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Jetted Active Galactic Nuclei

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Milano, Merate (LC)

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Foreword

- The **aim of this talk** is to draw your attention on some old and new discoveries on relativistic jets, and how to include them into a unified physical model for jetted AGN;

- This is **not** a challenge to the current unified model, but rather the request for an update and an improvement;

- **Martin Gaskell** in *Fifty years of quasars* (2012):

  "[…] I tell students that classification is one of the first step in science. As science progresses, however, I believe that we need to move toward physically meaningful classification schemes as soon as possible. To achieve this, we need to be willing to modify our definitions, or else we can impede progress."

Evolution of terminology and classification:

- **1978, Ed Spiegel, Pittsburgh conference social dinner:**
  - **B**L **La**c Objects + Optically Violently Variable Qua**sars** (OVV) → **Blazars**

- **1994-1995 Giommi & Padovani:**
  - Radio selected BL Lac (RBL) → Low-energy cutoff BL Lacs (**LBL**)
  - X-ray selected BL Lac (XBL) → High-energy cutoff BL Lacs (**HBL**)

- **1994, Laing:**
  - FRI, FRII → Low-Excitation Radio Galaxies (**LERG**), High-Excitation Radio Galaxies (**HERG**)

- **2017, Padovani:**
  - Radio-Loud AGN → Jetted AGN
  - Radio-Quiet AGN → Non-jetted AGN

The Unified Scheme by Urry & Padovani (1995)

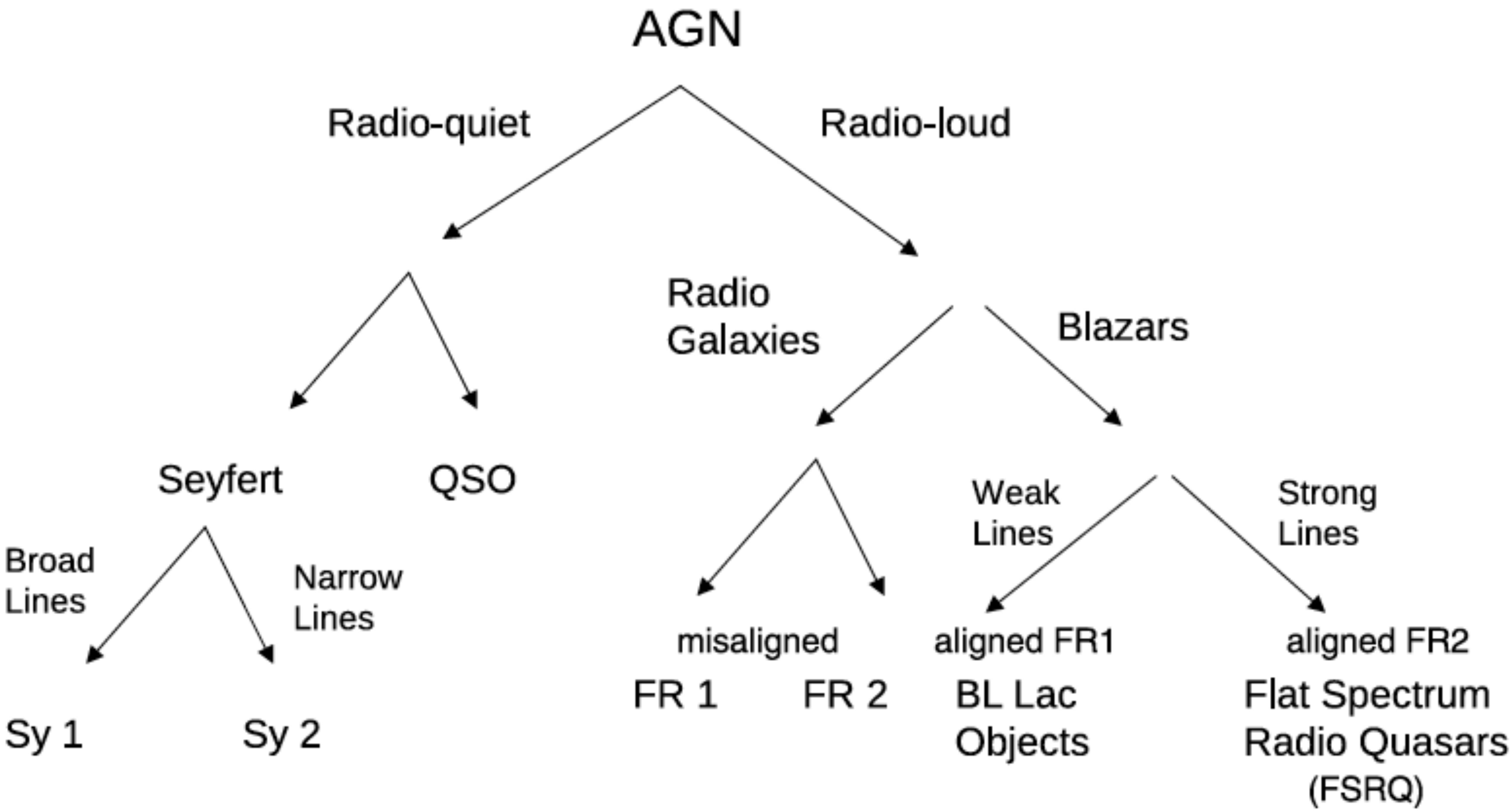
TABLE 1
AGN Taxonomy

Radio Loudness	Optical Emission Line Properties: Type 2 (Narrow Line)	Type 1 (Broad Line)	Type 0 (Unusual)
Radio-quiet:	Sy 2 NELG IR Quasar?	Sy 1 QSO	 BAL QSO?
Radio-loud:	NLRG { FR I, FR II }	BLRG SSRQ FSRQ	Blazars { BL Lac Objects, (FSRQ) }

Black Hole Spin?

Decreasing angle to line of sight

The Unified Scheme by Urry & Padovani (1995)



Today, still more or less unchanged… (Dermer & Giebels 2016)

Radio-Loud AGN (Urry & Padovani 1995)

Radio-Loud AGN	Strong Emission Lines (Photon-rich environment)	Weak/No Emission Lines (Photon-starving environment)
Beamed (blazar)	FSRQ	BL Lac Obj
Unbeamed (radio galaxy)	HERG (FRII)	LERG (FRI+FRII)

- High mass central black hole ($\gtrsim 10^8 M_\odot$, e.g. Ghisellini et al. 2010, Buttiglione et al. 2010, Tadhunter 2016);
  - Mass threshold for jet generation? (e.g. Laor 2000, Chiaberge & Marconi 2011)
- Giant Elliptical host galaxy (e.g. McLure et al. 1999, Urry et al. 2000, Dunlop et al. 2003);
- Jet power scaled by electron cooling (***blazar sequence***, Fossati et al. 1998, Ghisellini et al. 1998).

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That's all well and good, but…

Radio Loud/Quiet: Not a bimodal distribution!

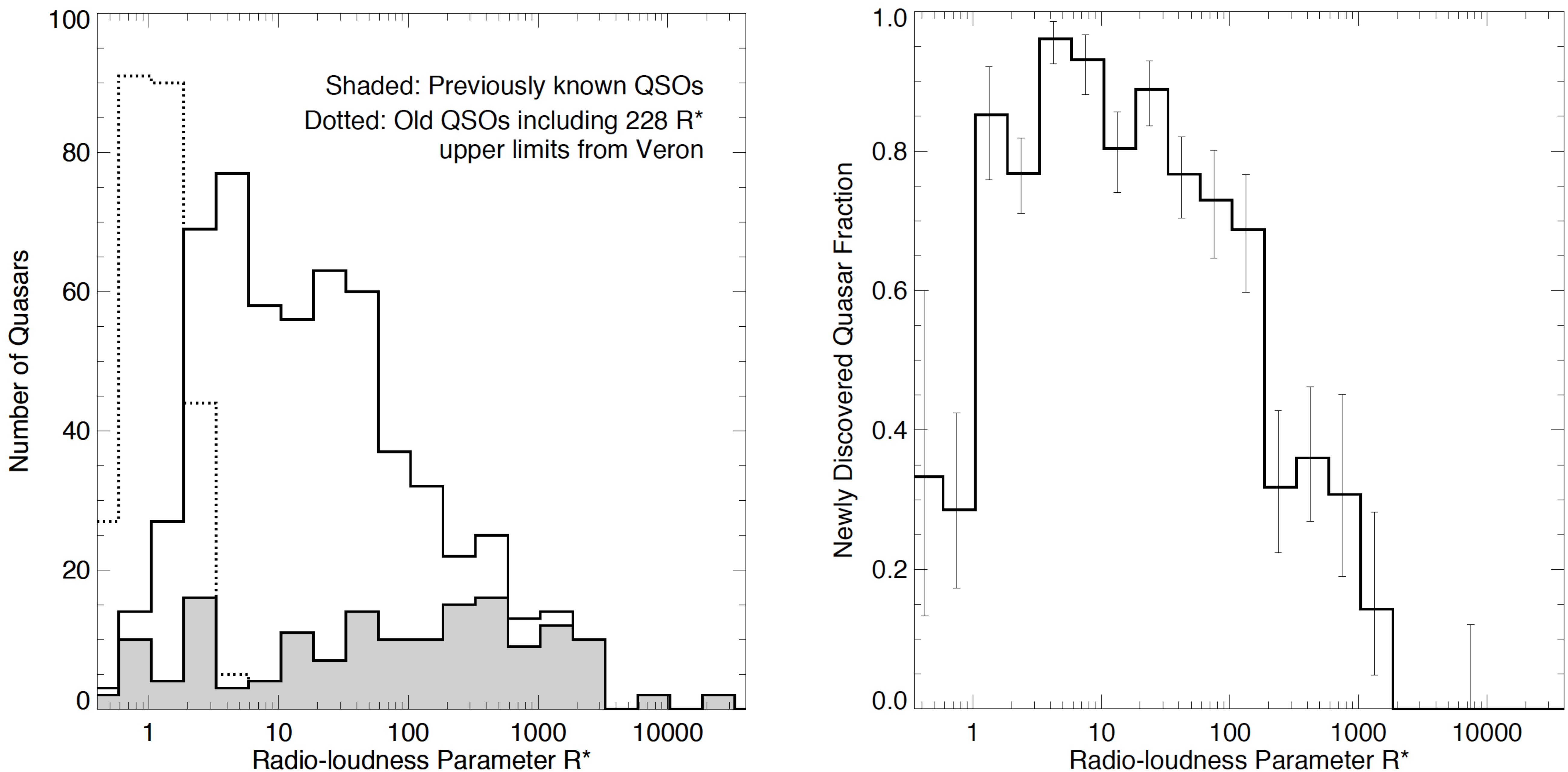
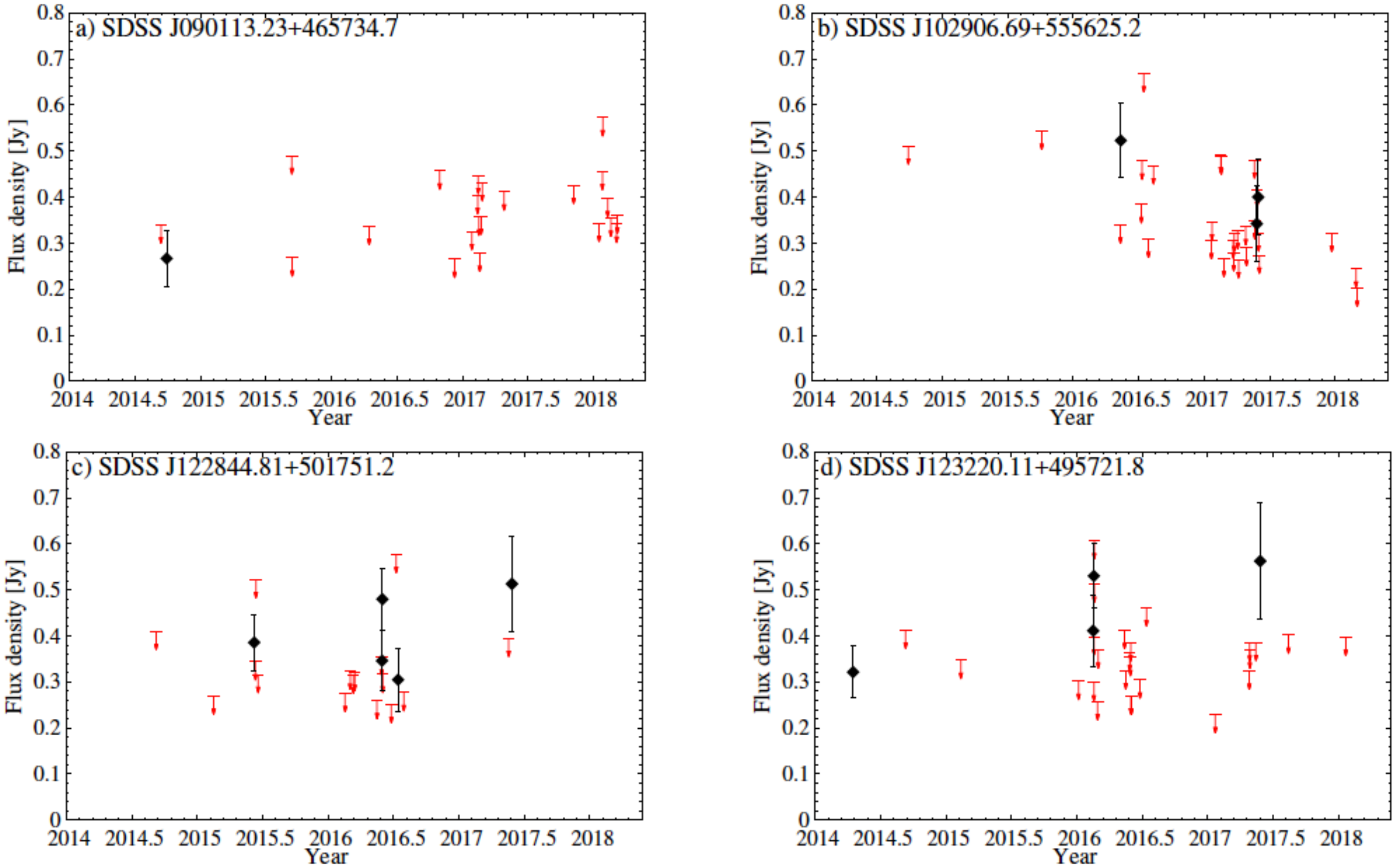


FIG. 15.—*Left*: Histogram of radio-optical ratio R^* (Stocke et al. 1992) for FBQS quasars. Shaded area represents previously known quasars. The dotted histogram includes R^* upper limits for Véron catalog objects in the FBQS area but not detected by FIRST. The Véron quasars (*shaded plus dotted histograms*) show a bimodal distribution of R^*, with a dip around $R^* = 3$–30, but the FBQS quasar counts rise continuously through that region and show no obviously evidence for bimodality. *Right*: Fraction of newly discovered quasars vs. R^*. The FBQS is increasing the number of known objects in the radio-quiet/radio-loud transition region ($R^* = 1$–100) by a large factor.

White et al. (2000)



Radio detection at 37 GHz of <u>radio-silent</u> NLS1s

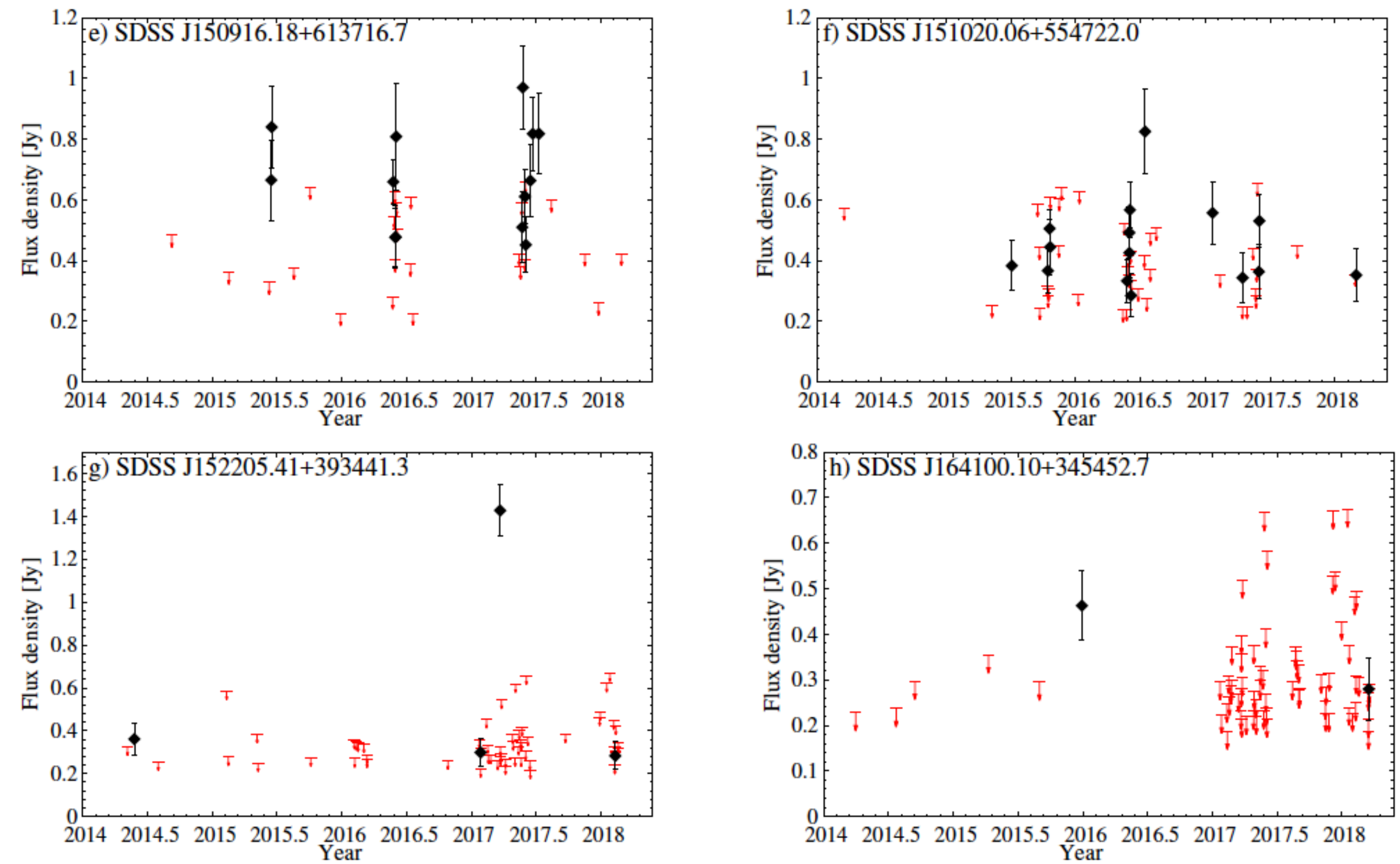
⬇

Radio-Loud/-Quiet: Meaningless!

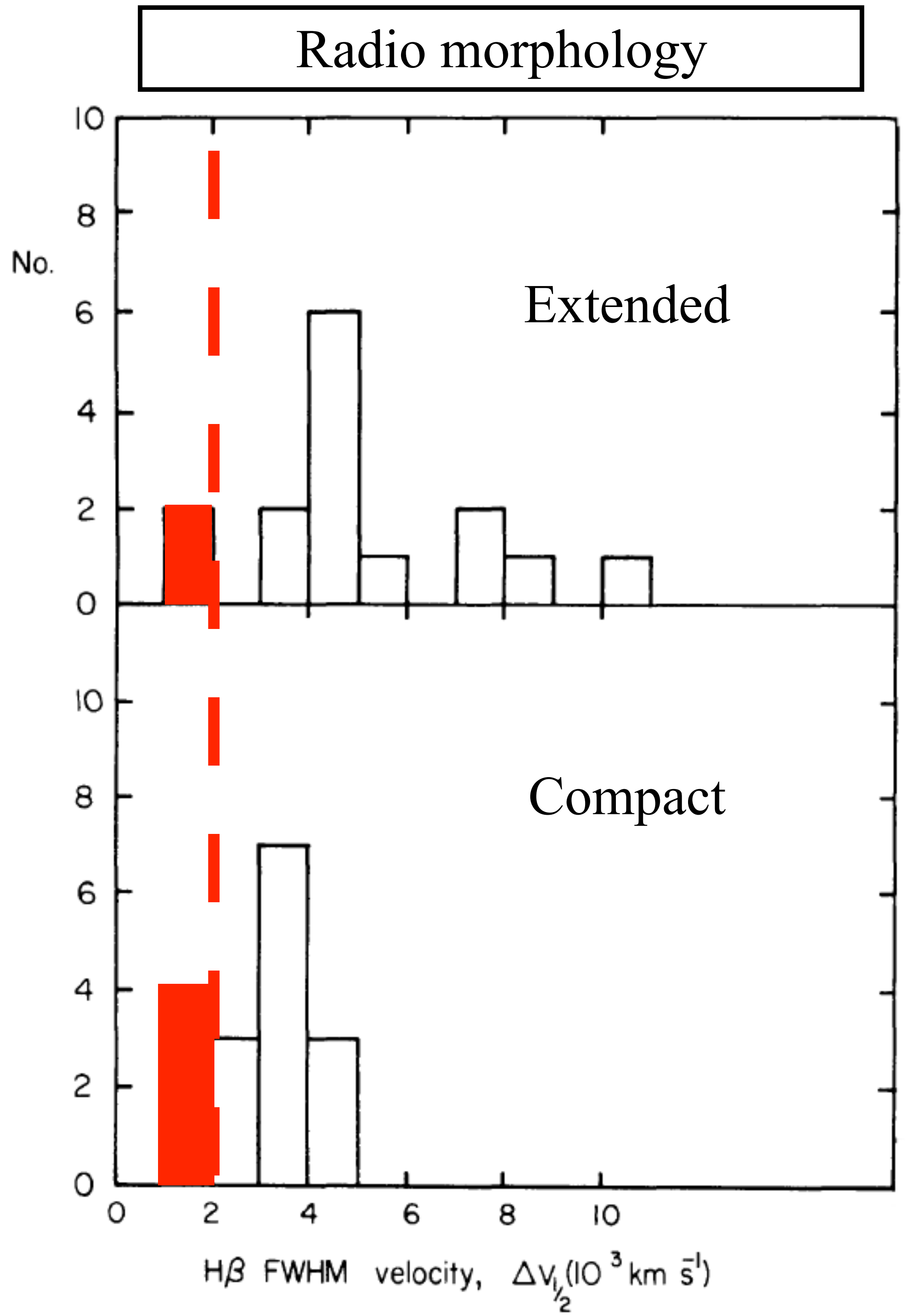
Lähteenmäki et al. (2018)

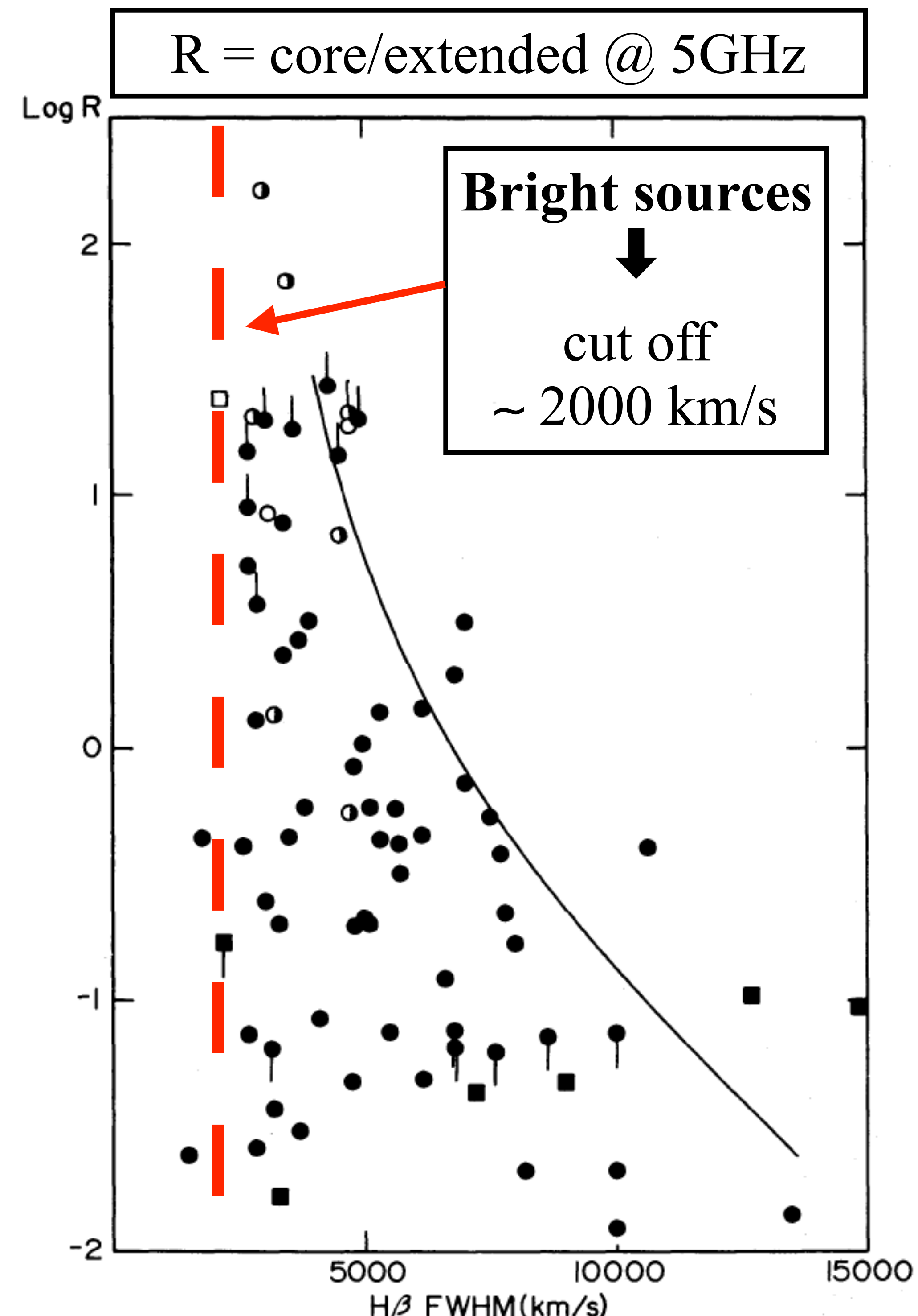
Metsähovi Radio Telescope (Finland)

These NLS1s were **never** detected in any previous survey at any radio frequency!



