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Accretion and jet power in active galactic nuclei

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Abstract The classical diagrams of radio loudness and jet power as a function of mass and accretion rate of the central spacetime singularity in active galactic nuclei are re-analyzed by including the data of the recently discovered powerful relativistic jets in Narrow-Line Seyfert 1 Galaxies. The results are studied in the light of the known theories of relativistic jets, indicating that, although the Blandford-Znajek mechanism is sufficient to explain the power radiated by BL Lac Objects, it fails to completely account for the power from quasars and Narrow-Line Seyfert 1 Galaxies. This favors the scenario outlined by Cavaliere & D'Elia of a composite jet, with a magnetospheric core plus a hydromagnetic component emerging when the accretion power increases and the disk becomes radiation-pressure dominated. A comparison with Galactic compact objects is also made, finding some striking similarities, indicating that since neutron stars are low-mass jet systems analogous to black holes, Narrow-Line Seyfert 1 Galaxies are low-mass counterparts of blazars.

Key words: galaxies: jets — BL Lacertae objects: general — quasars: general — galaxies: Seyfert

1 INTRODUCTION

Despite their omnipresence in the Universe and thousands of written papers, relativistic jets are still poorly understood and there is no consensus about their underlying mechanisms.

In the discussion after Blandford's seminal talk at the 1978 "Pittsburgh conference on BL Lac Objects," G. Burbidge raised one question about the possible importance of the host galaxy in the generation of relativistic jets in BL Lacs. Blandford answered that the host galaxy should not be a relevant detail, because the phenomena related to the jet occur within the central ten parsecs (Blandford & Rees 1978).

However, later observations seemed to support the idea that instead the host galaxy plays some role, with jets preferring ellipticals rather than spirals. By inverting Blandford's answer, Laor (2000) asked how it is possible that the jet, which indeed originated in the very inner part of a galaxy, could be related to the host. He suggested that one possible solution is that jets require large black hole masses ($\gtrsim 10^9\,M_\odot$), which in turn are hosted in ellipticals. On the other hand, active galactic nuclei (AGNs) with no jets have masses of the central singularity $\lesssim 3\times10^8\,M_\odot$. Sikora et al. (2007) confirmed some similar division, although with smoother boundaries, by finding that AGNs with $M \gtrsim 10^8\,M_\odot$ have radio loudness parameters three orders of magnitude greater than those AGNs with $M \lesssim 3\times10^7\,M_\odot$.

Sikora et al. (2007) also reported some differences between the radio loudness and accretion rate of the central black hole in spiral- and elliptical-hosted AGNs, where just a very few exceptions of spiral-hosted AGNs can display high accretion and high radio loudness. Generally, the radio loudness is greater when the accretion rate is lower, somehow recalling the jets in Galactic binaries, which are linked to low/hard states (see Belloni 2010 for recent reviews).

Recently, Broderick & Fender (2011) suggested a correction of the radio loudness due to the mass, which leads to the vanishing of the radio-loud/quiet dichotomy, leaving only a general trend of greater radio loudness as the accretion rate decreases.

Last, but not least, when speaking about jets, the black hole spin cannot be missing. This property seems to be "a finger in every pie" ("come il prezzemolo," an Italian saying), with its contribution mixed in every possible way.

This scenario has been perturbed by the recent discovery of high-energy γ rays from Narrow-Line Seyfert 1 Galaxies (γ-NLS1s, see Foschini 2011a for a recent review[1]). These AGNs have relatively small masses ($10^6 - 10^8 M_\odot$), high accretion rates ($0.1 - 1 L_{\rm Edd}$, see fig. 8 in Foschini 2011a), are generally hosted by spiral galaxies and could develop powerful relativistic jets, as luminous as those in blazars. Other differences with blazars refer to the full width half maximum (FWHM) of the broad permitted lines (in the case of Hβ, the value is $\gtrsim 2000$ km s^{-1} for blazars and $\lesssim 2000$ km s^{-1} for γ-NLS1s) and radio morphology, which is very compact ($\lesssim 10$ pc, see e.g. Gu & Chen 2010, except for one known case, PKS 0558$-$504, Gliozzi et al. 2010) for γ-NLS1s; blazars display extended structures, up to hundreds of parsecs. Therefore, even though the jets of γ-NLS1s are very similar to those in blazars, almost all the remaining fraction of AGNs and their host galaxies are different, meaning that γ-NLS1s are indeed a new class of γ-ray AGNs[2].

In the present work, I report on a comparative study of the main characteristics of the jets of blazars (BL Lac Objects and flat-spectrum radio quasars, FSRQs) and γ-NLS1s. I adopt a ΛCDM cosmology with $H_0 = 70$ km s^{-1} Mpc^{-1} and $\Omega_\Lambda = 0.73$ (Komatsu et al. 2011).

2 SAMPLE SELECTION

I have collected the data of 30 FSRQs and nine BL Lac Objects from Ghisellini et al. (2010) and added the four γ-NLS1s from Abdo et al. (2009a). The total jet power reported in those papers has been calculated by means of the spectral energy distribution (SED) modeling, according to Ghisellini & Tavecchio (2009). The same model calculates the masses and the accretion rates by fitting the optical/ultraviolet emission to a standard Shakura-Sunyaev accretion disk and the results have been cross-checked with the measurements made with other independent methods available in literature (mostly by the classical reverberation mapping technique).

