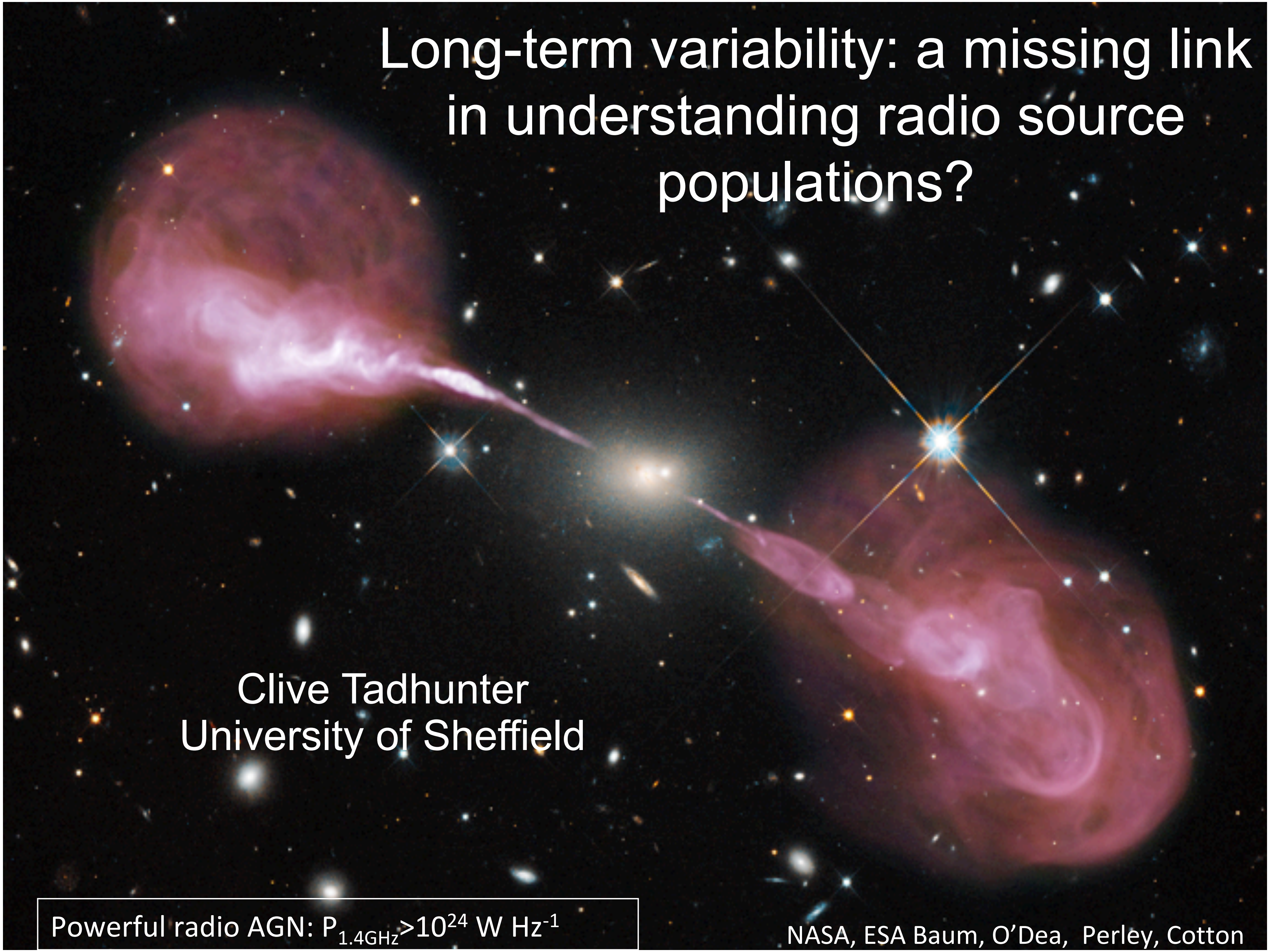

Long-term variability: a missing link in understanding radio source populations?
Clive Tadhunter
University of Sheffield
Powerful radio AGN: $P_{1.4GHz}$>10^{24} W Hz^{-1}
NASA, ESA Baum, O'Dea, Perley, Cotton

Powerful radio AGN samples

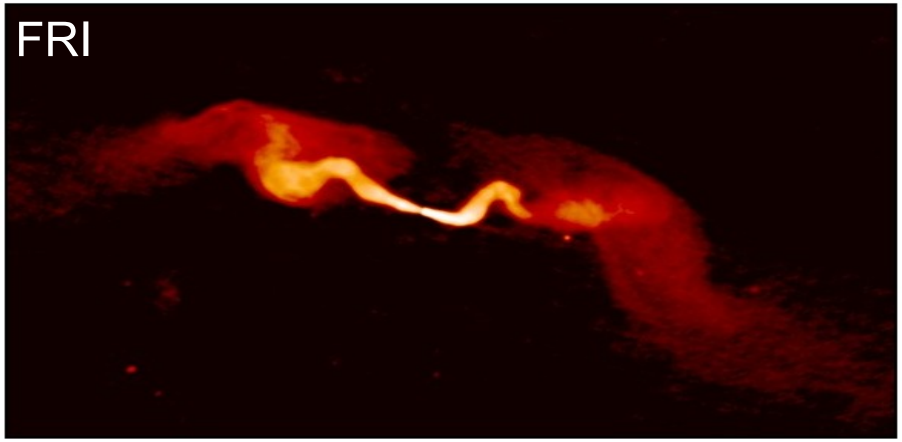
Sample	Selection
2Jy Dicken et al. (2009)	$S_{2.7\,\mathrm{GHz}} > 2\mathrm{Jy}$ $0.05 < z < 0.7$ $\delta < +10°$ $\alpha_{2.7}^{4.8} > +0.5$ $(F_\nu \propto \nu^{-\alpha})$
3CR Buttiglione et al. (2009)	$S_{178\,\mathrm{MHz}} > 9\mathrm{Jy}$ $z < 0.3$ $\delta > -5°$

Typically

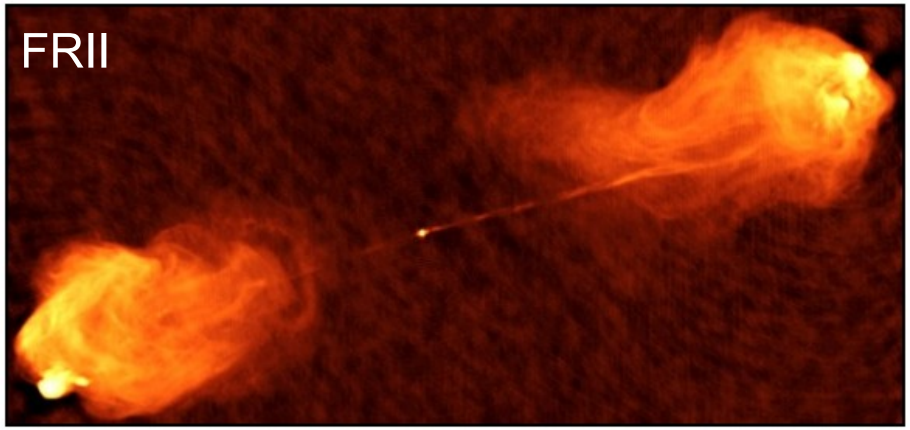
$P_{1.4GHz} > 10^{24}$ W Hz^{-1} for FRI

$P_{1.4GHz} > 10^{25}$ W Hz^{-1} for FRII

Classification of radio-loud AGN – I
Radio morphlogies



$$P_{178Mhz} < 5 \times 10^{25}\ W\ Hz^{-1}$$

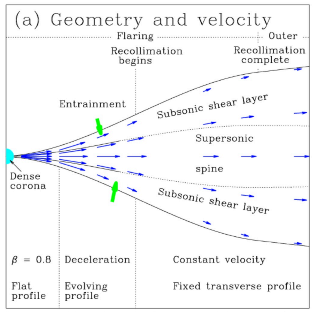


$$P_{178Mhz} > 5 \times 10^{25}\ W\ Hz^{-1}$$

What determines the radio morphology?