Small-mass/compact radio sources were present in early surveys (1979), but were lost when focusing on bright sources (1986)





Miley & Miller (1979)

Wills & Browne (1986)

Host Galaxy

- **Urry et al. (2000):**
  - 110 BL Lac Objects, $z < 1.3$
  - Most host galaxies are ellipticals, 1 disk galaxy, many unresolved or doubtful (➽ **disk < 8%**)

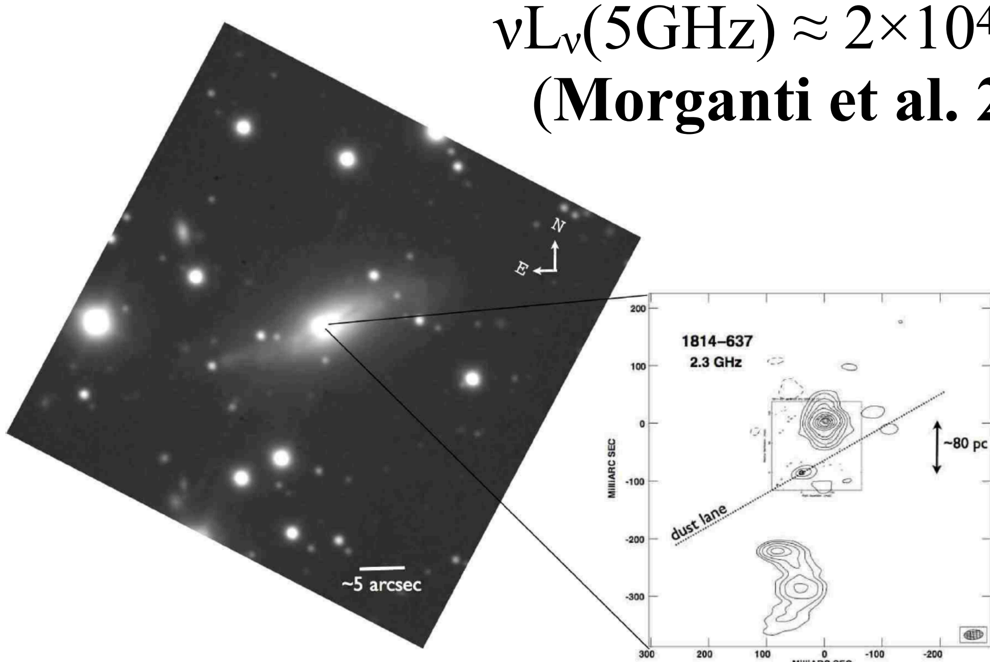
- **McLure et al. (1999), Dunlop et al. (2003):**
  - 13 radio-quiet quasars; 10 radio-loud quasars; 10 radio galaxies ($0.1 < z < 0.25$)
  - $M_V < -23.5$ ➽ **<u>all</u> the hosts are giant elliptical galaxies!**
  - **Both radio-loud and radio-quiet quasars: jet does not matter**
  - $M_{BH} \gtrsim 5\times10^8\ M_\odot$; $M_{BH,jet} \gtrsim 10^9 M_\odot$;

- **Hamilton et al. (2002, 2008):**
  - 70 quasars, $M_V < -23$, $0.06 < z < 0.46$
  - 43 radio-quiet, 26 radio-loud, 1 unknown
  - 24 spirals (4 radio-loud), 46 ellipticals (22 radio-quiet)

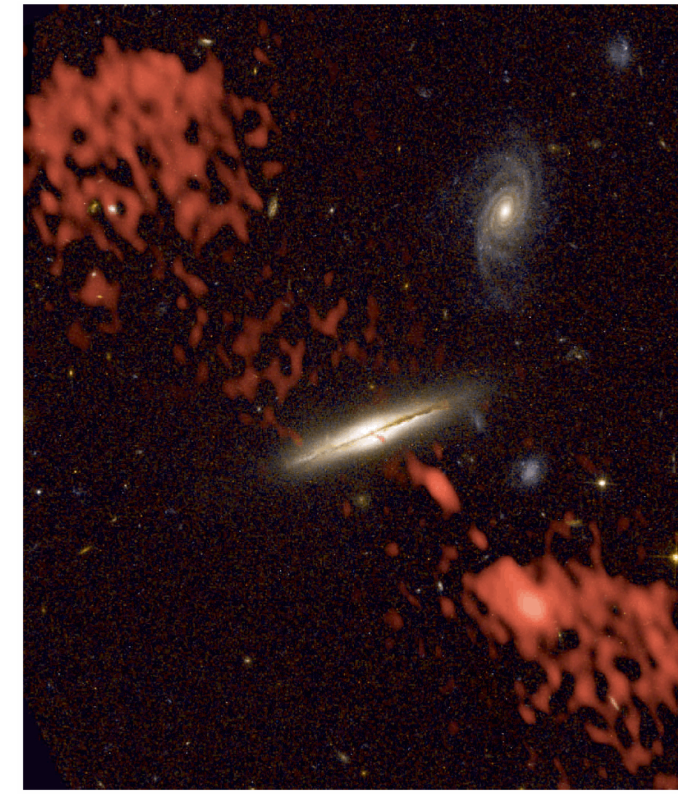
- **Inskip et al. (2010)**: 2Jy sample ($0.03 \leq z \leq 0.5$), 41 sources, **12% disk galaxies**;

Powerful Relativistic Jet in Disk Galaxies…

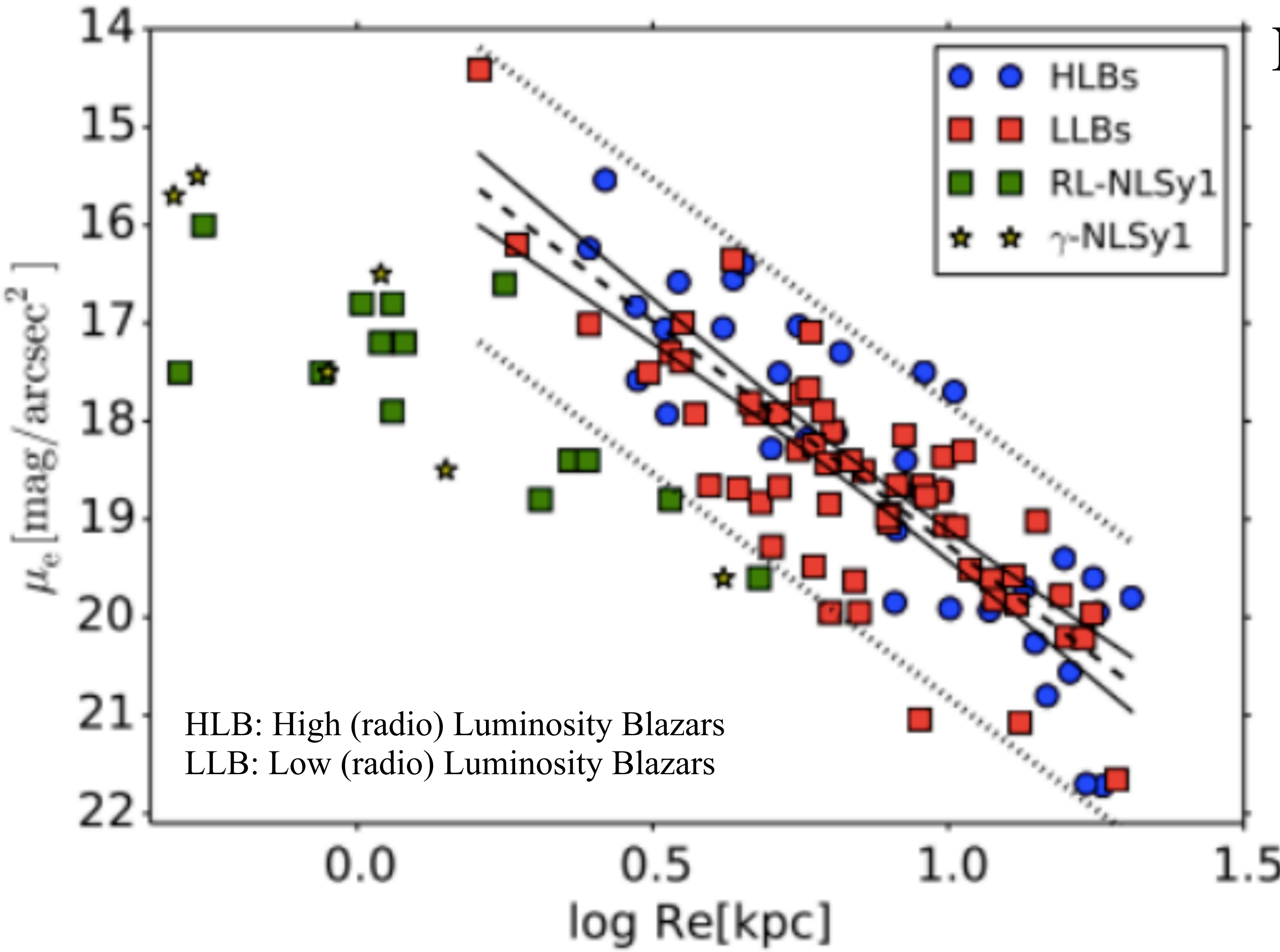
PKS 1814-637
νL_ν(5GHz) ≈ 2×10^{42} erg/s
(**Morganti et al. 2011**)



PMN J0315-1906
νL_ν(1.4GHz) ≈ 1.4×10^{40} erg/s
(**Keel et al. 2006**)



- **Coziol et al. (2017)**: SDSS ($z \leq 0.3$), 1953 sources, 22% radio-loud (430)
  - Radio morphology vs Host Galaxy:
    - Compact (53% Elliptical; **47% Spiral**)
    - Core + Jet (90% Elliptical; **10% Spiral**)
    - One lobe (100% Elliptical)
    - Two lobes (64% Elliptical; **36% Spiral**)
    - Compact weak radio sources have smaller BH masses (confirm 1979 Miley & Miller's results).



Narrow-Line Seyfert 1 Galaxies

Kotilainen et al. (2018):
Survey 26 NLS1, NOT (20 resolved),
z < 1

⬇

Pseudobulges are common
(➽ Mathur et al. 2012)

15/26 shows signs of mergers
(14/20 resolved)

11/20 have bars

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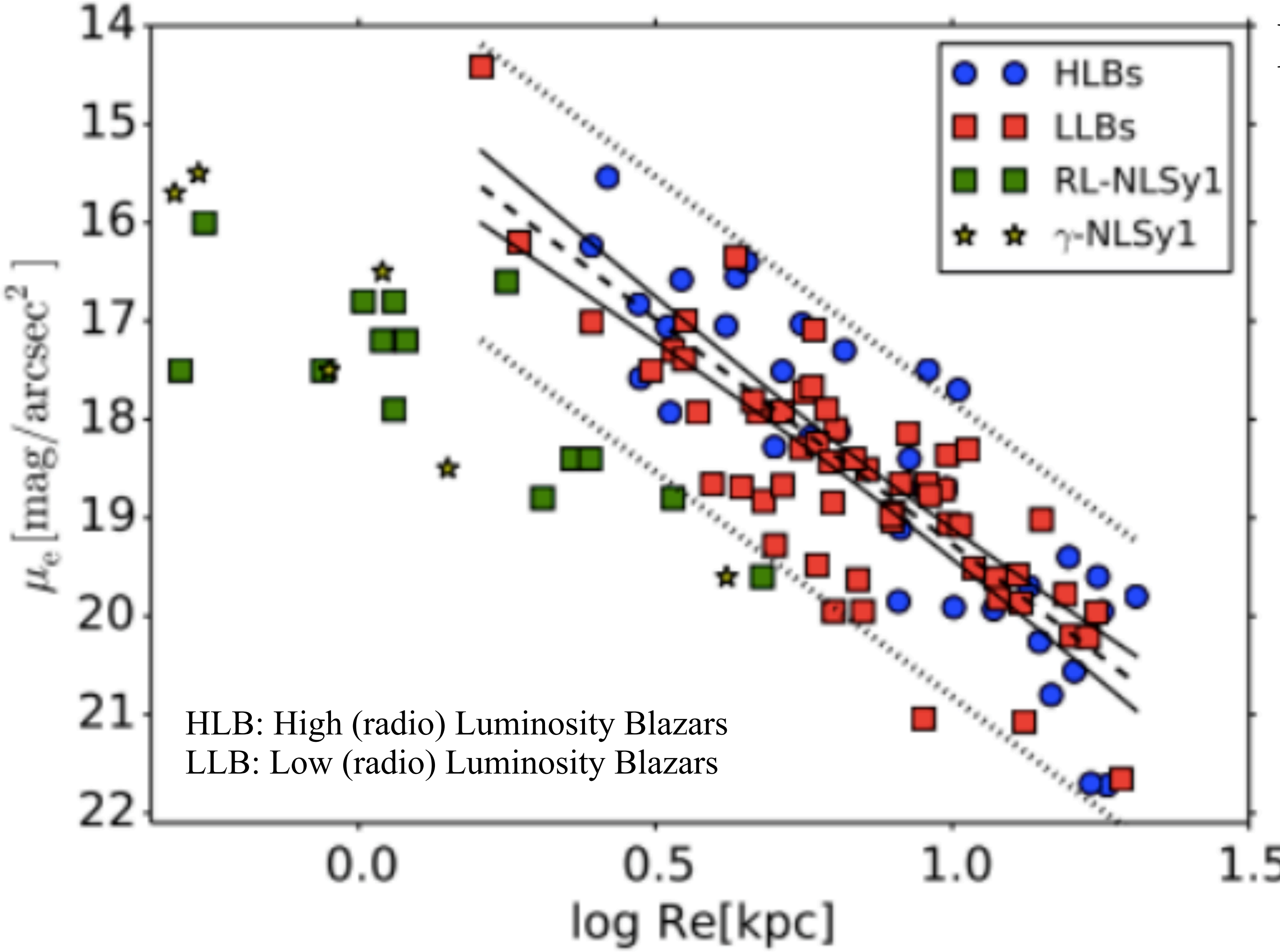

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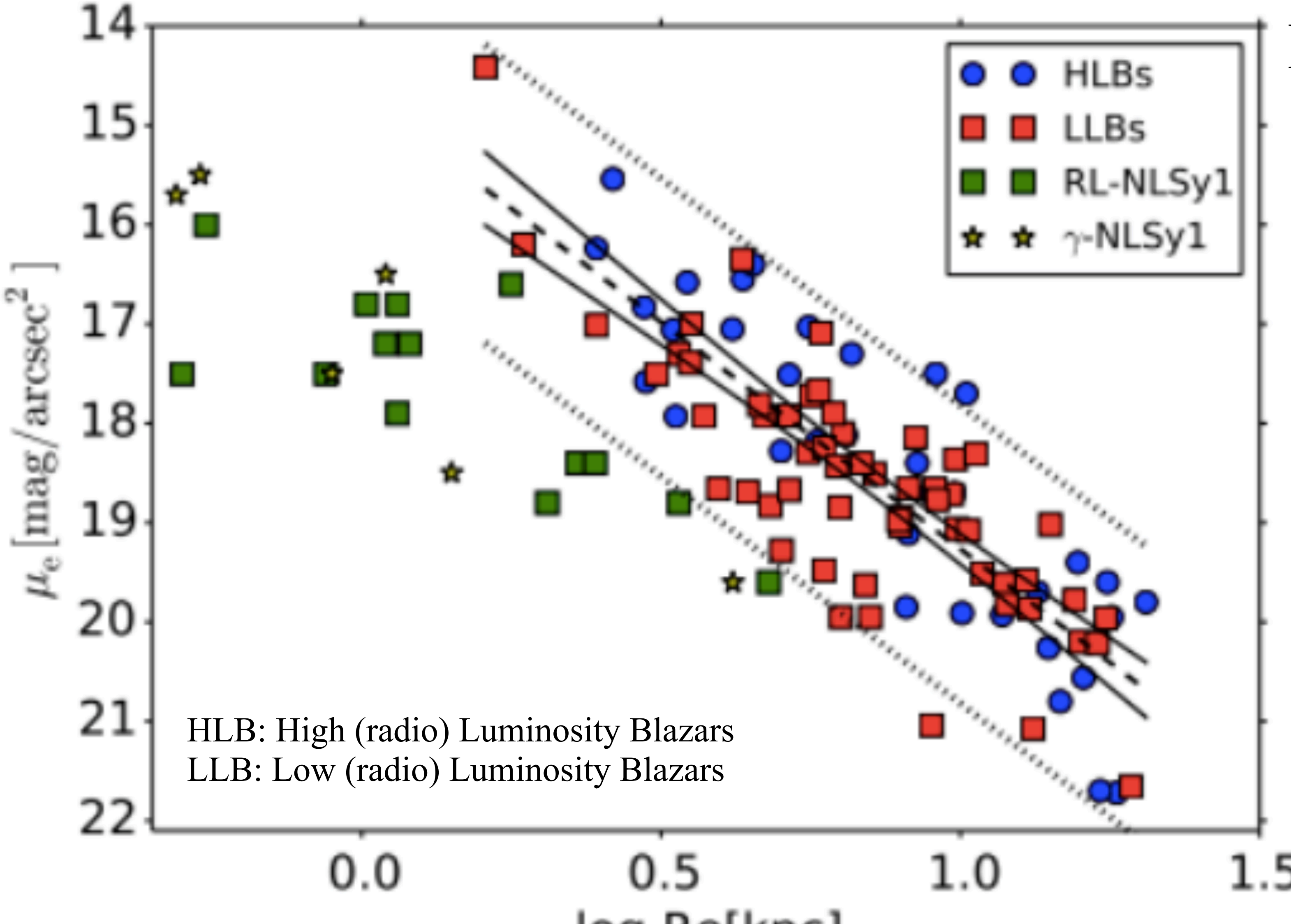
All are disk galaxies.



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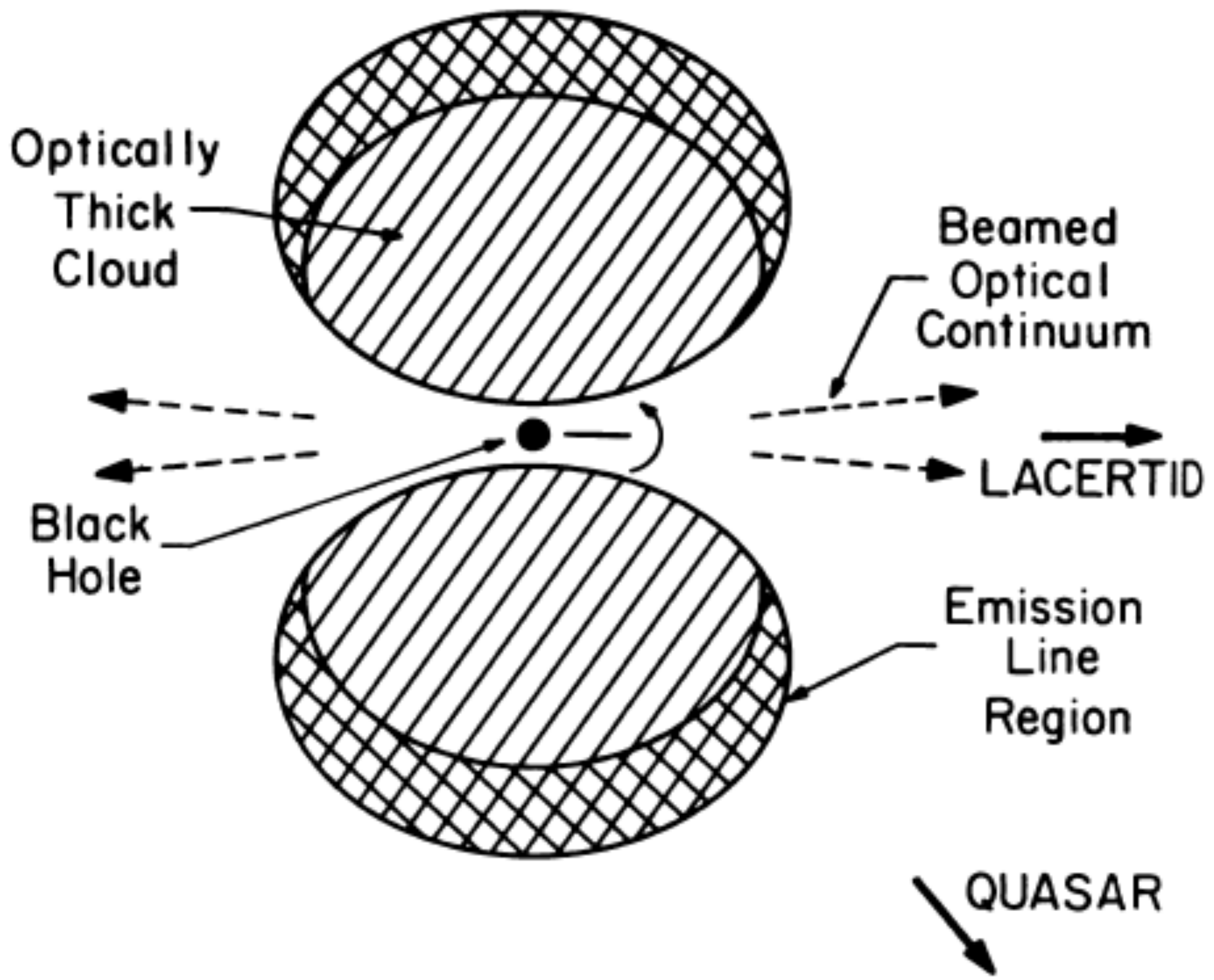
J0324+3410 (z=0.061):
Zhou et al. (2007): spiral (HST)
Antón et al. (2008): ring, merger (NOT)
León Tavares et al. (2014): ring, merger (NOT)

J1644+2619 (z=0.145):
Olguín-Iglesias et al. (2017): SB0 (NOT, J, 0.75”; K, 0.63” seeing)
D’Ammando et al. (2017): E (GranTeCan, J, 0.9” seeing)

J2007-4434 (z=0.24):
Kotilainen et al. (2016): pseudobulge+bar (VLT)

J2021-2235 (ULIRG, z=0.185):
Berton et al. (2018): ongoing interacting systems (Magellan)