Some BL Lacs only have an upper limit for the disk luminosity. Recently, weak Lyα emission lines (equivalent width $\ll 1$ Å) have been observed in Mkn 501 and Mkn 421 (Stocke et al. 2011). The disk luminosity [in Eddington units] calculated from these lines, by assuming that $L_{\rm disc} \sim 10 L_{\rm Ly\alpha}$, is 5.7×10^{-6} and 3.5×10^{-6} for Mkn 501 and Mkn 421, respectively (see Foschini 2011b). The non-detection of any line in PKS 2155$-$304 poses an upper limit tighter than the upper limit in Ghisellini et al. (2010). Therefore, in these three cases (Mkn 421, Mkn 501, PKS 2155$-$304), I adopt the values of the accretion from Stocke et al. (2011).

Radio data have been taken from the *Monitoring Of Jets in Active galactic nuclei with VLBA Experiments* (MOJAVE) at 15 GHz (Lister et al. 2009). When the source was not in the MOJAVE

[1] See also the Proceedings of the workshop "Narrow-Line Seyfert 1 Galaxies and Their Place in the Universe" (Milano, Italy, April 4–6, 2011) to have a recent summary of the knowledge on NLS1s: *http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=126*.

[2] Obviously, NLS1s are not newly classified as AGNs, since they were discovered by Osterbrock & Pogge (1985) more than one quarter century ago. However, NLS1s are newly classified as γ-ray emitters. The difference seems subtle, but it is important. Just to cite Mark Twain: "The difference between the right word and the almost right word is the difference between lightning and lightning-bug."

list, then data from NED[3] have been used. In case of multiple measurements, then the average was calculated. When possible, the measurements performed in the period covered by *Fermi*/LAT observations were considered. If no 15 GHz measurements were available, then data at the nearest frequency have been selected and converted to 15 GHz by adopting a flat radio spectral index ($\alpha_{\rm r} = 0$). The radio loudness parameter RL has been calculated by using the radio flux at 15 GHz and the ultraviolet flux at 200 nm, calculated from the accretion luminosity. Basically, RL is now a better indicator of the jet dominance over the accretion.

To increase the statistics of γ-NLS1s, I have also included the three newly discovered sources reported by Foschini (2011a) in the sample. In this case, no modeling is available and the jet power has been calculated by using the "calibration" of the Ghisellini & Tavecchio (2009) model (see Sect. 4). The source list is shown in Table 1.

3 WHO CARES ABOUT RADIO LOUDNESS?

Figure 1 displays the radio loudness versus the mass of the central black hole and its accretion luminosity in Eddington units, which in turn is proportional to the accretion rate. Figure 1 (top panel) can be compared with figure 4 of Sikora et al. (2007) and figure 1 of Woo & Urry (2002). The former reported a dependence of RL with the mass (high RL requires high masses), while the latter did not find this dependence. The sample studied in the present work is composed of AGNs with jets, so it is not exactly comparable with the larger samples of Sikora et al. (2007) and Woo & Urry (2002), but some interesting features are already visible.

I note a central region, broadly consistent with the results of Woo & Urry (2002). The γ-NLS1s are populating the region with high RL and low masses. The deviations from this central zone are quite localized in two regions: one where there are objects with high masses and low accretion rates, but with high RL (featureless BL Lacs); the other refers to objects with low masses, high accretion rates and low RL. This seems to suggest that the changes in the radio loudness are more linked to the accretion rate, rather than directly to the mass (see, however, Sect. 4). This is indeed what is shown in Figure 1 (bottom panel), where a trend of decreasing RL with increasing accretion rate is shown, which is in agreement with the results given in figure 3 of Sikora et al. (2007) and figure 1 of Broderick & Fender (2011).

It is worth noting that low-power jet sources can have either high or low RL. So, a high RL does not necessarily mean a powerful jet, but rather a low accretion rate. One could ask oneself if the radio loudness is still a meaningful parameter. The answer could be yes, if one wants to just know if an AGN has a jet or not; no, if one wants to perform a deeper study of relativistic jets.

4 JET POWER

Before continuing, it is worth performing some kind of "calibration" of the total jet power calculated according to the model by Ghisellini & Tavecchio (2009) by adding the radiative, magnetic and particle contributions. It is known that the luminosity of a relativistic jet is correlated with its radio core emission according to (Blandford & Königl 1979; Körding et al. 2006)

$$P_{\rm jet} \propto L_{\rm radio,core}^{12/17}, \qquad (1)$$

and, therefore, this relationship can be used as a way to "calibrate" the Ghisellini & Tavecchio's model. In this work, I used the radio data at 15 GHz, mostly from the MOJAVE Project, which in turn is based on high-resolution VLBA observations that allow researchers to have the best measurement of the core available to date. Obviously, in this case the three new γ-NLS1s (sources in italics in Table 1) have not been considered, since no modeling is available yet. Instead, the relationship

