Broad-band properties of flat-spectrum radio-loud narrow-line Seyfert 1 galaxies

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# Narrow-Line Seyfert 1 Galaxies

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<table>
<thead>
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<tbody>
<tr>
<td>FWHM H(\beta)</td>
<td>&lt; 2000 km/s</td>
</tr>
<tr>
<td></td>
<td>Goodrich 1989</td>
</tr>
<tr>
<td>[O\textsc{iii}]/H(\beta)</td>
<td>&lt; 3</td>
</tr>
<tr>
<td></td>
<td>Osterbrock &amp; Pogge 1985</td>
</tr>
<tr>
<td>Bump Fe\textsc{ii}</td>
<td>Yes ☑️ No obscuration</td>
</tr>
<tr>
<td></td>
<td>Osterbrock &amp; Pogge 1985</td>
</tr>
<tr>
<td>Mass Black Hole</td>
<td>(10^6)-(10^8) M(_\odot)</td>
</tr>
<tr>
<td></td>
<td>Peterson, Mathur, Decarli, Marconi, Bentz, Denney, Vestergaard, Woo, Wandel, Calderone…</td>
</tr>
<tr>
<td>Accretion rate</td>
<td>0.1-1 Eddington</td>
</tr>
<tr>
<td></td>
<td>Boroson &amp; Green 1992; Boller+ 1996</td>
</tr>
<tr>
<td>Host galaxy</td>
<td>spiral, mostly barred</td>
</tr>
<tr>
<td></td>
<td>Crenshaw+ 2003; Deo+ 2006</td>
</tr>
<tr>
<td>Star formation</td>
<td>Yes, high</td>
</tr>
<tr>
<td></td>
<td>Sani+ 2010; Caccianiga+ 2015</td>
</tr>
<tr>
<td>Age</td>
<td>Young, &lt; Gyr</td>
</tr>
<tr>
<td>Radio</td>
<td>7% is radio-loud</td>
</tr>
<tr>
<td></td>
<td>Komossa+ 2006; Cracco+ 2015</td>
</tr>
<tr>
<td></td>
<td>4% is radio-loud ((z &lt; 0.35))</td>
</tr>
<tr>
<td>(\gamma) rays</td>
<td>First detections by Fermi LAT</td>
</tr>
<tr>
<td>(MeV-GeV)</td>
<td>11 sources to date, increasing</td>
</tr>
<tr>
<td></td>
<td>Abdo+ 2009 (3 articles); Foschini+ 2010; …</td>
</tr>
<tr>
<td></td>
<td>Earlier attempt (negative) with Whipple at E &gt; 400 GeV (Falcone+ 2004).</td>
</tr>
</tbody>
</table>
Fig. 7.—Interpretive diagram showing how PC1-PC2 plane provides basis for classification of AGNs

Boroson (2002)
Sample selection (42 sources)

From literature:

Criteria:
- $\text{FWHM H}_\beta > 2000 \text{ km/s} + 10\% = 2200 \text{ km/s}$
- $\text{[OIII]}/H_\beta < 3$
- Bump Fe II
- Radio loudness $= S_{5\text{GHz}}/S_{440\text{nm}} > 10$
- $\alpha < 0.5$, $S_\nu \propto \nu^{-\alpha}$ [radio spectrum flat or inverted]
- Sources with only 1.4 GHz measurement (i.e. no spectral information) were also included (20/42)

Comparison samples:
- 57 flat-spectrum radio quasars (FSRQs) + 31 BL Lac Objects
Related and Ongoing Works

Related works:

- Angelakis+ (2015): intensive radio monitoring of 4 γ-NLS1s
- Berton+ (2015): search for the parent population - See previous talk
- Caccianiga+ (2014): study on individual source
- Caccianiga+ (2015): infrared properties of the present sample
- Gu, Chen, Komossa,… (2015): parsec scale radio emission of RLNLS1s
- Järvelä+ (2015): MW study of a sample of RLNLS1 - See previous talk
- Komossa+ (2006b): study on individual source
- Richards+ (2015), Richards & Lister (2015): parsec scale radio emission of RLNLS1s

Ongoing observations:

- Multifrequency Radio Survey (PI Lähteenmäki)
- VLA/VLBA survey (PI Richards)
- Effelsberg Radio monitoring (PI Angelakis)
- EVN observation on individual source (PI Caccianiga)
Central Black Hole Mass & Accretion Disc Luminosity

Masses NLS1 calculated by using line dispersion $\sigma$ less affected by:
- inclination,
- Eddington ratio,
- line profile.
(Peterson+ 2004, Collin+ 2006)

- **FSRQ**
- **BL Lac (↓ upper limits)**
- **RLNLS1**
- **$\gamma$-NLS1**
Observational Characteristics: Gamma rays

