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

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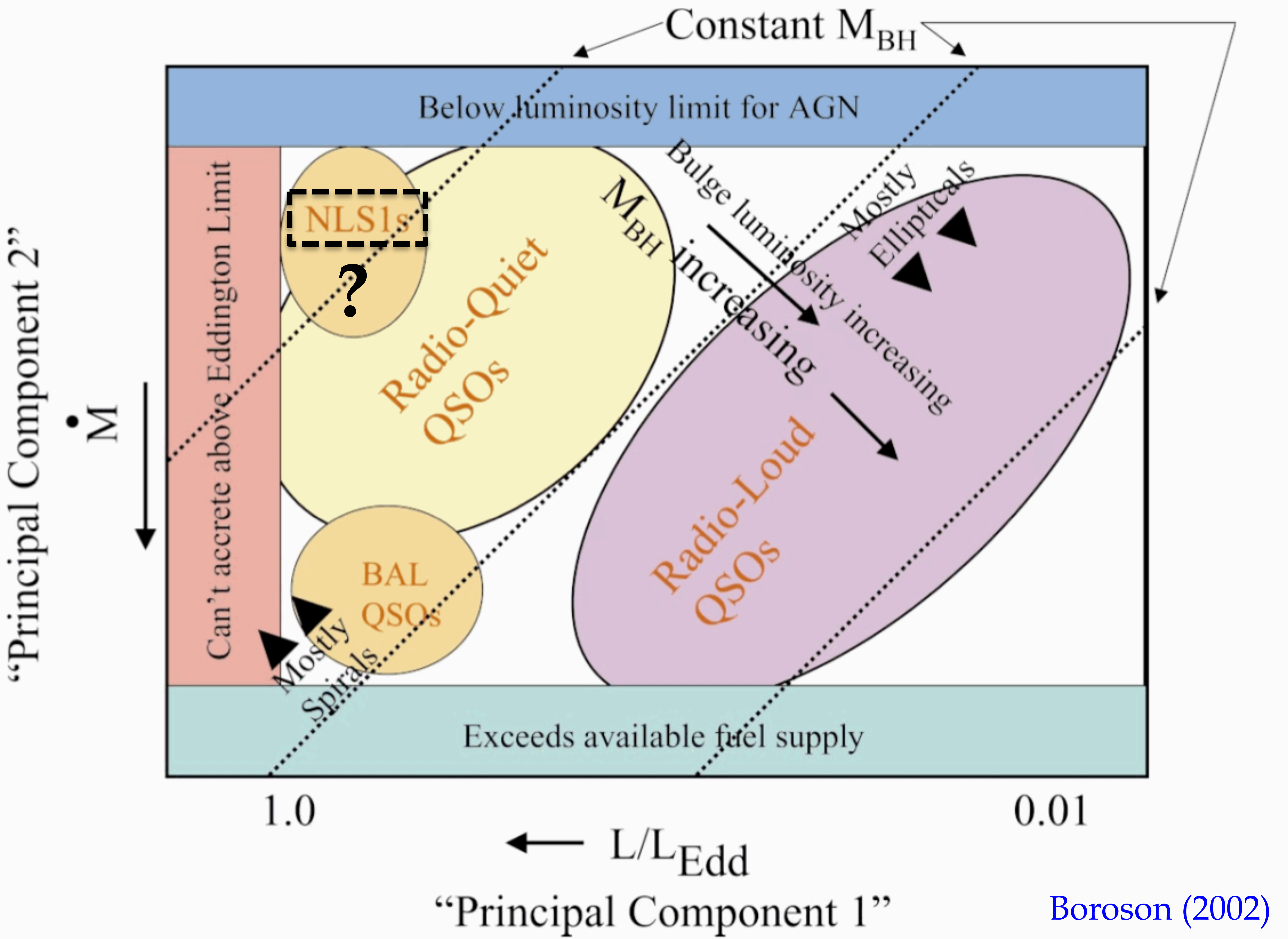
Ref: Foschini et al., 2015, A&A, 575, A13

Narrow-Line Seyfert 1 Galaxies

FWHM Hβ	< 2000 km/s	Goodrich 1989
[OIII]/Hβ	< 3	Osterbrock & Pogge 1985
Bump FeII	Yes ☞ No obscuration	Osterbrock & Pogge 1985
Mass Black Hole	10^6-10^8 $M_\odot$	Peterson, Mathur, Decarli, Marconi, Bentz, Denney, Vestergaard, Woo, Wandel, Calderone…
Accretion rate	0.1-1 Eddington	Boroson & Green 1992; Boller+ 1996
Host galaxy	spiral, mostly barred	Crenshaw+ 2003; Deo+ 2006
Star formation	Yes, high	Sani+ 2010; Caccianiga+ 2015
Age	Young, < Gyr	Grupe 1996, Grupe+ 1999, Mathur 2000, Mathur+ 2011, Orban de Xivry+ 2011
Radio	7% is radio-loud 4% is radio-loud ($z < 0.35$)	Komossa+ 2006; Cracco+ 2015
γ rays (MeV-GeV)	First detections by *Fermi* LAT 11 sources to date, increasing	Abdo+ 2009 (3 articles); Foschini+ 2010; … Earlier attempt (negative) with *Whipple* at E > 400 GeV (Falcone+ 2004).



Boroson (2002)

FIG. 7.—Interpretive diagram showing how PC1-PC2 plane provides basis for classification of AGNs

Sample selection (42 sources)

From literature:

- ☞ Previous surveys: Zhou & Wang (2002), Komossa+ (2006a), Whalen+ (2006), Yuan+ (2008)
- ☞ Studies on individual sources: Grupe+ (2000), Oshlack+ (2001), Zhou+ (2003, 2005, 2007), Gallo+ (2006)

Criteria:

- ☞ FWHM Hβ > 2000 km/s + 10% = 2200 km/s
- ☞ [OIII]/Hβ < 3
- ☞ Bump Fe II
- ☞ Radio loudness = $S_{5GHz}/S_{440nm} > 10$
- ☞ $\alpha < 0.5$, $S_\nu \propto \nu^{-\alpha}$ [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
  Ghisellini+ 2009, 2010; Tavecchio+ 2010.