[3] *http://ned.ipac.caltech.edu/*

Table 1 Source List in Alphabetical Order Per Type

Name	Type	z	$\log M/M_{\odot}$	$L_{\rm disc}/L_{\rm Edd}$	$S_{15\ \rm GHz}$	$\log P_{\rm jet}$	RL
AO 0235+164	B	0.940	9.00	3.0×10^{-2}	3.486	46.67	56784
BL Lac	B	0.069	8.70	$< 4.0 \times 10^{-4}$	4.122	44.97	26876
Mkn 421	B	0.031	8.70	3.5×10^{-6}	0.327	43.71	47394
Mkn 501	B	0.034	8.84	5.7×10^{-6}	0.848	43.48	63489
OJ 287	B	0.306	8.70	$< 3.0 \times 10^{-3}$	4.587	45.15	97424
PKS 0332−403	B	1.445	9.70	8.0×10^{-2}	1.781(*)	47.12	7060
PKS 0537−441	B	0.894	9.30	4.0×10^{-2}	10.667(*)	47.22	57107
PKS 2155−304	B	0.116	8.90	$< 1.1 \times 10^{-6}$	0.160(*)	44.97	700894
S5 1803+784	B	0.680	8.70	2.5×10^{-2}	2.709	46.82	46052
3C 273	Q	0.158	8.90	4.0×10^{-1}	24.002	47.79	558
3C 279	Q	0.536	8.90	2.5×10^{-2}	12.771	46.33	75558
3C 454.3	Q	0.859	9.00	2.0×10^{-1}	15.864	47.89	30610
B2 1520+31	Q	1.487	9.40	1.5×10^{-2}	0.402	46.62	18441
B2 1846+32A	Q	0.798	8.70	1.3×10^{-1}	0.496	46.61	2434
B3 0650+453	Q	0.933	8.48	1.0×10^{-1}	0.332	46.90	5302
B3 0917+449	Q	2.190	9.78	2.0×10^{-1}	2.100	47.61	9427
B3 1633+382	Q	1.813	9.70	1.0×10^{-1}	3.312	47.12	20254
PKS 0227−369	Q	2.115	9.30	1.0×10^{-1}	0.287(*)	47.38	6955
PKS 0347−211	Q	2.994	9.70	1.0×10^{-1}	0.474	47.05	13560
PKS 0454−234	Q	1.003	9.40	5.0×10^{-2}	1.820	46.55	8452
PKS 1454−354	Q	1.424	9.30	1.5×10^{-1}	1.230(*)	47.60	6236
PKS 1502+106	Q	1.838	9.48	1.3×10^{-1}	1.641	47.07	13397
PKS 2023−07	Q	1.388	9.48	5.0×10^{-2}	1.005	46.94	9480
PKS 2144+092	Q	1.113	9.00	1.0×10^{-1}	0.845	47.01	6490
PKS 2201+171	Q	1.076	9.30	4.0×10^{-2}	1.088	46.78	9532
PKS 2204−54	Q	1.215	9.00	1.8×10^{-1}	1.277(*)	47.11	6926
PKS 2227−08	Q	1.559	9.18	1.1×10^{-1}	5.158	47.31	61576
PKS B0208−512	Q	0.999	8.84	1.4×10^{-1}	2.893(*)	46.49	16954
PKS B1127−145	Q	1.184	9.48	2.5×10^{-1}	2.558	47.32	3101
PKS B1508−055	Q	1.185	9.30	2.0×10^{-1}	0.769	46.63	1752
PKS B1510−089	Q	0.360	8.84	4.0×10^{-2}	2.401	46.79	3960
PKS B1908−201	Q	1.119	9.00	2.0×10^{-1}	6.727	46.92	26215
PMN J2345−1555	Q	0.621	8.60	6.0×10^{-2}	0.635(*)	45.97	4485
S3 2141+17	Q	0.211	8.60	1.2×10^{-1}	0.942	45.28	273
S4 0133+47	Q	0.859	9.00	1.0×10^{-1}	3.536	47.11	13646
S4 0954+55	Q	0.895	9.00	2.0×10^{-2}	0.210	45.46	4517
S4 1030+61	Q	1.400	9.48	4.0×10^{-2}	0.400	46.69	4832
S4 1849+67	Q	0.657	8.78	5.0×10^{-2}	2.700	46.41	17548
SBS 0820+560	Q	1.418	9.18	1.5×10^{-1}	1.682(*)	46.91	11236
1H 0323+342	S	0.061	7.00	9.0×10^{-1}	0.353	44.36	40
FBQS J1102+2239	S	0.453	7.62	4.0×10^{-1}	0.003	44.57	13
PKS 1502+036	S	0.409	7.30	8.0×10^{-1}	0.496	46.21	1926
PKS 2004−447	S	0.240	6.70	2.0×10^{-1}	0.227(*)	44.16	4198
PMN J0948+0022	S	0.585	8.18	4.0×10^{-1}	0.473	46.72	1153
SBS 0846+513	S	0.584	7.56	4.7×10^{-1}	0.225	46.34	1937
SDSS J1246+0238	S	0.363	7.34	7.6×10^{-1}	0.036	45.30	102

(B: BL Lac Object; Q: FSRQ; S: γ-NLS1). The mass, disk luminosity and jet power [erg s^{-1}] are from Ghisellini et al. (2010) for the blazars and Abdo et al. (2009a) for the γ-NLS1. The radio flux density [Jy] are from the MOJAVE Project or from NED (indicated with *; in the case of PKS 1454−354 I adopted the value from Abdo et al. 2009b). The γ-NLS1s in italics are the new discoveries reported by Foschini (2011a). In this case, the jet power has been calculated with the correlation reported in Section 4. The last column indicates the radio-loudness parameter.