- Properties of central engine. Differences in central engine (e.g. accretion rate) leading to variations in jet speed and intrinsic power

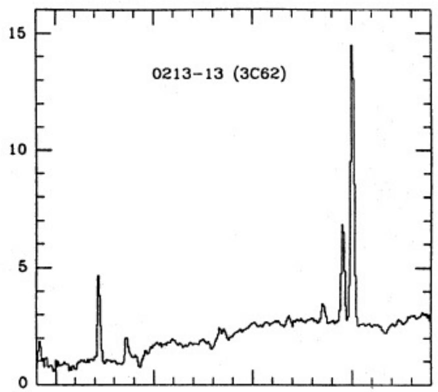
- Environment. Similar central engines but differences in gaseous environment into which jet propagates (e.g. entrainment leading to jet disruption)



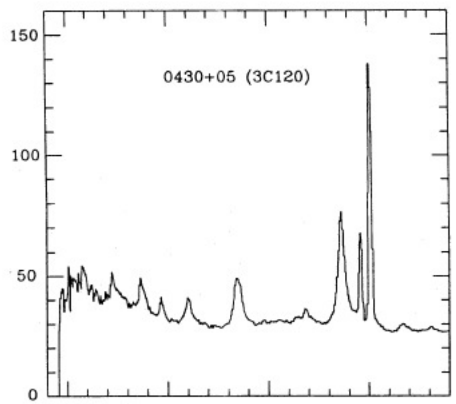
- Or some combination...

Classification of radio-loud AGN – II
Optical spectra

Narrow-line radio galaxy (NLRG)

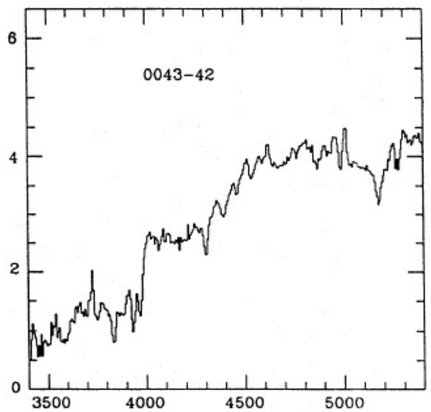


Anisotropy+ orientation



Broad-line radio galaxy or quasar (BLRG/Q)

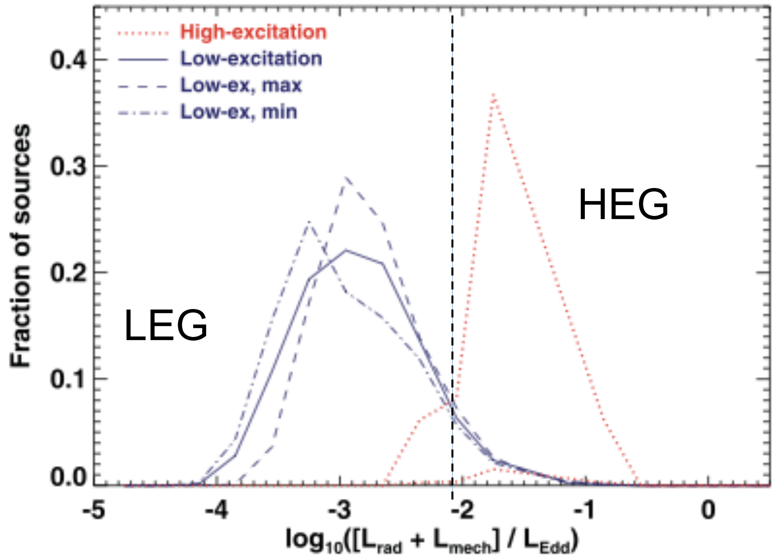
Strong-line radio galaxies (SLRG)
[or high excitation radio galaxies (HERG/HEG)]



Weak line radio galaxy (WLRG)
[or low excitation radio galaxy (LERG/LEG)]

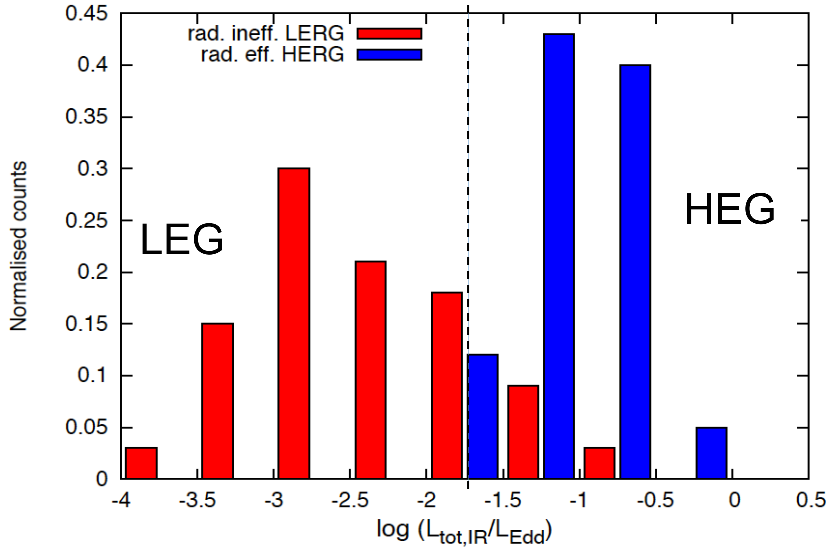
Fuelling rate: evidence for an Eddington switch

Best & Heckman (2012)



SDSS/NVSS selected sample
(using optical spectroscopy for L_{bol})

Mingo et al. (2014)

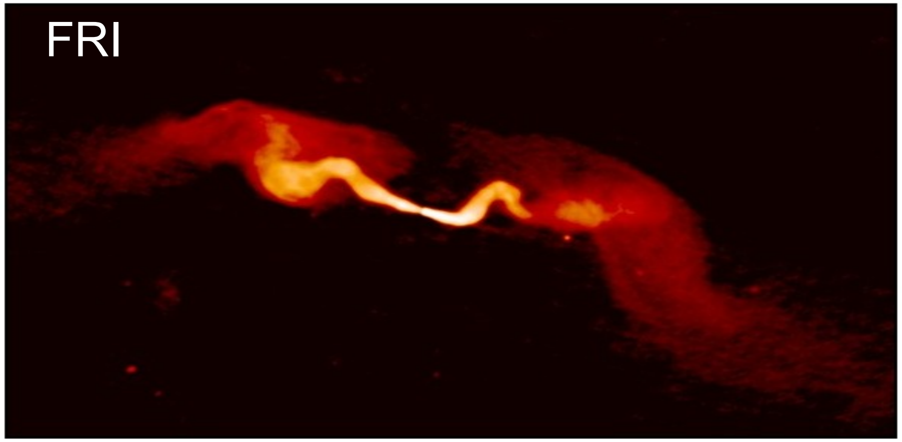


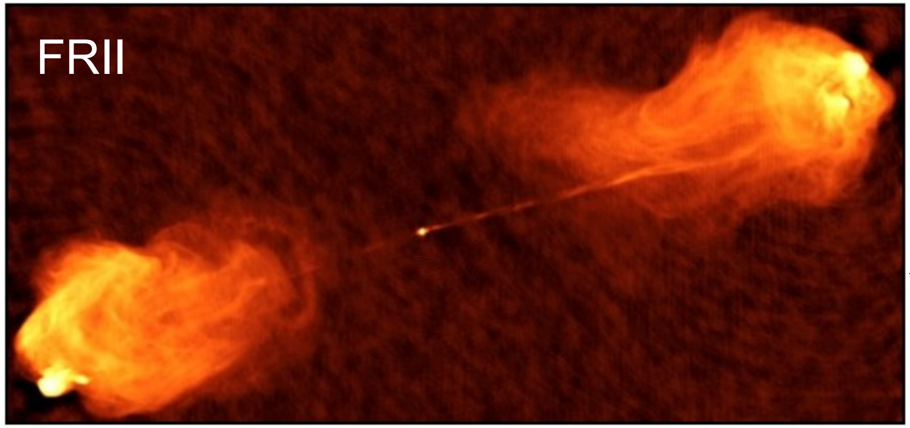
Local 2Jy and 3CR samples
(using mid-IR data for L_{bol})