Related and Ongoing Works

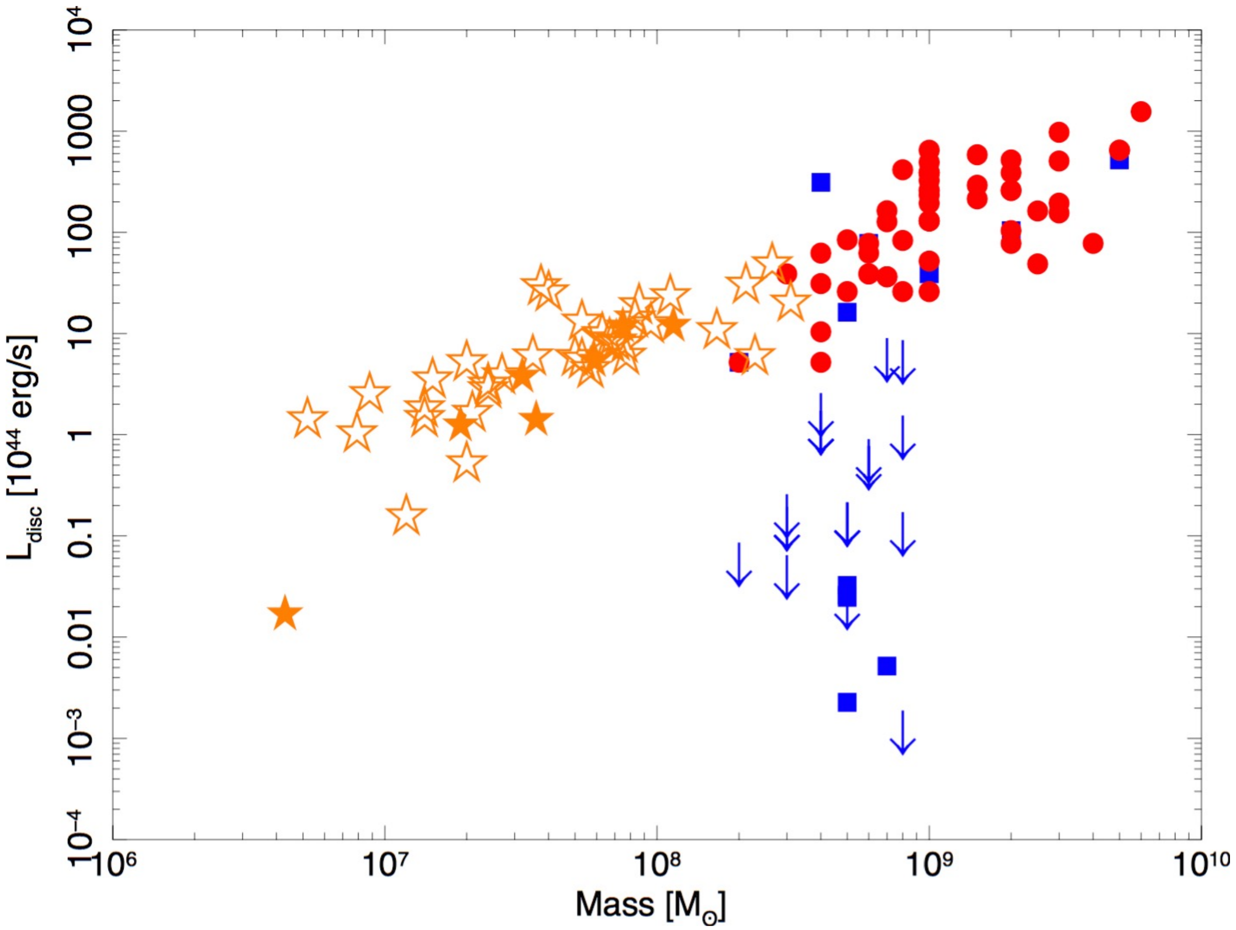
Related works:

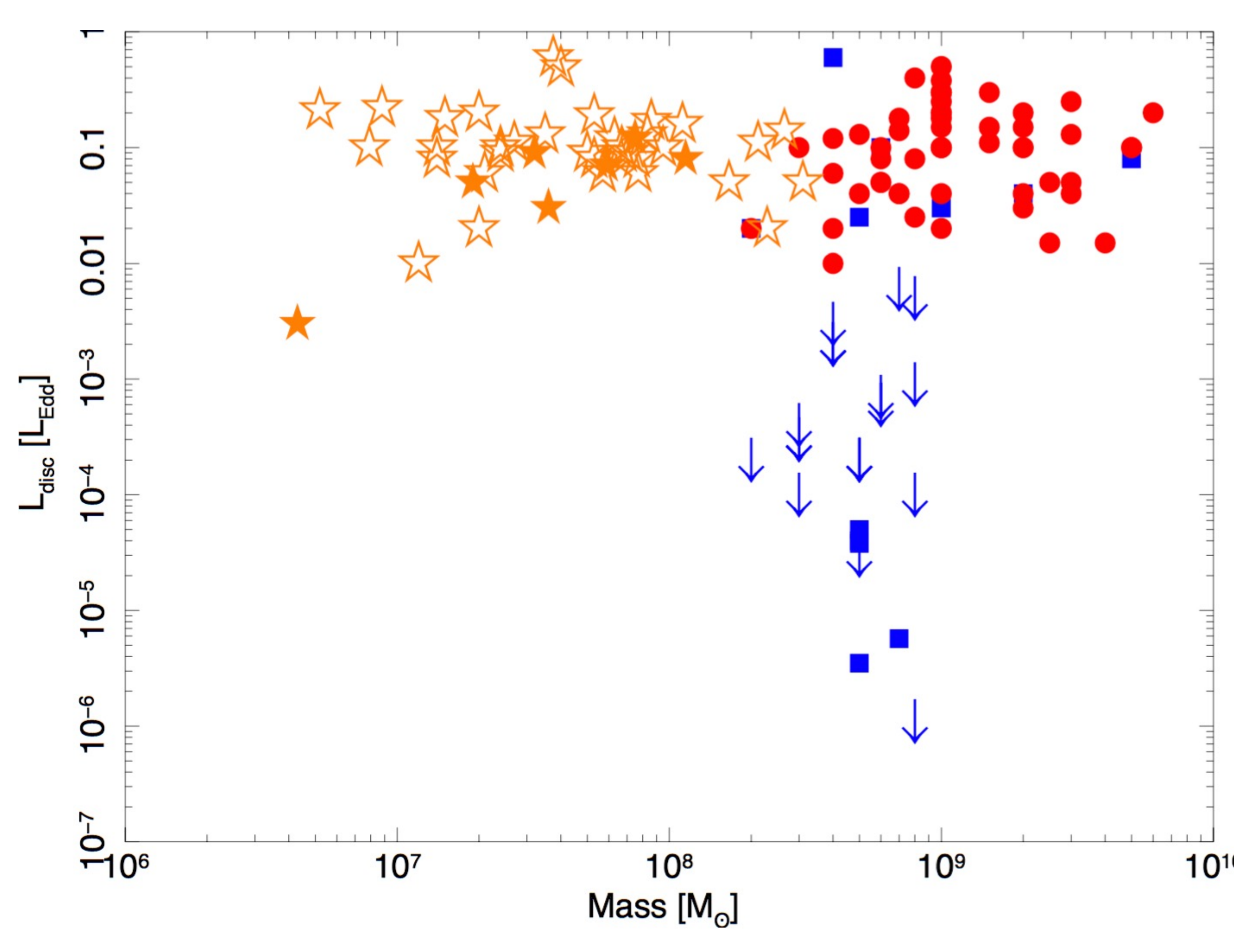
- ☞ Angelakis+ (2015): intensive radio monitoring of 4 γ-NLS1s
- ☞ Berton+ (2015): search for the parent population - **See previous talk**
- ☞ Caccianiga+ (2014): study on individual source
- ☞ Caccianiga+ (2015): infrared properties of the present sample
- ☞ Gu, Chen, Komossa,… (2015): parsec scale 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 σ less affected by:

- inclination,
- Eddington ratio,
- line profile.