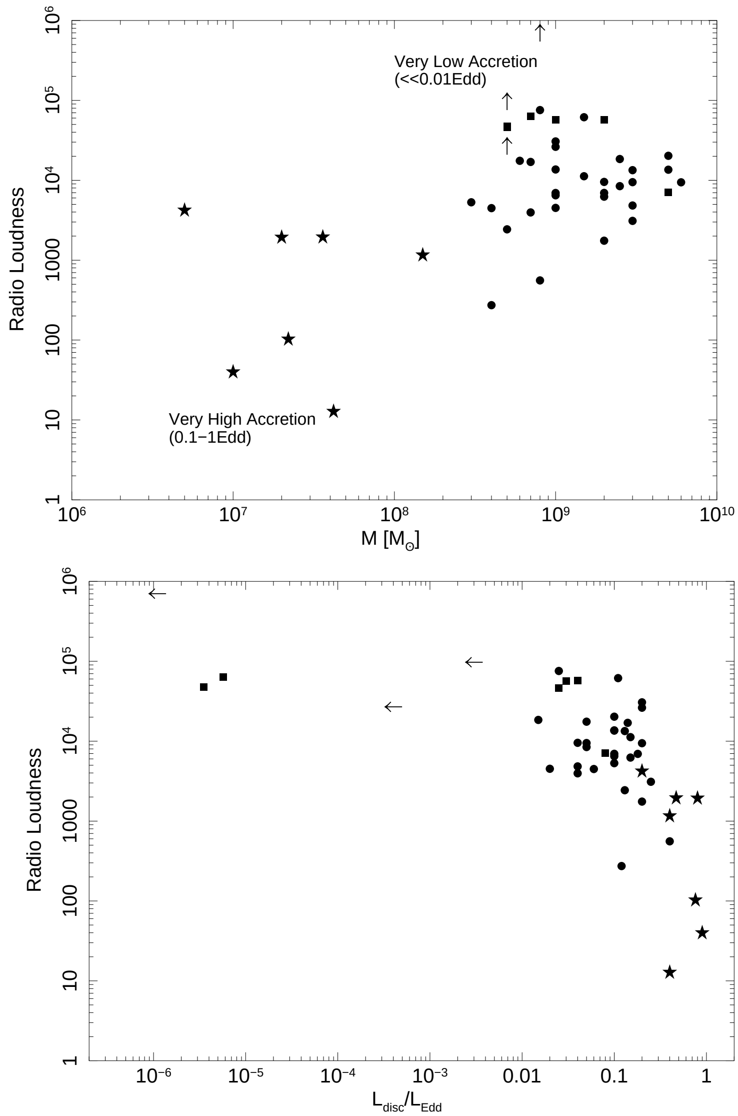

Fig. 1 Radio loudness versus mass of the central black hole (*top panel*) and disk luminosity in Eddington units (*bottom panel*). Circles indicate FSRQs; squares and arrows (upper limits) are for BL Lac Objects; stars represent γ-NLS1s.

obtained and shown below has been used to calculate the jet power of these three sources from the radio measurements.

The results are displayed in Figure 2, where the correlation is already visible by eye. The search for correlation has been performed by using the `ASURV Rev. 1.2` software package (Lavalley et al. 1992), which makes use of the algorithms by Feigelson & Nelson (1985) and Isobe et al. (1986). The correlation is confirmed by the Spearman's $\rho = 0.8$ ($P_{\rm chance} < 10^{-4}$) and a high Z value of the Kendall's test ($Z = 5.6$, $P_{\rm chance} < 10^{-4}$). The two powers are linked by the following

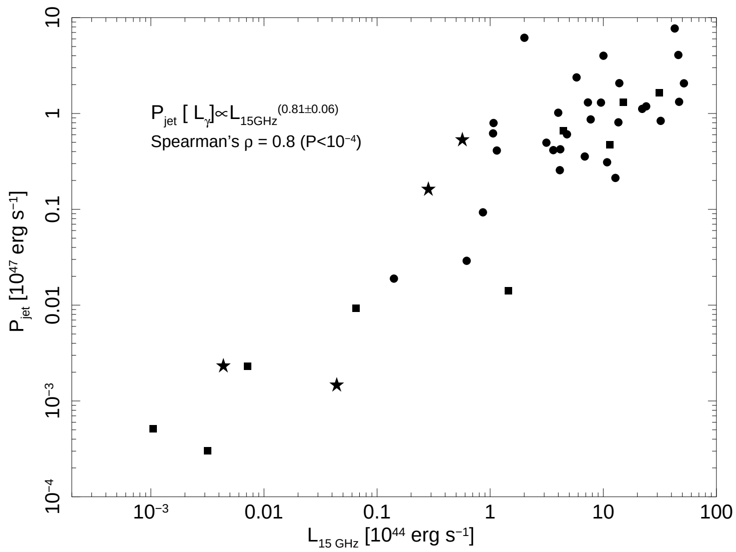

Fig. 2 Jet power versus radio power at 15 GHz. Circles indicate FSRQs; squares and arrows (upper limits) are for BL Lac Objects; stars represent γ-NLS1s.