Transition from WLRG/LEG to SLRG/HEG due to switch between radiatively-efficient accretion disk and radiatively-inefficient accretion flow (RIAF) at fixed Eddington ratio (~1%)

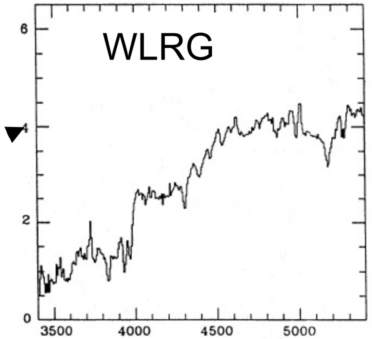
Correlations between optical and radio classifications

Radio

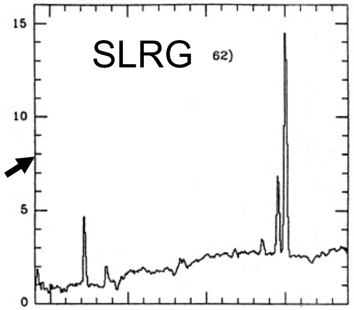




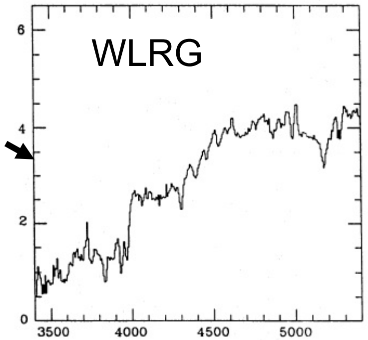
Optical



FRI almost invariably WLRG



SLRG almost invariably FRII



Some FRII (~10-20%) are WLRG

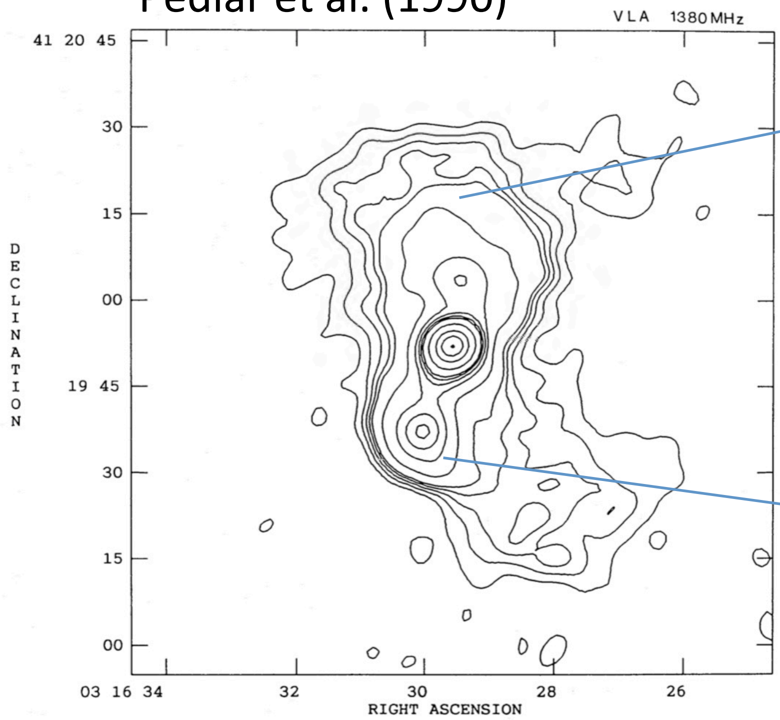
Classification breakdown for 2Jy and 3CR sample

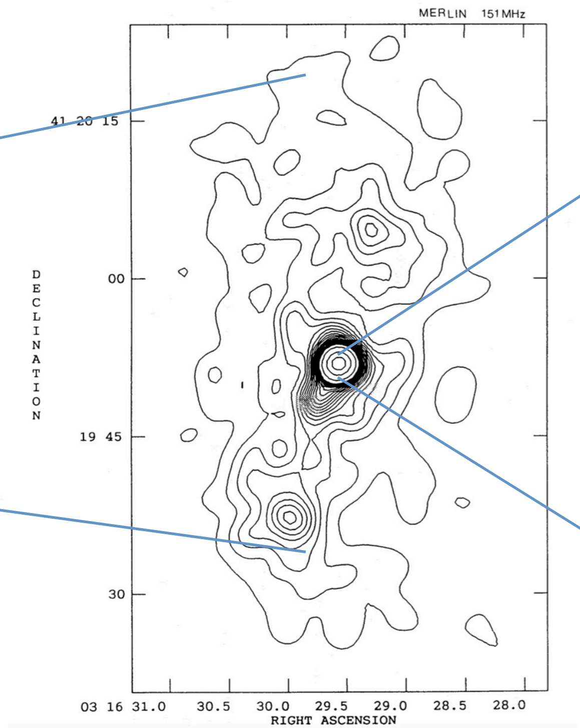
Type	Sample (N)	%WLRG	%NLRG	%BLRG/QSO
FRI	3CR (22)	100	0	0
	2Jy (15)	100	0	0
FRII	3CR (78)	24	54	21
	2Jy (39)	23	41	36
CSS/GPS	3CR (4)	25	75	0
	2Jy (7)	0	71	29
FRI/FRII	3CR (5)	60	40	0
	2Jy (4)	100	0	0
Other	3CR (4)	25	25	50
	2Jy (2)	0	0	100

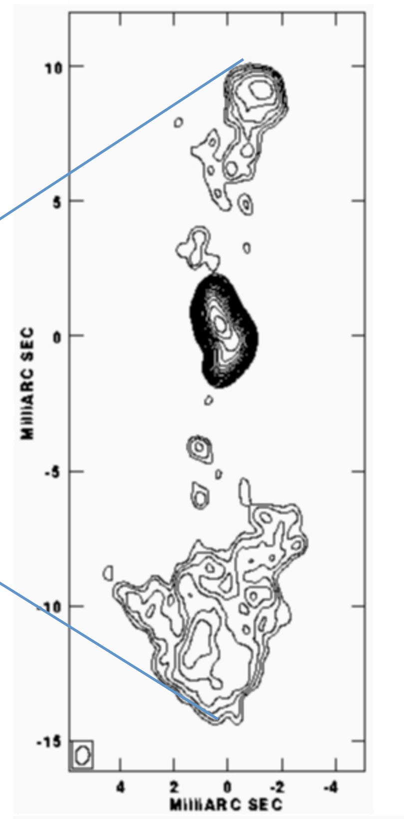
Tadhunter et al. (2016)

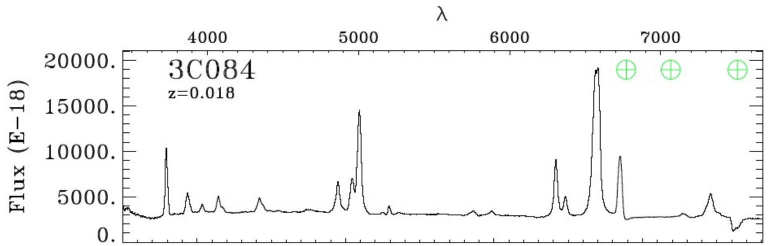
A possible FRI/SLRG exception: 3C84

Pedlar et al. (1990)









Buttiglione et al. (2009)

Originally classified as an FRI by Fanaroff & Riley (1974), 3C84 (NGC1275) but has a peculiar radio morphology and strong optical emission lines (→ SLRG/HEG)

Link between optical and radio classifications

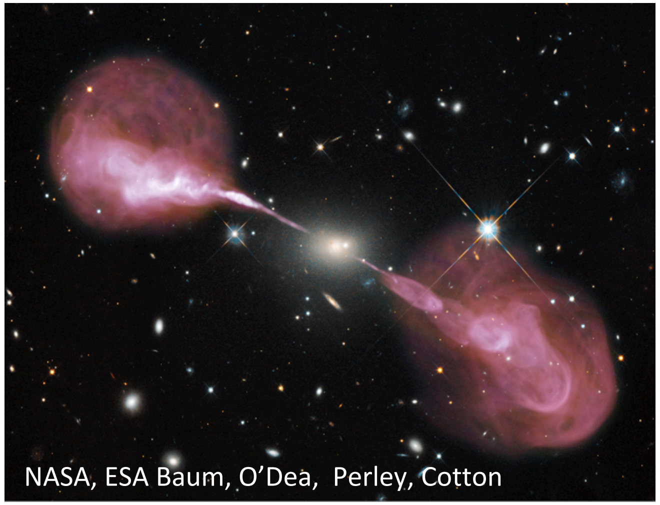
- FRI invariably associated with WLRG/LEG and SLRG/HEG with FRII
- WLRG/SLRG divide due to accretion rate and Eddington switch
  - → Suggests that FRI/FRII divide might also be related to accretion rate
- WLRG/FRII are misfits...
- But could we explain WLRG/FRII properties in terms of long-term variability?