(Peterson+ 2004, Collin+ 2006)

● FSRQ

■ BL Lac (↓ upper limits)

☆ RLNLS1

★ γ-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

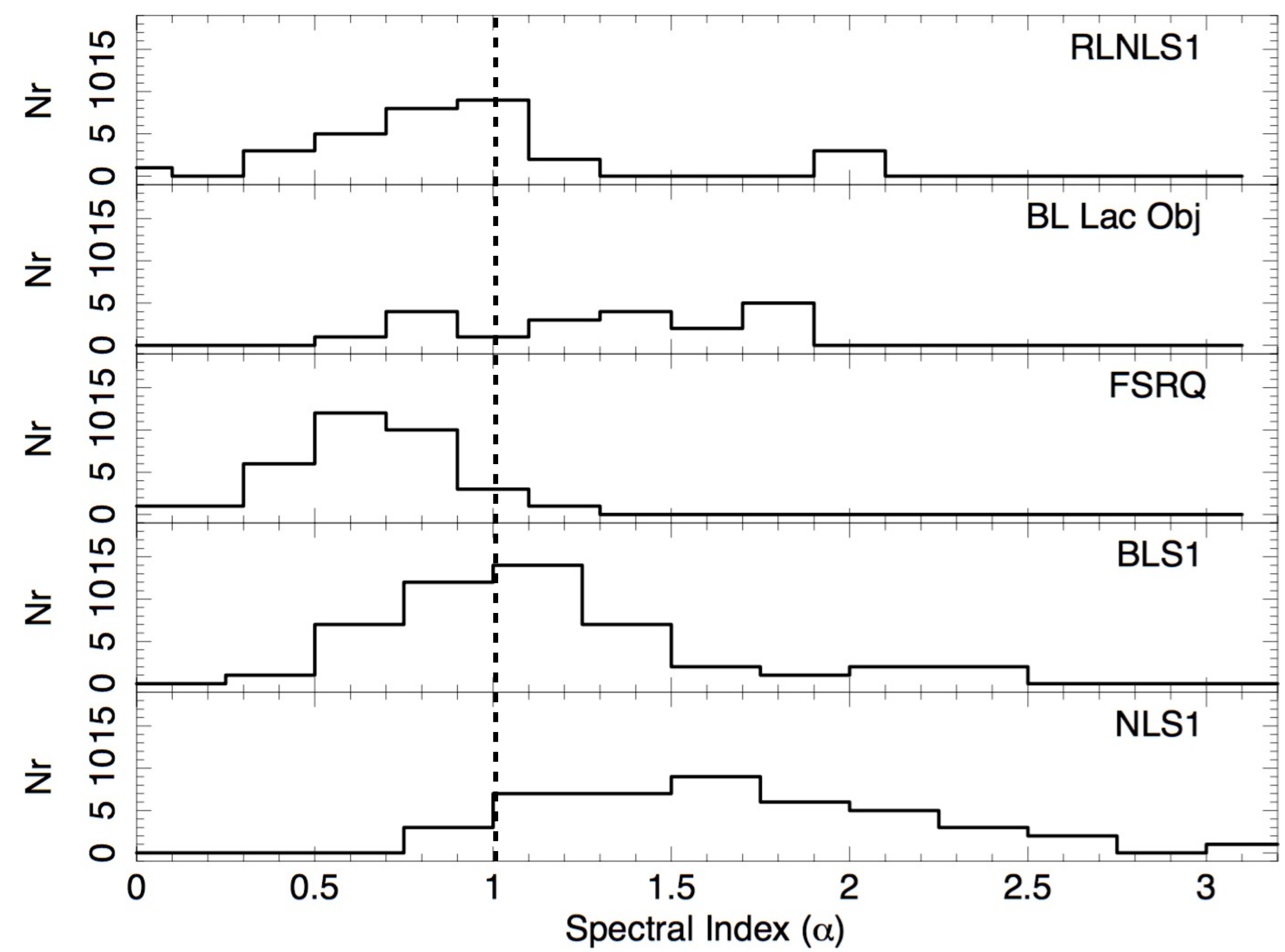
Observational Characteristics: X rays

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

Average spectral index 1.0 ± 0.5 (median 0.8)

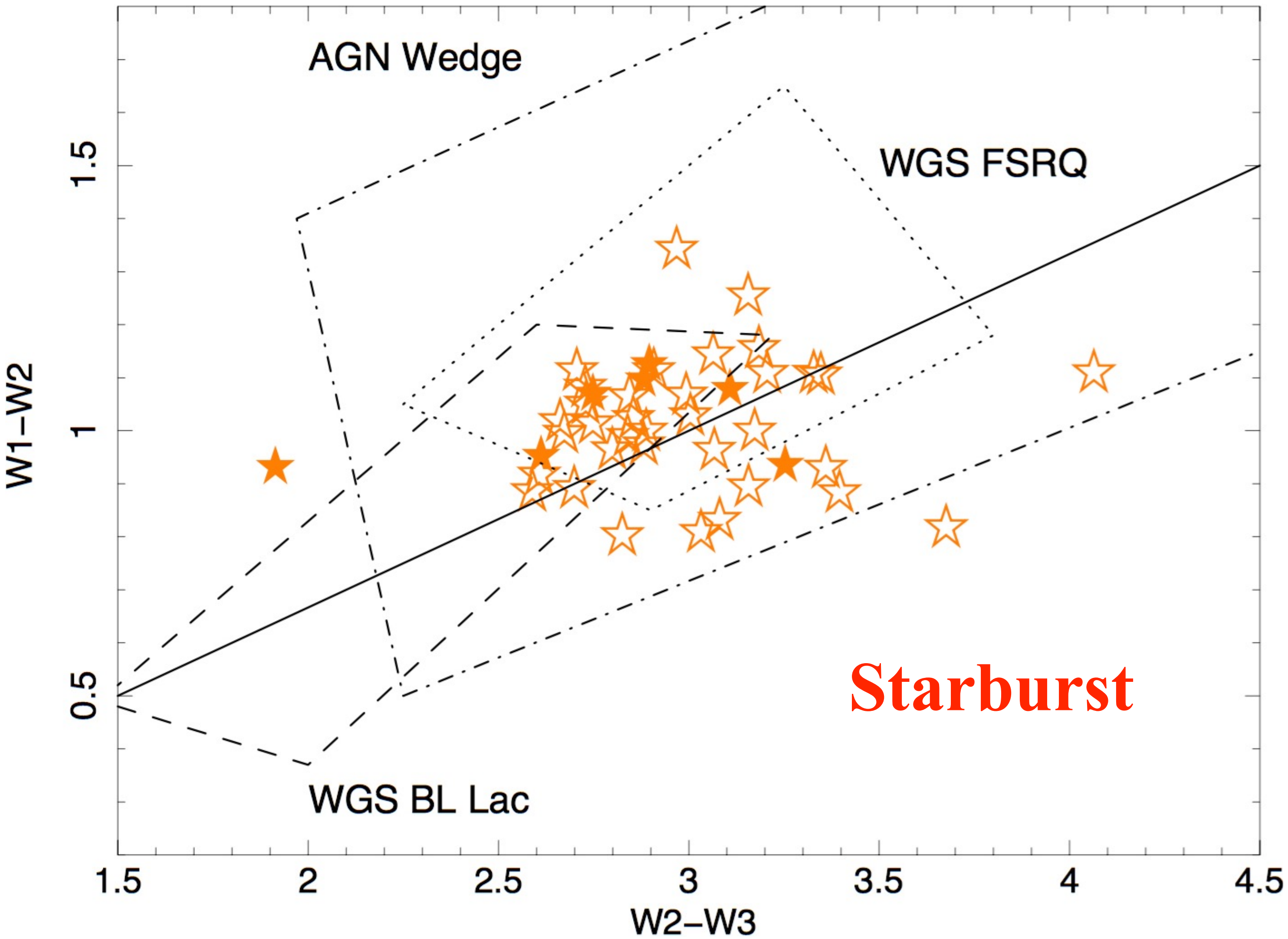
Comparison samples:
FSRQs: 0.58
BL Lac Objects: 1.2
Broad-Line Seyfert 1 (BLS1): 1.1
Narrow-Line Seyfert 1 (NLS1): 1.7