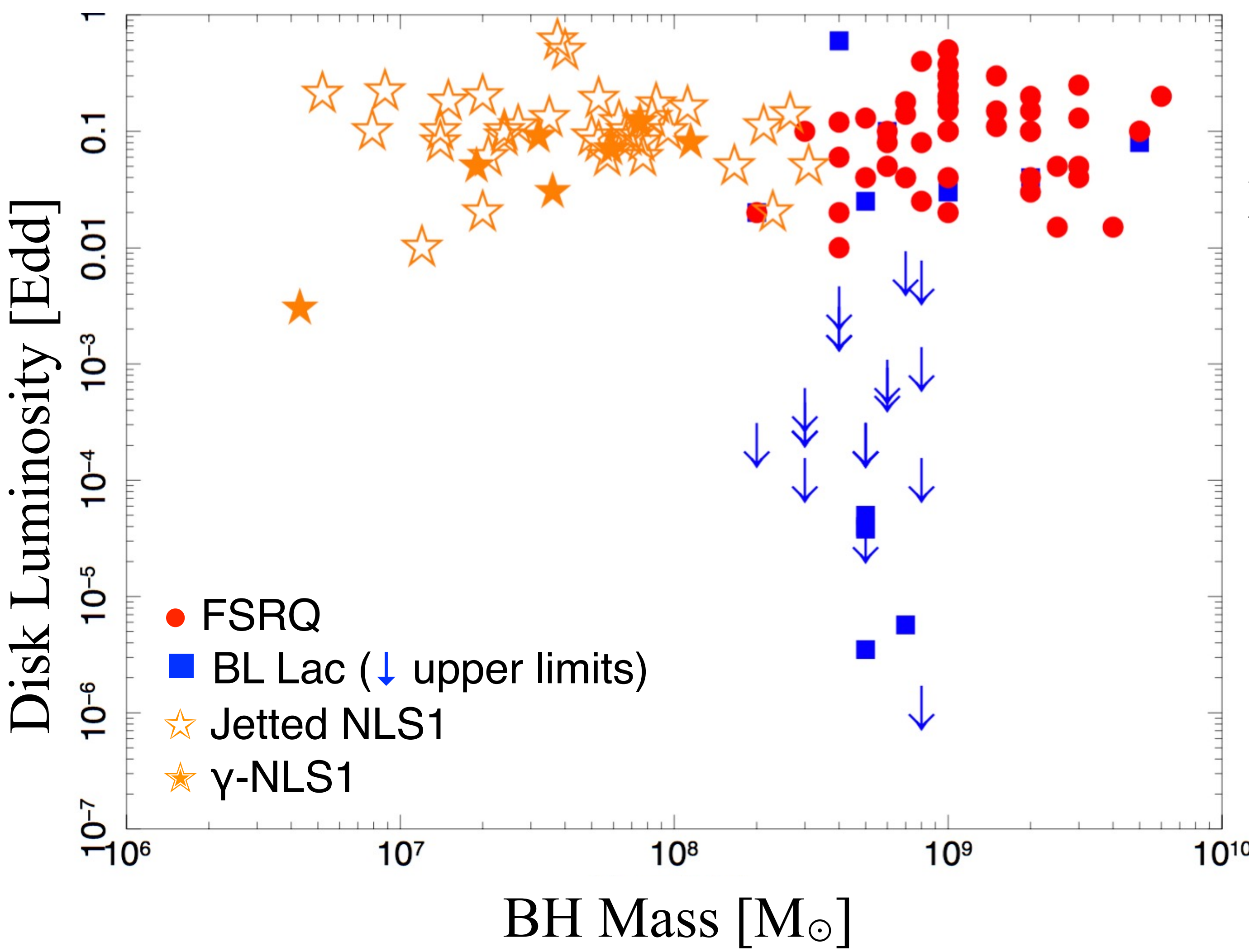
The host galaxy does not affect the relativistic jet generation!



"As the continuum emission is proposed to originate in the central 10 pc, I don't think the nature of the surrounding object is particularly relevant to the model."
[Roger Blandford, 1978]

<u>This does not exclude some mutual feedback between the jet and the host.</u>

Jetted Narrow-Line Seyfert 1 Galaxies



Detection at high-energy gamma rays (Abdo et al. 2009; Foschini et al. 2010, three papers + one proceeding);

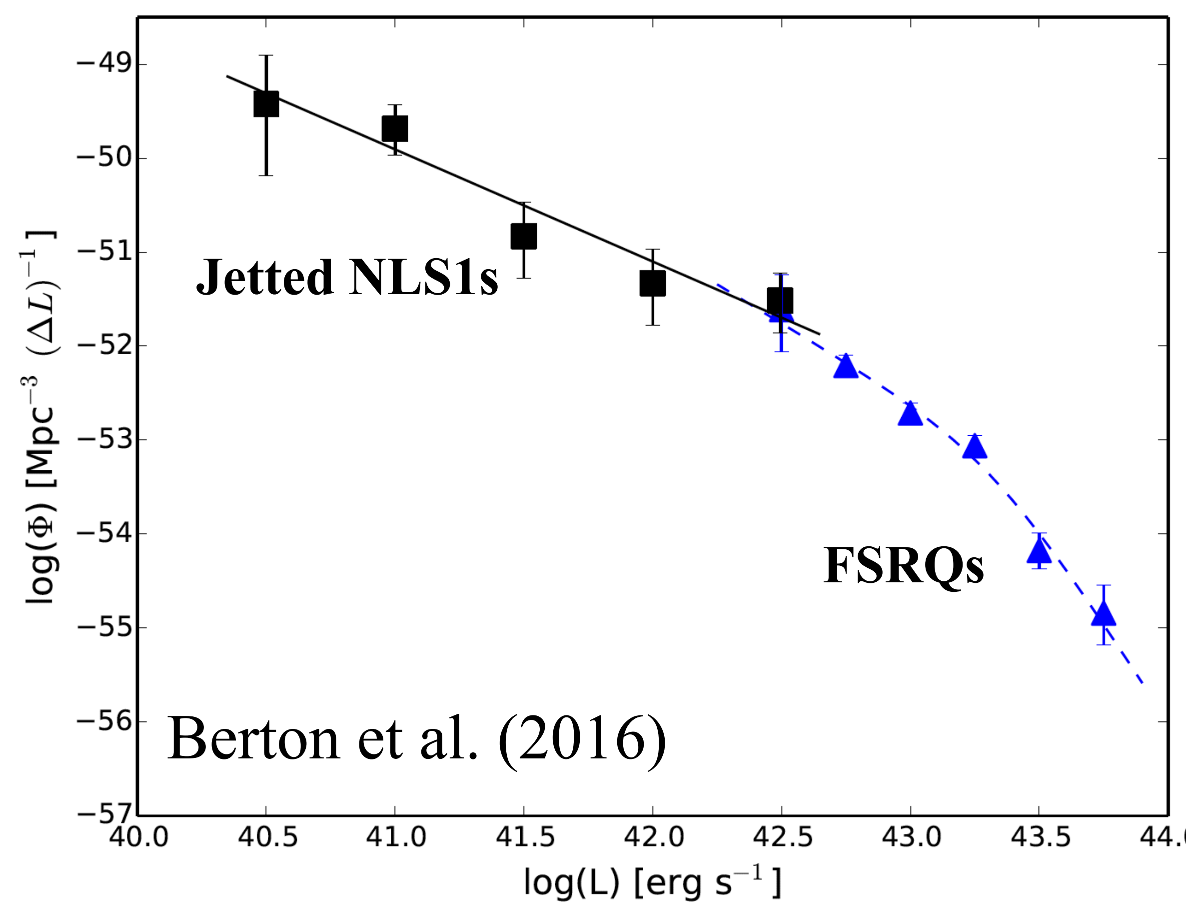
General properties (Foschini et al. 2015):

- Small black hole mass (~$10^{6\text{-}8}M_\odot$);
- High accretion luminosity (0.1-1 Edd);
- Strong emission lines;
- Relatively low jet power;
- Low-mass tail of FSRQ

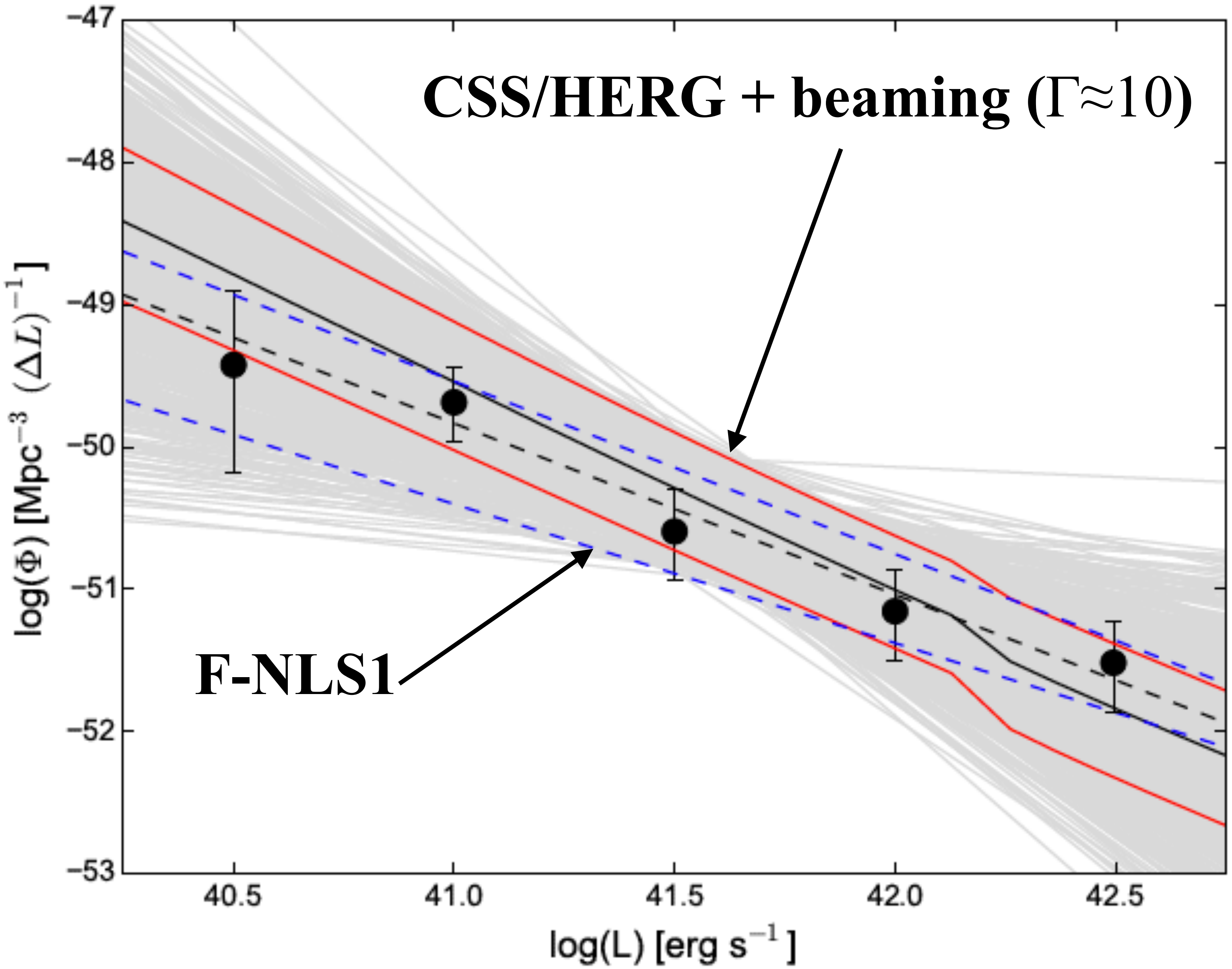
Superluminal radio jet (~10c, Lister et al. 2016);

(see also Angelakis et al. 2015, Lähteenmäki et al. 2017 for radio properties)

Caccianiga et al. (2015): Enhanced star formation activity.



Search for the parent population of Jetted NLS1s



Luminosity Functions
(Berton et al. 2016, PhD thesis)

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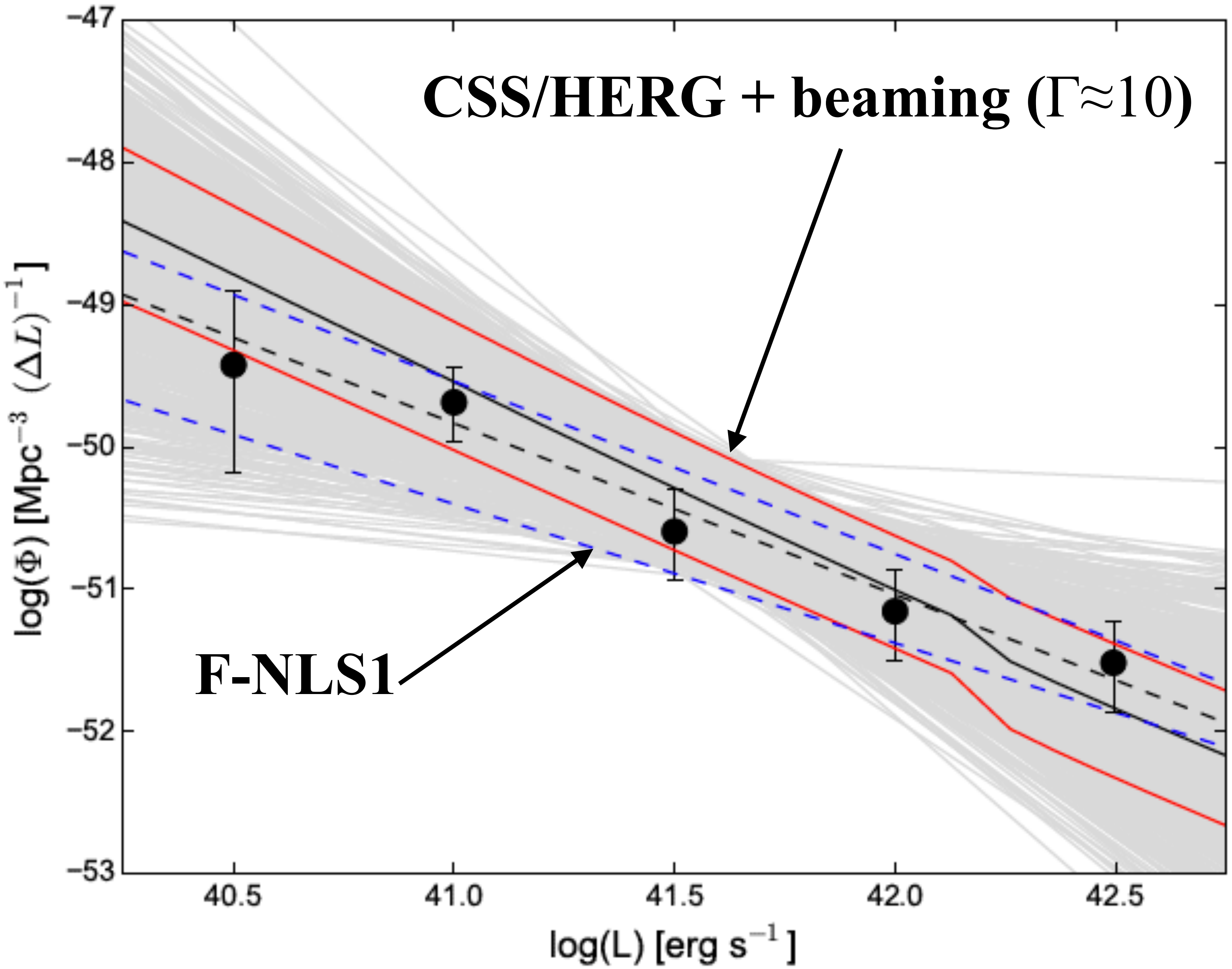
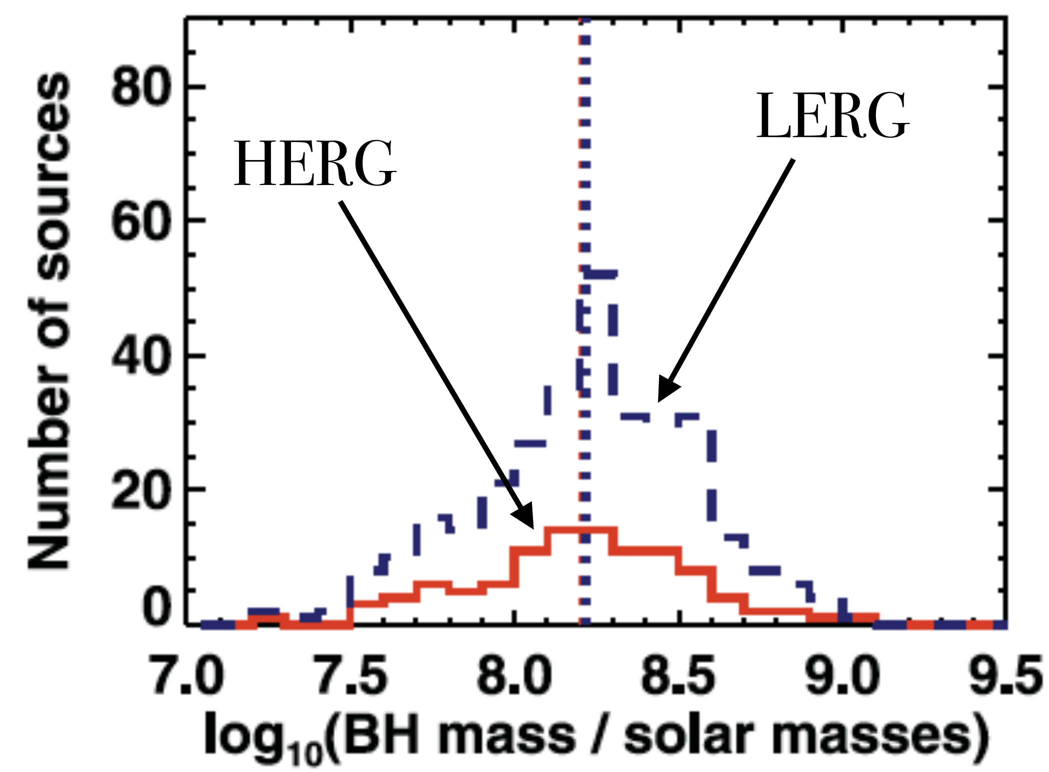


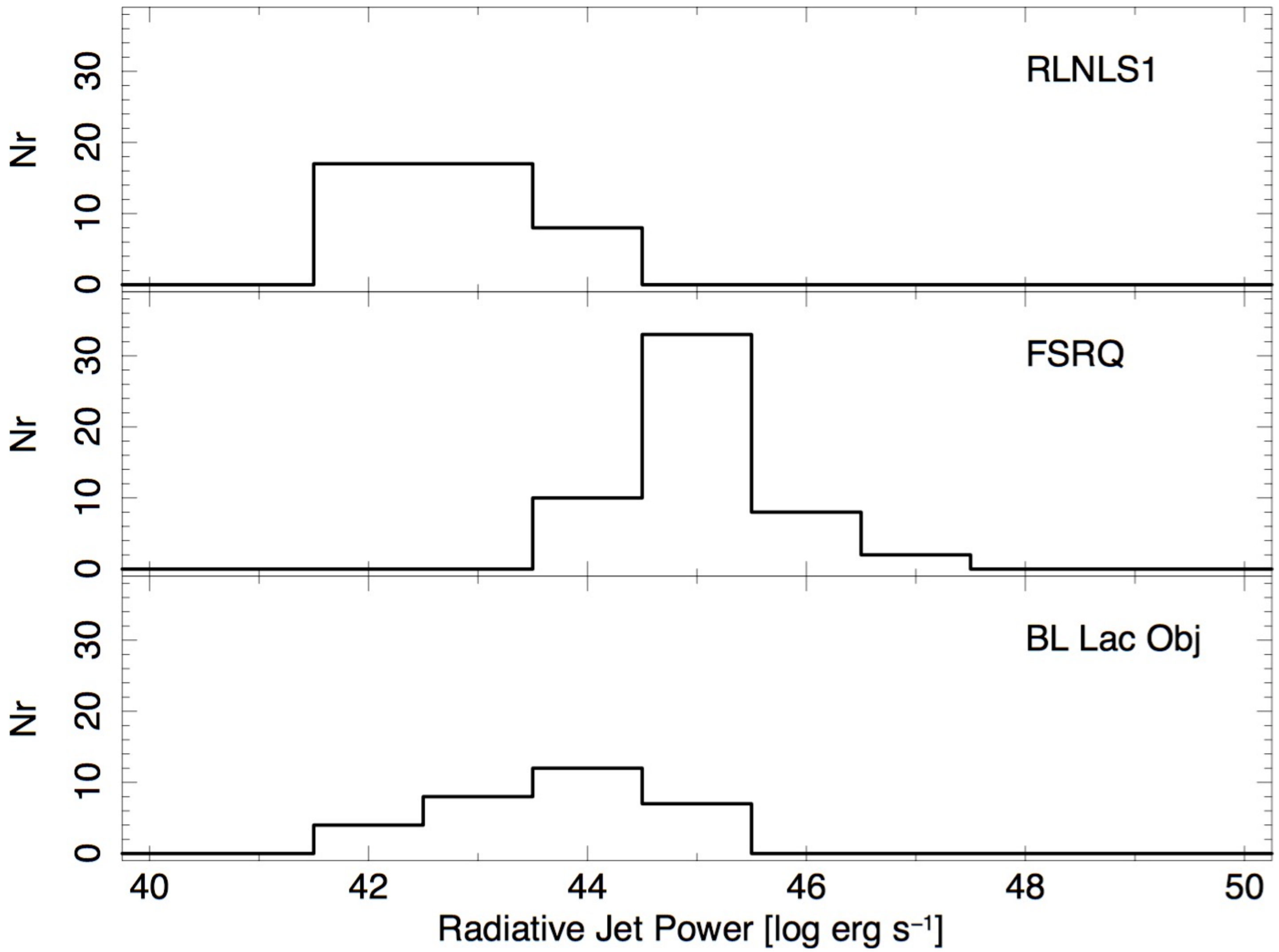
Luminosity Functions
(Berton et al. 2016, PhD thesis)

Best & Heckman (2012):
7302 radio-loud AGN
(SDSS+NVSS+FIRST)
$0.01 \leq z \leq 0.3$, HERG/LERG

"HERGs are typically of lower stellar mass, with lower black hole masses, bluer colours, lower concentration indices and less pronounced 4000Å breaks indicating younger stellar populations…"



Jet Power



Foschini et al. (2015)