AGN radial extents and light crossing times

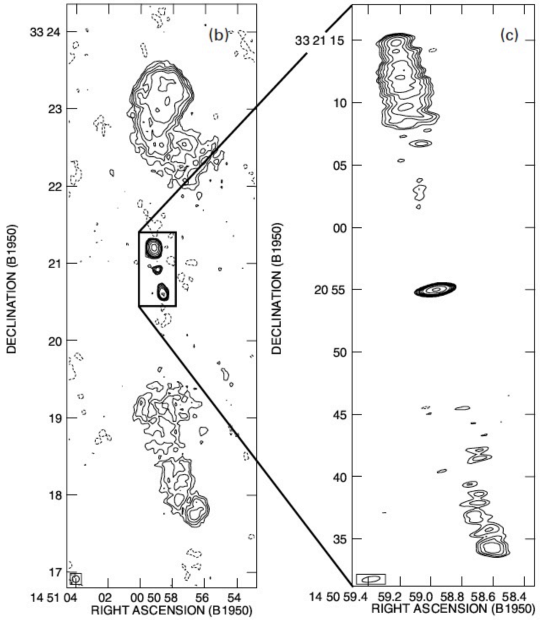
Region	Radial extent	Light travel time
Broad-line region	0.003 – 0.3 pc	0.01 – 1 yr
Torus	0.1 – 100 pc	0.3 – 300 yr
Narrow-line region	0.003 – 3 kpc	10 – 10,000 yr
Radio source	10^{-5} – 4 Mpc	30 – 10^{7} yr

Evidence for radio source intermittency

Her A

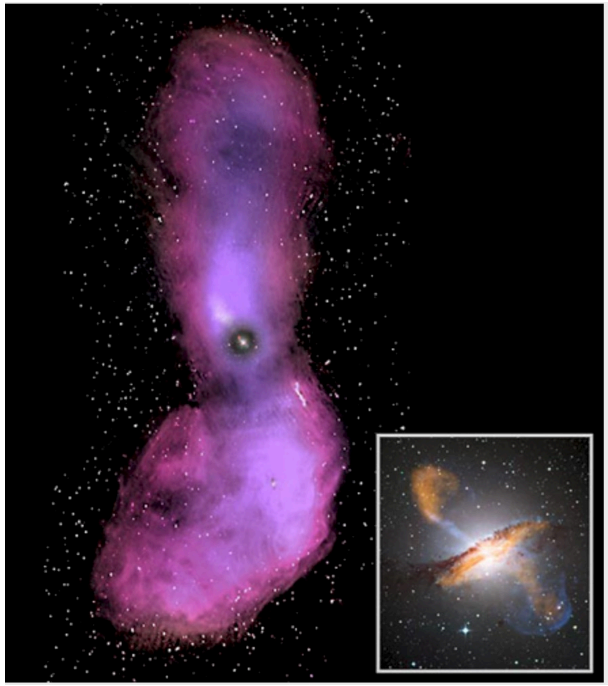


Double-double source



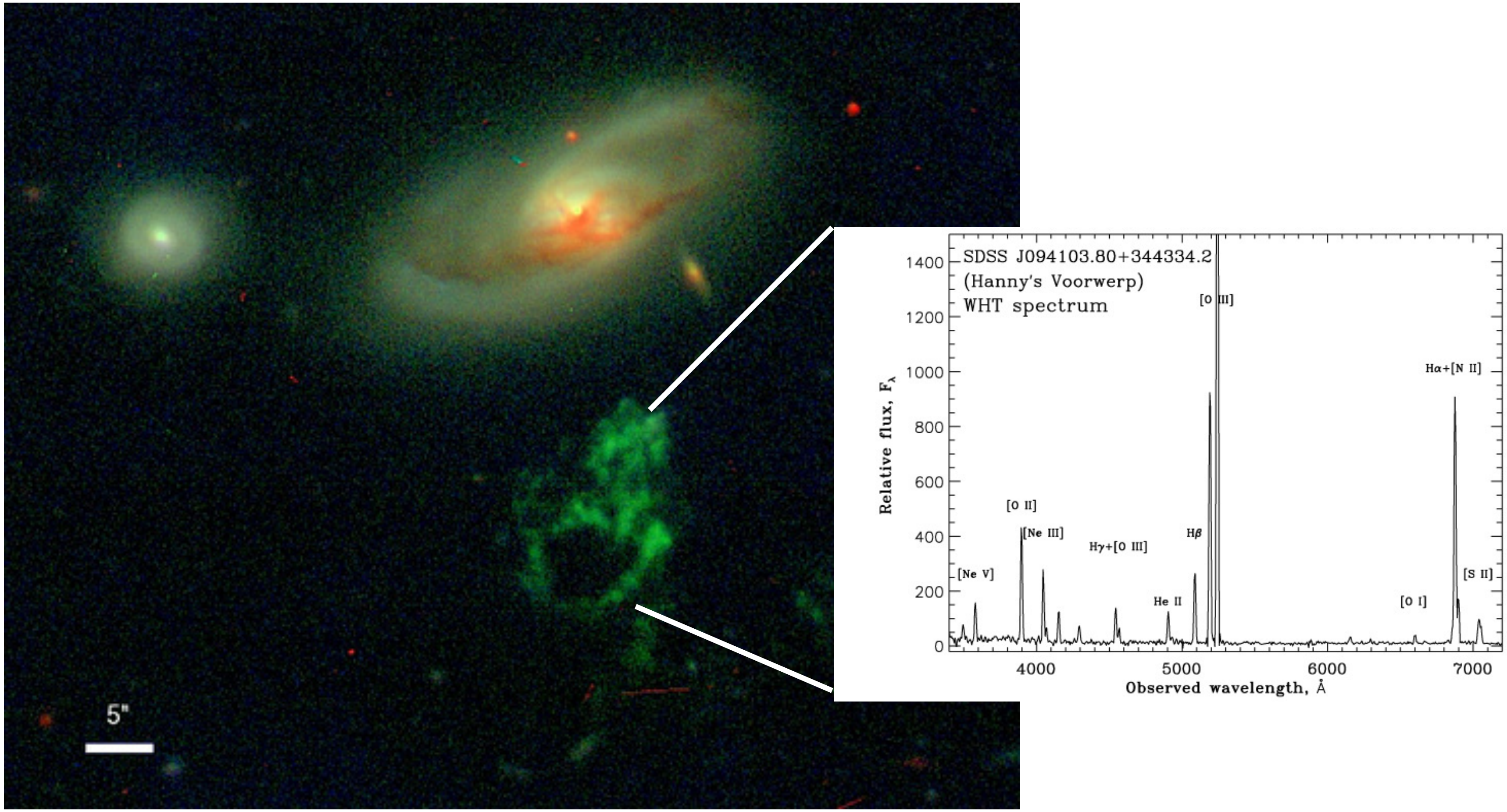
Schoenmakers et al. (2001)

