Long-term variability: a missing link in understanding radio source populations?

Clive Tadhunter
University of Sheffield

Powerful radio AGN: $P_{1.4\text{GHz}} > 10^{24} \text{ W Hz}^{-1}$

NASA, ESA Baum, O’Dea, Perley, Cotton
Powerful radio AGN samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>Selection</th>
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</thead>
</table>
| **2Jy** Dicken et al. (2009) | $S_{2.7\,\text{GHz}} > 2\text{Jy}$  
|                 | $0.05 < z < 0.7$  
|                 | $\delta < +10^\circ$  
|                 | $\alpha_{2.7} > +0.5$  
|                 | ($F_v \propto v^{-\alpha}$)  |
| **3CR** Buttiglione et al. (2009) | $S_{178\,\text{MHz}} > 9\text{Jy}$  
|                 | $z < 0.3$  
|                 | $\delta > -5^\circ$  |

Typically

- $P_{1.4\,\text{GHz}} > 10^{24}$ W Hz$^{-1}$ for FRI
- $P_{1.4\,\text{GHz}} > 10^{25}$ W Hz$^{-1}$ for FRII
Classification of radio-loud AGN – I
Radio morphologies

FRI

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

FRII

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

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

Anisotropy + orientation

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

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%)

Best & Heckman (2012)

Mingo et al. (2014)

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

Local 2Jy and 3CR samples (using mid-IR data for $L_{\text{bol}}$)
Correlations between optical and radio classifications

Radio

FRI

Optical

WLRG

FRI almost invariably WLRG

SLRG

SLRG almost invariably FRII

FRIII

WLRG

Some FRII (~10-20%) are WLRG
## Classification breakdown for 2Jy and 3CR sample

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

Tadhunter et al. (2016)
A possible FRI/SLRG exception: 3C84

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

<table>
<thead>
<tr>
<th>Region</th>
<th>Radial extent</th>
<th>Light travel time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad-line region</td>
<td>0.003 – 0.3 pc</td>
<td>0.01 – 1 yr</td>
</tr>
<tr>
<td>Torus</td>
<td>0.1 – 100 pc</td>
<td>0.3 – 300 yr</td>
</tr>
<tr>
<td>Narrow-line region</td>
<td>0.003 – 3 kpc</td>
<td>10 – 10,000 yr</td>
</tr>
<tr>
<td>Radio source</td>
<td>$10^{-5}$ – 4 Mpc</td>
<td>30 – $10^7$ yr</td>
</tr>
</tbody>
</table>
Evidence for radio source intermittency

Her A

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

Schoenmakers et al. (2001)
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 have been interpreted as objects in which AGN switched off $\sim 10^4 - 10^7$ yr ago

Buttiglione et al. (2010), Capetti et al. (2013)
PKS0347+05: a recently “switched off” AGN?

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

$\Rightarrow$ Average lifetime of FRII radio sources: $t_{\text{rad}} = \frac{D_m}{2c f_{\text{wrg}}}$

$\sim 5 \times 10^6$ yr
Level of intermittency of radio-loud AGN activity

Fraction of time that AGN “off” $< f_{\text{wrlg}}$

$\sim 0.1$ (high power 2Jy FRII)

$\Rightarrow$ 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 $\sim$6 – 9 Myr ago
Far-IR properties of WLRG – 1 2Jy WLRG/FRI

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)

Dicken et al. (2008, 2018)
Far-IR properties of WLRG – II 2Jy WLRG/FRII

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

Dicken et al. (2018)
Relationship between ISM mass and classification of radio AGN in 2Jy sample

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

Dicken et al. (2018)
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 ($P_{\text{core}}/P_{\text{ext}} < 10^{-3}$ 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...