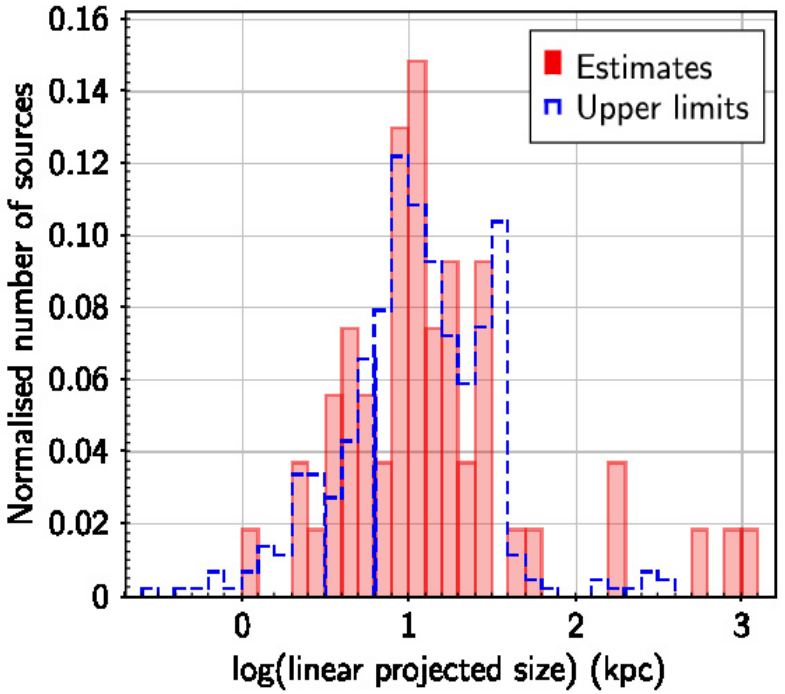
- Radio-luminous NLS1s are preferentially found at higher redshifts
- Increase in luminosity with z is consistent with the fact the AGN number increases with z having peak at z ~ 2.