Cen A



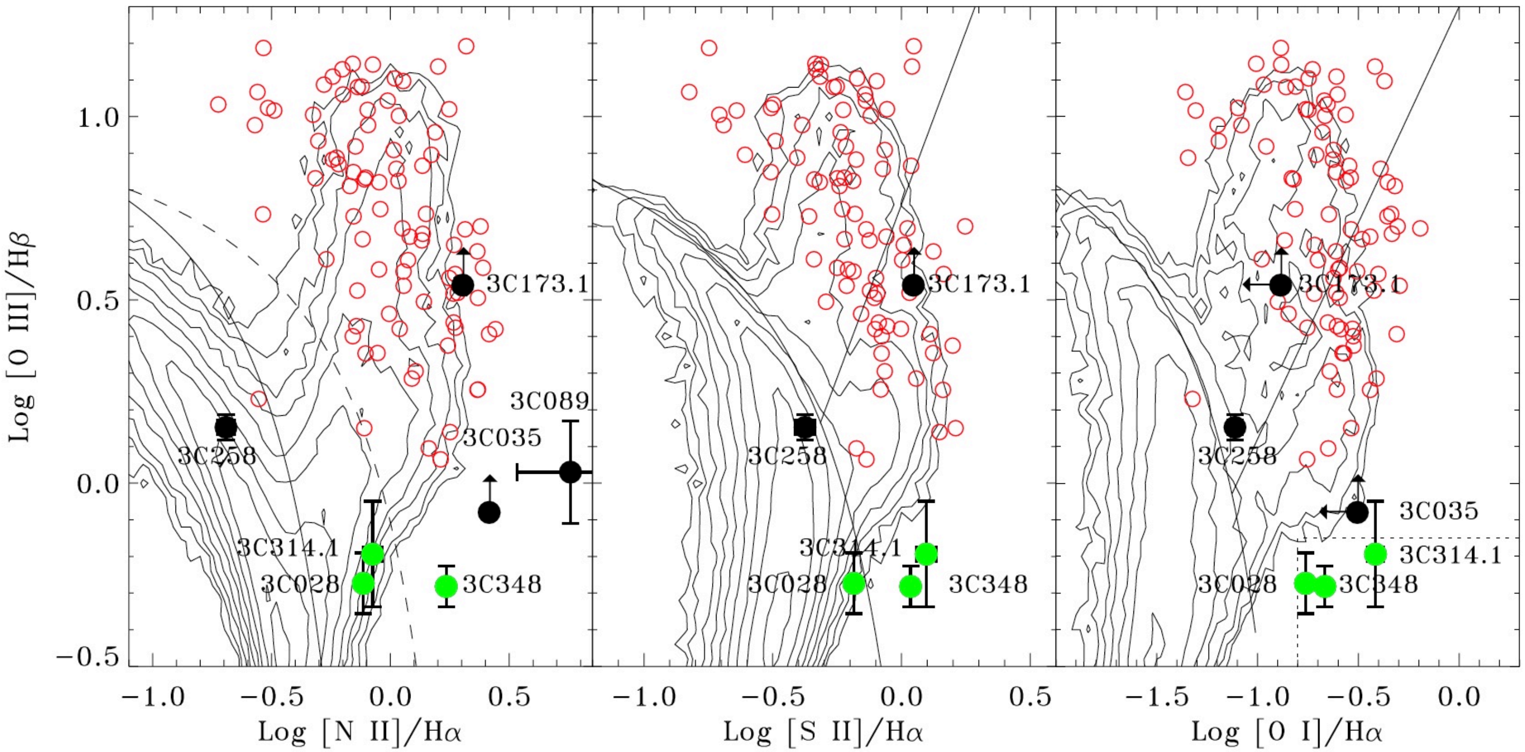
Evidence for substantial variability in radio output on timescales >10,000s yr!

Hanny's object



Hannys object has been interpreted as the light echo of a luminous AGN in the nearby spiral galaxy that switched off ~50,000 yr ago (Lintott et al. 2009)

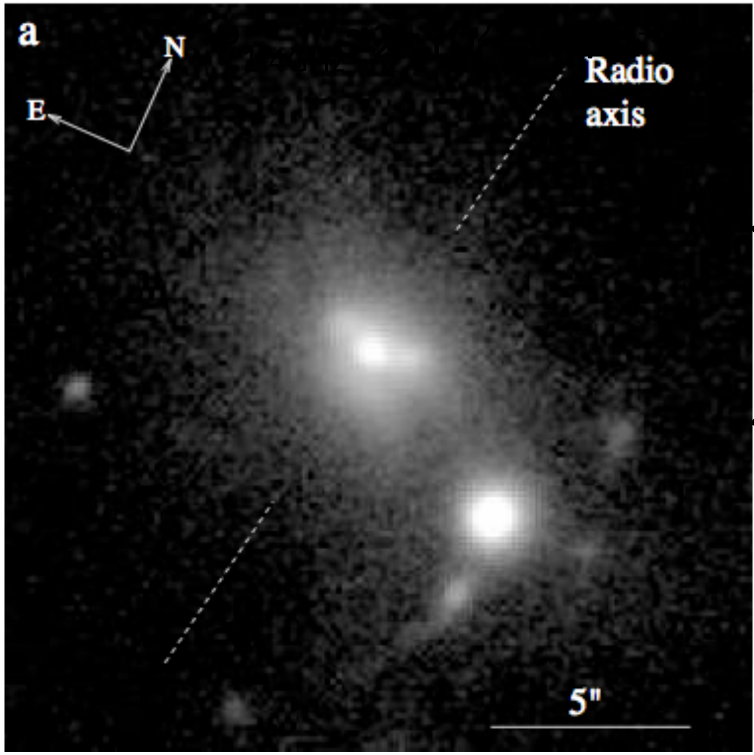
Extreme low excitation radio galaxies

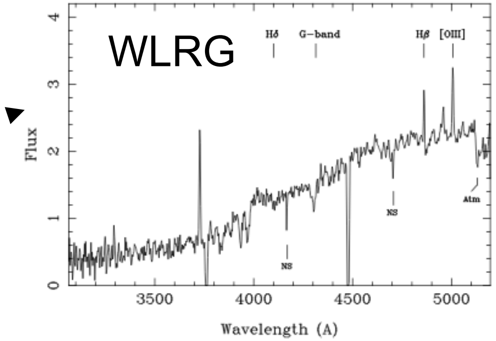


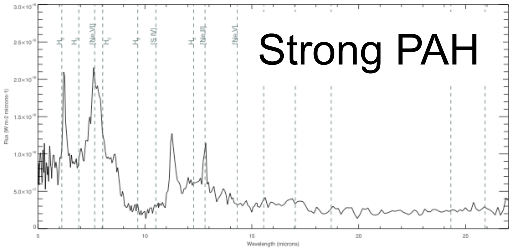
Extreme low excitation radio galaxies have been interpreted as objects in which AGN switched off ~$10^4 - 10^7$ yr ago

Buttiglione et al. (2010), Capetti et al. (2013)

PKS0347+05: a recently “switched off” AGN?