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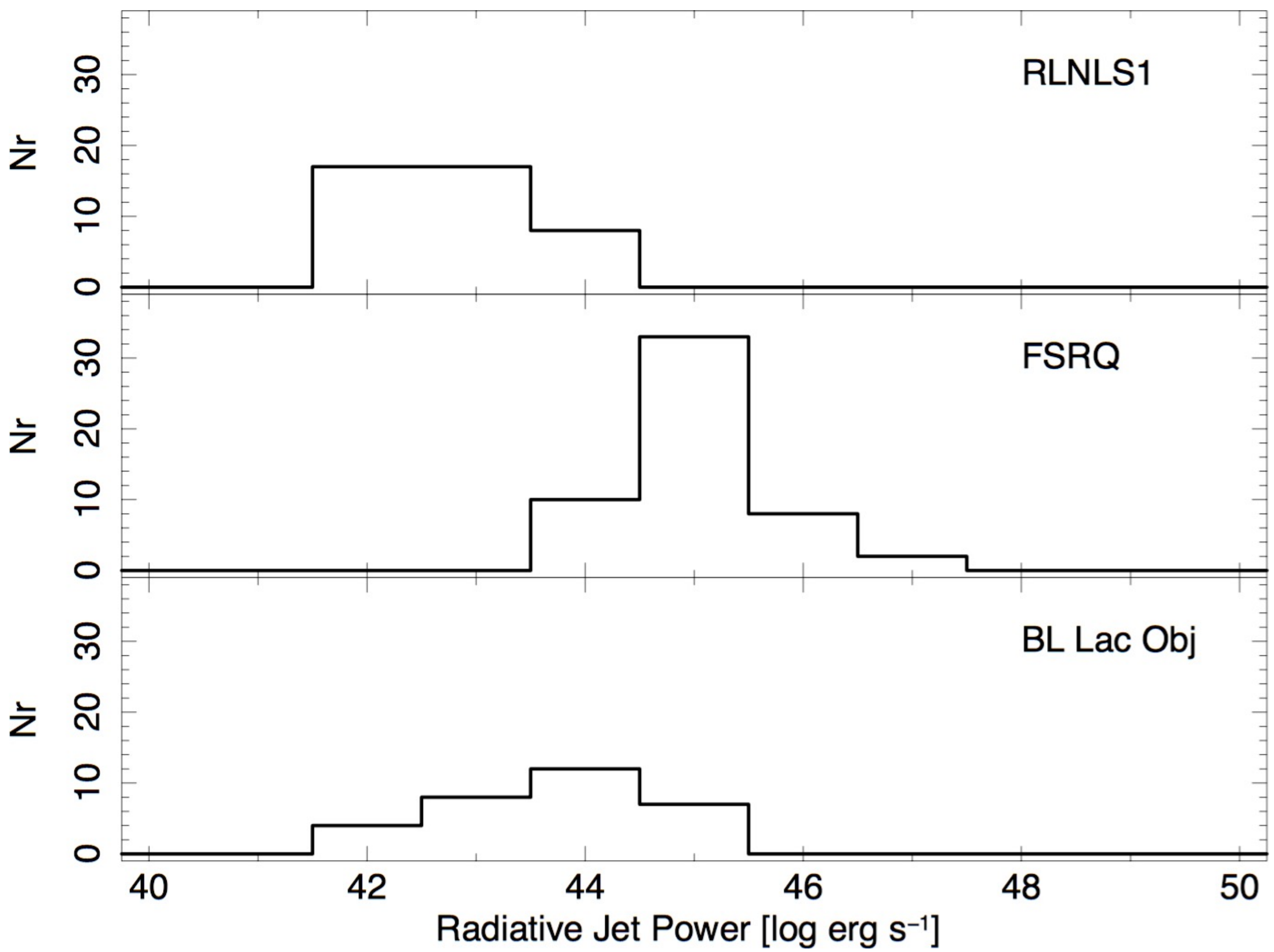
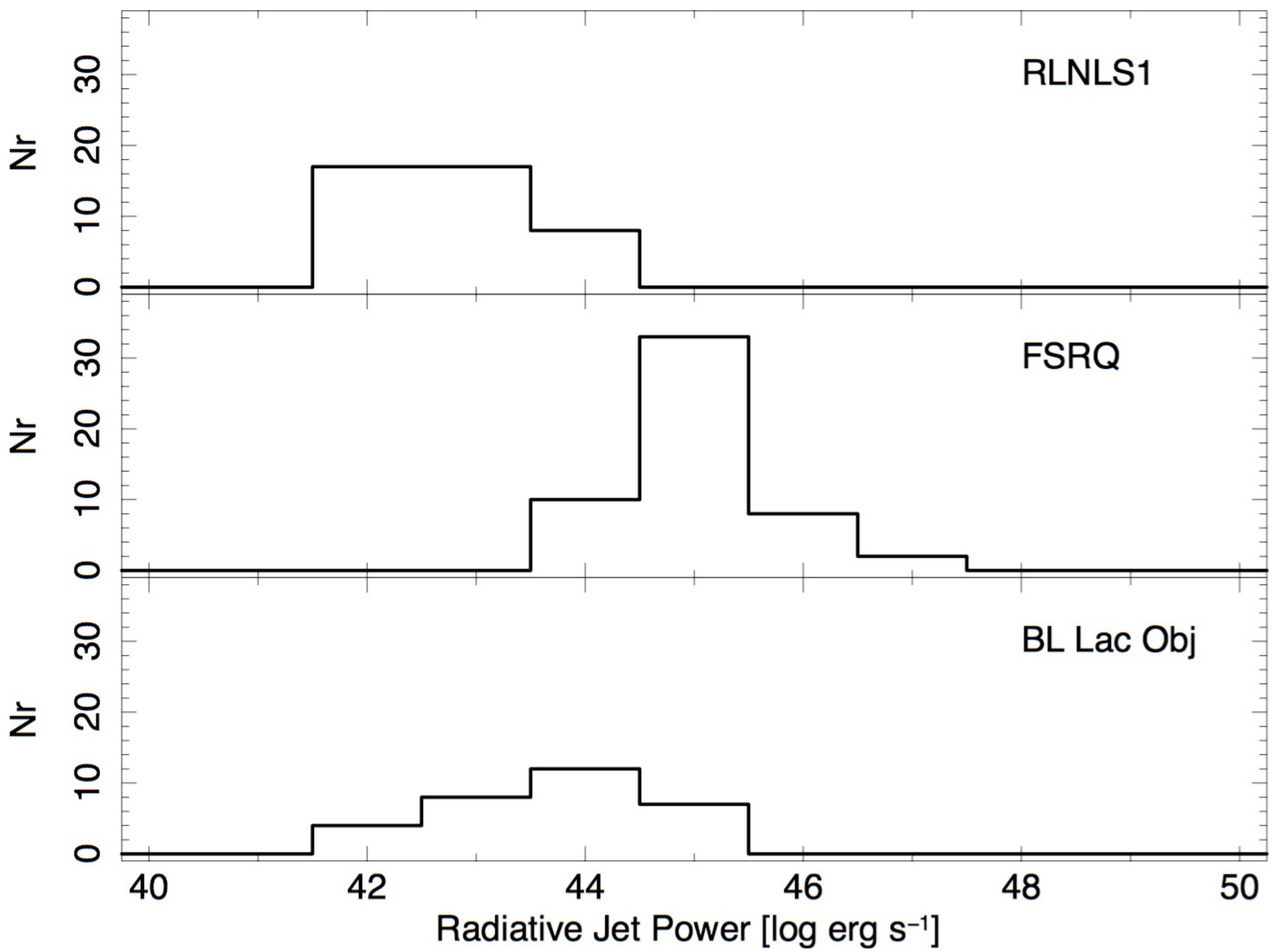


Foschini et al. (2015)

Strong Disk & Emission Lines ⤵
Photon-rich environment ⤵
Efficient Cooling ⤵
High Jet Power
(Ghisellini et al. 1998)

Jet Power



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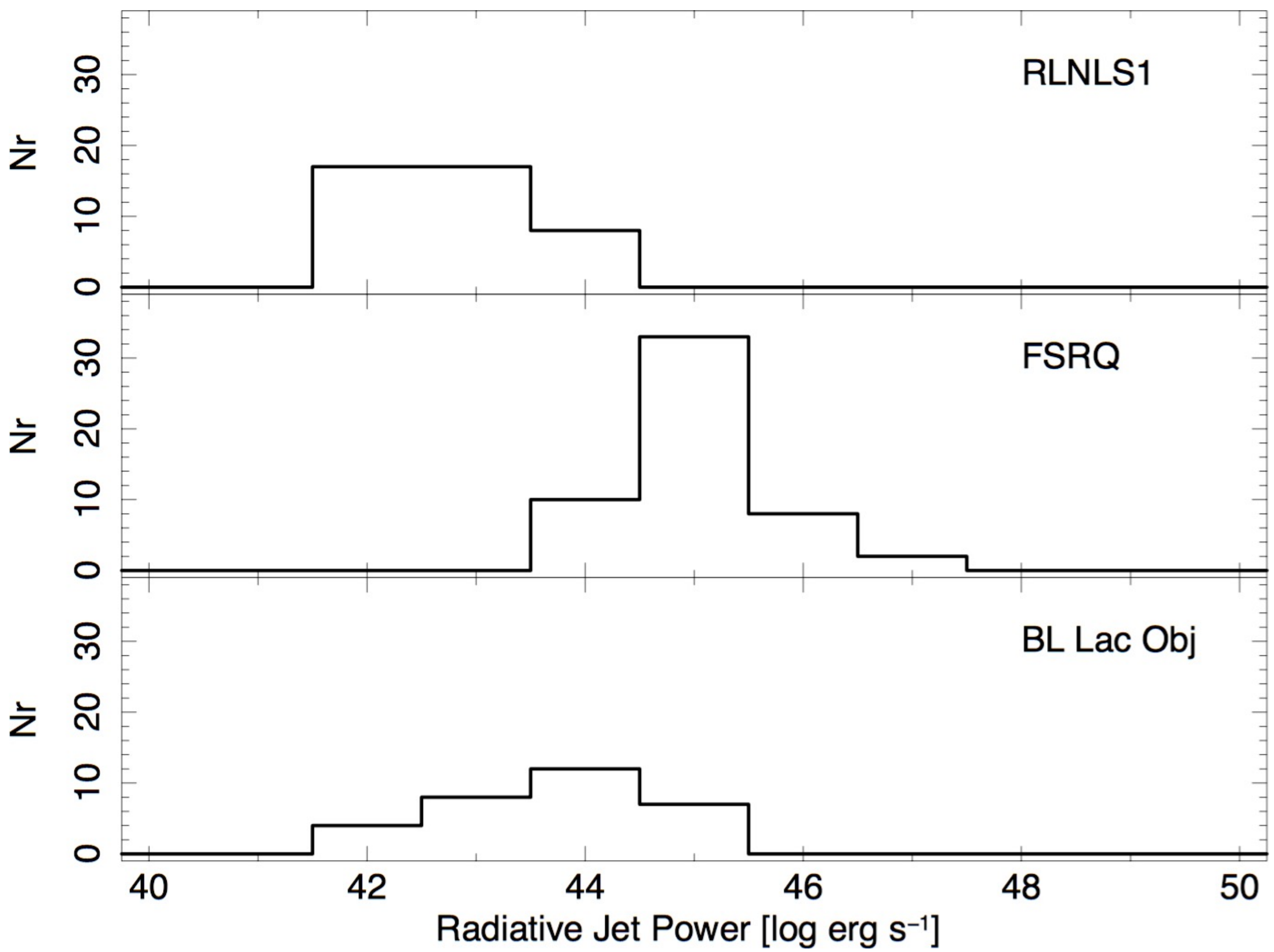

Foschini et al. (2015)

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High Jet Power
(Ghisellini et al. 1998)

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Inefficient Cooling ↓
Low Jet Power
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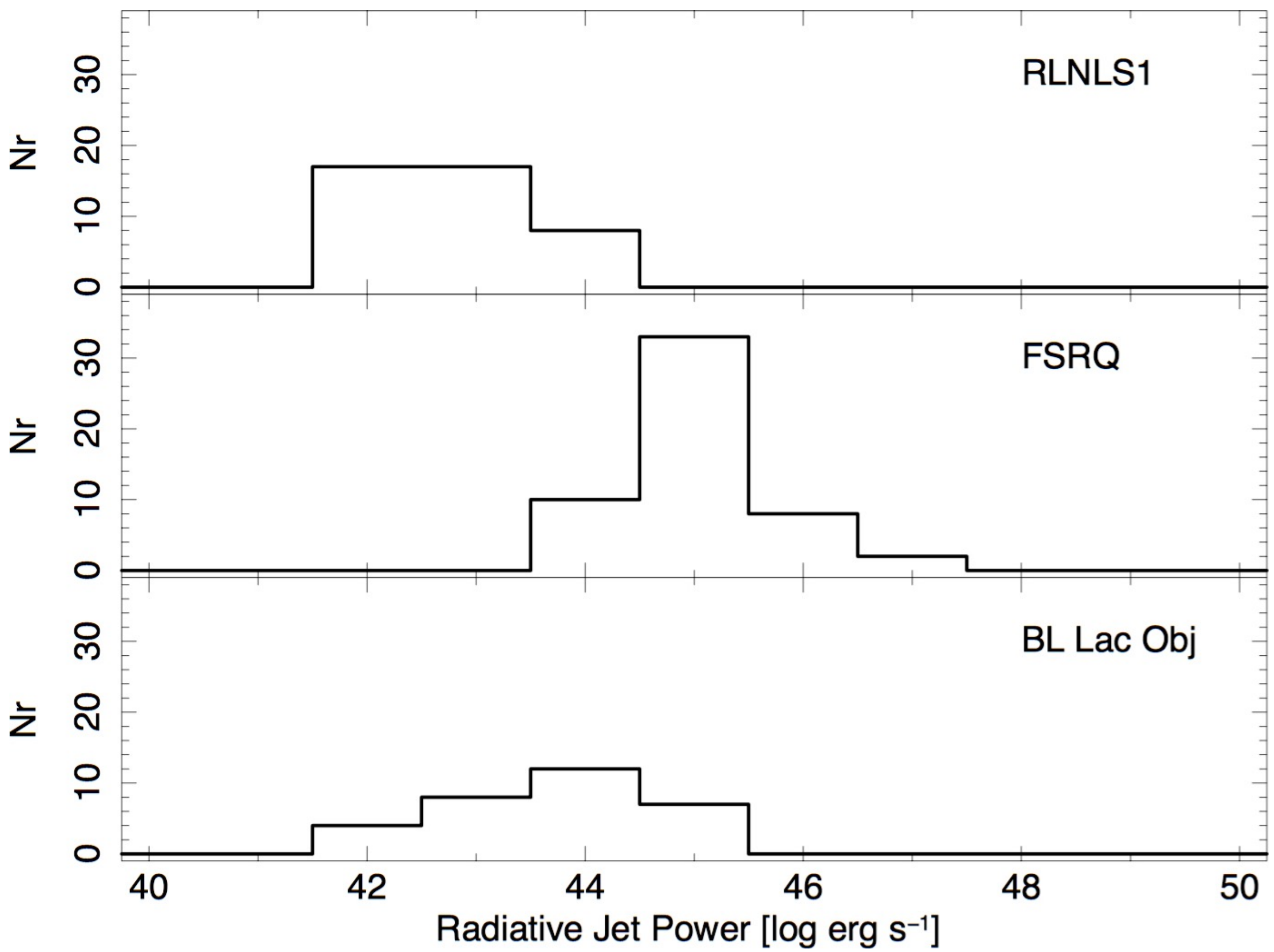
Blazar Sequence

Jet Power



Foschini et al. (2015)

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Photon-rich environment
Efficient Cooling
Low Jet Power ?

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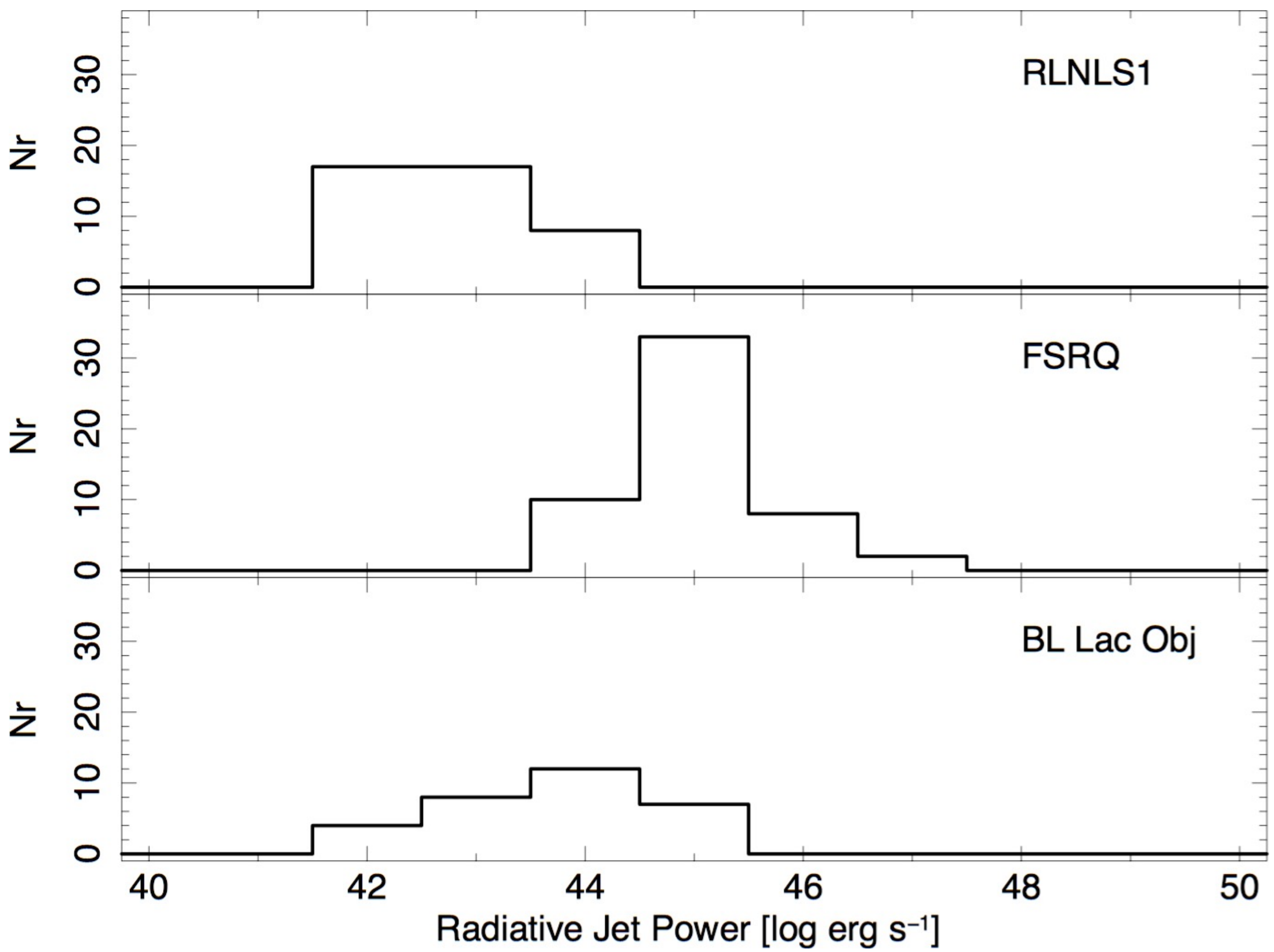

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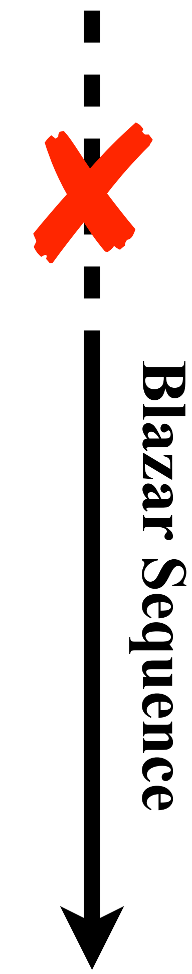
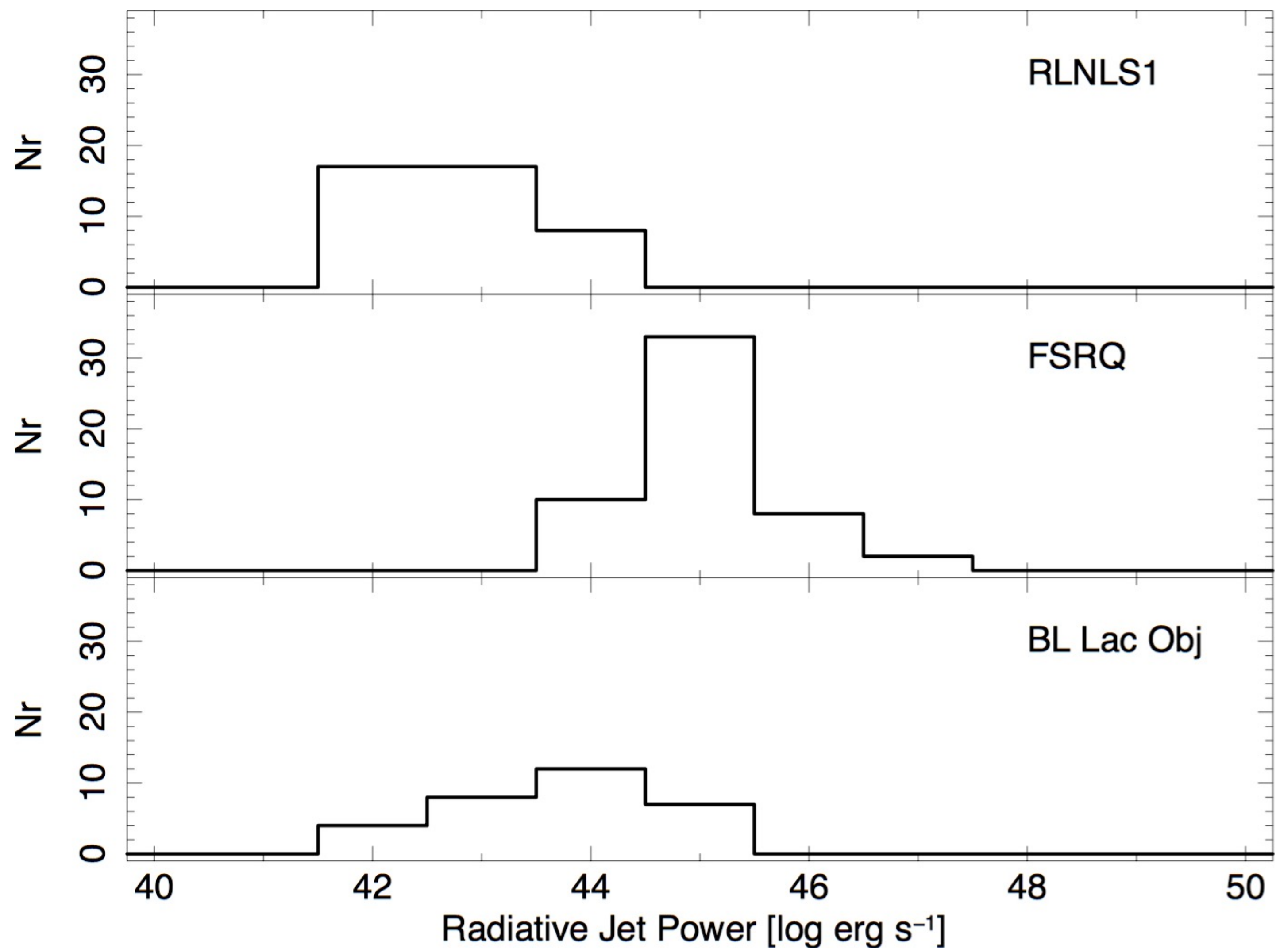


Jet Power

Jetted NLS1s do have small BH mass ☞ Scaling Jet Power (Heinz & Sunyaev 2003) ☞ OK



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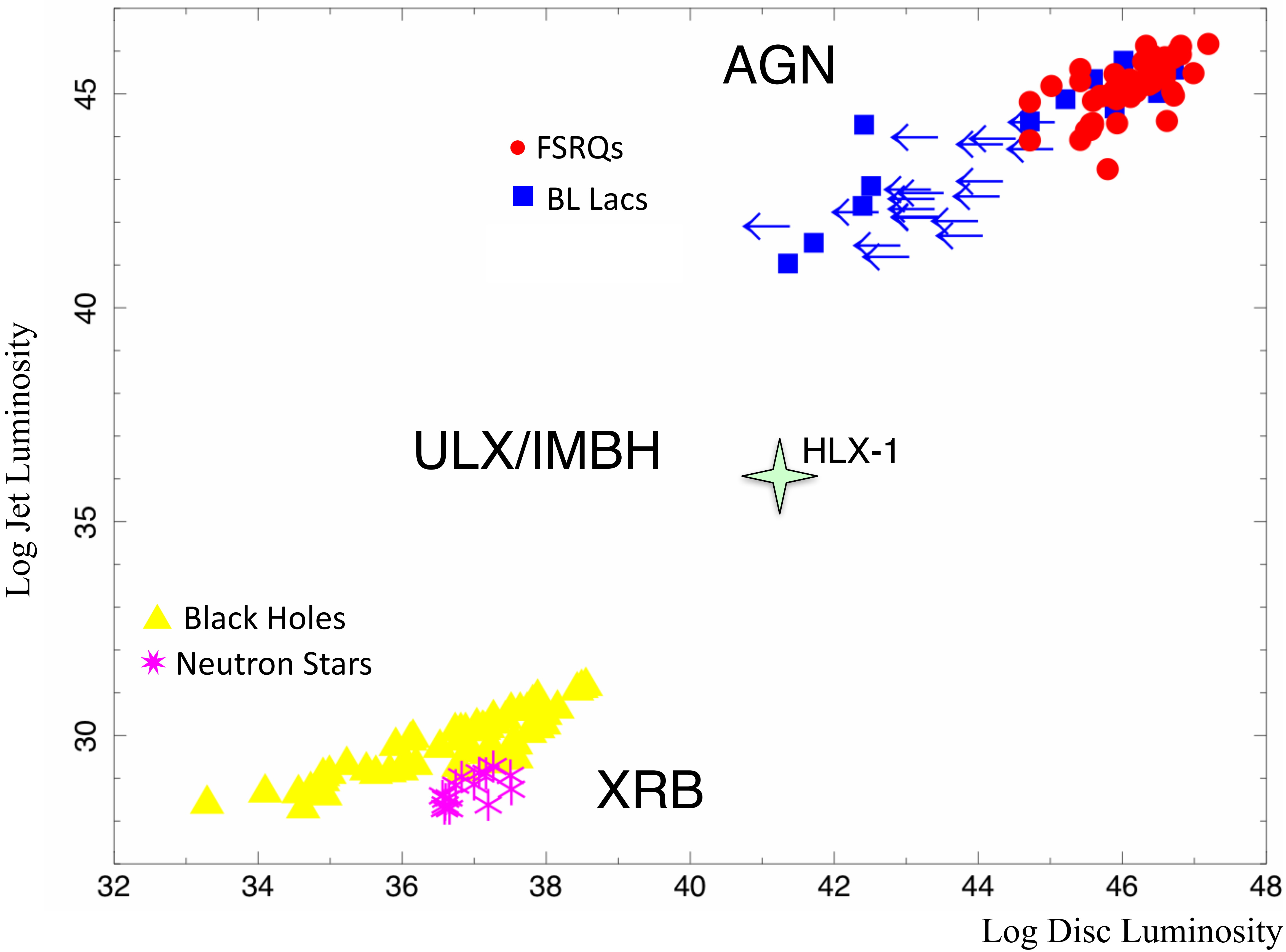
Blazar Sequence