equation

$$\log P_{\rm jet} = (11 \pm 3) + (0.81 \pm 0.06) \log L_{15\ \rm GHz}. \quad (2)$$

The index 0.81 is not exactly consistent with the theoretical value of $12/17(\sim 0.71)$ in Equation (1), but the difference is not very significant by taking into account the error. In addition, it is worth noting that the present sample is basically built on a limited sample. When more data will be added, the correlation is likely to improve. It is possible to have an idea of the robustness of the result, by cross-checking with similar results obtained by other authors with more complete samples. Since the jet power is directly linked to the power emitted in high-energy γ rays, it is possible to compare Equation (2) with other correlations between radio and γ rays. For example, Bloom (2008) found

$$L_{400\ \rm MeV} \propto L_{8.4\ \rm GHz}^{0.77\pm0.03}, \quad (3)$$

while Ghirlanda et al. (2011) found a steeper index, but by using the integrated luminosity at $E >$ 100 MeV

$$L_{>100\ \rm MeV} \propto L_{20\ \rm GHz}^{1.07\pm0.05}. \quad (4)$$

Therefore, I conclude that the "calibration" of the Ghisellini & Tavecchio's model (Eq. (2)) is reliable, in spite of the above mentioned caveats.

It is then possible to check if there is any dependence of the jet power on the mass. Figure 3 (top panel) displays the corresponding plot. The presence of γ-NLS1s now fills the part for low masses. The dashed/dot-dashed lines are just to highlight the branches that are much more evident (but inverted) in the graphic of the jet power versus the accretion luminosity in Eddington units, as displayed in Figure 3 (bottom panel). FSRQs and BL Lac Objects are placed along a line from low power/low accretion to high power/high accretion. This is the well-known "blazar main sequence" (see the region delimited by the dot-dashed lines), where FSRQs have a strong disk and evolve to poorly accreting BL Lac Objects (Cavaliere & D'Elia 2002; Böttcher & Dermer 2002; Maraschi & Tavecchio 2003). It can also be read as the "blazar cooling sequence" as revised by Ghisellini & Tavecchio (2008), where the jet power is a function of the accretion rate. In this case, powerful disks

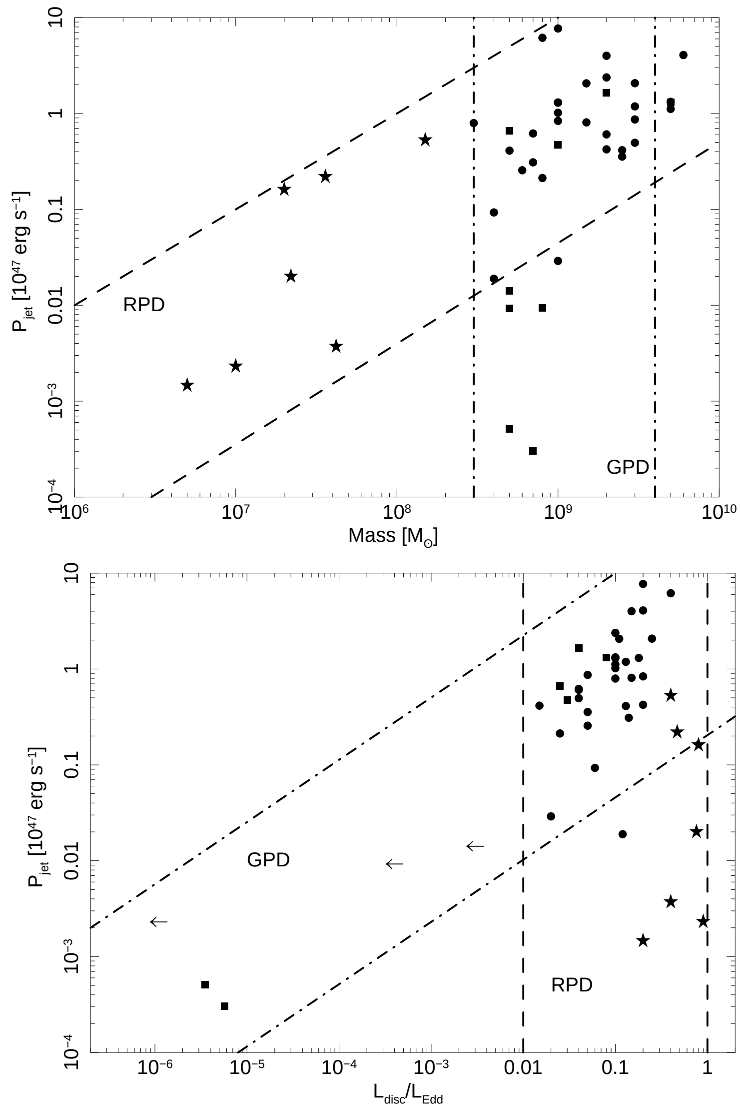

Fig. 3 Jet power versus mass of the central black hole (*top panel*) and the accretion luminosity in Eddington units (*bottom panel*). See the text for more details. Circles indicate FSRQs; squares and arrows (upper limits) are for BL Lac Objects; stars represent γ-NLS1s.

determine a rich environment where electrons can efficiently cool (high power blazars), while on the opposite side there are BL Lacs with weak disks and hence a photon-starved environment, which in turn implies a greater difficulty in cooling relativistic electrons. However, I note immediately that γ-NLS1s develop a separate branch (see the region delimited by the dashed lines), where a low power jet is associated with a highly accreting disk.