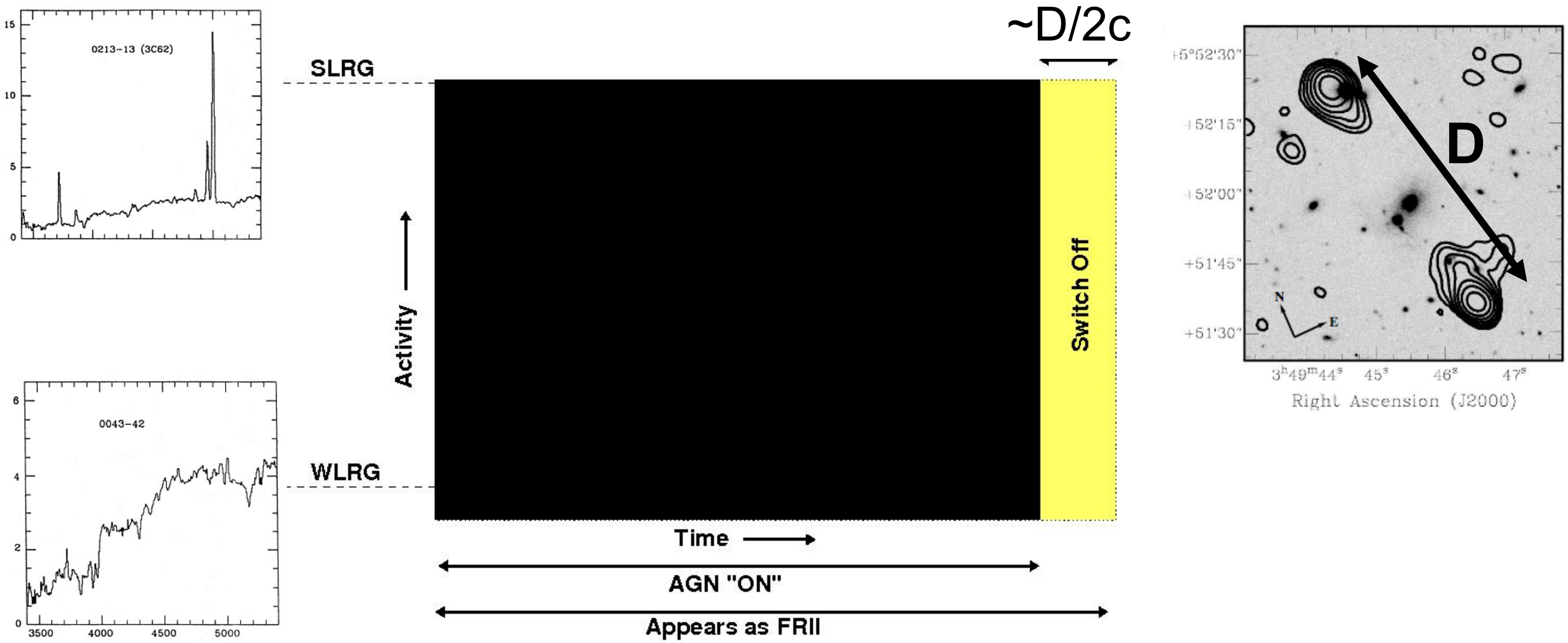




Tadhunter et al. (2012)

The source PKS0347+05 has an extremely powerful FRII radio source, PAH evidence for strong star formation, and a large gas/dust mass, yet shows only weak emission line activity at optical and mid-IR wavelengths ➔ likely that this radio source as recently “switched off”

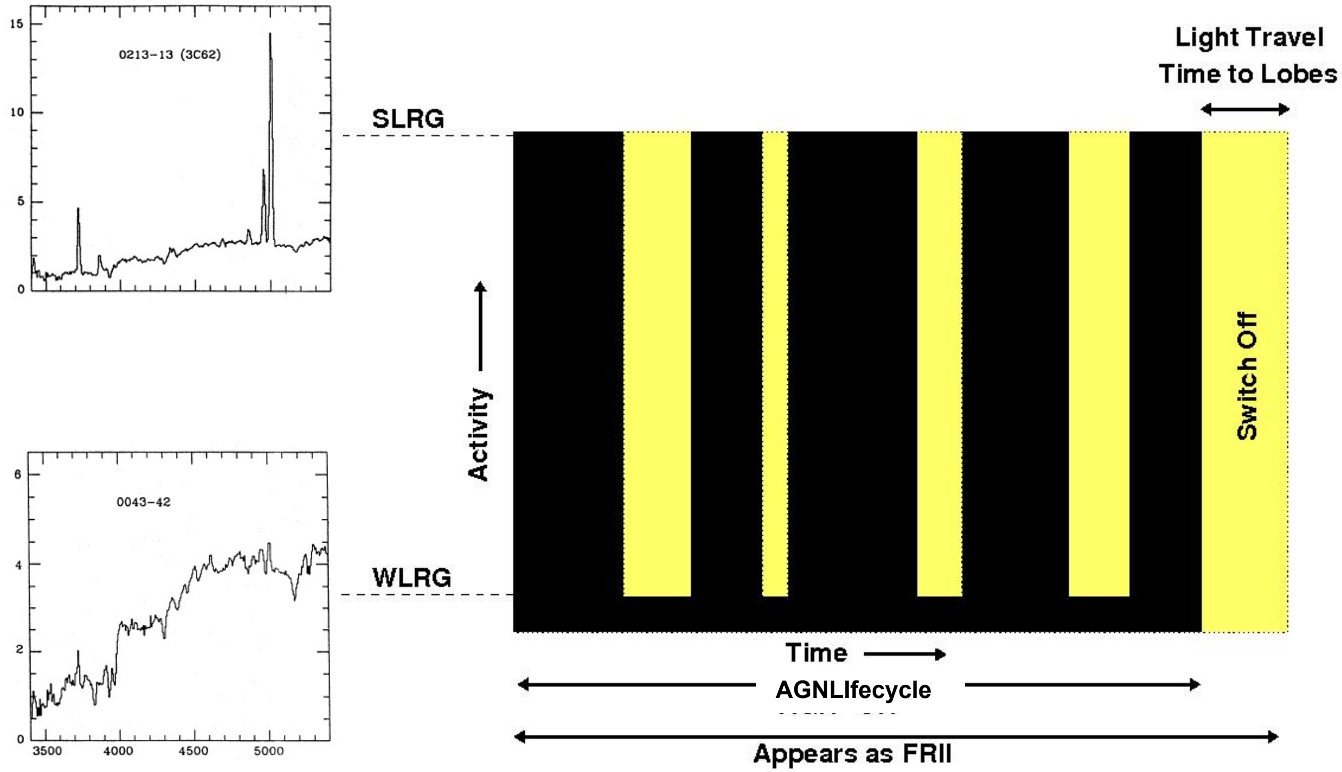
Light travel time effects



Hot spots remain visible for time ~D/2c after AGN has switched off. Fraction of WLRG in population of powerful FRII 2Jy radio sources (for $P_{5GHz} > 10^{26}$ W Hz^{-1}) $f_{wlrg} = 0.1$; and mean diameter D_m~300 kpc.

➔Average lifetime of FRII radio sources: $t_{rad} = D_m/(2cf_{wlrg})$
~5×10^6 yr

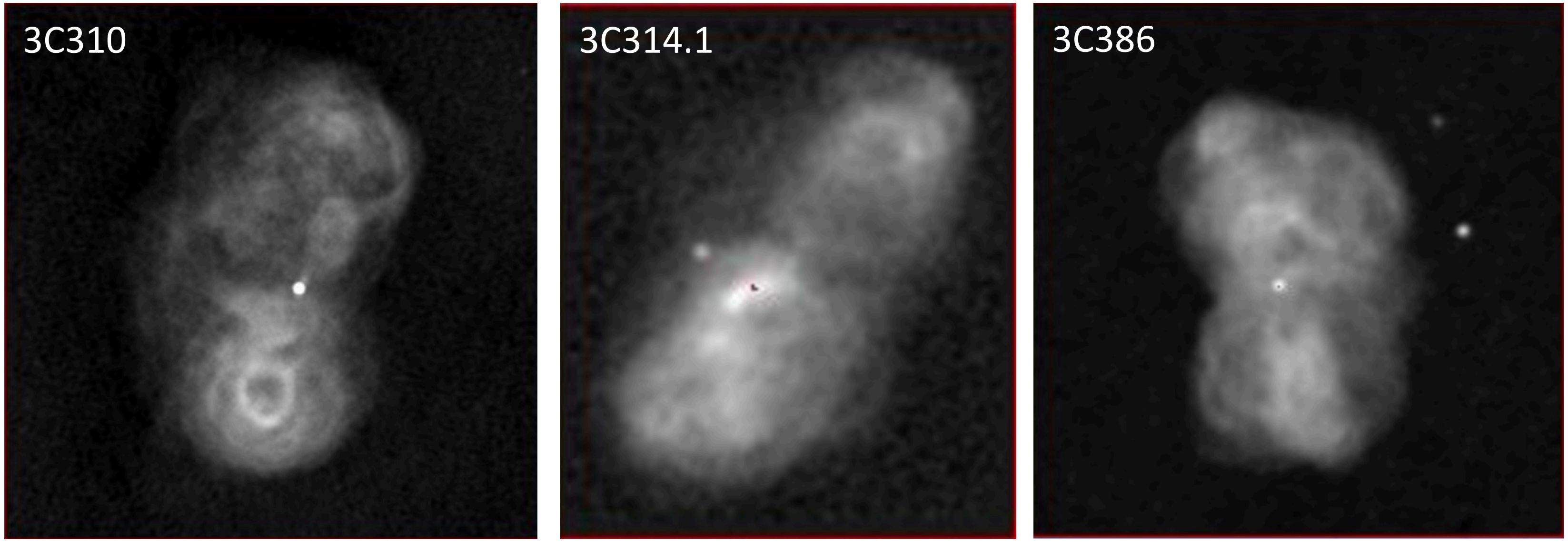
Level of intermittency of radio-loud AGN activity