Unification of Relativistic Jets (*Foschini 2011-2014*)



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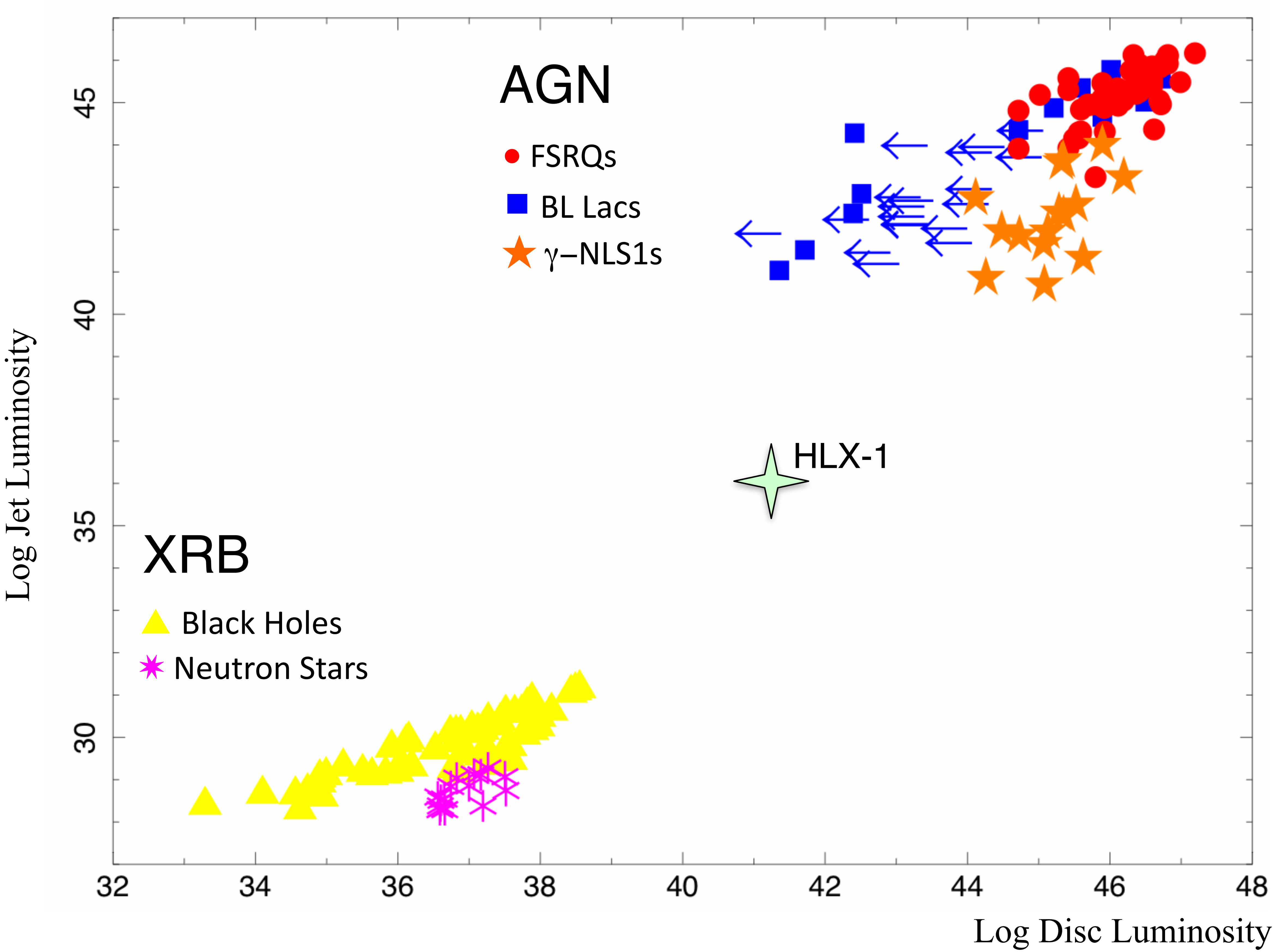
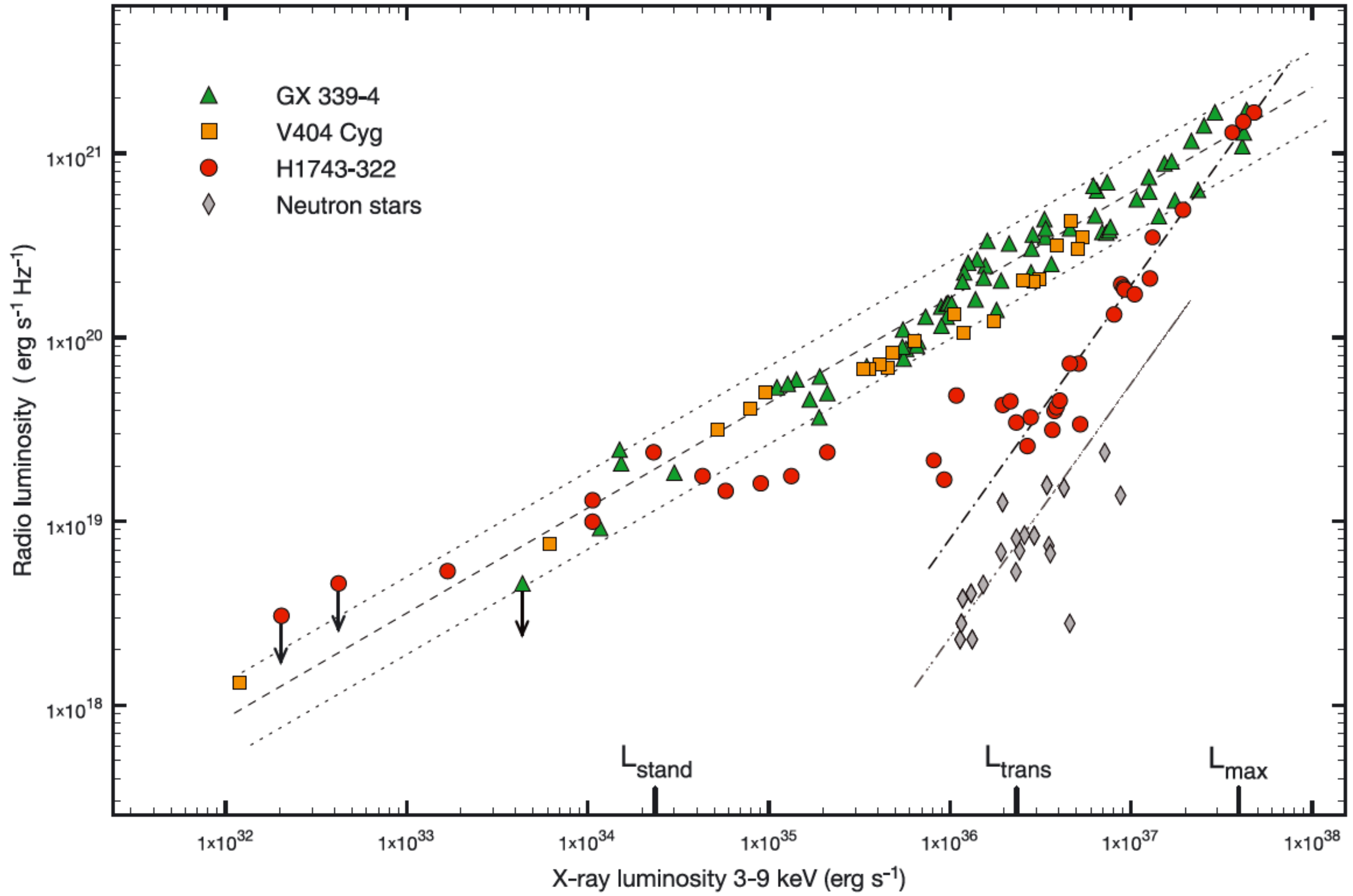




X-Ray Binaries

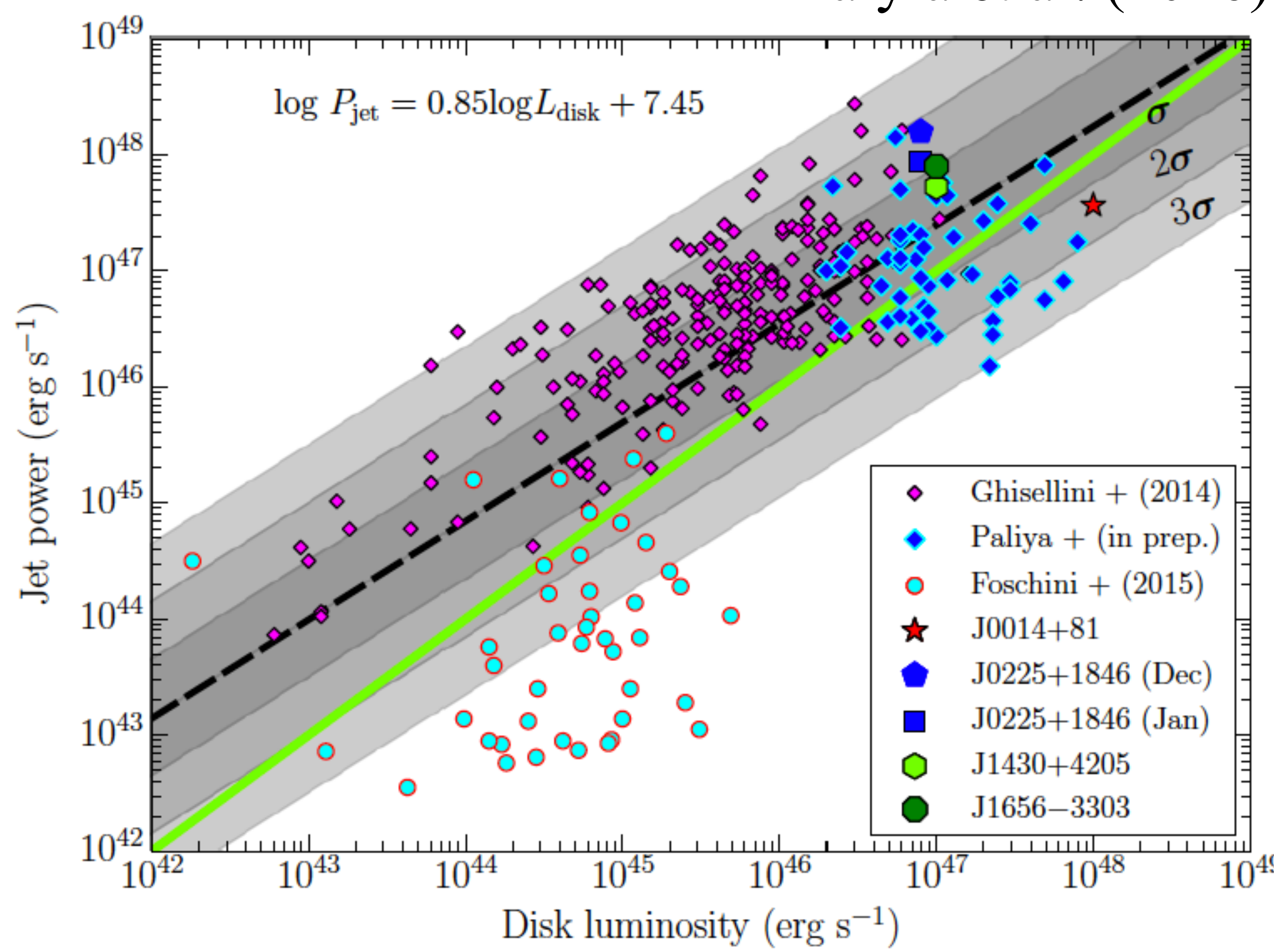
(Neutron Stars, Stellar-Mass Black Holes)

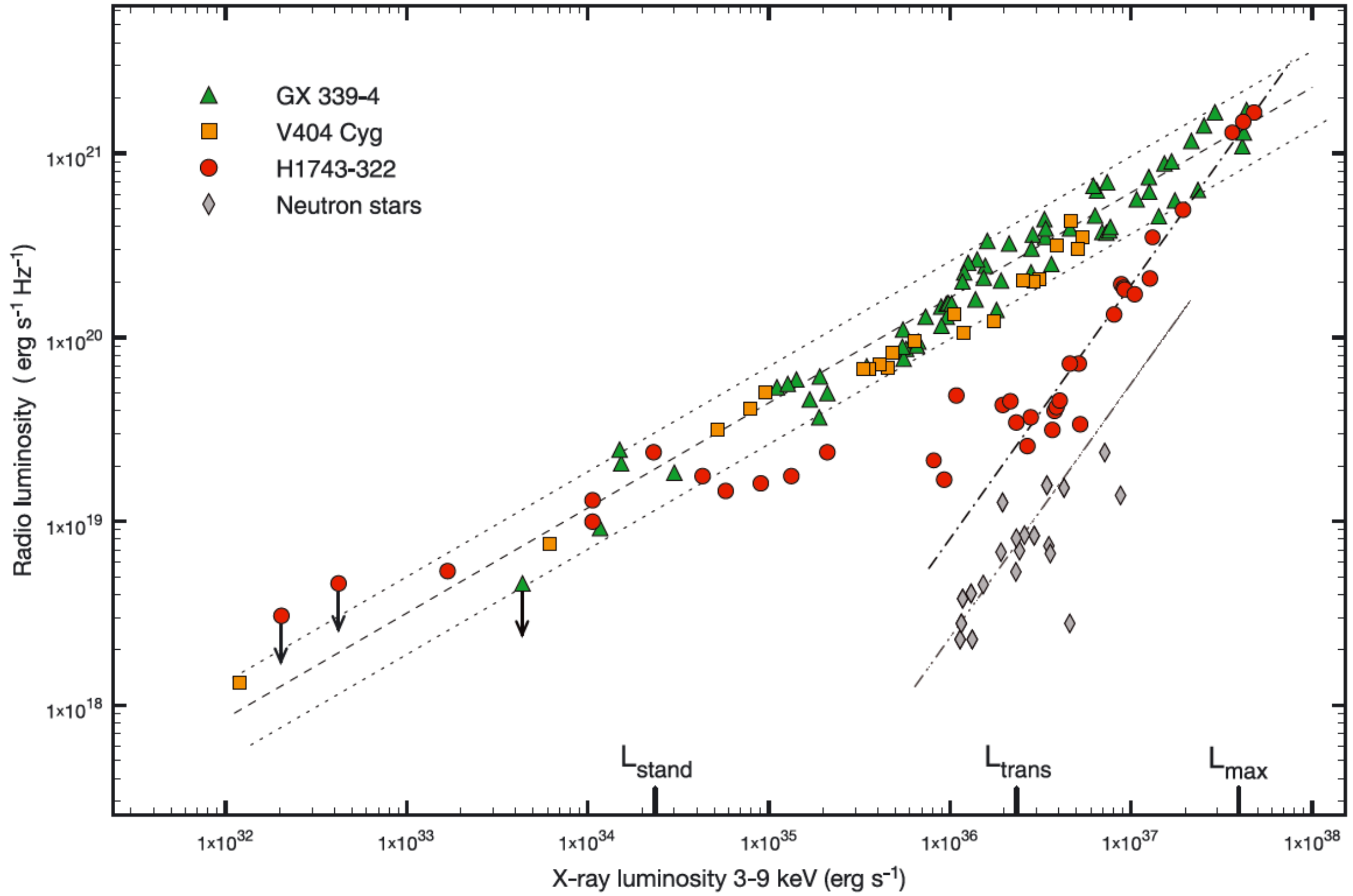
Coriat et al. (2011)

Active Galactic Nuclei

(FSRQ, BL Lac Objects, Jetted NLS1)

Palyia et al. (2016)





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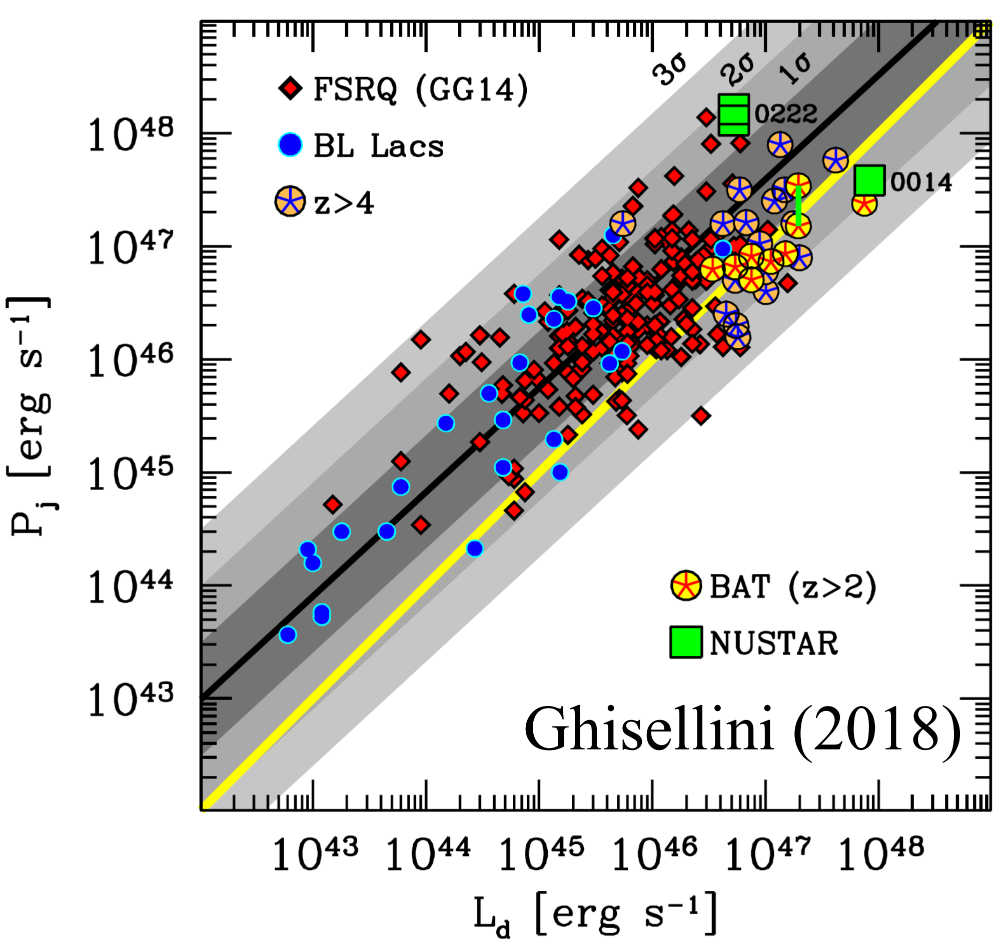