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



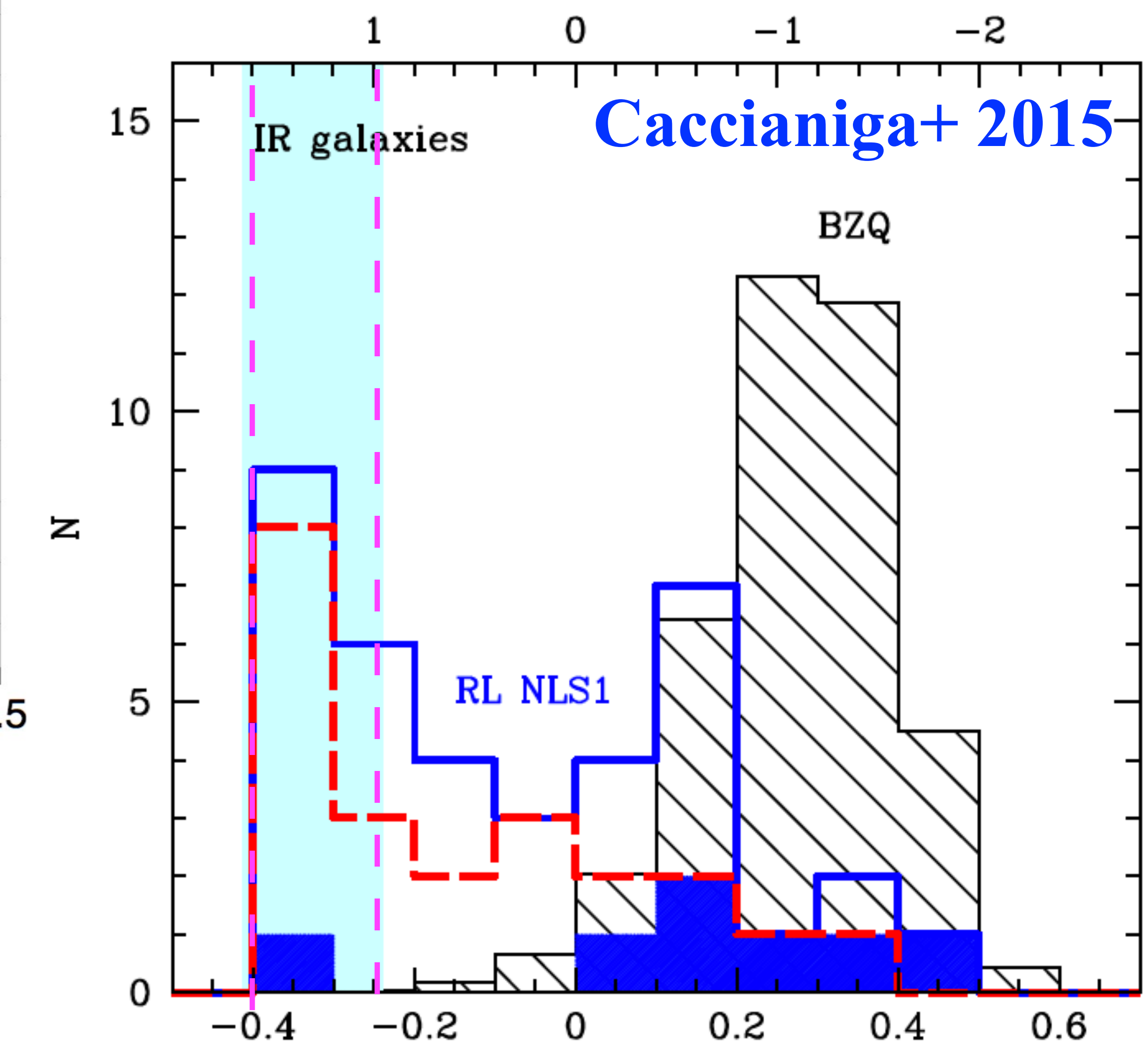
43 radio-quiet NLS1s
50 Broad-Line Seyfert 1 (BLS1)
from Grupe+ (2010).

Observational Characteristics: Infrared (*WISE*)



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

$$q22 = \log\,(S_{22\,\mu\mathrm{m}}/S_{1.4\ \mathrm{GHz}}).$$



$$\alpha_{1.4}^{22} = -\frac{\log\,(S_{1.4\ \mathrm{GHz}}/S_{22\,\mu\mathrm{m}})}{\log\,(\nu_{1.4\ \mathrm{GHz}}/\nu_{22\,\mu\mathrm{m}})}$$

W1 = 3.4 μm
W2 = 4.6 μm
W3 = 12 μm
W4 = 22 μm

BZCat (Massaro+ 2009)
IR Galaxies (Rieke+ 2009)

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)

J2007-4434 ☞ Schulz+ (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

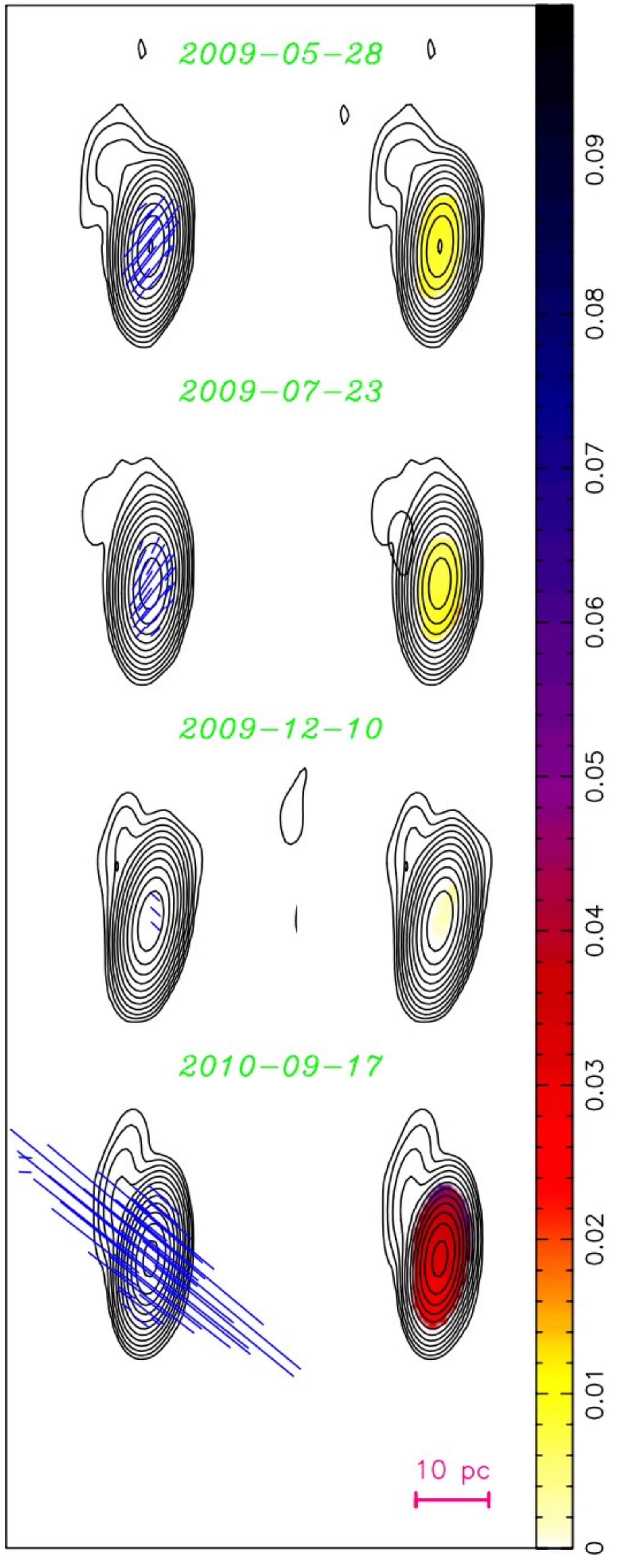
VLBA 2cm, MOJAVE,

analysis by Y. Y. Kovalev in Foschini+ (2011)