Also in this case, it is possible to compensate the small, inhomogeneous sample in the comparison with another larger sample. In this case, one can compare Figure 3 (bottom panel) of the present work with figure 5 of Ghisellini et al. (2011). The blazar part is confirmed, with the branch at low accretion where $L_{\rm disc} \propto \dot{m}^2$ and the high-accretion zone with $L_{\rm disc} \propto \dot{m}$, while the present work adds the γ-NLS1s branch.

Figure 3 also shows two different regimes: one where the jet power depends on the accretion (GPD, dot-dashed lines) and the other where it scales with the mass (RPD, dashed lines). BL Lac objects are in the accretion-dependent regime, while FSRQs and γ-NLS1s are in the mass-dependent regime. Indeed, it is easy to recognize that the difference in the jet power between FSRQs and γ-NLS1s can be explained by the difference of mass between the two classes of AGNs. These two regimes remind us of the known theories on jets. The labels RPD and GPD in Figure 3 are the acronyms of Radiation-Pressure Dominated and Gas-Pressure Dominated regimes and their meaning can be understood in the next Section.

5 MAGNETOSPHERIC, HYDROMAGNETIC, HYBRID: THE FLAVORS OF JETS

One advantage of SED modeling is that it is possible to separate the different components of the power emitted by the jet: kinetic (particles), magnetic field and radiation. Therefore, it is easier to compare with the theories.

Basically, the known mechanisms of relativistic jets can be broadly divided into three classes:

1. *Magnetospheric Jet:* the jet extracts rotational energy from the black hole and the accretion disk, through the slip between the magnetic fields at the hole and it is anchored at the accretion disk by the frame-dragging. Therefore, a black hole is needed to provide the Lense-Thirring effect, while the disk mainly provides the electric charges to be accelerated. The reference paper is Blandford & Znajek (1977) (BZ, 1977), but also Macdonald & Thorne (1982) represents an interesting alternative explanation of the same mechanism by adopting the membrane paradigm (Thorne et al. 1986). It can be considered the analog for black holes of the pulsar magnetosphere by Goldreich & Julian (1969). Some “precursors” of the BZ theory are Penrose (1969); Ruffini & Wilson (1975); Lovelace (1976), who developed the analogy with an electric machine, and Blandford (1976), who elaborated an embryo version of the BZ effect in a flat spacetime. The BZ power depends on the mass of the black hole (which in turn affects the frame-dragging amplitude), the spin (magnetic fields slip) and the magnetic field at the event horizon.
2. *Hydromagnetic Jet:* it is a centrifugally-driven jet and it extracts the rotational energy of the accretion disk. There is no need for a black hole; only an accretion disk is necessary. The reference work is Blandford & Payne (1982), with some precursors also in this case: Piddington (1970); Sturrock & Barnes (1972); Ozernoy & Usov (1973). The power extracted in this way is proportional to the disk’s magnetic field, the size of the disk and its angular speed.
3. *Hybrid models (“hydromagnetospheric”):* basically these models are a mixture of the two above cases. Interesting models are Phinney (1983) and Meier (1999), which in turn are an evolution of Punsly & Coroniti (1990). A hybrid model has been recently adopted by Garofalo et al. (2010) to speculate on the observed differences in AGNs with relativistic jets.

In the BZ theory, the magnetic field of the disk is pushed toward the event horizon by the Maxwell pressure. The standard disk magnetic field depends on the accretion rate $\dot{m}$ and it is possible to find two regimes (Ghosh & Abramowicz 1997; Moderski & Sikora 1996). One refers to a strong accretion disk, dominated by the radiation pressure (RPD, radiation pressure dominated). The jet luminosity that can be extracted through the BZ mechanism saturates to the value (Ghosh & Abramowicz 1997)

$$L_{\rm BZ,RPD} = 2 \times 10^{44} M_8 (J/J_{\rm max})^2, \tag{5}$$

where M_8 is the black hole mass in units of $10^8\,M_\odot$ and J is the angular momentum of the black hole.

The second case is complementary to the first one and refers to a GPD disk (i.e. low accretion, Ghosh & Abramowicz 1997)

$$L_{\rm BZ,GPD} = 8 \times 10^{42} M_8^{11/10} \dot{m}_{-4}^{4/5} (J/J_{\rm max})^2, \tag{6}$$

where $\dot{m}_{-4}$ is the accretion rate in units of 10^{-4}. The dividing line of the two regimes is at $\dot{m} \sim 5.6 \times 10^{-3}$, which corresponds to $L_{\rm disc}/L_{\rm Edd} \sim 5.6 \times 10^{-4}$, by adopting the usual value for the efficiency equal to $\eta = 0.1$ [4]. From Figure 3, it is easy to recognize that BL Lacs are basically in the GPD regime (hence the jet power depends on the accretion, according to Eq. (6)), while FSRQs and γ-NLS1s are in RPD (jet power scales with the mass, according to Eq. (5)).