Fraction of time that AGN "off" < f_{wlrg}
~0.1 (high power 2Jy FRII)

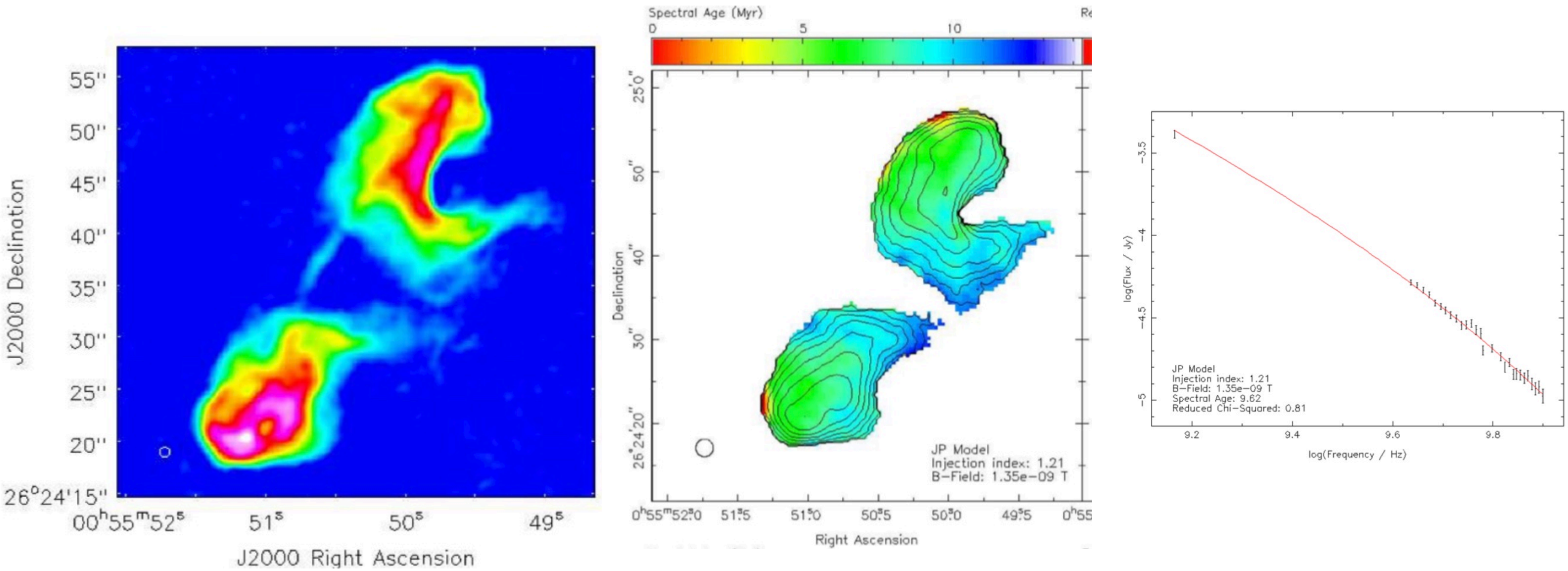
➔The quasar is "on" for the overwhelming majority of the time for a particular triggering event/activity cycle.

Link between relaxed/fat doubles and WLRG/FRII



~50% of 25 WLRG/FRI in 3CR and 2Jy are relaxed/fat doubles compared with only ~10% of the SLRG/FRII

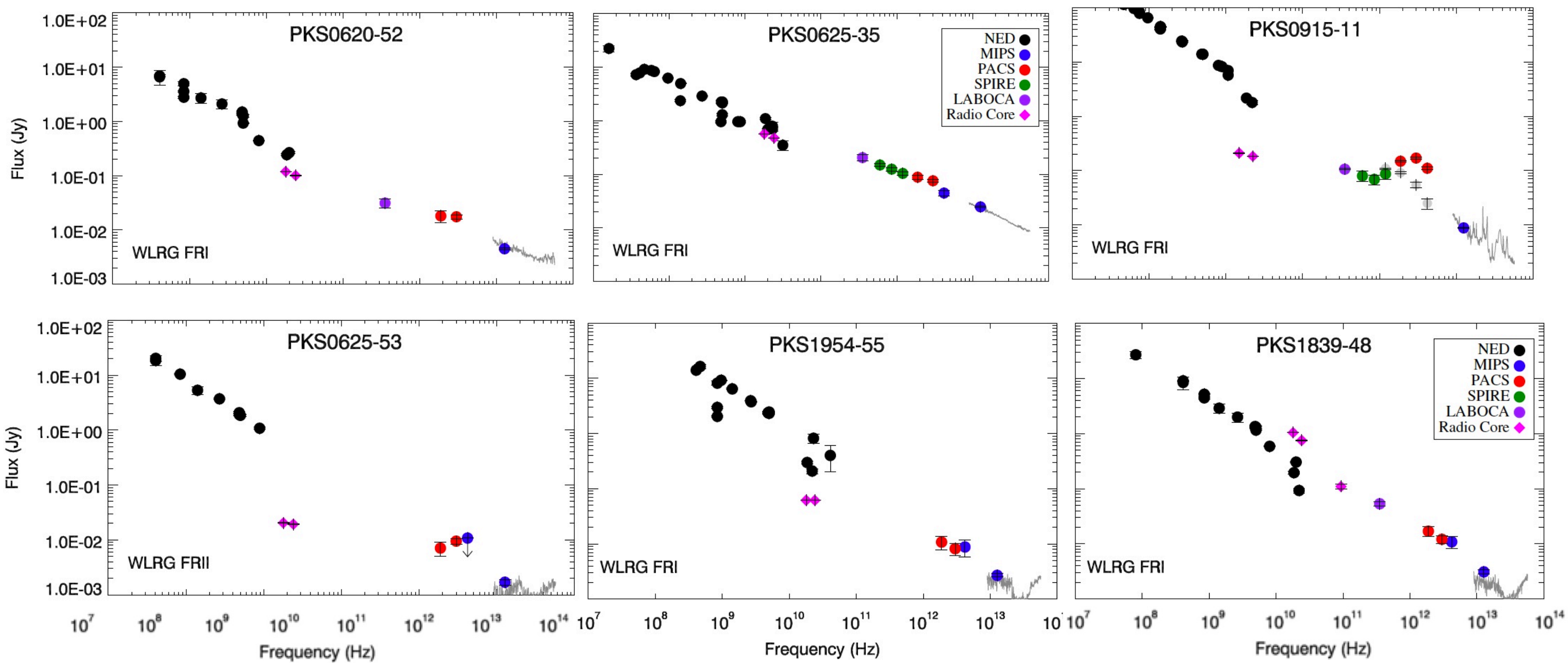
Evidence that ELERG/FRII 3C28 is a radio relic



Harwood et al. (2015)