Radio sizes of NLS1s

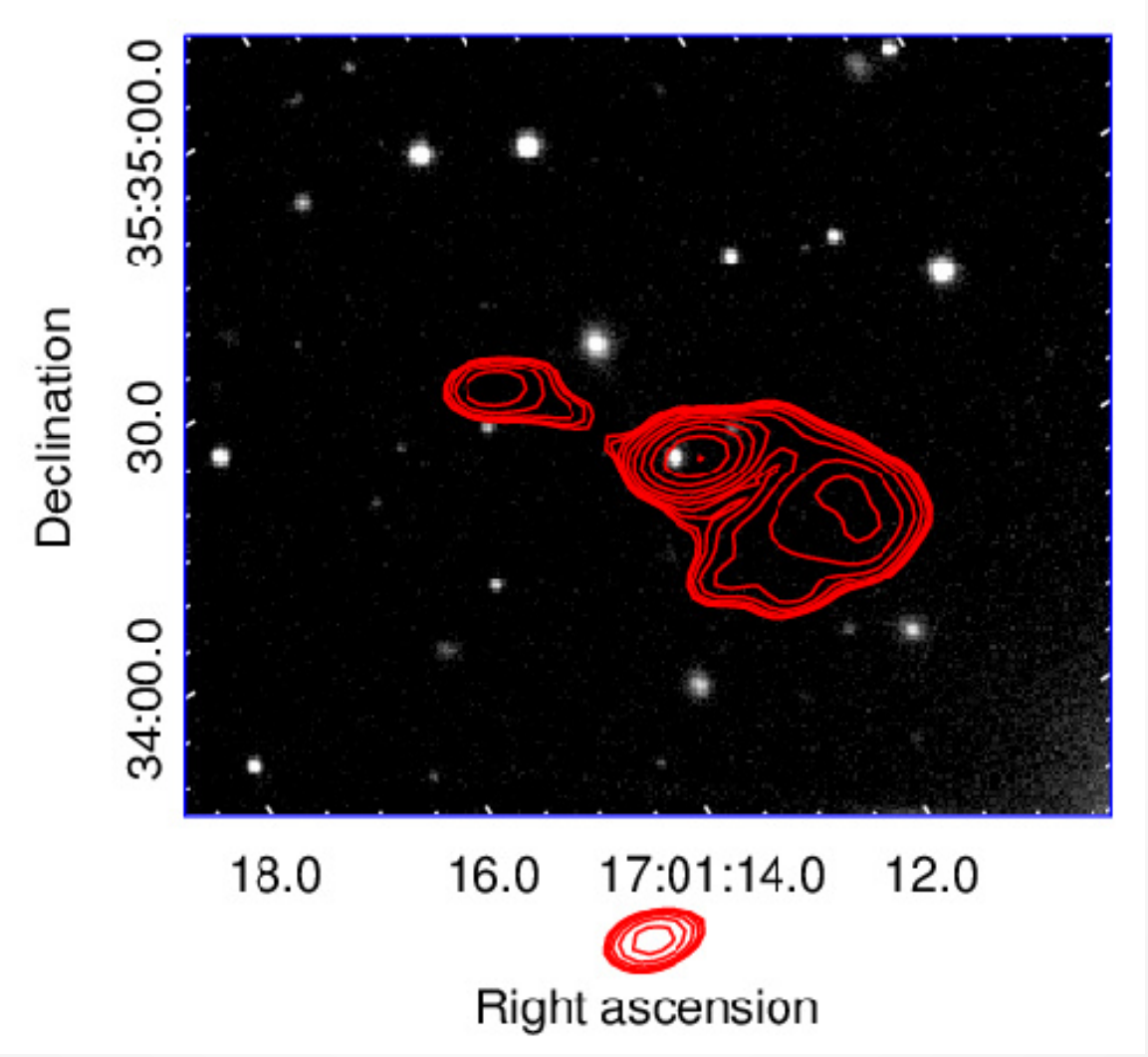
- In general, radio-sizes of NLS1s are small (< 30 kpc for unresolved sources)
- Nearly 10% radio-detected NLS1s shows sizes > 1 kpc (resolved sources)
- A few NLS1s show large sizes similar to radio galaxies --> narrow line radio galaxies
- Most radio-luminous NLS1s appear compact, often unresolved in FIRST