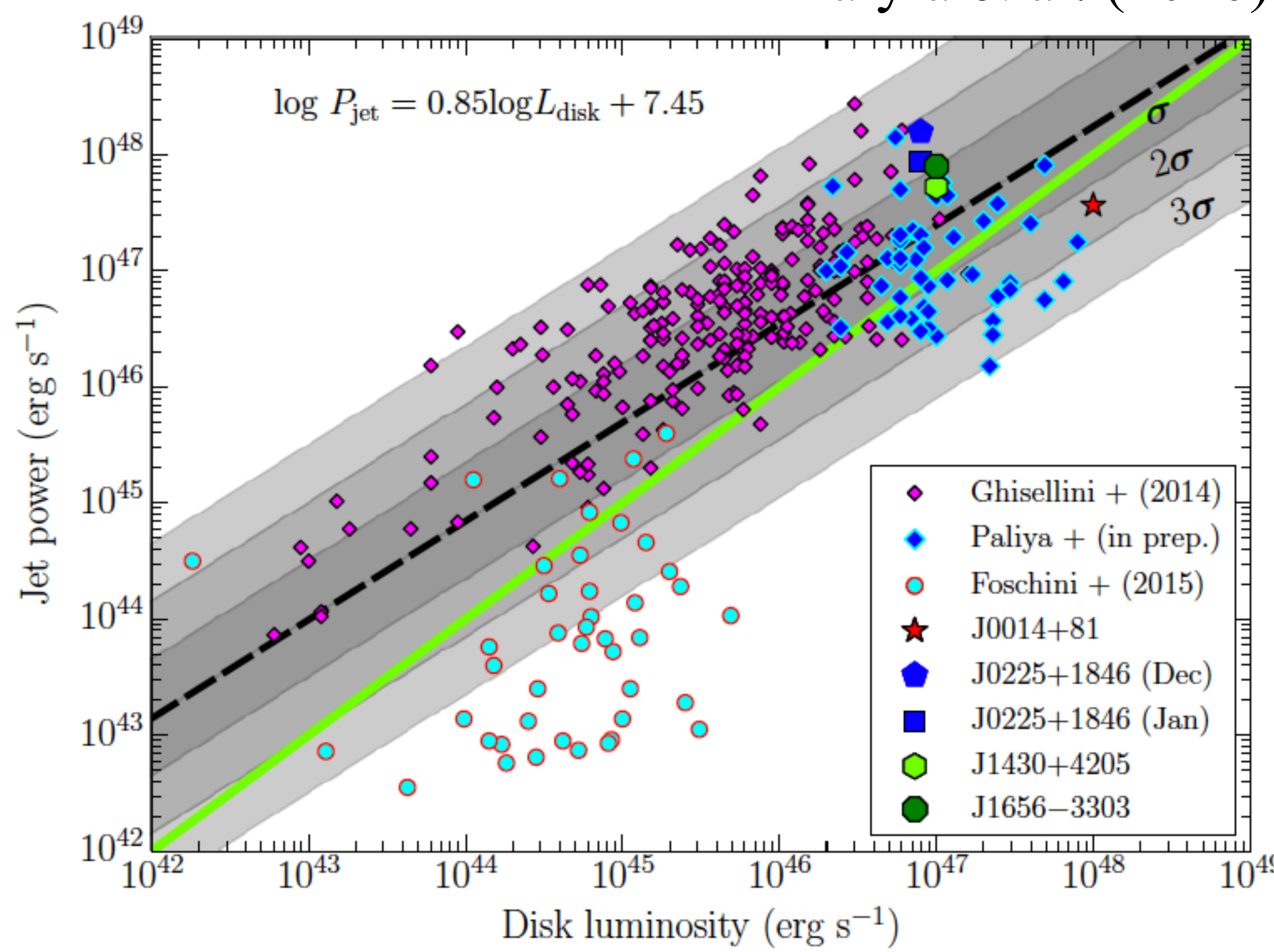

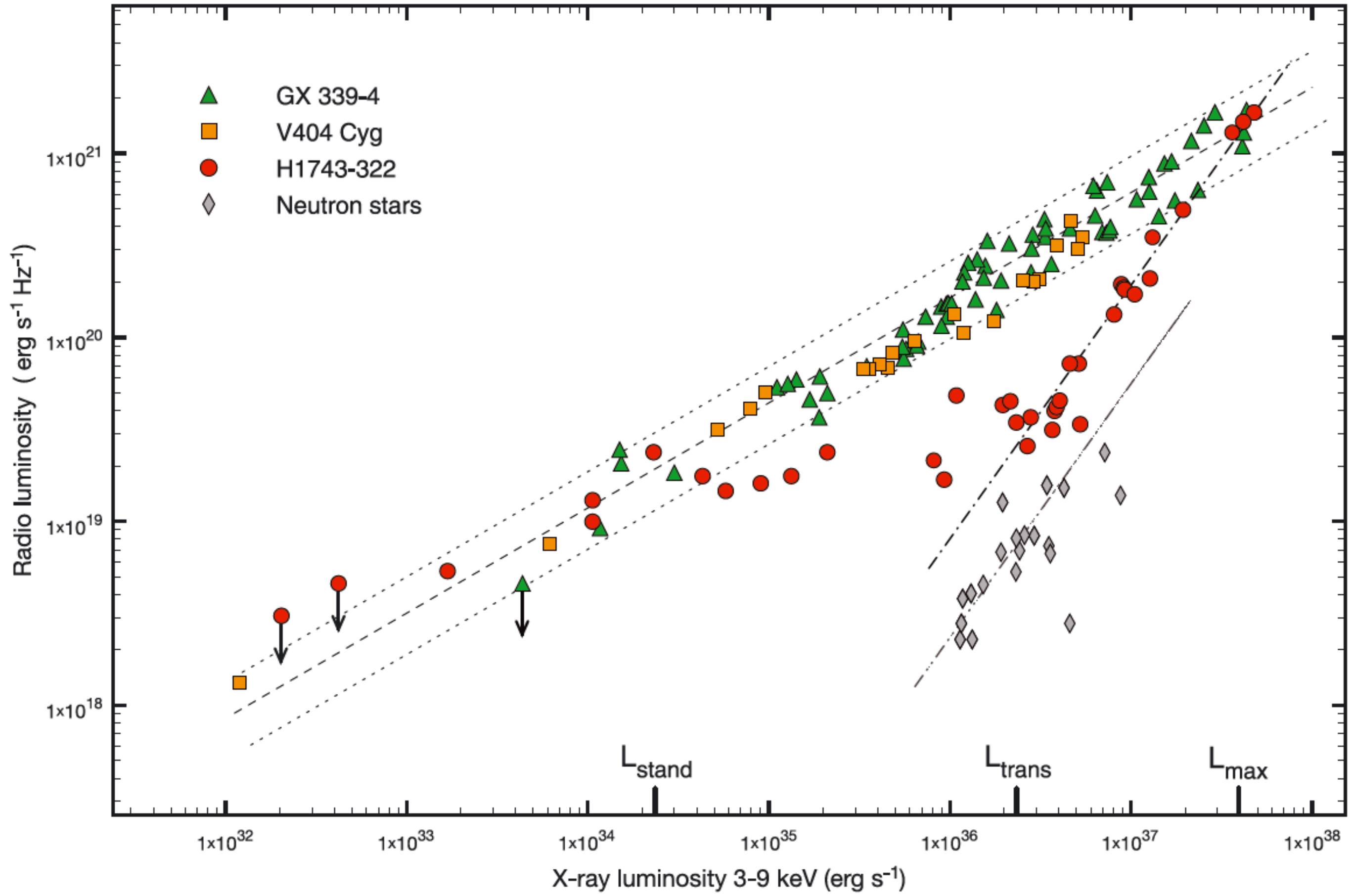

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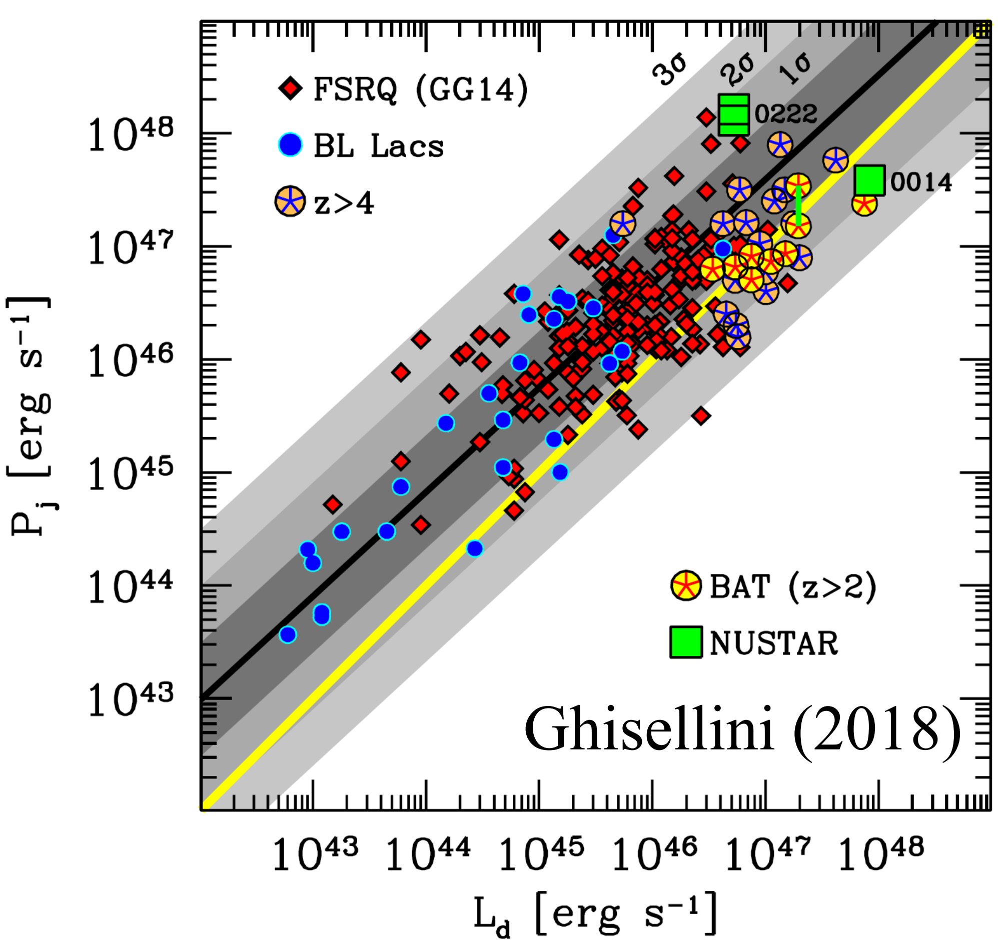
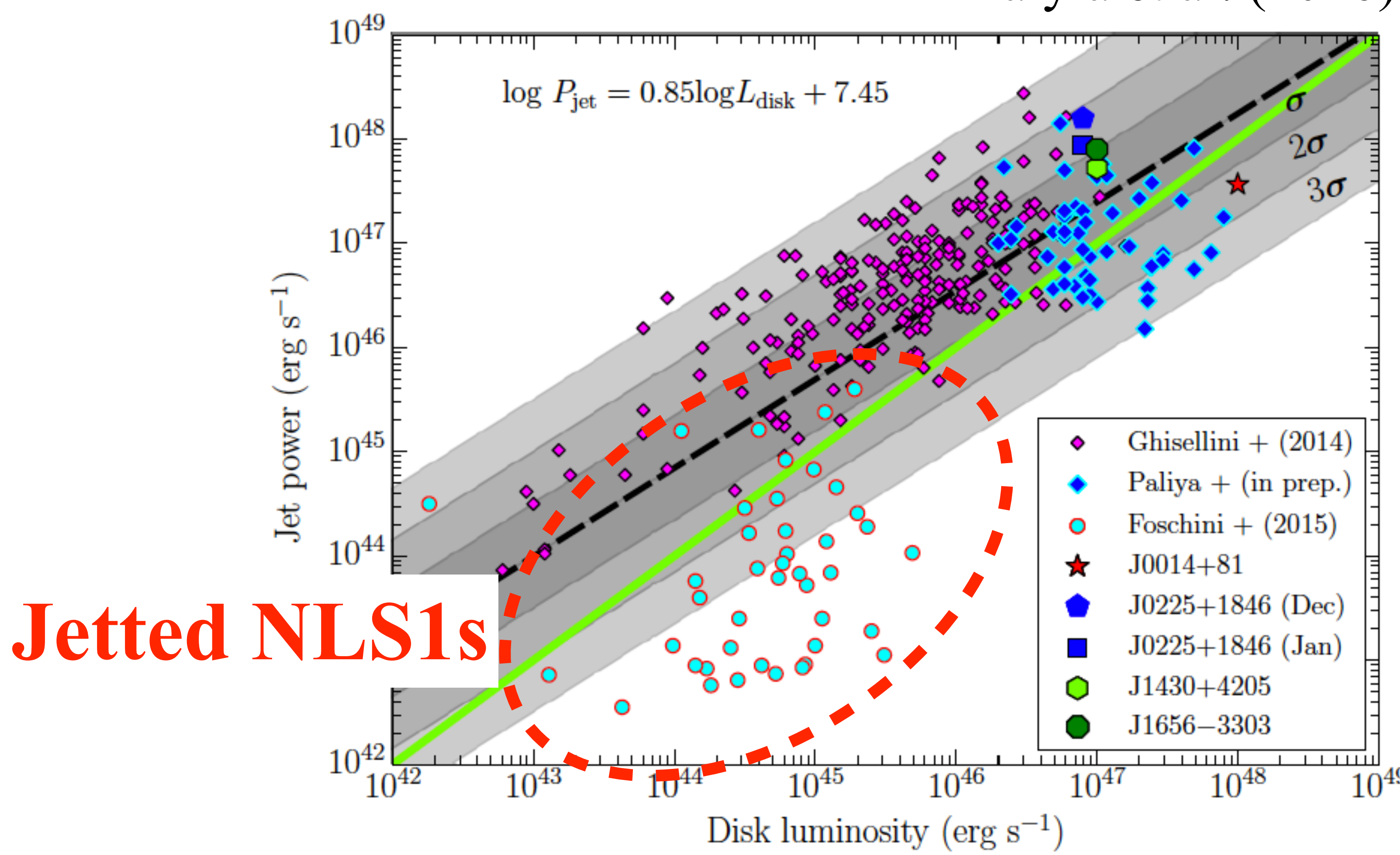
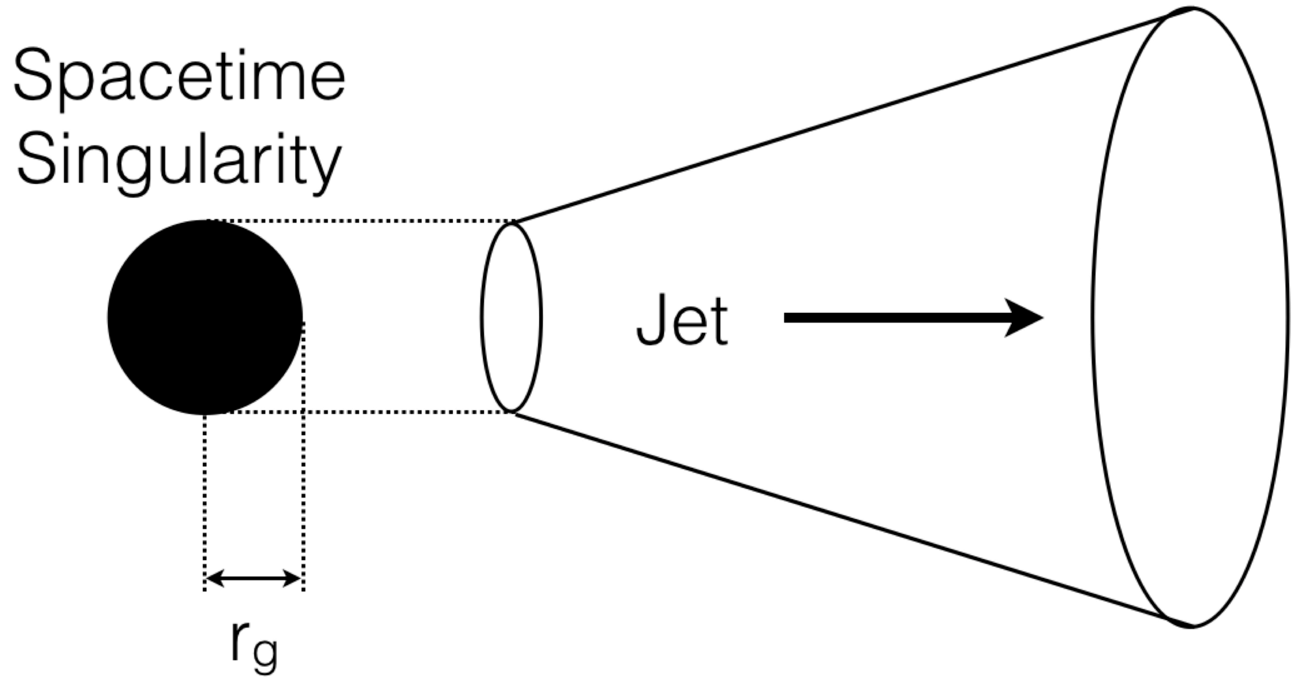
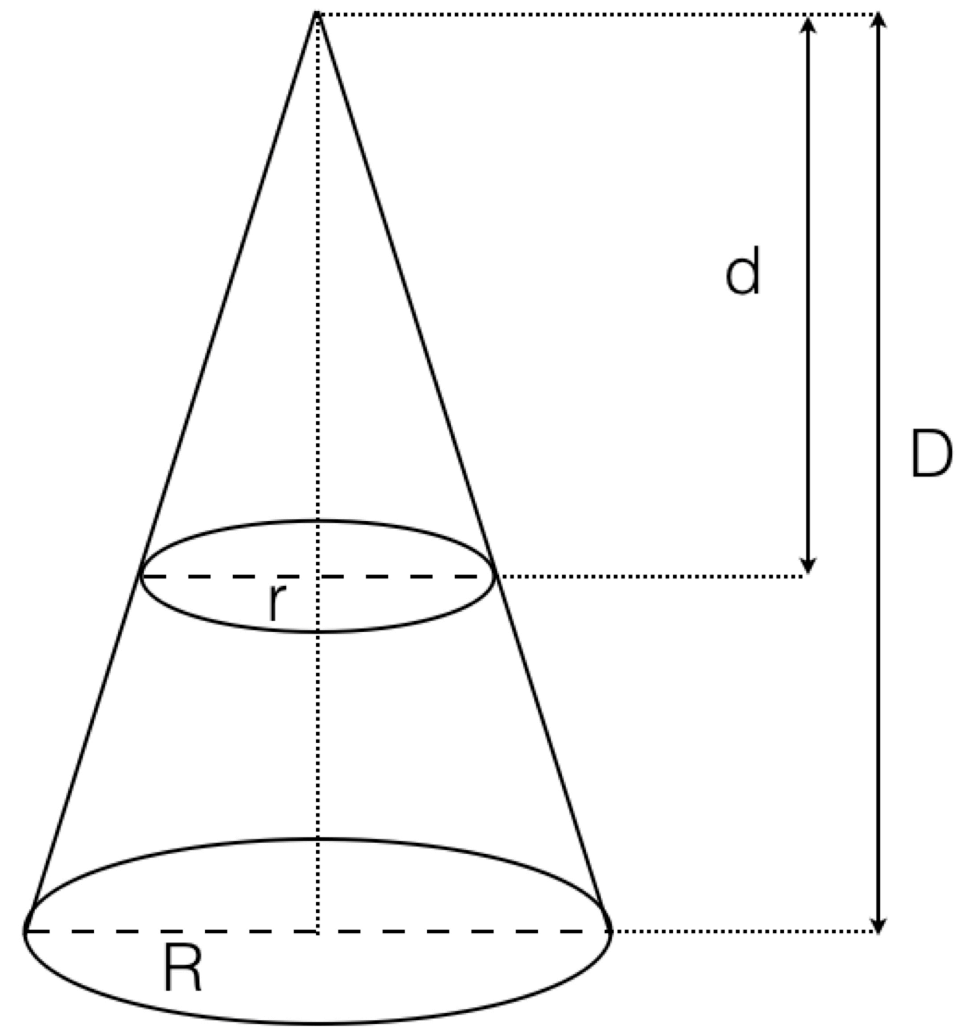




Jet Scaling Theory: Heinz & Sunyaev (2003)



General Relativity: mass = geometry

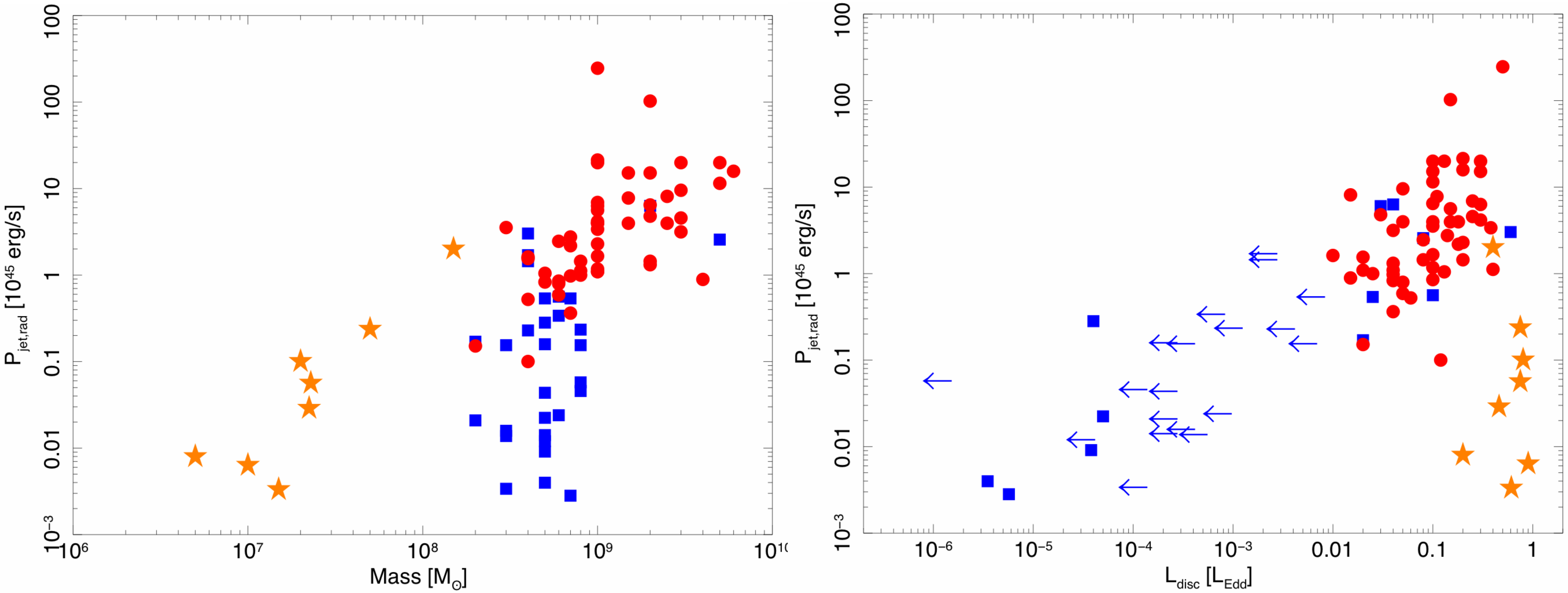


Self-similarity

Table 1. The dependence of B and C on M and $\dot{m}$, and the scaling indices ξ_M and $\xi_{\dot{m}}$ for different accretion modes (rows 1–3), and for the Ansatz that the mechanical jet luminosity $W_{\rm jet}$ should be proportional to the disc power $L_{\rm disc}$ (row 4), assuming $p = 2$.

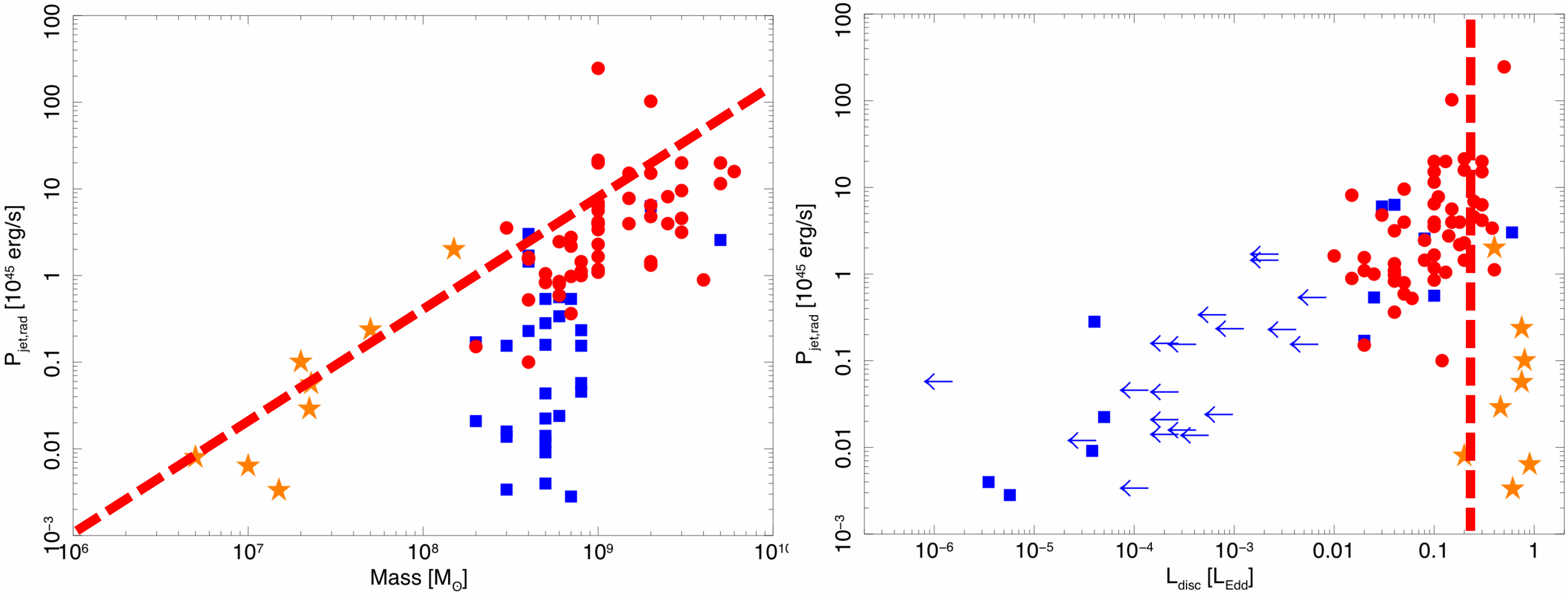
	Injection mode	$B^2 \propto C$	ξ_M	$\xi_{\dot{m}}$
1	ADAF	$\dot{m}/M$	$17/12 - \alpha/3$	$17/12 + 2\alpha/3$
2	rad. press. disc	M^{-1}	$17/12 - \alpha/3$	0
3	gas press. disc	$\dot{m}^{4/5} M^{-9/10}$	$(187 - 32\alpha)/120$	$(17/12 + 2\alpha/3)4/5$
4	$W_{\rm jet} \propto L_{\rm disc}$	$\dot{m}/M$	$17/12 - \alpha/3$	$17/12 + 2\alpha/3$