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

EVPA swing ~ 90°

Polarisation intensity drop



Observational Characteristics: Short Timescale Variability

Name	γ rays	X-rays	*uvw2*	*uvm2*	*uvw1*	*u*	*b*	*v*
J0134 − 4258		−0.071 ± 0.025 (3.8)						
J0324 + 3410	0.10 ± 0.03[a] (3.8)	−0.079 ± 0.012 (4.4)	0.09 ± 0.03 (10.7)	0.10 ± 0.04 (7.6)	<0.43 (4.1)	7 ± 3 (6.1)	<0.7 (4.0)	<0.28 (3.6)
J0849 + 5108	12 ± 8[b] (4.7)	<18 (3.5)			<0.27 (3.6)			
J0948 + 0022	<0.8[b] (5.4)	<0.21 (5.2)	0.12 ± 0.07 (6.3)	0.09 ± 0.05 (6.1)	0.08 ± 0.03 (7.3)	0.07 ± 0.03 (7.9)	0.06 ± 0.03 (7.8)	0.05 ± 0.03 (5.7)
J0953 + 2836					<18 (3.1)			
J1031 + 4234						<0.15 (3.0)		
J1038 + 4227							<12 (3.4)	
J1047 + 4725			<0.83 (3.4)					
J1102 + 2239						<0.24 (3.1)		
J1238 + 3942			<0.58 (3.4)					
J1505 + 0326	1.3 ± 0.5[b] (6.6)							<0.04 (3.8)
J1629 + 4007		−0.12 ± 0.02 (3.5)	<0.49 (3.7)			<0.17 (4.1)	<0.23 (3.2)	<0.09 (3.6)
J2007 − 4434	6 ± 2[b] (12)	<0.19 (3.3)	<0.12 (3.0)			<0.30 (3.1)		<0.14 (3.1)

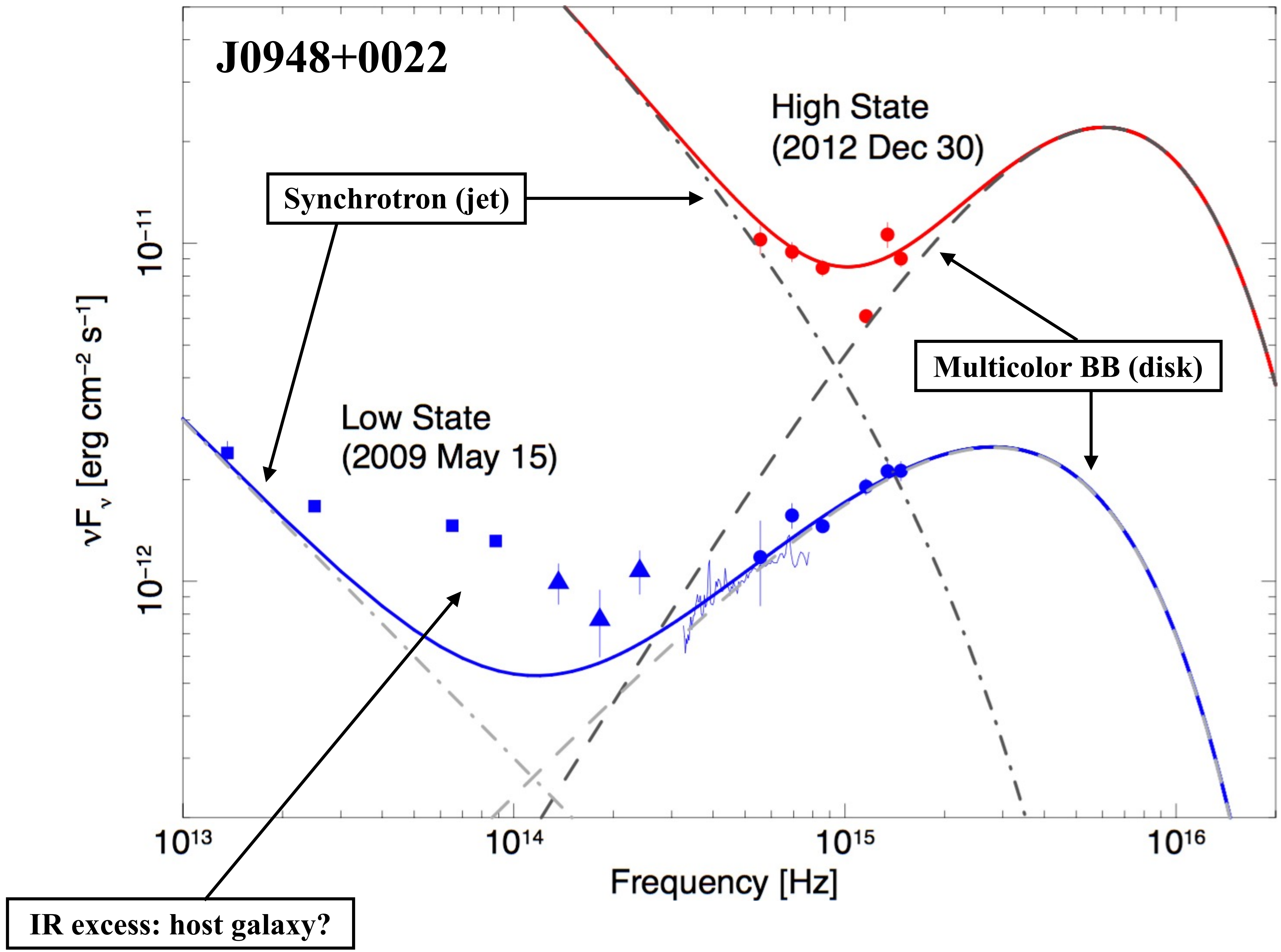
Notes. For each source, it is indicated the τ [days] and, in the second row between parentheses, the significance of the flux change [σ].