7/42 (17%) sources detected at high-energy gamma rays (0.1-100 GeV)

Average spectral index 1.6 ± 0.3 (median 1.7)
One outlier: J0849+5108 hard spectrum (1.00-1.18)

Fermi LAT samples (Ackermann+ 2011):
FSRQs: 1.4 ± 0.2
LSP BL Lacs: 1.2 ± 0.1
ISP BL Lacs: 1.1 ± 0.1
HSP BL Lacs: 0.9 ± 0.2

More detections after the present work:
- one source in the present sample:
  - J1644+2619 (D’Ammando+ 2015) 8/42 (19%)
- three sources not in the present sample:
  - J1222+0413 (Yao+ 2015)
  - J1443+4725 (Liao+ 2015) steep radio spectrum
  - J2314+2243 (Komossa+ 2015) steep radio spectrum
Observational Characteristics: X rays

38/42 (90%) sources detected at X rays (0.3-10 keV)

Average spectral index $1.0 \pm 0.5$ (median 0.8)

**Comparison samples:**
FSRQs: 0.58
BL Lac Objects: 1.2
Broad-Line Seyfert 1 (BLS1): 1.1
Narrow-Line Seyfert 1 (NLS1): 1.7

No Fe Kα line except for J0324+3410 (cf Abdo+ 2009)
E = 6.5 ± 0.1 keV
EW = 91 eV

43 radio-quiet NLS1s
50 Broad-Line Seyfert 1 (BLS1) from Grupe+ (2010).
Observational Characteristics: Infrared ($WISE$)

$WISE$ Gamma-ray Strip (WGS) (Massaro+ 2012)
AGN Wedge (Mateos+ 2012, 2013)

![Graph showing AGN Wedge and Starburst regions with WISE bands W1, W2, W3, W4 values: W1 = 3.4 $\mu$m, W2 = 4.6 $\mu$m, W3 = 12 $\mu$m, W4 = 22 $\mu$m.]

$q_{22} = \log \left( \frac{S_{22 \mu m}}{S_{1.4 \text{ GHz}}} \right)$.

$\alpha_{1.4} = -\frac{\log \left( \frac{S_{1.4 \text{ GHz}}}{S_{22 \mu m}} \right)}{\log \left( \frac{\nu_{1.4 \text{ GHz}}}{\nu_{22 \mu m}} \right)}$

Caccianiga+ 2015

IR galaxies
BZQ
RL NLS1

28th Texas Symposium, Disks & Jets Session, 17 December 2015, Geneva
Observational Characteristics: Radio

21-1/42 (48%) sources have only 1.4 GHz measurement
(J0953+2836 observed at 9 GHz by Richards & Lister 2015)
12/42 (28%) sources were detected <1.4 GHz (74-843 MHz)

5/42 sources were targets of intensive monitoring and MW Campaigns
(Effelsberg, Metsähovi, RATAN-600, IRAM, MOJAVE, TANAMI)

J0324+3410, J0849+5108, J0948+0022, J1505+0326 ≠ Angelakis+ (2015)

7/42 sources showed inverted spectral index

Average spectral index 0.1 ± 0.3 (median 0.3)

Comparison:
Abdo+ (2010) (Fermi LAT Bright AGN Sample) ≠ 0.03 ± 0.23 [1-100 GHz]
Hovatta+ (2014) [8-15 GHz] ≠ FSRQs (133) = -0.22 ≠ BL Lacs (33) = -0.19
Tornikoski+ (2000) [2.3-8.4 GHz] ≠ BL Lacs + HPQ = -0.13 ≠ LPQ = 0.05
Nieppola+ (2007) 398 BL Lacs ≠ [5-37 GHz] = -0.25 ≠ [37-90 GHz] = 0.0
Observational Characteristics: Radio
VLBA 2cm, MOJAVE,
analysis by Y. Y. Kovalev in Foschini+ (2011)

J0948+0022
Changes in radio polarisation properties before
the $\gamma$-ray outburst 2010 July 7-10

- EVPA swing $\sim 90^\circ$
- Polarisation intensity drop
Observational Characteristics: Short Timescale Variability

