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The jet–disc connection in AGN

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Abstract. We present our latest results on the connection between the accretion rate and the power of relativistic jets. To this aim we use blazars, whose jet is pointing at us, with visible broad emission lines, along with broad lineless radio–galaxies. We trace the jet power with two proxies (gamma–ray and radio luminosities), while the broad emission lines are a direct measure of the accretion disc luminosity. We find a correlation between the broad emission line and the gamma–ray or luminosities in blazars, suggesting a direct tight connection between the jet and the accretion rate. Only extending our analysis to radio–galaxies, and using as jet tracer the radio luminosity, we are finally able to conclude that jetted AGN can accrete both through a radiatively efficient accretion disc and a hot accretion flow, depending on the accretion rate. We finally observe the transition between the two states among the family of jetted AGN.

1. Introduction

The connection between accretion structure and jet emission in AGN is a crucial point to understand the physics behind the launching process of the jet. A matter of debate regards the presence and behavior of relativistic jets relative to the different accretion regimes. The canonical sub–classification scheme applied to blazars (jetted AGN with jets directed towards us; Urry & Padovani 1995) is commonly interpreted as a hint for different accretion regimes. Flat Spectrum Radio Quasars (FSRQs), that are classified as blazars with prominent broad emission lines ($EW > 5$Å), are thought to accrete through a radiatively efficient accretion disc, while BL Lacertae objects (BL Lacs) are generally thought to be characterized by an inefficient accretion flow, and this should be the reason of broad emission lines with smaller equivalent width ($EW < 5$Å).

However, the EW–based classification cannot be a reliable tracer of a difference in the accretion regime. The EW is in fact a measure of the line dominance over the continuum. In the case of blazars, the overall continuum is generally heavily contaminated by the non–thermal emission from the relativistic jet. For this reason, the equivalent width cannot be considered a measure of line strength. This misclassification clearly does not help in understanding whether jet and specific accretion modes are coexistent in AGN, nor if there is an intrinsic difference between FSRQs and BL Lacs. Another classification must be considered.

Ghisellini *et al.* (2011) suggested a classification that truly relies on the accretion rate of the sources: dividing blazars depending on their Eddington ratios, traced by the luminosity emitted from the broad line region. We managed to enlarge the blazar sample later on (Sbarrato *et al.* 2012), finding that indeed an EW–based classification can be misleading to understand the accretion features of blazars.

This is certainly a hint that FSRQs and BL Lacs accrete on average at different rates, but to understand if there is actually a difference in the accretion regime, one must test the behaviour of broad emission lines compared to the accretion rate itself. Since the jet power is thought to be proportional to the accretion rate itself, to study the BLR luminosity as a function of $\dot{M}$, we can *compare the jet and BLR emissions* (Sbarrato *et al.* 2014).

2. Broad line region and accretion rate

The plasma that emits broad emission lines is most likely directly ionized by the UV photons emitted from the accretion structure. The BLR plasma clouds are thought to re–emit a fraction $\sim 10\%$ of the light coming from the ionizing source (Baldwin & Netzer 1978; Smith *et al.* 1981). Therefore, the luminosity emitted from the BLR ($L_{\rm BLR}$) is a good tracer of the ionizing luminosity emitted from the accretion structure ($L_{\rm ion} \simeq 10 L_{\rm BLR}$).

Depending on the accretion regime, the ionizing luminosity can be a different fraction of the overall accretion luminosity. In the case of a standard optically thick, geometrically thin accretion disc (Shakura & Sunyaev 1973), the ionizing luminosity is always a relevant fraction of the disc luminosity ($L_{\rm d}$). We can then reasonably assume that $L_{\rm BLR} \simeq 10\% L_{\rm d}$. In the case of a standard disc, the emitted luminosity is proportional to the accretion rate ($\dot{M}$) via a fixed value of the radiative efficiency (η): $L_{\rm d} = \eta \dot{M} c^2$.

In the case of an advection dominated accretion flow (ADAF; Narayan & Yi 1994), i.e. the most common radiatively inefficient accretion flow, the fraction of ionizing luminosity emitted from the whole structure is less, and varies with the accretion rate. An ADAF spectrum is in fact different for different values of the accretion rate, and its overall luminosity varies as $L_{\rm ADAF} \propto \dot{M}^2$, since the efficiency η is not a fixed value, but depends linearly on the accretion rate (Narayan, Garcia & McClintock 1997). Moreover, the spectral profile changes with $\dot{M}$ (see Fig. 1 in Mahadevan 1997), and therefore the ionizing fraction of the ionizing luminosity changes. From the spectrum proposed by Mahadevan (1997), one can derive that $L_{\rm ion} \propto \dot{M}^{3.5}$ (Sbarrato *et al.* 2012). Hence, the BLR luminosity have the same dependence on the accretion rate.