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

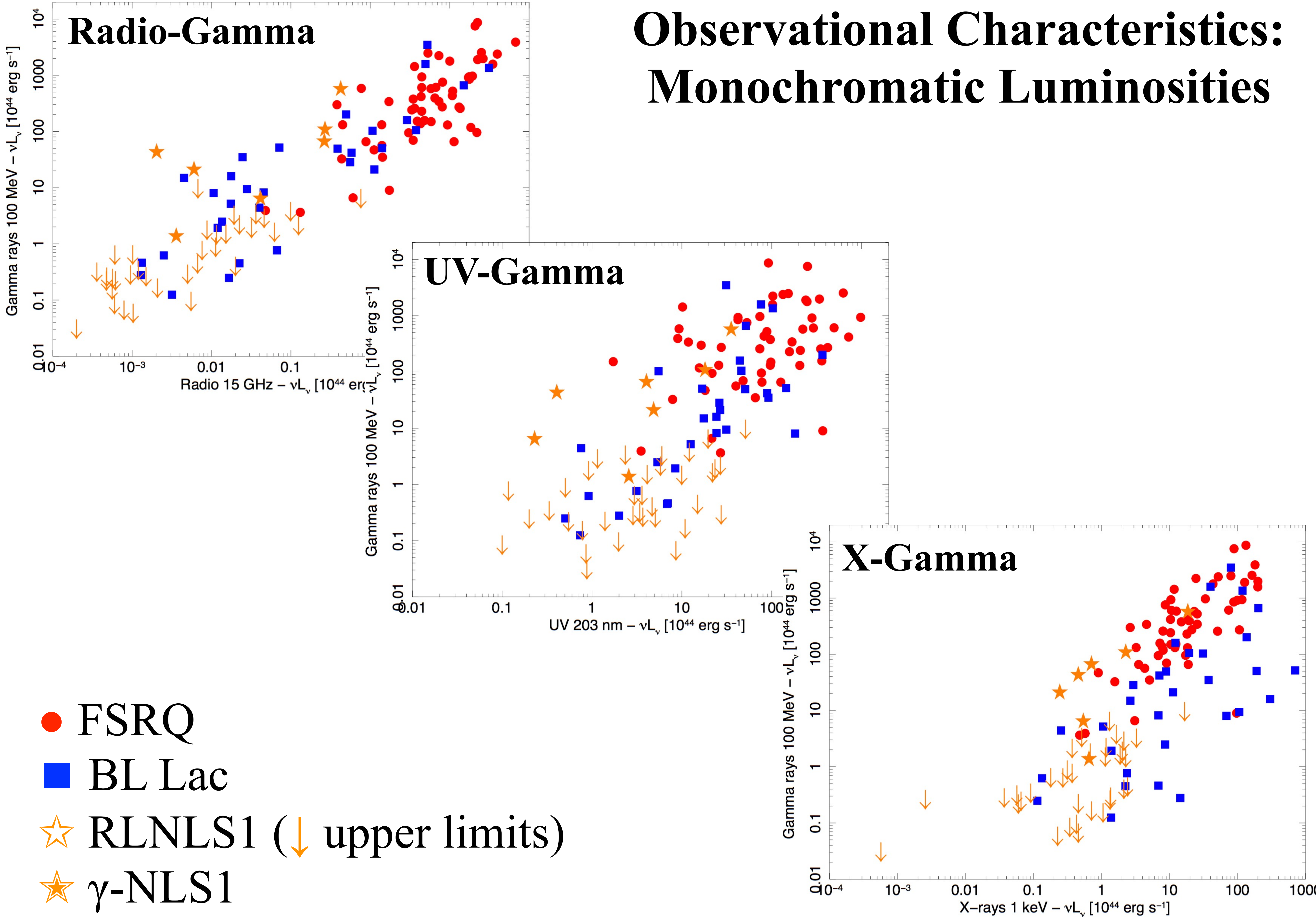
1 h = 0.042 d
6 h = 0.25 d

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

Observational Characteristics: Spectral Variability

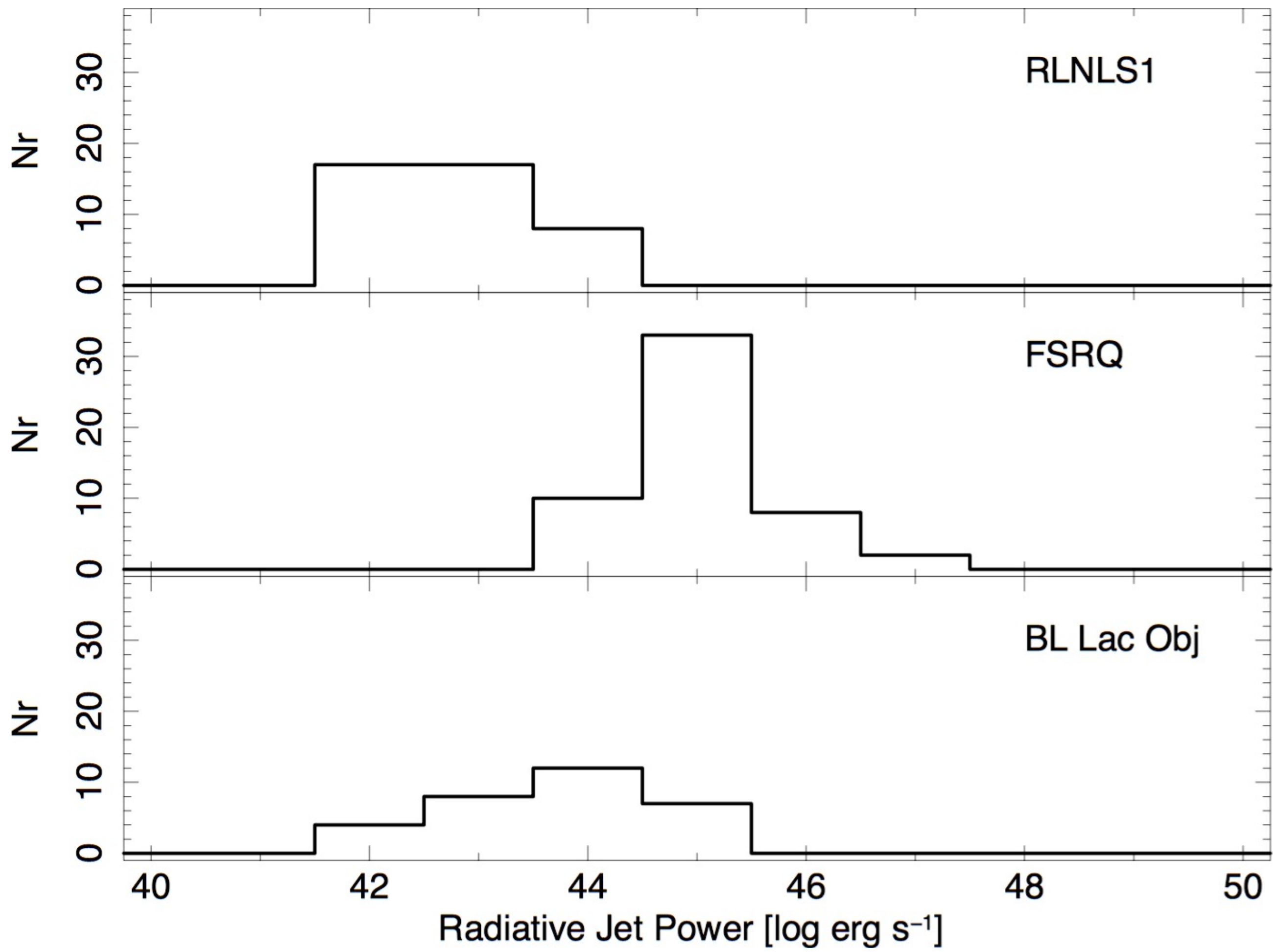