Source switched off ~6 – 9 Myr ago

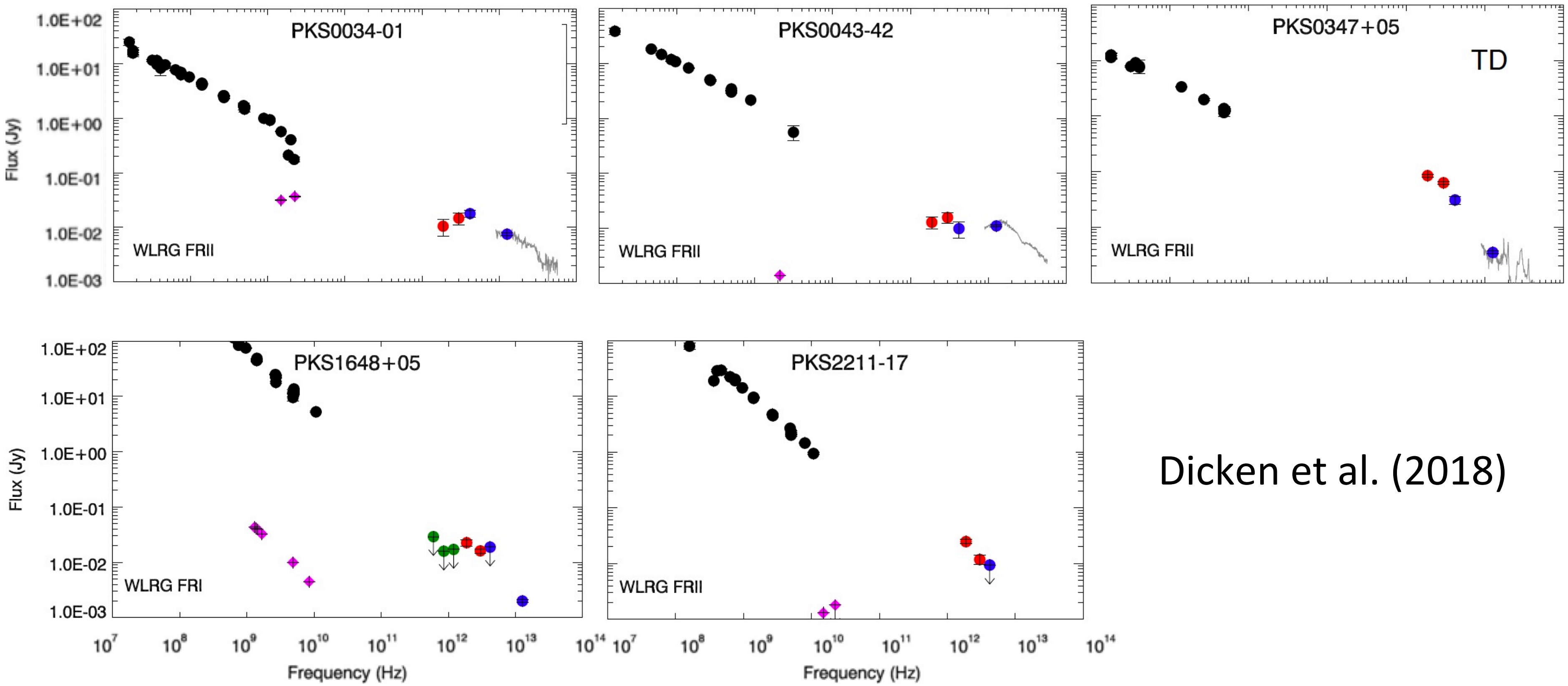
Far-IR properties of WLRG – I 2Jy WLRG/FRI



Dicken et al. (2008, 2018)

Only 1/6 FRI/WLRG in the 2Jy sample show evidence for thermal dust emission at far-IR wavelengths (see also Cleary et al. 2007; Dicken et al. 2008; Leipski et al. 2009; van der Volk et al. 2010)

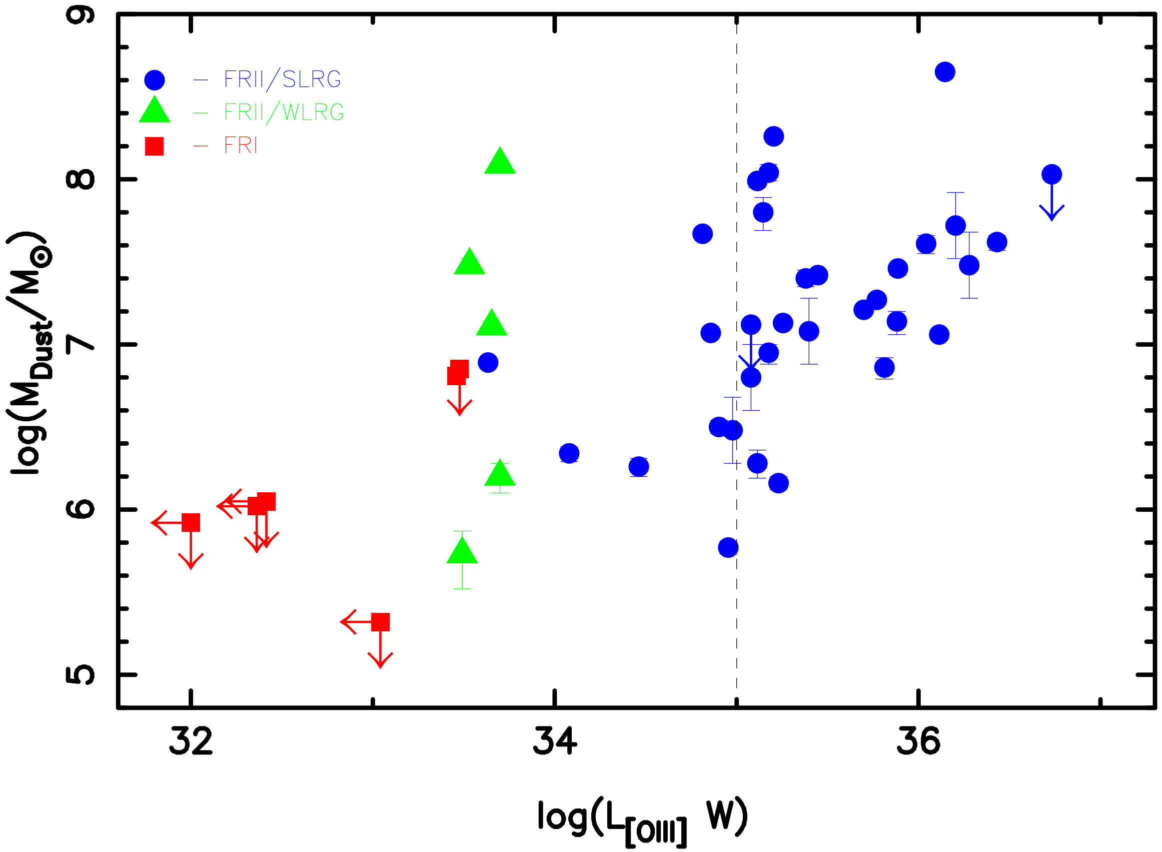
Far-IR properties of WLRG – II 2Jy WLRG/FRII



Dicken et al. (2018)

All 5 WLRG/FRII in the 2Jy sample show evidence for thermal dust emission at far-IR wavelengths.

Relationship between ISM mass and classification of radio AGN in 2Jy sample



Dicken et al. (2018)

Dust masses of WLRG/FRII are more similar to those of SLRG/FRII than those of FRI

Arguments against WLRG/FRII as "switched off" SLRG/FRII

- Some WLRG/FRII have relatively bright radio cores

But...

- Radio cores in at least some WLRG/FRII substantially weaker relative to total emission than in typical SLRG/FRII ($P_{core}/P_{ext} < 10^{-3}$ at 2.3GHz)

- If objects dropped to lower accretion rate, cores wouldn't necessarily be much weaker (radio cores in FRI stronger than in FRII)

- Tend to be in richer galaxy environments

But...

- Selection effect: dense gaseous environment could increase timescale over with relic radio source is visible by confinement effects

- Duty cycle of intermittent activity might be faster in clusters due to nature of fuel supply

Conclusions

- Links between FRI and WLRG, and SLRG and FRII, suggest that not just optical activity, but also radio morphology, linked to accretion rate (e.g. Eddington switch)
- WLRG/FRII apparently discrepant, but might be explained as SLRG/FRII that recently switched off, or entered phase of lower activity
- The rarity of WLRG/FRII suggests that, within a cycle of SLRG activity, the AGN is “on” for >75 − 90% of the time (many millions of years...)