Comparing $L_{\rm BLR}$ with a good tracer of the accretion rate, one should be able to observe these two different behaviors in sources with different accretion rates. The transition between the two regimes is thought to occur at $\dot{M}/\dot{M}_{\rm Edd} \simeq 0.1$, i.e. $L_{\rm d}/L_{\rm Edd} \sim 10^{-2}$ if we assume $\eta = 0.1$ and $L_{\rm Edd} = \dot{M} c^2$ (Shakura & Sunyaev 1973).

As already said, the jet power is thought to be proportional to the accretion rate in jetted AGN. We therefore compare $L_{\rm BLR}$ with jet power tracers for a sample of jetted sources, to look for the two different behaviors and the transition between the regimes.

3. Tracing accretion and jet powers

We first tried to investigate the jet–accretion relation in the blazar class, focusing on the γ–ray luminosity as a tracer for the jet emission. We collected a sample of broad line blazars from the samples of FSRQs and BL Lacs detected by *Fermi*/LAT in the γ–rays (Shaw *et al.* 2012; 2013). We then added the previously considered broad line blazars from Ghisellini *et al.* (2011) and Sbarrato *et al.* (2012).

Fig. 1 shows the broad line region luminosity as a function of the γ–ray luminosity for this sample. The objects are labelled according to the classifications in Sbarrato *et al.* (2014). The two quantities are well linearly correlated in the blazar family. This is a good confirmation of the direct relation between jet and accretion power in AGN. On the other

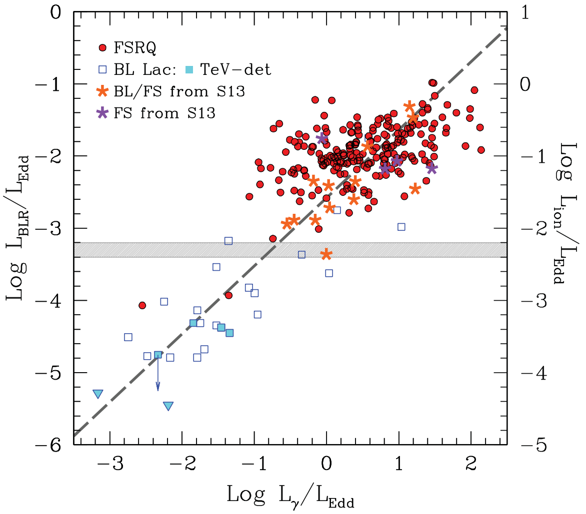

Figure 1. Broad line region luminosity as a function of γ–ray luminosity, both normalized to the Eddington luminosity. Different symbols correspond to different classifications, as labelled. The dashed line is the result of a least square fit. The grey stripe indicates the luminosity divide between FSRQs and BL Lacs, located at $L_{\rm BLR}/L_{\rm Edd} \sim 5 \times 10^{-4}$.

hand, no hint of a change in slope is visible. According to the original formulation of the Shakura–Sunyaev (1973) accretion disc, a change in slope towards a steeper slope should occur at $L_{\rm BLR}/L_{\rm Edd} \sim 5 \times 10^{-4}$. Either there is no transition in the accretion regime, or it happens at lower accretion rates. Sharma *et al.* (2007) suggested that the transition occurs at $\dot{M}/\dot{M}_{\rm Edd} \sim 10^{-4}$. According to this hypothesis, with only this blazar sample, we could not observe such a transition, since we do not have low enough accreting objects. Blazars with such a low accretion rate, in fact, should correspond to the truly lineless BL Lacs, that we cannot include in our work, since their redshift cannot be derived because of the lack of lines.

Since we are not able to reach very low accretion rates by considering only blazars, we then extended our study to a sample of low excitation radio–galaxies (LEGs), using instead the radio luminosity to trace the jet emission. To this aim, we consider the LEG sample compiled by Buttiglione *et al.* (2010), that also provide radio core luminosities, surely emitted form the jet and therefore as good tracer of the accretion rate as the radio emission in blazars.

The different viewing angles under which we observe blazars and radio–galaxies affect their radio emission. The radio luminosity is in fact emitted from the relativistically beamed jet. The beaming implies that if the source has the jet oriented to our line of sight, we observe a flux enhanced of a factor $F_{\rm radio} \propto \delta^{3+\alpha}$ (Dermer 1995), where $\delta = [\Gamma(1-\beta\cos\theta_{\rm v})]^{-1}$ is the beaming factor.