Kpc-scale jets in NLS1s

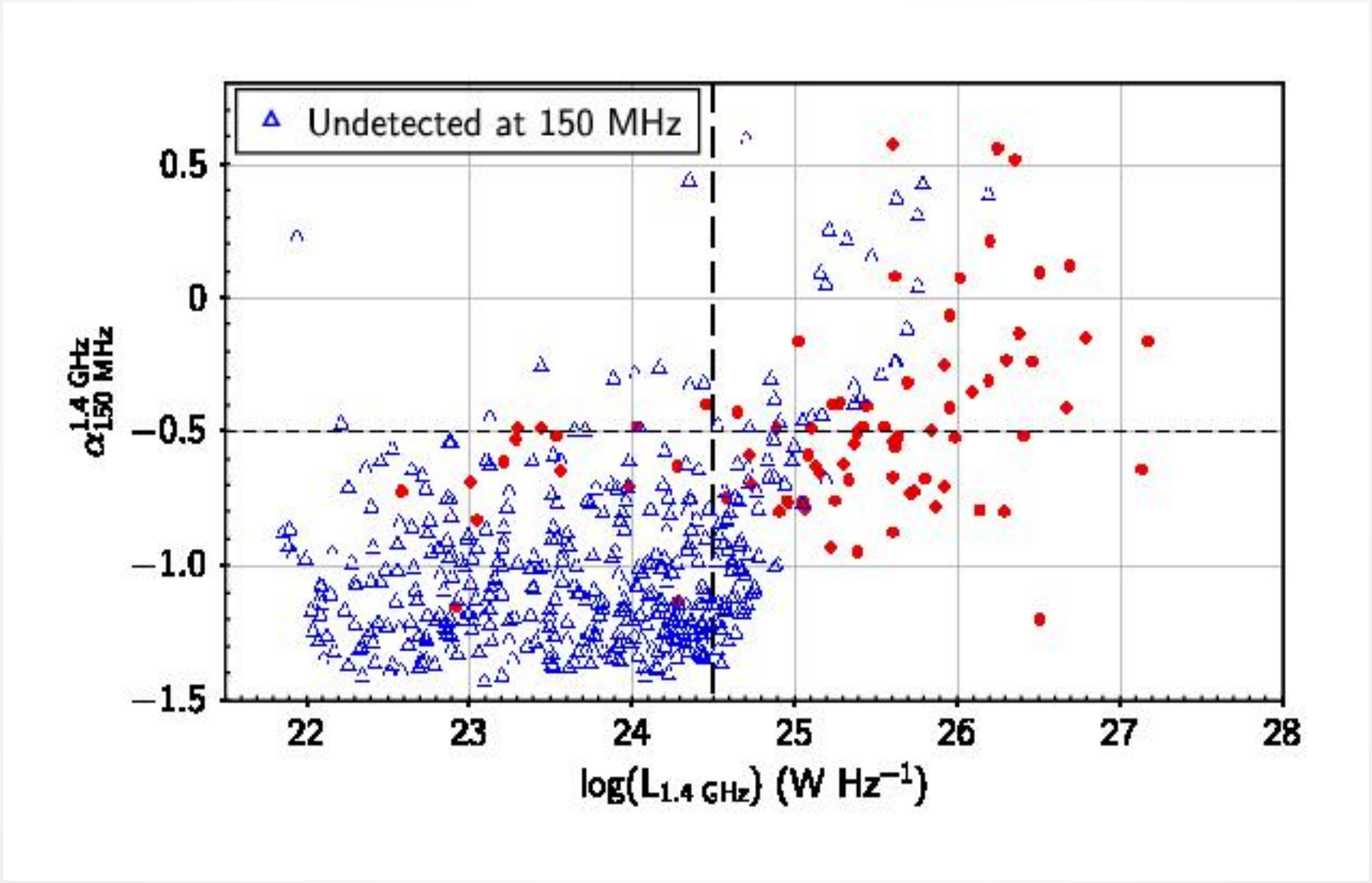
325 MHz and 610 Mhz uGMRT images show extended Kpc-scale radio jet-lobe structures
Asymmetry in radio lobes can be understood if jet are oriented closer to line-of-sight.