Jet Power as a function of mass and accretion rate



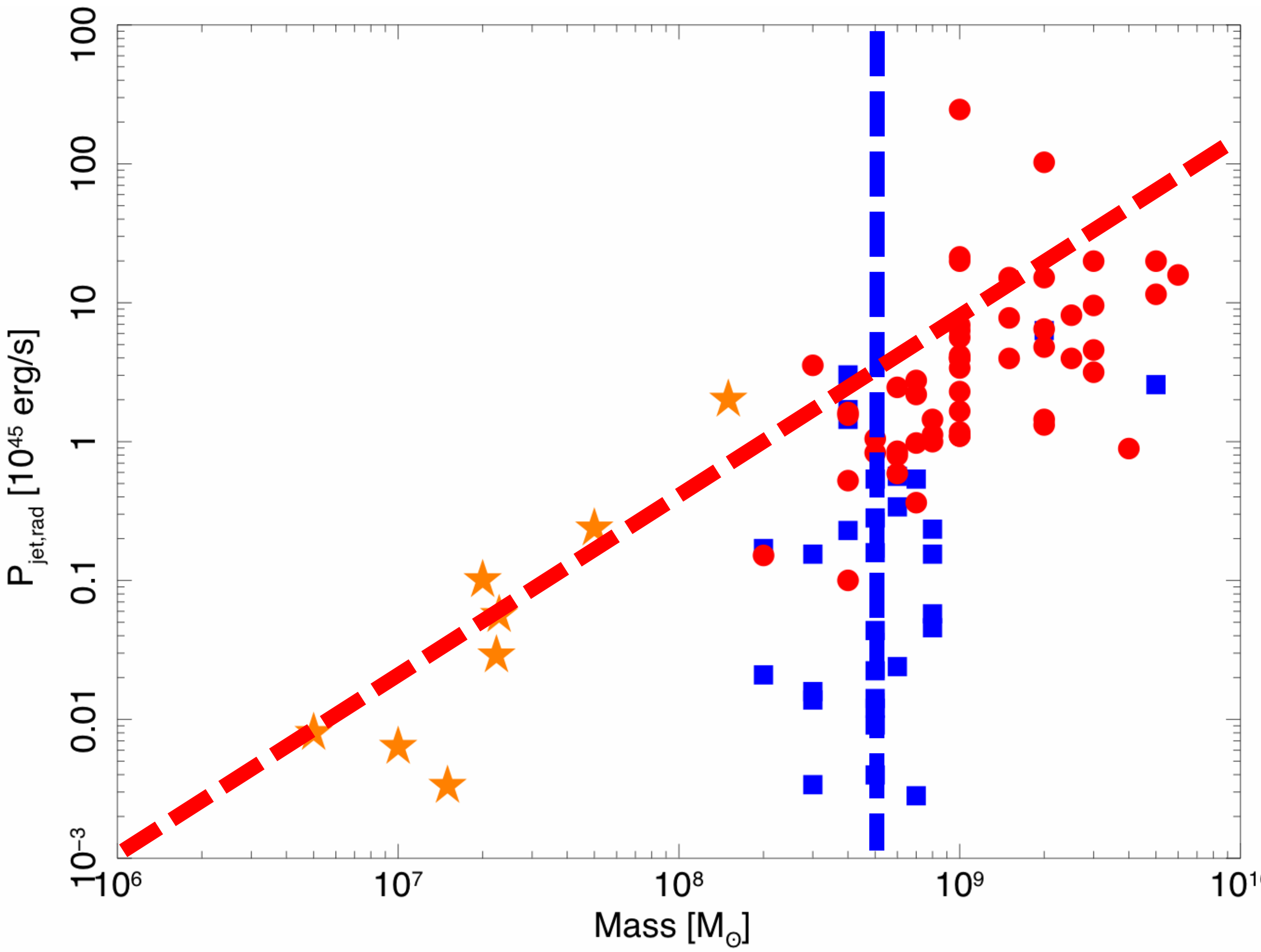
Foschini (2011)

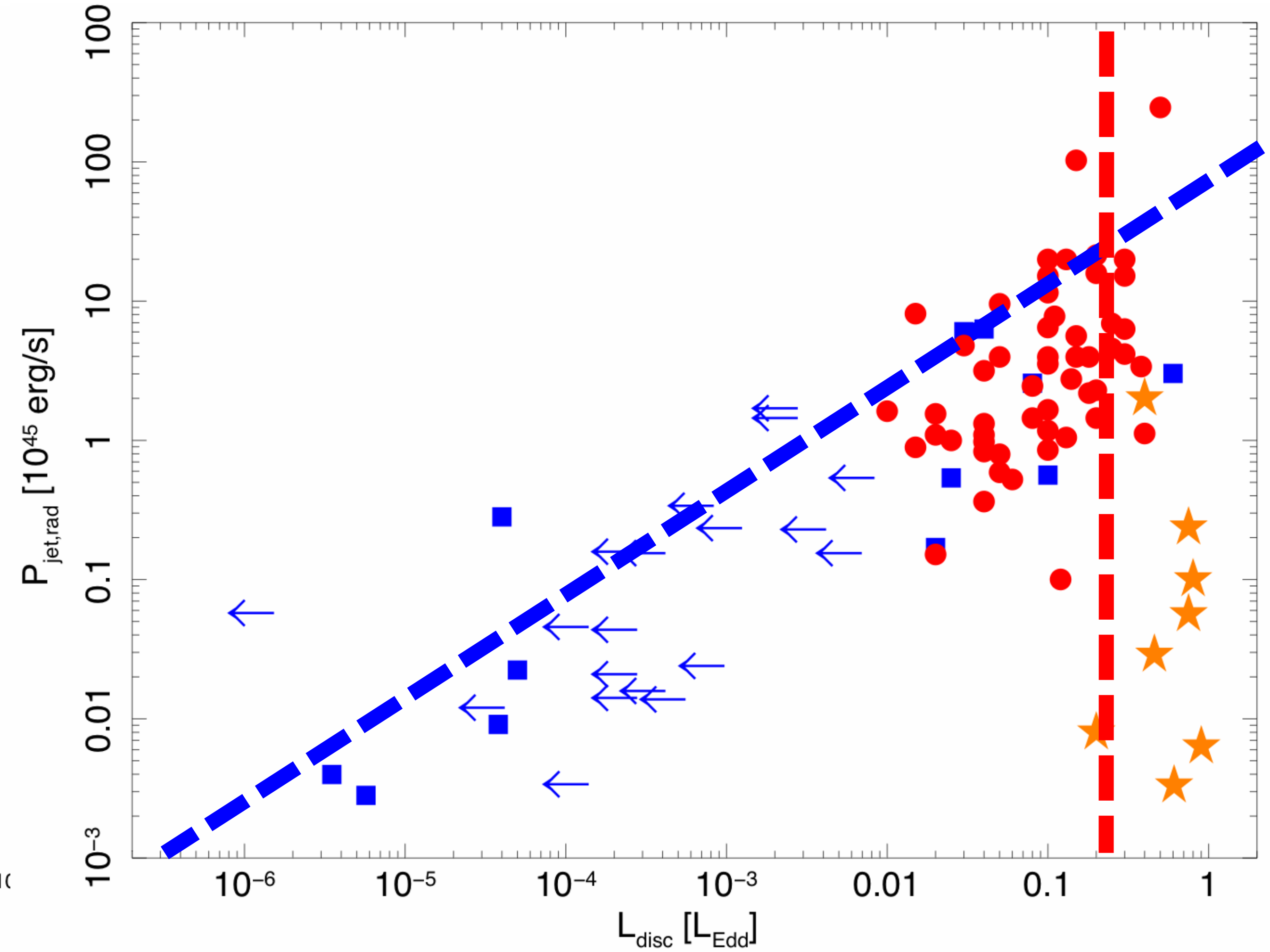
Jet Power as a function of mass and accretion rate



Foschini (2011)

Jet Power as a function of mass and accretion rate





Foschini (2011)

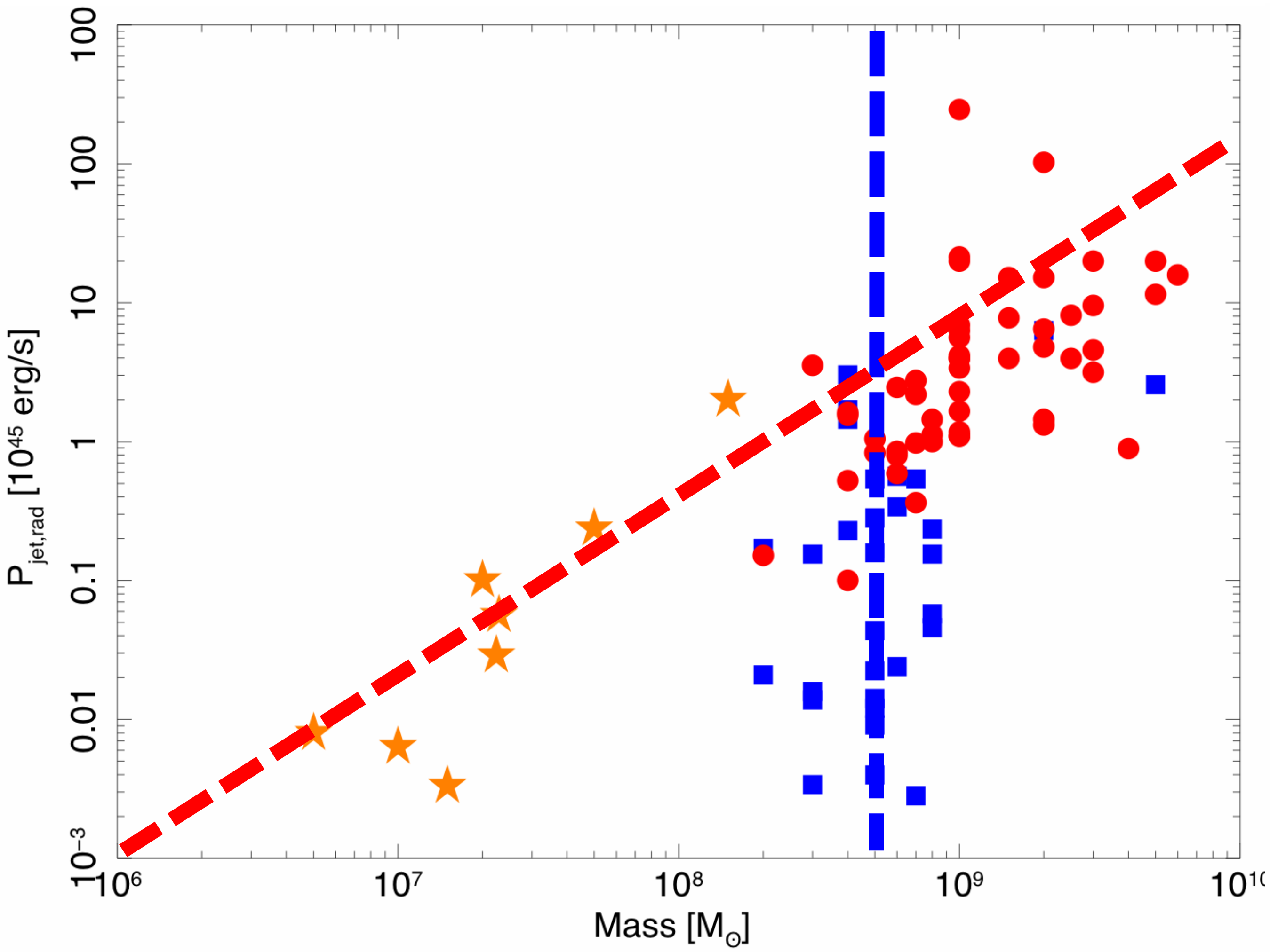
Jet Power as a function of mass and accretion rate

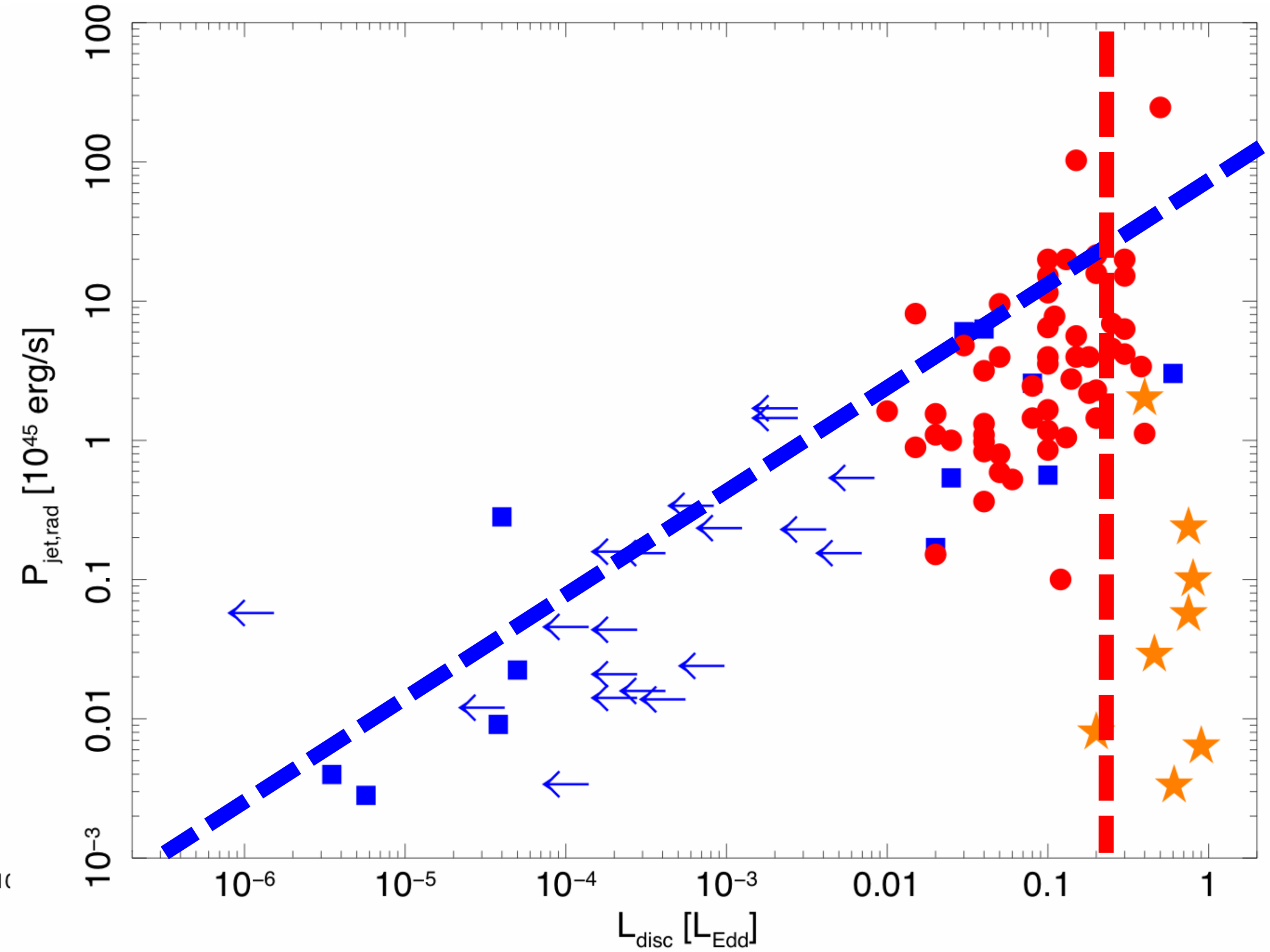
$$L_{BZ}\ (\mathrm{erg\ s^{-1}}) = \begin{cases} 2.10^{44} M_8 (J/J_{max})^2 \\ 8.10^{42} M_8^{11/10} \dot{m}_{-4}^{4/5} (J/J_{max})^2 \end{cases}$$

Radiation Pressure Dominated (disk)

Gas Pressure Dominated (disk)

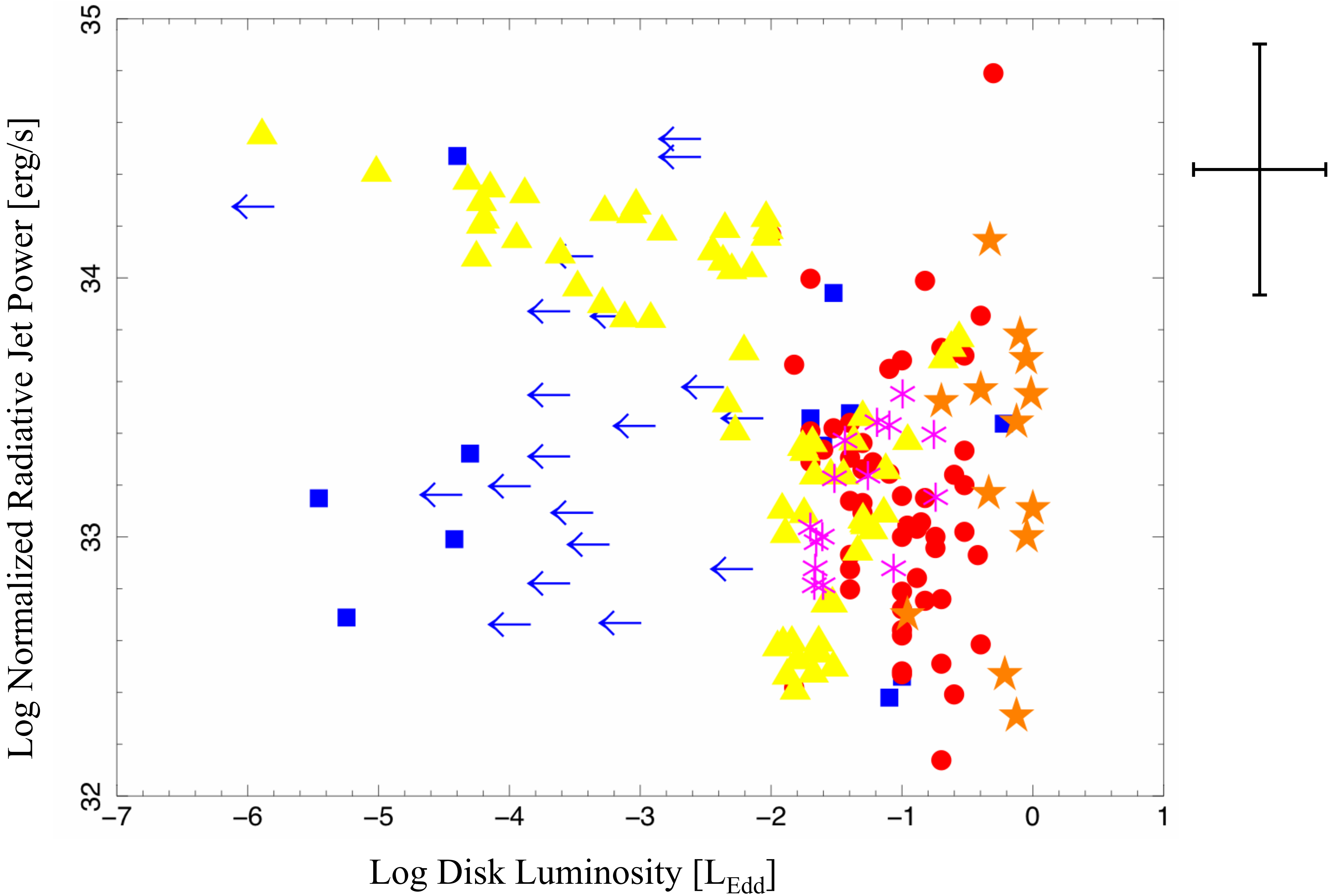
Moderski & Sikora (1996); Gosh & Abramowicz (1997)





Foschini (2011)

Unification of Relativistic Jets (*Foschini 2011-2014*)

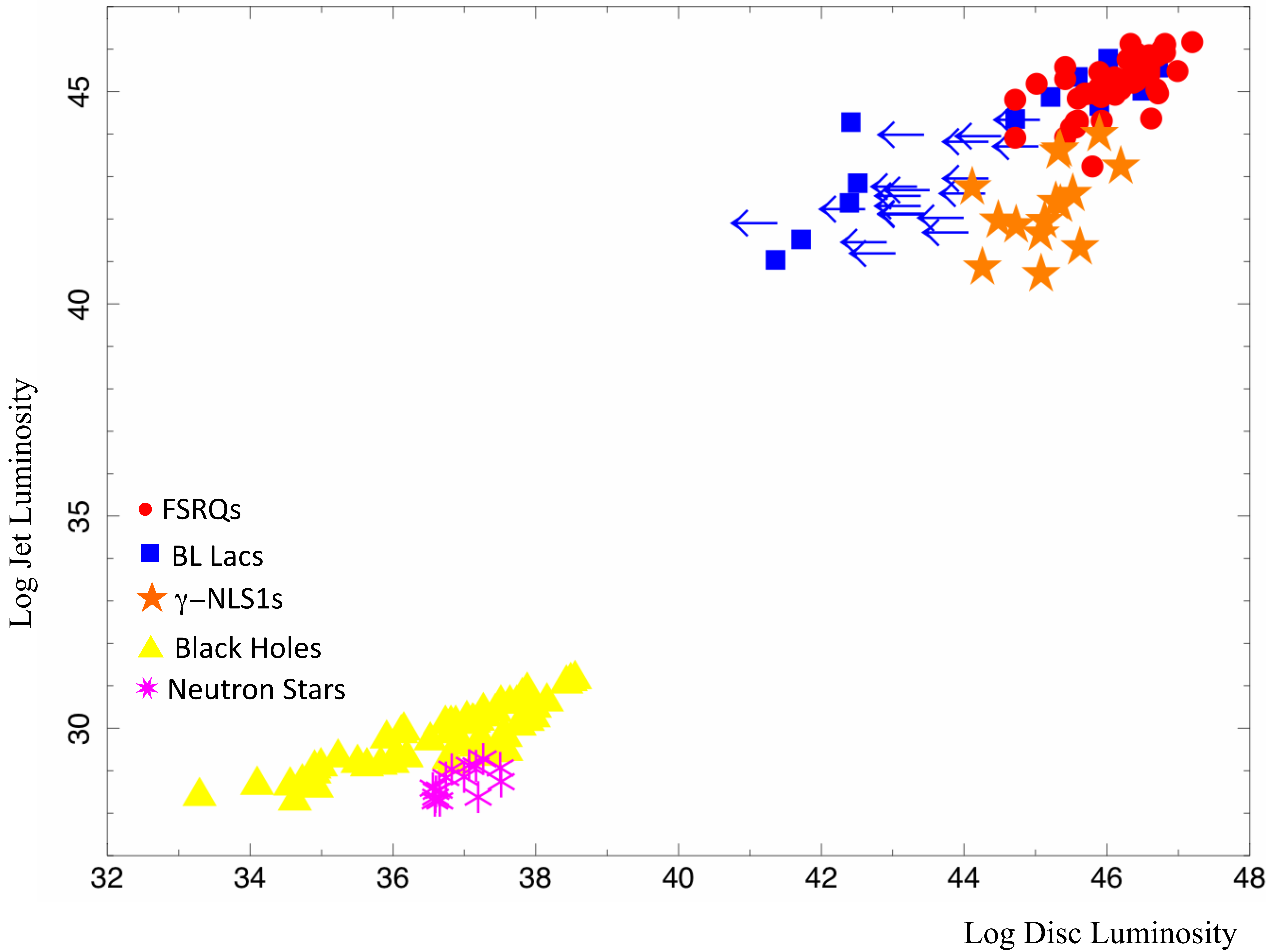


Measurement errors are about one order of magnitude. The remaining dispersion likely to be due to the lack of knowledge about the **spin** (Heinz & Sunyaev 2003; Mościbrodzka et al. 2016).

Mario Livio's Conjecture (1997):

"[…] I will make the assumption that the jet formation mechanism, namely, the mechanism for acceleration and collimation, is the same in all of the different classes of objects which exhibit jets. […] It should be noted right away that the emission mechanism which render jets visible in the different classes of objects, are very different in objects like, for example, YSOs and AGN."