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<thead>
<tr>
<th>Name</th>
<th>γ rays</th>
<th>X-rays</th>
<th>$u\omega_2$</th>
<th>$u\omega m_2$</th>
<th>$u\omega_1$</th>
<th>$u$</th>
<th>$b$</th>
<th>$v$</th>
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<tbody>
<tr>
<td>J0134 − 4258</td>
<td>−0.071 ± 0.025</td>
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<tr>
<td>J0324 + 3410</td>
<td>0.10 ± 0.03</td>
<td>−0.079 ± 0.012</td>
<td>0.09 ± 0.03</td>
<td>0.10 ± 0.04</td>
<td>&lt;0.43</td>
<td>7 ± 3</td>
<td>&lt;0.7</td>
<td>&lt;0.28</td>
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<tr>
<td>J0849 + 5108</td>
<td>12 ± 8</td>
<td>&lt;18</td>
<td></td>
<td></td>
<td>&lt;0.27</td>
<td>4.1</td>
<td>6.1</td>
<td>3.6</td>
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<tr>
<td>J0948 + 0022</td>
<td>&lt;0.8</td>
<td>&lt;0.21</td>
<td>0.12 ± 0.07</td>
<td>0.09 ± 0.05</td>
<td>0.08 ± 0.03</td>
<td>0.07 ± 0.03</td>
<td>0.06 ± 0.03</td>
<td>0.05 ± 0.03</td>
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<tr>
<td>J0953 + 2836</td>
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<td>J1031 + 4234</td>
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<tr>
<td>J1038 + 4227</td>
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<tr>
<td>J1047 + 4725</td>
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<td></td>
<td></td>
<td>&lt;0.83</td>
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<tr>
<td>J1102 + 2239</td>
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<td></td>
<td>&lt;0.24</td>
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<tr>
<td>J1238 + 3942</td>
<td></td>
<td></td>
<td>&lt;0.58</td>
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<tr>
<td>J1505 + 0326</td>
<td>1.3 ± 0.5</td>
<td>(6.6)</td>
<td></td>
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<tr>
<td>J1629 + 4007</td>
<td>−0.12 ± 0.02</td>
<td>(3.5)</td>
<td>&lt;0.49</td>
<td></td>
<td>&lt;0.17</td>
<td>&lt;0.23</td>
<td>&lt;0.09</td>
<td></td>
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<tr>
<td>J2007 − 4434</td>
<td>6 ± 2</td>
<td>(12)</td>
<td>&lt;0.19</td>
<td>&lt;0.12</td>
<td>&lt;0.30</td>
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</tbody>
</table>

Notes. For each source, it is indicated the $\tau$ [days] and, in the second row between parentheses, the significance of the flux change [$\sigma$].

References. (a) Paliya et al. (2014); (b) Foschini (2011a).

**J0948+0022:**
~2 min variability with XMM (to be confirmed because SPF)
2-3 min variability optical polarisation (Itoh+ 2013)

1 h = 0.042 d
6 h = 0.25 d
Observational Characteristics: Spectral Variability

J0948+0022

Synchrotron (jet)

High State
(2012 Dec 30)

Low State
(2009 May 15)

Multicolor BB (disk)

IR excess: host galaxy?
Observational Characteristics: Monochromatic Luminosities

- FSRQ
- BL Lac
- RLNLS1 (upper limits)
- γ-NLS1

28th Texas Symposium, Disks & Jets Session, 17 December 2015, Geneva
Calculated Characteristics: Jet Power
Unification of Relativistic Jets (Foschini 2011-2014)

Before Fermi/LAT

Log Jet Luminosity vs. Log Disc Luminosity

- Red dots: FSRQs
- Blue squares: BL Lacs
- Yellow triangles: Black Holes
- Pink stars: Neutron Stars

HLX-1
Unification of Relativistic Jets (Foschini 2011-2014)

After Fermi/LAT

- FSRQs
- BL Lacs
- γ-NLS1s

Log Jet Luminosity vs. Log Disc Luminosity

Black Holes
Neutron Stars

HLX-1

**Radiation Pressure Dominated disk**

\[ \log P_{jet,rad} \propto \frac{17}{12} \log M \]

**Advection Dominated Accretion Flow**

**Gas Pressure Dominated disk**

\[ \log P_{jet,rad} \propto \frac{17}{12} \log M + \frac{1}{2} \log \frac{L_{disk}}{L_{Edd}} \]
Unification of Relativistic Jets (Foschini 2011-2014)

Conclusions

- RLNLS1s seem to be the low mass tail of FSRQs;

- Different observational characteristics (e.g. lines width, variability, jet power) seem to be the effect of a relatively small mass of the central black hole;

- Jet power: once renormalised for the mass, it is comparable with blazars;
  - Normalisation depends mostly on the mass and less on the accretion rate (theory Heinz & Sunyaev 2003; confirmed by observations Foschini 2011-2014);

- The only real difference seems to be about the host galaxy, which shows a strong star formation (see also Caccianiga+ 2015);

- Small number of known RLNLS1s: why?
  - Low observed power? Comparable to BL Lacs, but latter brighter at X-rays (indeed, X-ray selected)
  - Intermittent jet?
    - ⚔️ radiative instability (Czerny+ 2009)
    - ⚔️ aborted jet (Ghisellini+ 2004)
  - Actual small number? Hopes from new facilities (e.g. SKA, Berton+ 2015)