Radio spectra of NLS1s

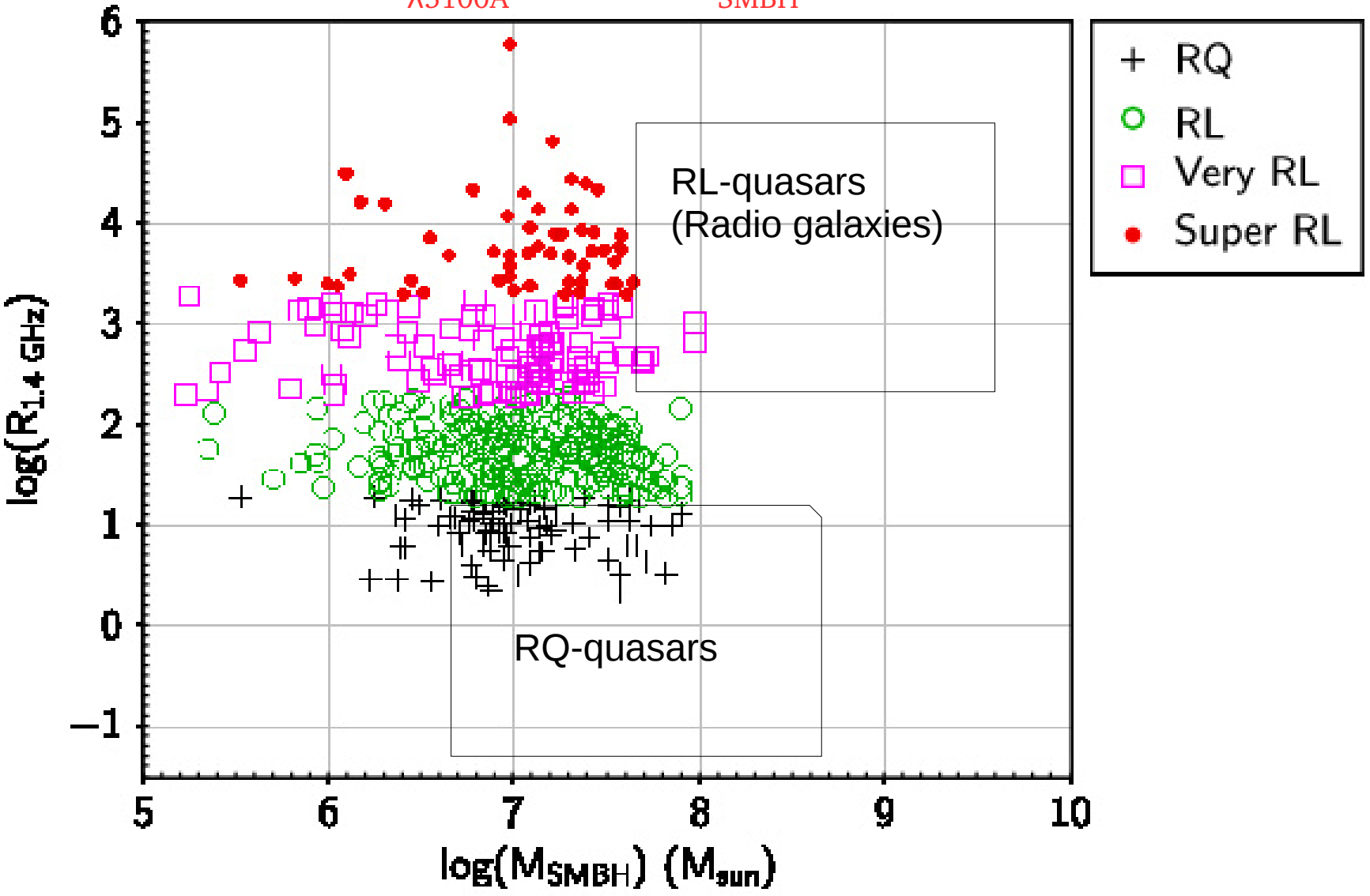
Derived from 1.4 GHz FIRST and 150 MHz TGSS