Confirmed! At least for AGN and XRBs



Log Jet Luminosity
Log Disc Luminosity
30
35
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45
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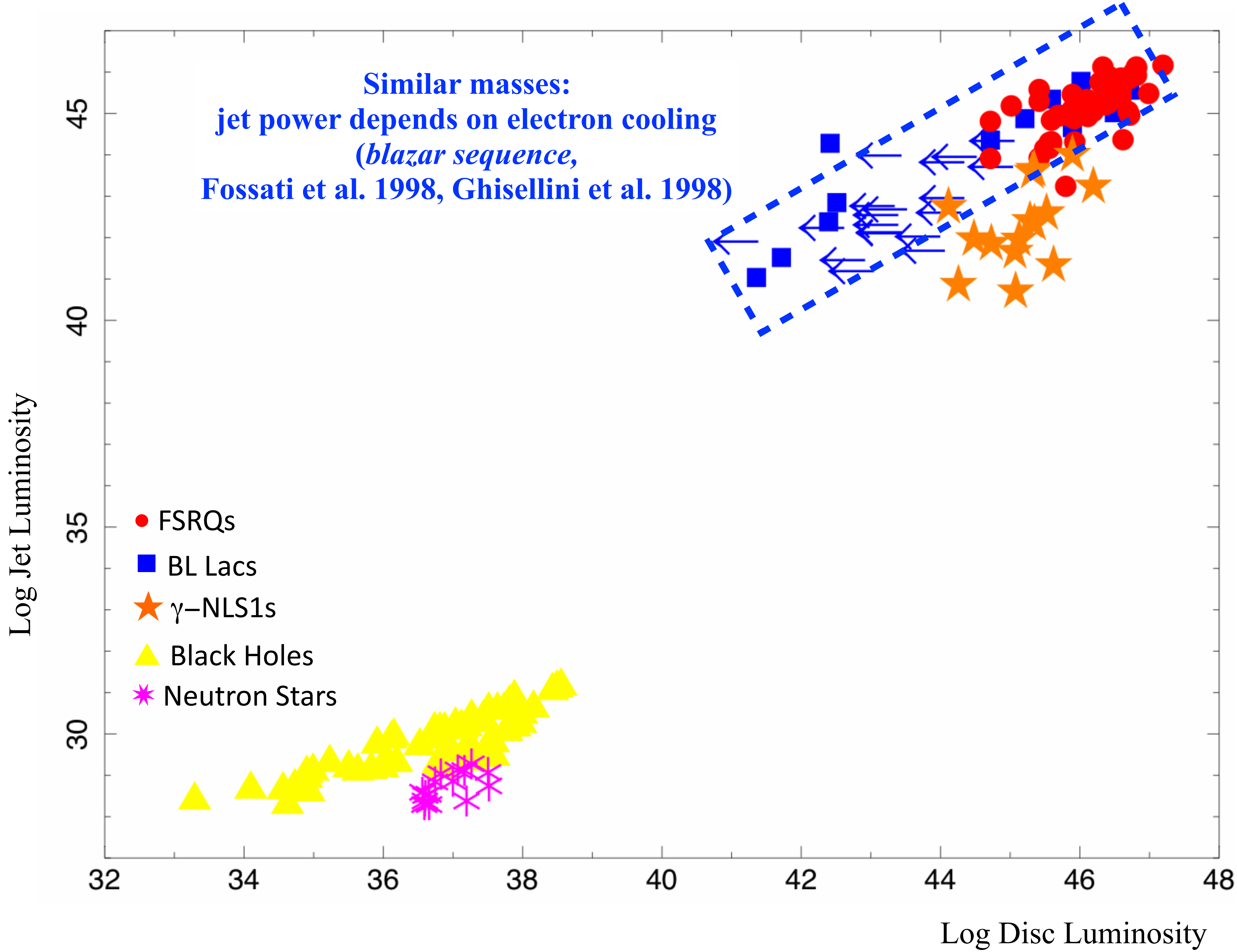
38
40
42
44
46
48
FSRQs
BL Lacs
γ–NLS1s
Black Holes
Neutron Stars


Similar masses:
jet power depends on electron cooling
(*blazar sequence*,
Fossati et al. 1998, Ghisellini et al. 1998)
FSRQs
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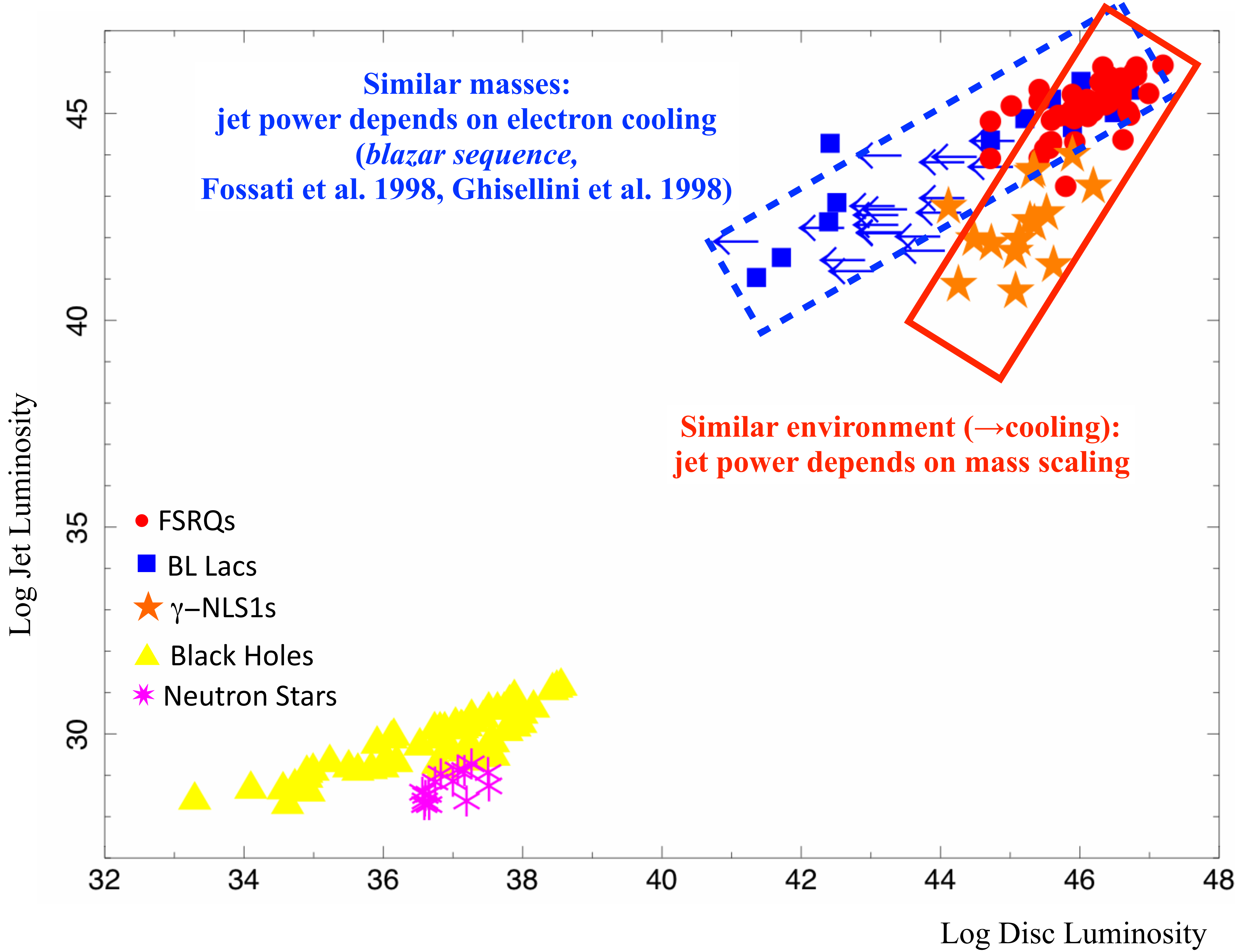

Similar masses:
jet power depends on electron cooling
(blazar sequence,
Fossati et al. 1998, Ghisellini et al. 1998)
Similar environment (→cooling):
jet power depends on mass scaling
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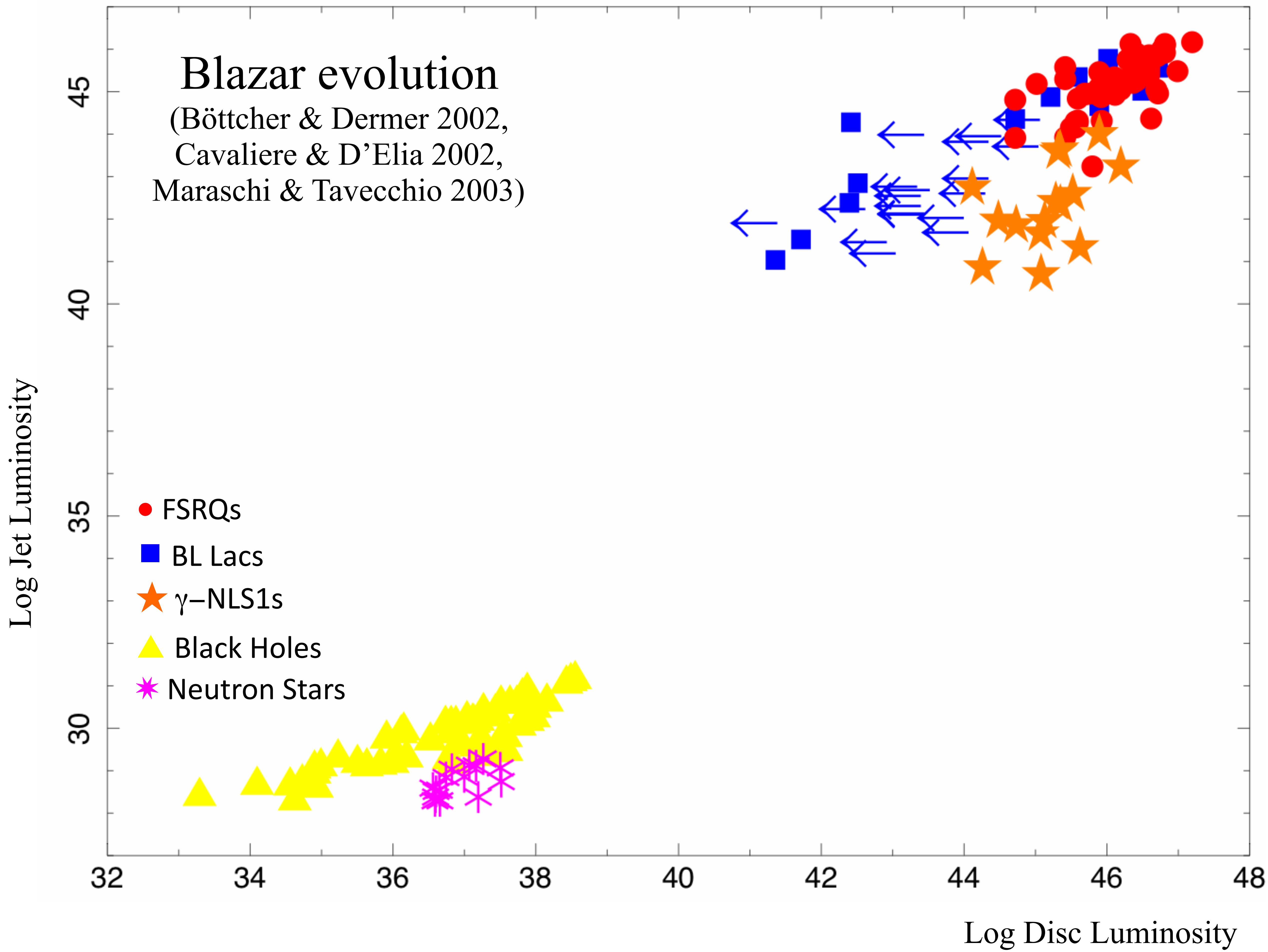
Blazar evolution
(Böttcher & Dermer 2002,
Cavaliere & D'Elia 2002,
Maraschi & Tavecchio 2003)
FSRQs
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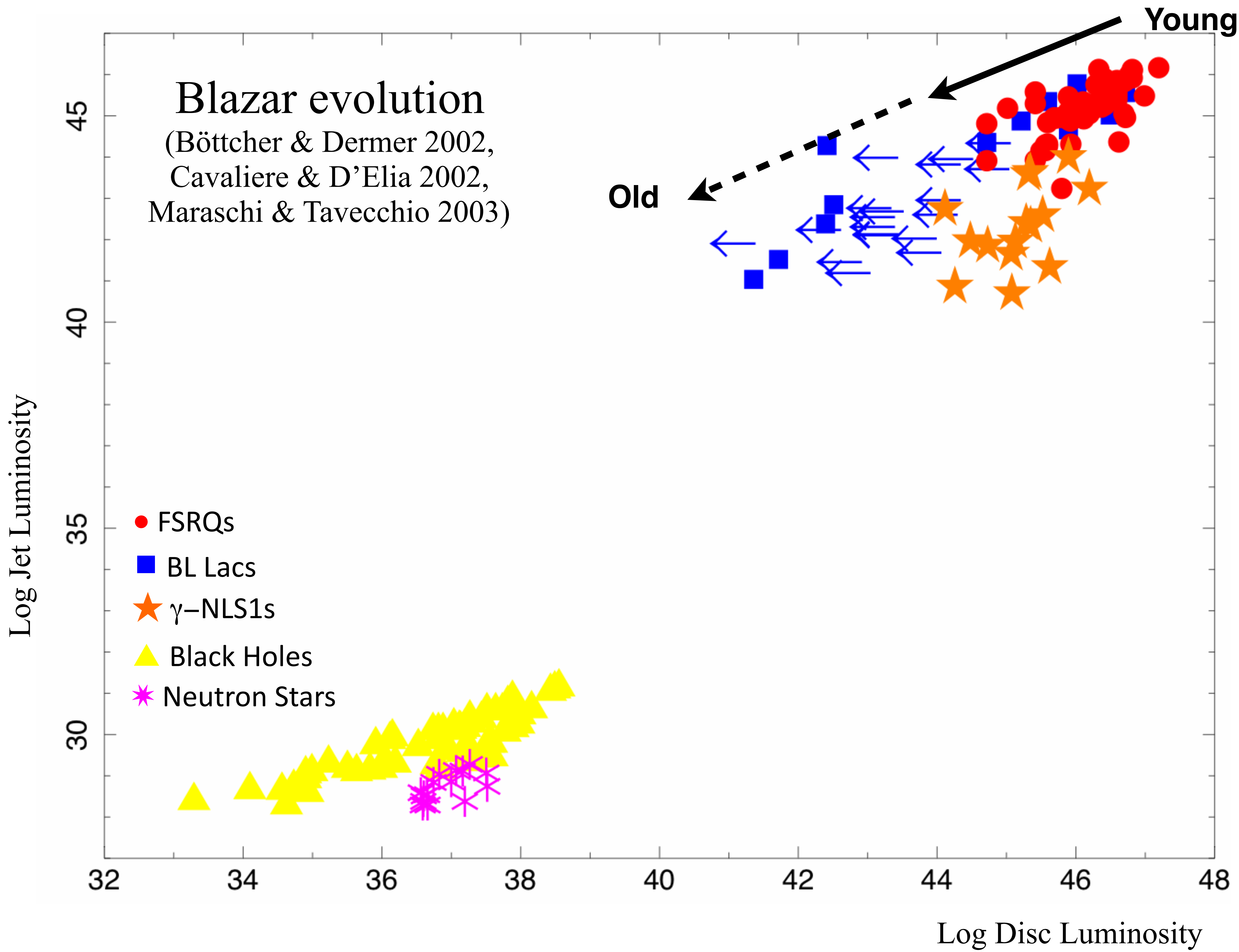
Young
Old
Blazar evolution
(Böttcher & Dermer 2002,
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FSRQs
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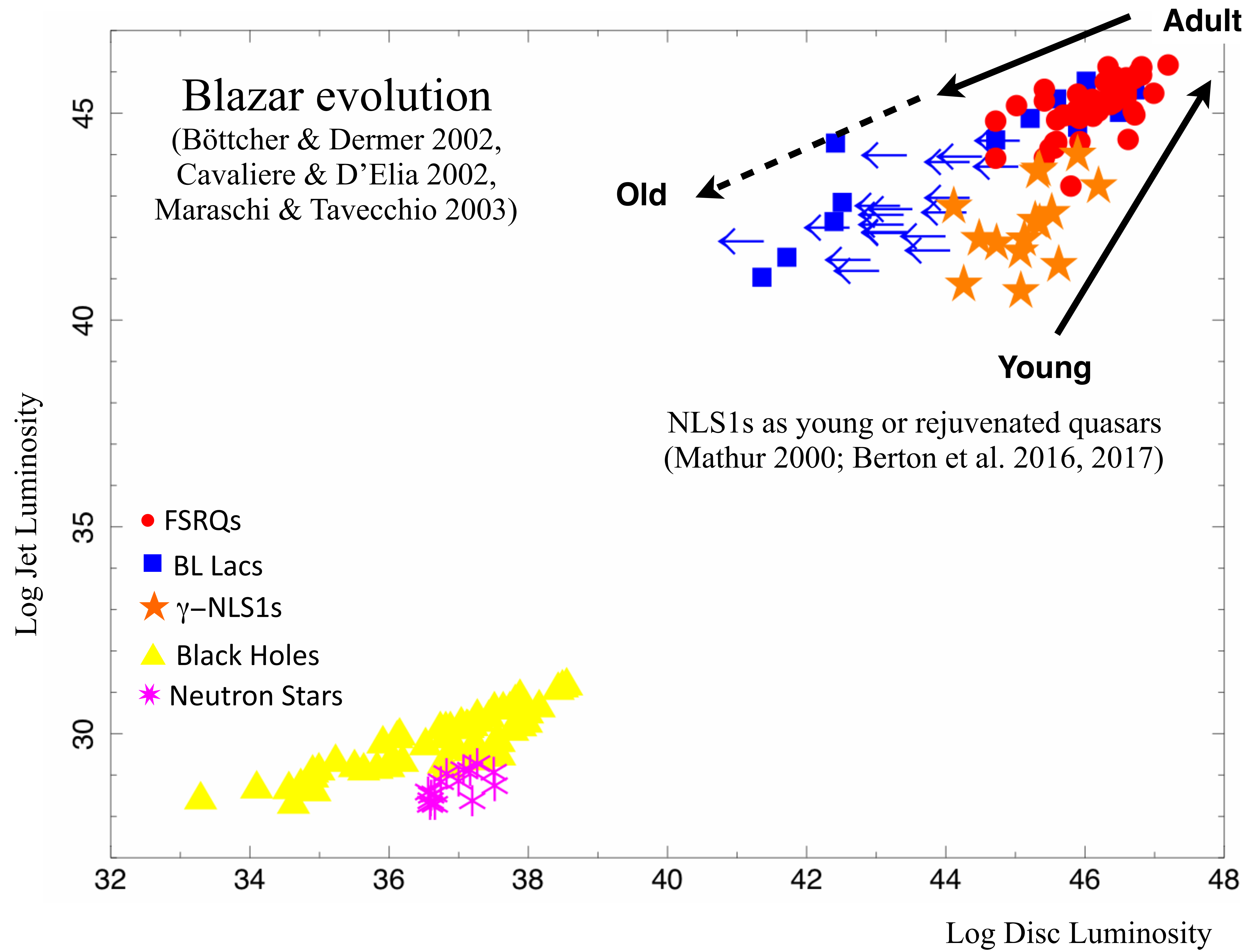

Blazar evolution
(Böttcher & Dermer 2002,
Cavaliere & D'Elia 2002,
Maraschi & Tavecchio 2003)
Adult
Old
Young
NLS1s as young or rejuvenated quasars
(Mathur 2000; Berton et al. 2016, 2017)
FSRQs
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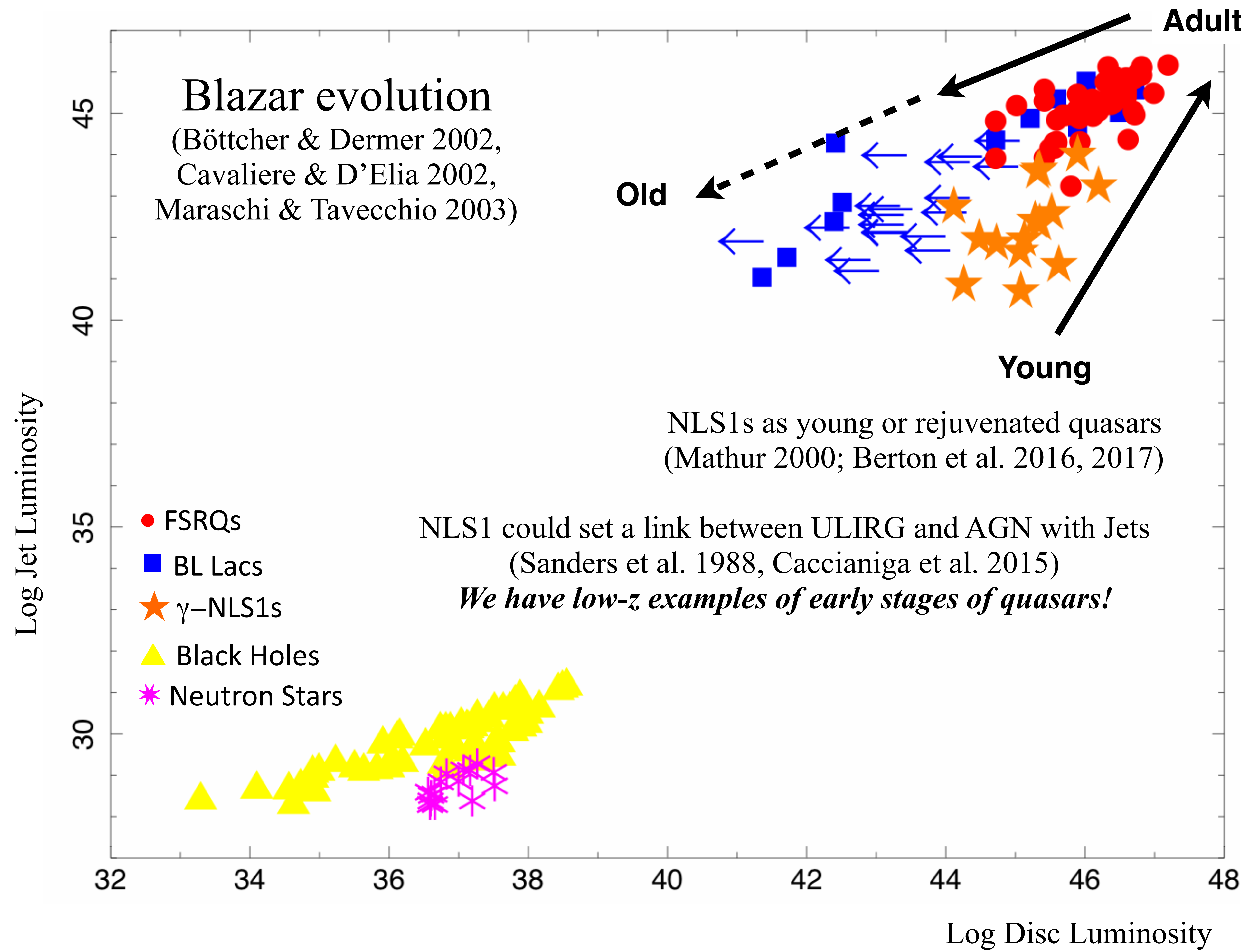

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Adult
Old
Young
NLS1s as young or rejuvenated quasars
(Mathur 2000; Berton et al. 2016, 2017)
NLS1 could set a link between ULIRG and AGN with Jets
(Sanders et al. 1988, Caccianiga et al. 2015)
We have low-z examples of early stages of quasars!
FSRQs
BL Lacs
γ−NLS1s
Black Holes
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To update the Unified Scheme for Jetted AGN…

Jetted AGN	Strong Emission Lines	Weak/No Emission Lines
Beamed (blazar?)	FSRQ + NLS1	BL Lac Obj
Unbeamed (radio galaxy?)	HERG + CSS	LERG

However…

- **Blazar** and **Radio Galaxy** are terms today associated to a certain type of cosmic sources: **high black hole mass**, **elliptical host galaxy**, …
- Risk to lose important information/differences by simply adding NLS1s and CSS to the scheme under the blazar and radio galaxy labels (different black hole mass, different host,…);
- Not a negligible detail: remind **biases** in previous works caused by selecting only bright sources:
  - threshold mass in jet generation (→ no unification with XRB jets)
  - blazar sequence (partially revised to include also small-mass quasar, although considered only as "pollution"; Ghisellini & Tavecchio 2008; Ghisellini et al. 2017)
- **Martin Gaskell** (2012): "When you attach different classifications to things, it is all too easy to get convinced that they are different things". On the opposite, if you attach the same name to different things, it is all too easy to get convinced that they are the same thing.

The Physical Unified Scheme for Jetted AGN

Let’s keep observational differences, but unify the sources by means of a physical scheme.

Jetted AGN	Efficient Cooling	Inefficient Cooling
High Mass	**HMEC** (FSRQ, HERG)	**HMIC** (BL Lac obj, LERG)
Low Mass	**LMEC** (NLS1, CSS)	**LMIC?**

(Foschini, L., 2017, What we talk about when we talk about blazars?, *Frontiers in Astronomy and Space Science*, **4**, id. 6)

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$$M \sim 10^8 M_\odot$$

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$M \sim 10^8 M_\odot$

$L_{disk}/L_{Edd} \sim$ 0.01-0.001

[equivalent to Excitation Index~1; cf Best & Heckman (2012)]

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