By taking into account the above caveats, it is therefore possible to calculate the jet luminosity with the BZ theory and compare with the observed radiative power dissipated calculated through the SED modeling[5]. The results are shown in Figure 4. The BZ luminosity has been calculated according to Equations (5) and (6), with the $\eta \propto \sqrt{L_{\rm disc}/L_{\rm Edd}}$ and $J/J_{\rm max} = 1$ (see Foschini 2011c for some notes on the efficiency). It is therefore the maximum value of luminosity that can be produced by the BZ mechanism. As the luminosity of the disk decreases, the BZ mechanism is more than sufficient to produce the observed jet luminosity. The fact that $P_{\rm jet,rad} < L_{\rm BZ}$ can be explained by taking into account different values of $J/J_{\rm max} < 1$ in Equations (5) and (6). In addition, equations (5) and (6) of Ghosh & Abramowicz (1997) have been elaborated on by assuming the constant slip factor[6] s is equal to the maximum possible ($s = 0.25$). This is the reference value adopted by most authors, but it refers to a radial magnetic field. As noted by Blandford & Znajek (1977), a parabolic field has a slightly lower efficiency (75% of the radial field).

Nevertheless, the important information is that BL Lacs with low accretion could essentially be powered by the BZ mechanism or at least there is no need to invoke alternative or additional mechanisms. This is in agreement with the fact that these are objects at the end of their evolution, as already outlined by Cavaliere & D'Elia (2002) and Maraschi & Tavecchio (2003). The disk becomes progressively weaker, but it is sufficient to provide the force necessary for some electric charges to be accelerated. The magnetic field of the hole is quite strong, since it is the result of the field that the disk has pushed toward the event horizon during its lifetime.

As the disk luminosity increases, the jet power also increases and exceeds the BZ luminosity. By also taking into account the presence of the spin factor, we found that the observed luminosity is greater than the calculated one by $2-3$ orders of magnitude, which cannot be explained with the source variability or the errors in the measurements of parameters. Since this occurs at high disk luminosities, it is reasonable to expect the possibility of a contribution to the jet luminosity from hydromagnetic winds from the disk, thus creating some hybrid mechanisms. The MHD luminosity according to the hybrid model by Meier (1999) could be more than three orders of magnitudes greater than that from a simple magnetospheric jet.

Moreover, the evolutionary path could play some role: both FSRQs and γ-NLS1s are young sources, with highly accreting disks, but although this is the right condition to trigger hydromagnetic winds, it could also be noted that the disk could not have had sufficient time to push a strong magnetic field to the hole and therefore the magnetospheric contribution to the jet would be small.

The present data do not allow us to distinguish the contribution from the different mechanisms, but we can confirm the broad scenario already outlined by Cavaliere & D'Elia (2002), where the BZ phenomenon is the backbone of the jet and becomes increasingly hybridized as the accretion increases. The two regimes, GPD and RPD (Ghosh & Abramowicz 1997), are still valid, but with

[4] The efficiency is generally dependent on the accretion luminosity in the presence of advection, but the basic conceptual result does not change.

[5] In this case, I do not use the data of the three new γ-NLS1s because there is no SED model available yet.

[6] $s = \omega_{\rm F}(\omega_{\rm H} - \omega_{\rm F})/\omega_{\rm H}^2$, where $\omega_{\rm H}$ is the angular speed of the black hole and $\omega_{\rm F}$ is that of the magnetic field coming from the disk.

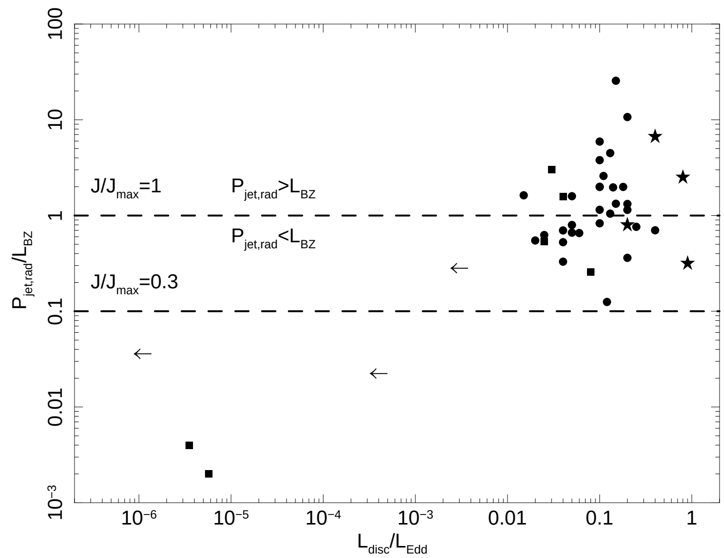

Fig. 4 Ratio between the observed jet radiative power and the calculated luminosity according to the BZ theory. See the text for more details. Circles indicate FSRQs; squares and arrows (upper limits) are for BL Lac Objects; stars represent γ-NLS1s.

the warning that the jet mechanism becomes hybridized in the RPD regime. The strong disk, on one hand contributes to saturating the accretion regime of the BZ mechanism, and on the other hand enhances the jet power with the rise of hydromagnetic winds or the hybridization mechanisms. Being much more efficient (e.g. Meier 1999), but still dependent on the mass, it can explain why it is possible to find powerful jets even in small AGNs, like γ-NLS1s. It is worth noting the discovery of ultra-fast outflows with $v \sim (0.04 - 0.15)c$ in some highly accreting radio galaxies reported by Tombesi et al. (2010). Although these winds are moving at relativistic speeds, their discovery indicates that some hydromagnetic windy activity is also present in AGNs with relativistic jets, thus enforcing the idea of a hybrid mechanism.