Radio-luminous NLS1s tend show flat/inverted radio spectra



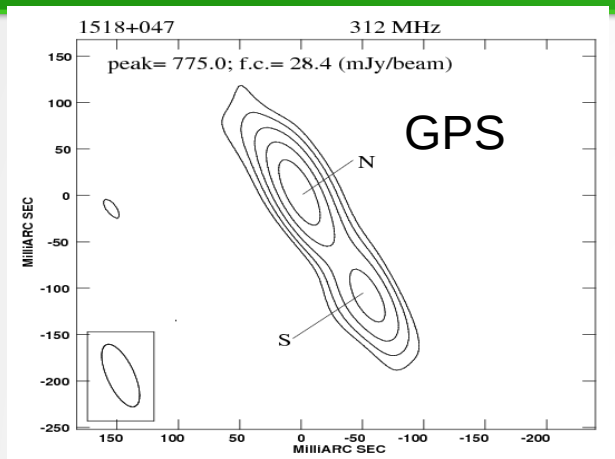
Radio-Loudness Vs. M_{SMBH}

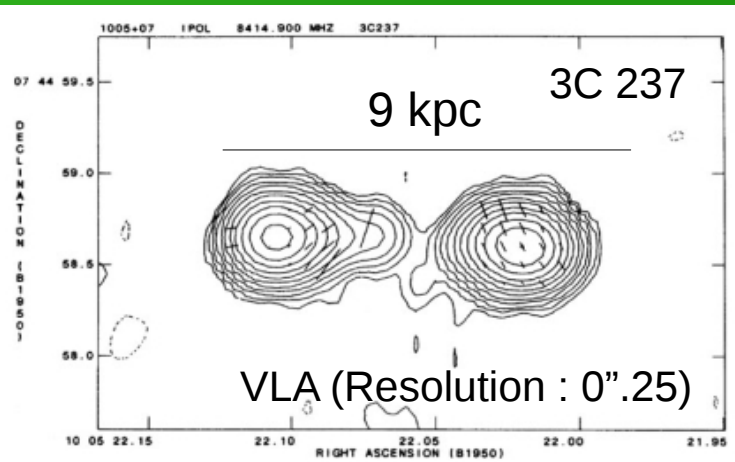
$L_{\lambda 5100A}$ ----> M_{SMBH}



Are RL-NLS1s young radio galaxies?

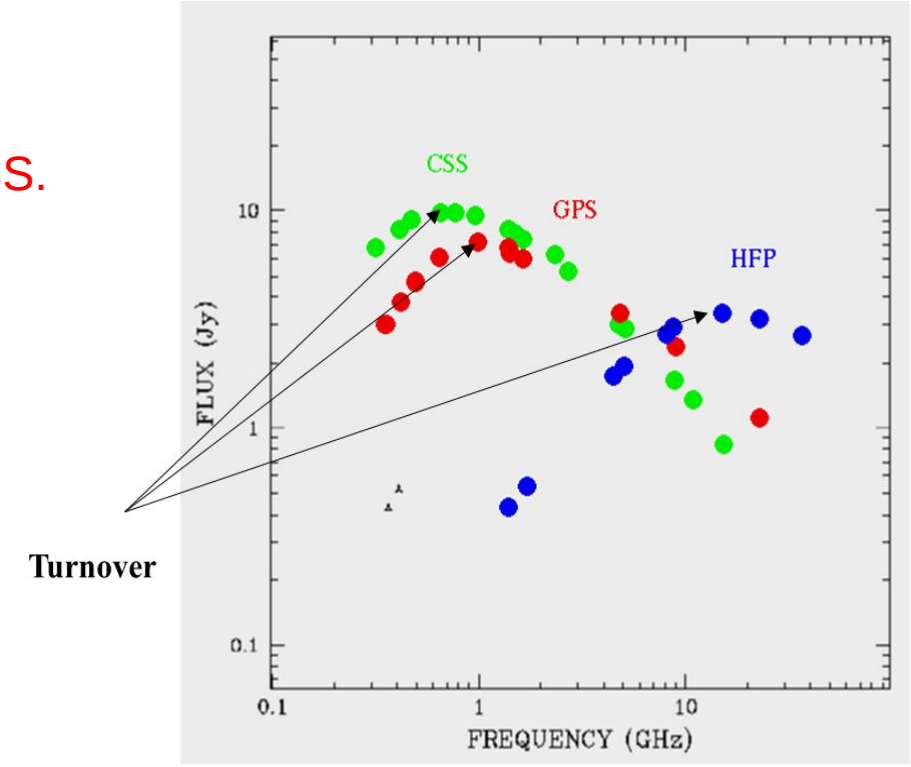
Giga-hertz Peaked Spectrum (GPS) and Compact Steep Spectrum (CSS)





Pc-scale jet from VLBA (Morganti et al. 2010)

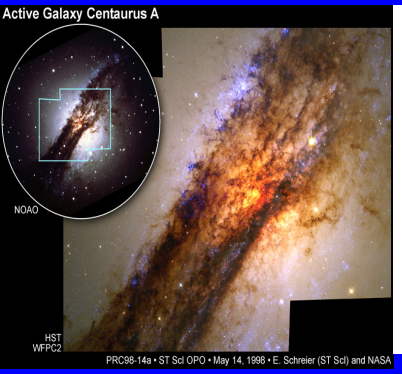
- RL-NLS1s show properties similar to GPS and CSS.
- CSS sources (few kpc) are larger than GPS and peaks around few 100 MHz (Snellen et al. 2000)
- GPS sources peak around 1 GHz and shows two lobes at parsec scale