To properly compare blazars and radio–galaxies, therefore, we have to make homogeneous their beaming level. We chose to “beam” the radio–galaxies assuming a spine–layer structure for their jets (Ghisellini *et al.* 2005). In this hypothesis, the radio luminosity is not emitted from the highly relativistic ($\Gamma \sim 10$) spine responsible for high–energy emission, but from a slower layer that surrounds this central structure ($\Gamma \sim 3$). We assume an average viewing angle $\theta_{\rm v} \sim 40°$ for these sources, since we do not have any information of their specific orientation. We rigidly shift them of a factor $\sim 100 = (\delta_{\rm blazar}/\delta_{\rm radio-gal})^3$.

Fig. 2 shows the broad line region luminosity as a function of the beamed radio luminosity, both normalized to the Eddington luminosity. All the radio–galaxies in our

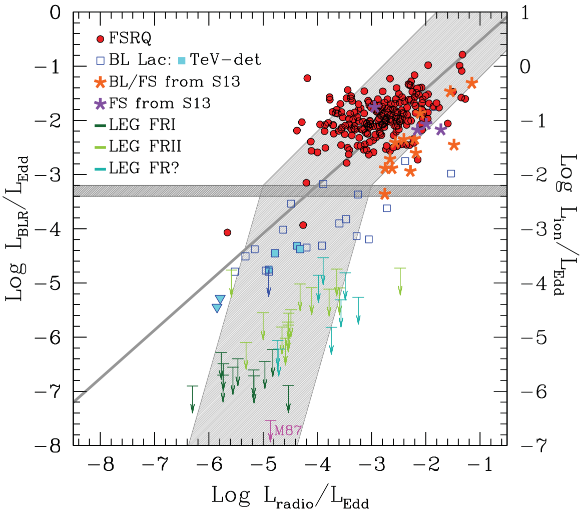

Figure 2. Luminosity of the broad line region (in Eddington units) for the sources from our samples as a function of the radio luminosity (in Eddington units). Different symbols correspond to different samples or a different classification of the sources, as labelled. The dashed line indicates the bisector, rescaled to pass through the FSRQs. The dark grey horizontal stripe indicates the luminosity divide between FSRQs and BL Lacs at $L_{\rm BLR}/L_{\rm Edd} \sim 5 \times 10^{-4}$. The light grey stripe indicates the expected distribution of the luminosities if they were produced by a Shakura–Sunyaev accretion disc for $L_{\rm BLR}/L_{\rm Edd} \sim 5{\times}10^{-4}$ and an ADAF with a Mahadevan–like spectrum ($L_{\rm d} \propto \dot{M}^{3.5}$).

sample have only upper limits on their $L_{\rm BLR}$, derived as in Sbarrato *et al.* (2014), since they are explicitly selected as lineless sources.

It is immediately clear that the presence of LEGs highlights a change in slope of the accretion–jet relation. For the first time, signatures of both radiatively efficient and inefficient accretion regimes are found in a sample of jetted AGN. The transition between the two regimes seems to occur at the value suggested by Shakura & Sunyaev (1973): $\dot{M}/\dot{M}_{\rm Edd} \sim 0.1$. Besides being too disperse to provide strong enough clues, BL Lacs do not show the transition without radio–galaxies, probably because they are transition objects (they show weak emission lines, in fact).

We cannot draw strong conclusions on the slope of $L_{\rm BLR}(\dot{M})$, but we can conclude that is much steeper than linear, and likely much steeper than $L_{\rm BLR} \propto \dot{M}^2$. The indicative grey stripe in Fig. 2, in fact, shows the expected behavior for the ADAF spectrum by Mahadevan (1997), i.e. $L_{\rm BLR} \propto \dot{M}^{3.5}$.

4. Conclusions

To study the accretion process in jetted AGN, we cannot rely only on blazars, since they do not allow studies on extremely wide accretion ranges. Specifically, with only blazars we lack objects with low accretion rates.

Considering blazars and radio–galaxies *together*, instead, we can explore the whole possible accretion rate range. With a composite sample, we were able to cover an accretion rate range large enough to cover the transition between a radiatively efficient accretion disc and an inefficient accretion flow.

Such a transition occurs at the expected value of $L_{\rm BLR}/L_{\rm Edd} \sim 5 \times 10^{-4} - 10^{-3}$, that corresponds to $\dot{M}/\dot{M}_{\rm Edd} \sim 0.1$. Below this threshold, the ionizing luminosity (traced by the broad line region one) decreases with a slope steeper than $\propto \dot{M}^2$. An extreme slope $\propto \dot{M}^{3.5}$ cannot be excluded.

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