6 SIMILARITIES WITH GALACTIC BINARIES JETS

As is currently understood, relativistic jets are rather ubiquitous structures in the Universe and therefore it is necessary to find the basic laws describing how to scale the jet power with the mass, down to stellar mass compact objects. Recently, Coriat et al. (2011) made a detailed study of Galactic binaries regarding the correlation between the radio emission at 8.4 GHz, which represents the jet power, and the X-ray luminosity ($3 - 9$ keV), which in turn samples the disk emission in Galactic binaries (see fig. 5 in Coriat et al. 2011). They identified two main branches: one is the "inefficient" branch, characterized by $L_{\rm radio} \propto L_{\rm X}^{0.6}$ and $L_{\rm disc} \propto \dot{m}^{2-3}$. The other is the "efficient" branch, where $L_{\rm radio} \propto L_{\rm X}^{1.4}$ and $L_{\rm disc} \propto \dot{m}$.

The data available for this study do not allow us to perform detailed correlations with significant tests, however Figure 5 displays some striking similarities with figure 5 of Coriat et al. (2011). BL Lac objects seem to sample the inefficient branch, while FSRQs and γ-NLS1s are on the efficient one.

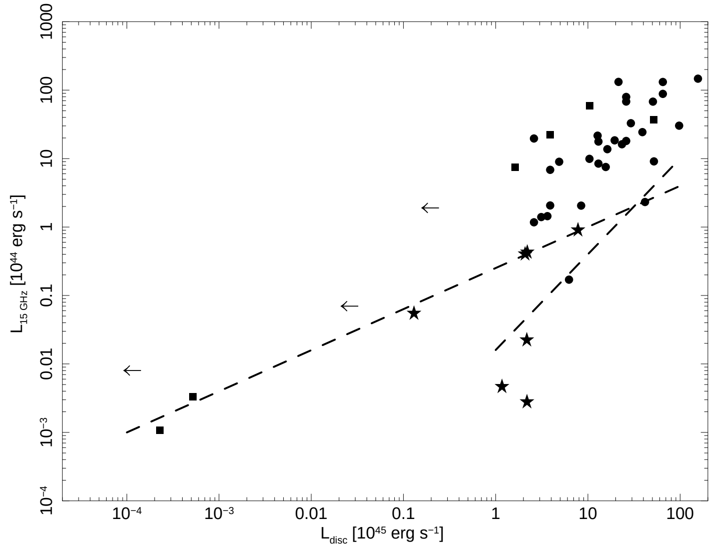

Fig. 5 Jet power from radio measurements versus accretion luminosity. Two dashed lines having the same slopes of the inefficient and efficient branches of Galactic binaries as found by Coriat et al. (2011) are displayed for comparison. See the text for more details. Circles indicate FSRQs; squares and arrows (upper limits) are for BL Lac objects; stars represent γ-NLS1s.

Please note that to perform a proper comparison, it is necessary to take into account that the accretion disk in AGNs has its peak emission in the ultraviolet band, while in binaries it emits mostly in the X-ray band.

The difference in disk luminosities between Galactic binaries and AGNs is about nine orders of magnitude, which can be explained with the mass difference: a few solar masses for binaries and $10^8 - 10^9\,M_\odot$ for most of the AGNs in this sample. On the other hand, the difference of the radio power is about 14 orders of magnitude, which cannot be explained with the difference in mass.

Stellar mass black holes are on a similar track with BL Lacs and FSRQs. Interestingly, the γ-NLS1s, often compared to Galactic black holes in a high soft state, occupy a region similar to that of neutron stars in the diagram by Coriat et al. (2011). So, like neutron stars are the low mass sources in the realm of Galactic compact objects, the γ-NLS1s are the low mass part of the AGN kingdom. See Foschini (2011c) for more details on the similarities between jets in AGNs and Galactic binaries.

7 FINAL REMARKS

The discovery of high-energy γ rays from NLS1s has perturbed the traditional scenario of AGNs with powerful relativistic jets. The new information carried by adding this class of sources helped to improve our knowledge of the jet mechanisms, although not yet in a definitive way. It has confirmed the existence of two main branches for the AGNs with powerful relativistic jets in the framework of the BZ theory: one driven by the accretion and the other where the accretion contribution is saturated and is therefore scaled by the mass of the central object. However, when high accretion rate saturates the BZ power, the rise of hydromagnetic wind contributes to increasing the jet power. Observations are strongly needed to improve the sample of γ-NLS1s.

Interestingly, there is now a striking similarity with a similar diagram (accretion versus jet power) in Galactic compact objects. While BL Lac objects and FSRQs have their similar counterpart in Galactic black holes in different states, the γ-NLS1s now occupy a region similar to that of neutron stars, thus completing the similarity between extragalactic and Galactic classes of compact objects. However, the difference of 14 orders of magnitude in the jet power cannot be explained simply with a mass scaling. What is missing?

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