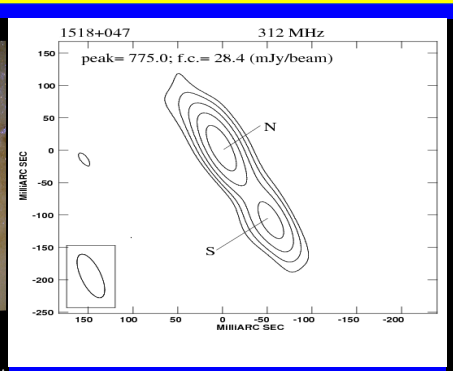


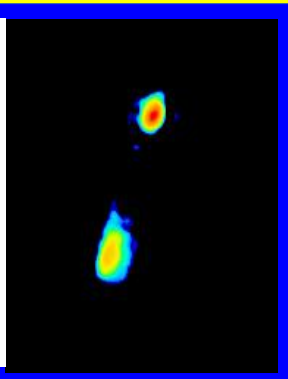
Multi-frequency multi-scale observations of RL-NLS1s are needed.

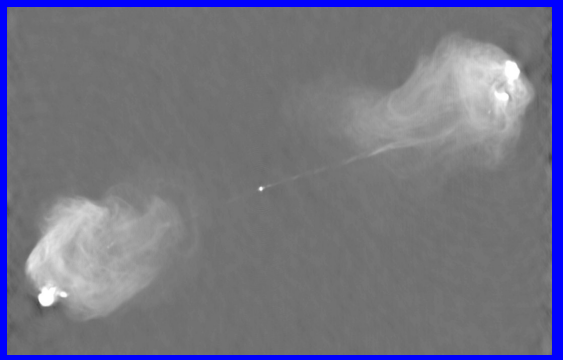
Evolution of AGN radio-jets

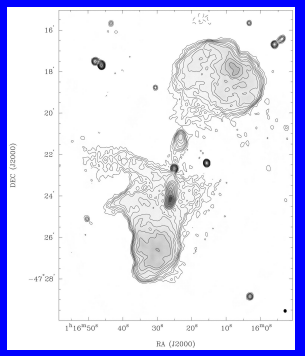
NLS1s











- **Birth → Infancy (GPS/CSO) → Youth (CSS) → Adulthood (FRI/II) → Death/Rebirth**
- **<100 10^2-10^4 yrs 10^4-10^6 yrs 10^6-10^8 yrs >10^8 yrs**
- **Acc.disk <NLR (10-1000pc) <Gal (1-20Kpc) IGM (20-1000Kpc) IGM (20-1000Kpc)**
- **IR GHz Peaked 100 MHz Peaked Steep Spectrum USS (sp. break)**

Radio jets in NLS1s

Compact radio emission attributed following scenarios:

(1) Youth scenario : Radio-jets are in an early evolutionary stage and may continue to grow to Mpc-scale extended radio sources (Fanti et al. 1995).

(2) Frustration scenario : The growth of radio-jet is retarded (stagnated) by the dense interstellar medium (ISM) within the host galaxy (Carvalho 1994, 1998).

(3) Orientation effect : powerful jets oriented along the line of sight give compact size and higher luminosity due to beaming effect.

Summary

- Radio-detection rate of NLS1s is fairly small (4.5%)
- NLS1s have lower radio detection rate in compared to BLS1s

- Mostly compact but a small fraction (10%) having kpc-scale radio structures

- There are unconventional powerful RL-NLS1s with low SMBH ($< 10^8 M_{sun}$) --> Blazar-like
- Lower SMBH with higher spin can make AGN radio-loud

- Possible evoltionary stage : young phase or may be stagnated


Thank you