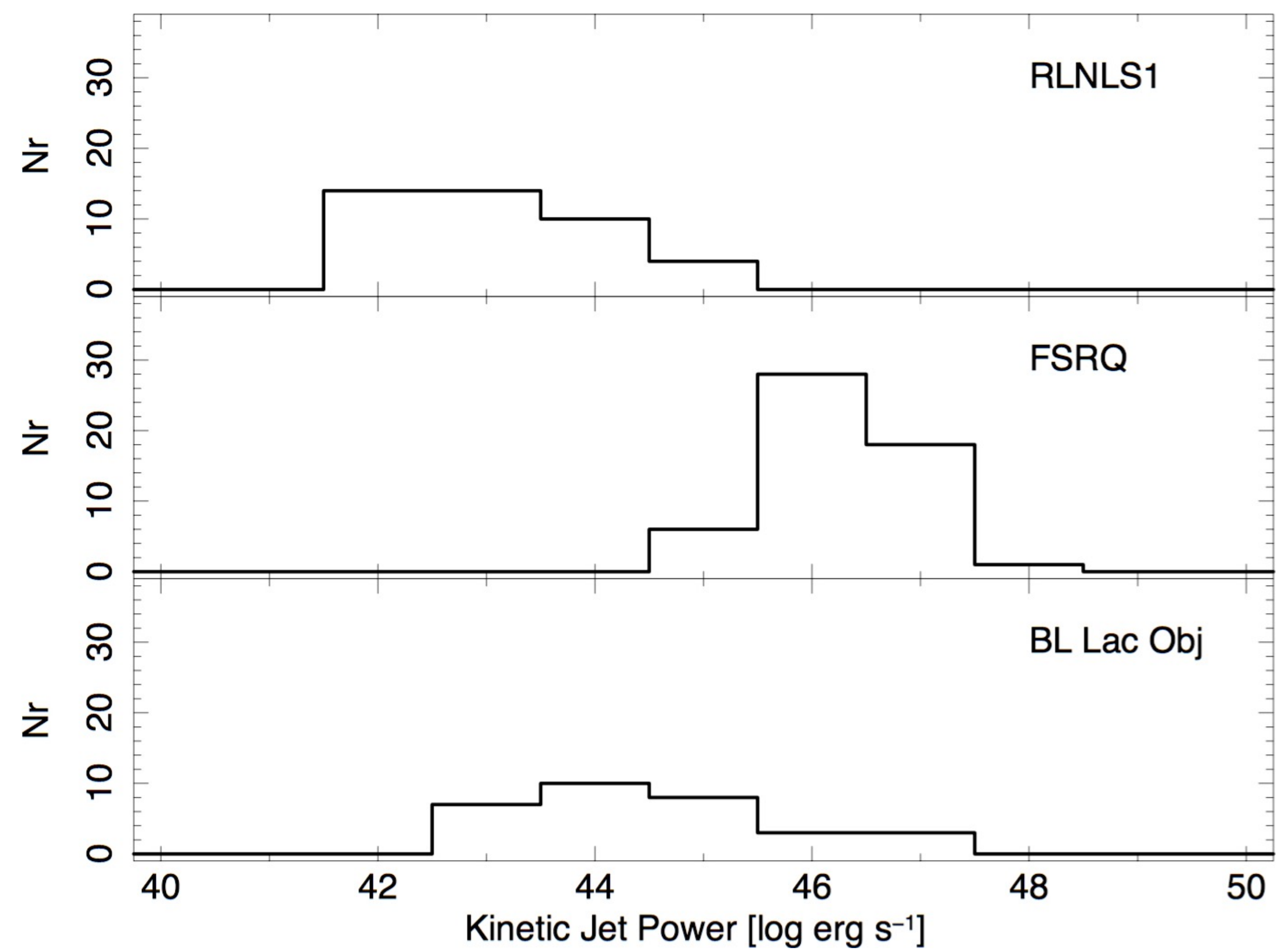
Observational Characteristics: Monochromatic Luminosities



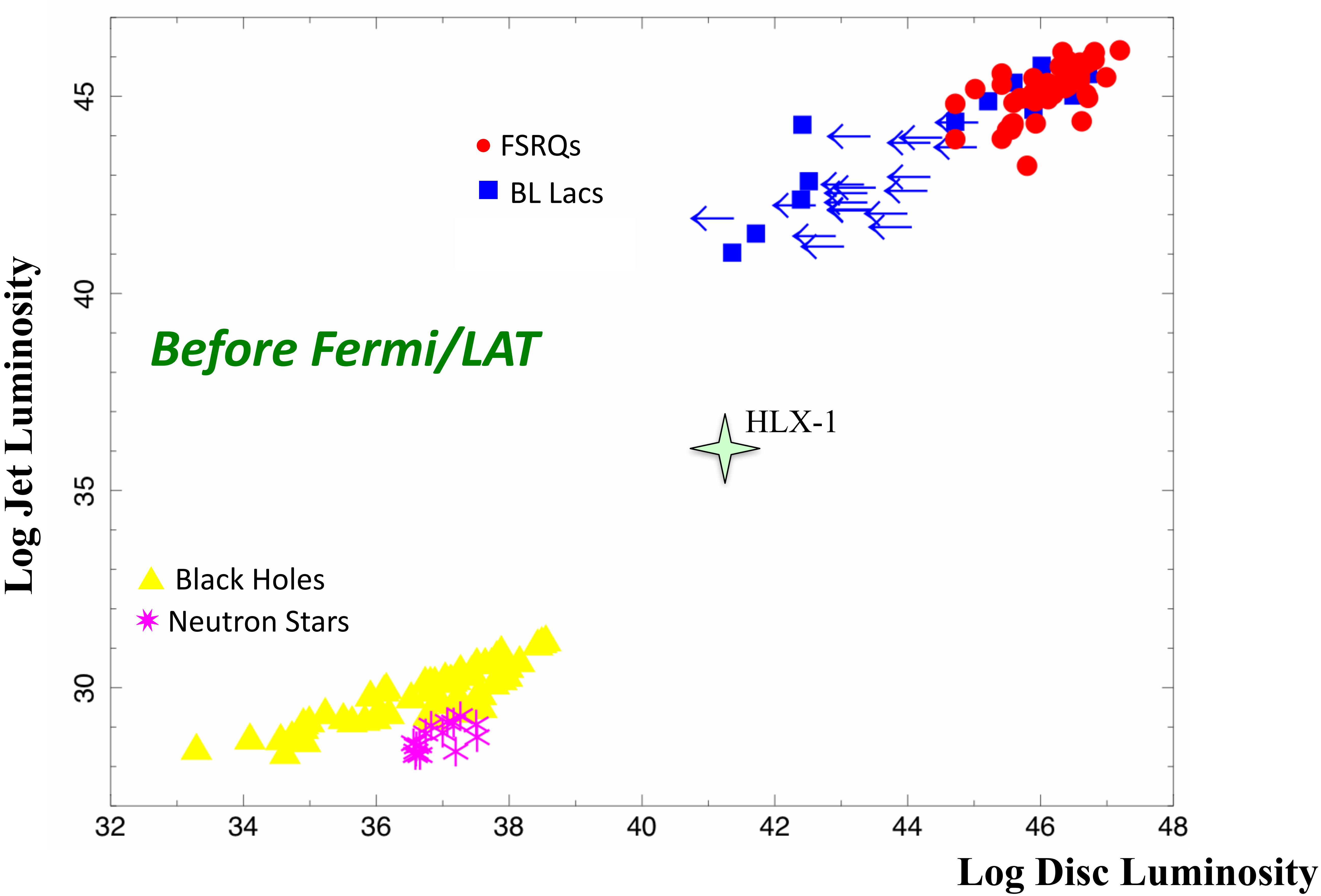
- ● FSRQ
- ■ BL Lac
- ☆ RLNLS1 (↓ upper limits)
- ★ γ-NLS1

Calculated Characteristics: Jet Power





Unification of Relativistic Jets (Foschini 2011-2014)



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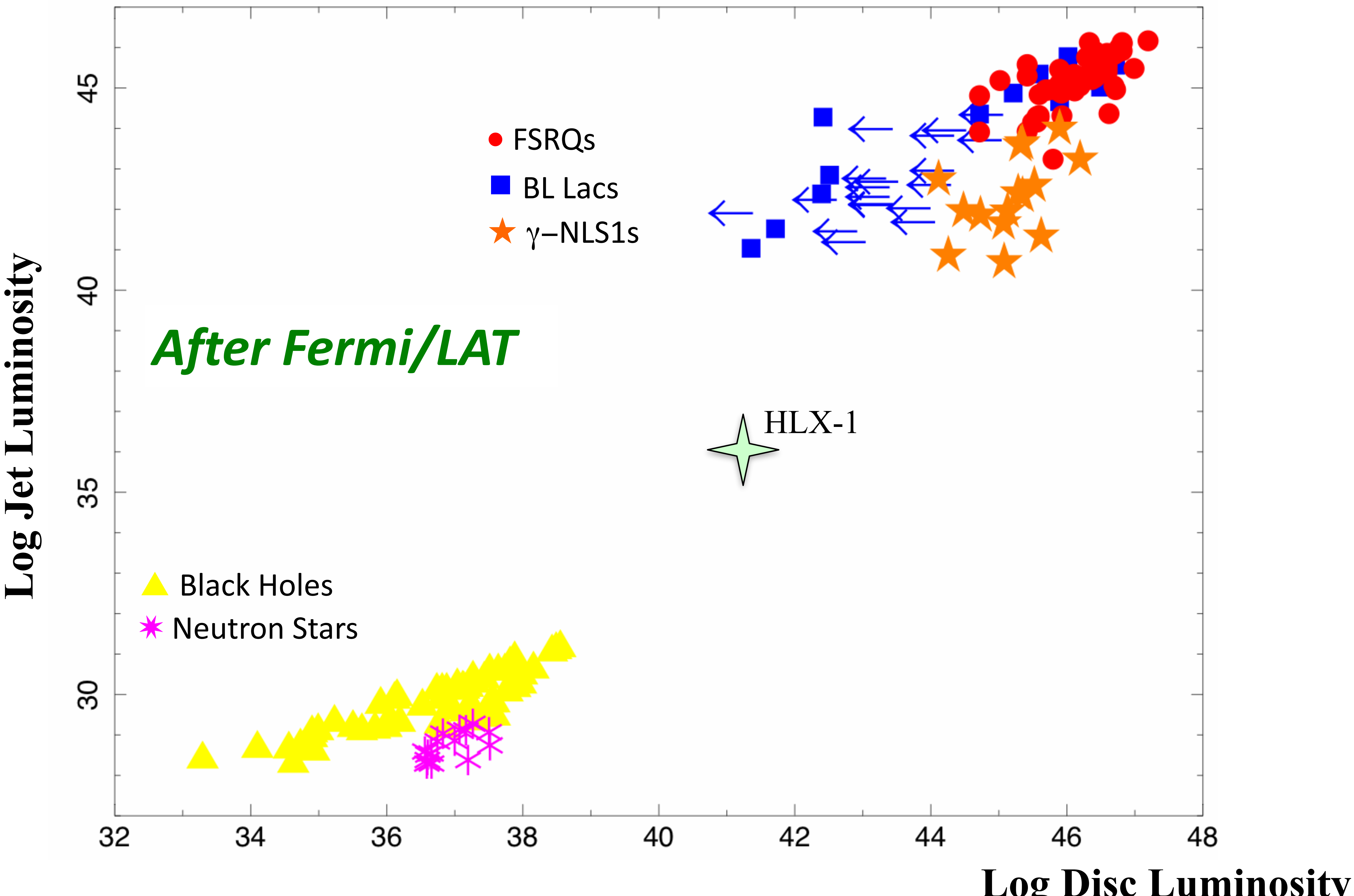


Scaling Theory: Heinz & Sunyaev (2003)

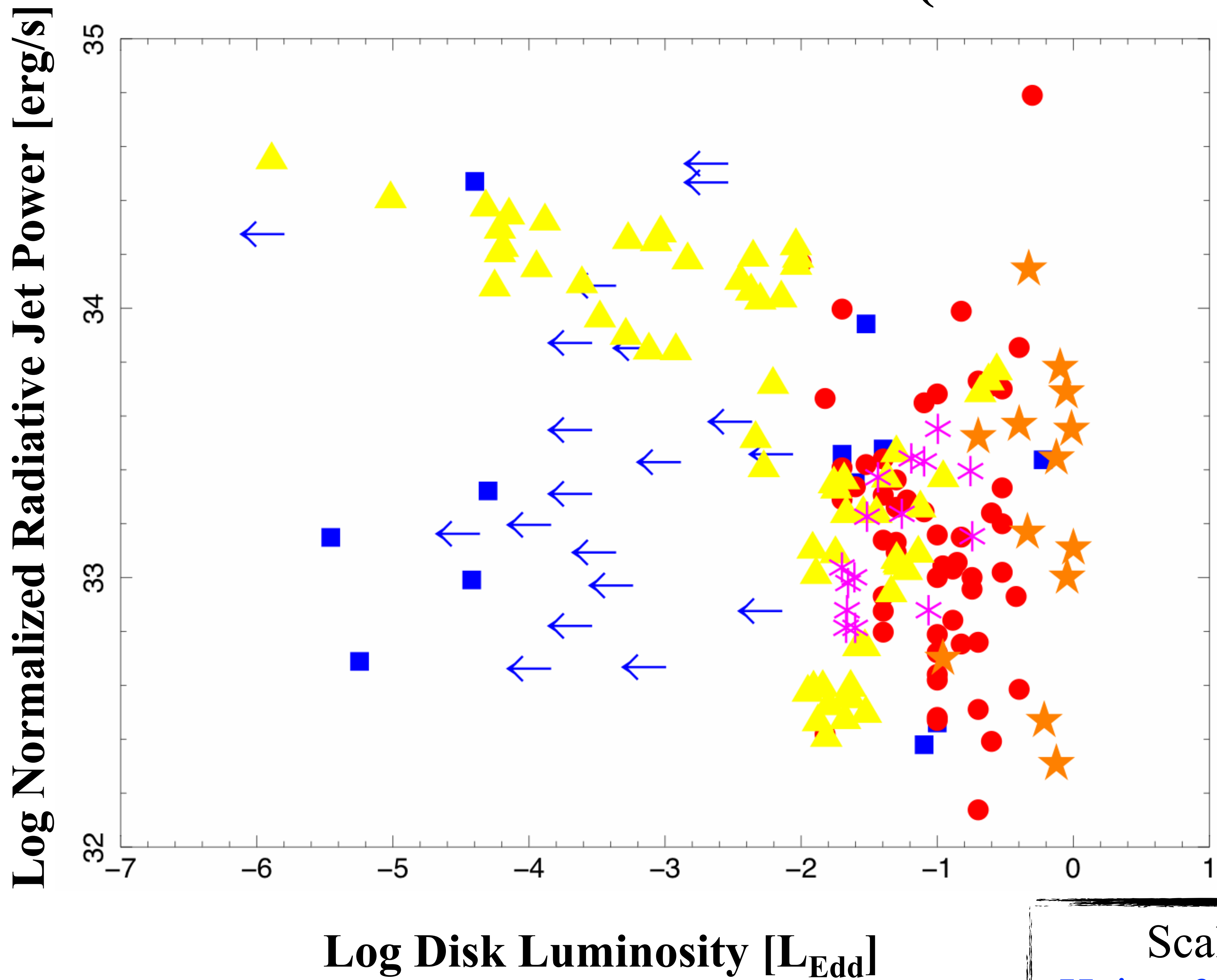
Radiation Pressure Dominated disk

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

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)



Scaling Theory:
Heinz & Sunyaev (2003)

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)