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The disk-jet connection of Fermi 2LAC blazars

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HIGHLIGHTS

- We compose 3 samples of blazars.
- Correlated observed bolometric & line luminosity for blazars, Fs and Bs.
- Correlated intrinsic bolometric & line luminosity for Fs & Bs, different slopes.
- Suggestion: a strong disk-jet link.
- Suggestion: Fs & Bs have different accreting modes.

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ABSTRACT

In this article, an estimator of the radiative power for blazars is proposed and is used in the study of the link between the accretion disk power and jet power. The results lend support to the disk-jet symbiosis. Since the blazars are strongly beamed sources, our results suggest that the Doppler enhancement of the sources needs to be removed to obtain physically reasonable results in the disk-jet connection study. The results after de-beaming suggest that FSRQs are accreting in the radiatively efficient regime, while the BL Lac population shows a flatter dependence between jet power and disk power, possibly due to a mixture of sources in the radiatively efficient (the broad lined BL Lacs) and inefficient (the bulk of the BL Lac population) regimes.

1. Introduction

Blazars, consisting of Flat Spectrum Radio Quasars (FSRQs) and BL Lacertae Objects (BL Lacs), are one of the most extreme sub-class of Active Galactic Nuclei (AGN). Most of the observed properties of blazars can be attributed to their relativistic jet whose axis is pointing to the observers (see e.g. Urry and Padovani, 1995). The formation of the jets is one of the most significant issues in astrophysics and various mechanisms responsible for the process have been proposed (e.g. BZ version Blandford and Znajek, 1977, BP version Blandford and Payne, 1982 and hybrid versions (Punsly and Coroniti, 1990; Meier, 1999 and Nemmen et al., 2007)). The magnetic field that is sustained by the accretion is of vital importance in all the models channeling the power from the black hole or the accretion disk into the jet. This provides a solid physical ground for a strong link between the jet production and accretion process. Thus a disk-jet connection has been one of the key issues in the study of blazars (Maraschi and Tavecchio, 2003).

In the phenomenological studies of disk-jet link, several authors have found significant correlation between the accretion power and the jet power (e.g. Baum and Heckman, 1989; Rawlings et al., 1989; Cao and Jiang, 1999, 2001; Wang et al., 2002; Xie et al., 2007; Chen et al., 2009; Liu and Bai, 2010; Sbarrato et al., 2012; Du et al., 2013, and Sbarrato et al., 2014). Their results support the existence of a disk-jet symbiosis.

It is noted that the jet power, as well as the disk power, cannot be measured directly, and observed estimators of them must be employed. The proxies for jet power usually come from the observed emission power. It is well known that a typical spectral energy distribution (SED) of blazars, in the $\log(\nu L_\nu) - \log\nu$ diagram, has a two hump shape, representing two radiation mechanisms at work. The lower energy component is attributed to synchrotron emission process and the higher energy hump is attributed to inverse Compton (IC) process. Therefore, when limited by the data coverage, the monochromatic emission or radiation in a given frequency interval could be used to estimate the jet power (e.g. Cao and Jiang, 1999; Xie et al., 2007; Sbarrato et al., 2012 and Sbarrato et al., 2014). When the observation of synchrotron component is available, the peak luminosity of it could also served as the proxy of the jet power (e.g. Wang et al.; 2002, Chen et al., 2009 and Du et al., 2013). The extended radio luminosity of sources might be the indicator of the jet power as well (Baum and Heckman, 1989; Rawlings et al., 1989; Cao and Jiang, 2001 and Liu and Bai, 2010).

However, the Compton Dominance (CD), defined as the ration of the peak luminosities between the synchrotron and the IC components, thus representing the relative significance of the two

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components, varies from source to source (see e.g. Finke, 2013). Therefore, a proxy for jet power taking the radiation from both of the components into considerations is more accurate than the above estimators. Thanks to the increasing simultaneous or quasi-simultaneous coverage of the blazar SEDs in recent years, observational information about both the synchrotron and IC emission is available unprecedentedly. In Section 2, a tracer of jet power of this kind, the L_{bol}, is proposed for analyzing the disk-jet connection for a sample of blazars from Fermi 2LAC sample, the second catalogue of AGNs detected by the *Fermi* LAT in two years of scientific operation (Ackermann et al., 2011a). The proxy for disk power is the luminosity of the broad line region (BLR), L_{BLR}, as often used in literature (e.g. Cao and Jiang, 1999; Sbarrato et al., 2012; Sbarrato et al., 2014).

On the other hand, since the blazars are strongly beamed sources (e.g. Urry and Padovani, 1995), how the Doppler boosting, which plays an important role in the properties of emissions, affects the disk-jet link requires investigation. This is done in Section 3.

2. The correlation between L_{bol}^{obs} and L_{BLR}

Sample I of 159 sources, including 122 FSRQs and 37 BL Lacs from Fermi 2LAC catalogoue, is compiled. Each source has peak luminosity of synchrotron and IC component, and L_{BLR}. The peak luminosities derived from a polynomial fitting to the blazar SED are from Finke (2013). The L_{BLR} are calculated in literatures (Cao and Jiang, 1999; Wang et al., 2002; Liu et al., 2006; Shen et al., 2011; Sbarrato et al., 2012) and (Shaw et al., 2012) following the method described in Celotti et al. (1997). The data of sample I are listed in Table 1.

We hereby propose the tracer for the jet power, the observed bolometric luminosity L_{bol}^{obs} as below

$$L_{bol}^{obs} = L_{Syn}^{peak} + L_{IC}^{peak} \quad (1)$$

here, L_{Syn}^{peak} and L_{IC}^{peak} are the observed peak luminosity of the synchrotron and IC component, respectively. Since the majority of the emission are being radiated at the peak of either the synchrotron or the IC component, this estimator taking the advantage of the unprecedented coverage of the blazar SED is obviously better than previous ones mentioned above.

Correlation analysis is applied to the relationship between $logL_{BLR}$ and $logL_{bol}^{obs}$ for FSRQs and BL Lacs, respectively. The results are listed in Table 2.

The above data and fitting lines are shown in Fig. 1.

The use of luminosity often causes bias due to the common dependence of the luminosity distance on the red shift z. To obtain a genuine correlation, one has to exclude the effect of such dependence. One possible approach is the data randomization method proposed by Pavlidou et al. (2012) and applied by Ackermann et al. (2011b). Alternatively, the partial correlation coefficient between A and B, excluding the effect of z, can be obtained as below (Padovani, 1992)

$$r_{A,B,z} = \frac{r_{A,B} - r_{A,z} r_{B,z}}{\sqrt{(1 - r_{A,z}^2)(1 - r_{B,z}^2)}} \quad (2)$$

where $r_{A,\,B}$ stands for the common Pearson correlation coefficient between two variables A and B.

When Eq. (2) is applied to FSRQs and BL Lacs in Sample I, partial correlation coefficients are obtained as $r_{bol,BLR,z}^{FSRQ} = 0.52\,(p < 5 \times 10^{-4})$ and $r_{bol,BLR,z}^{BLLac} = 0.41(p < 1.3 \times 10^{-2})$, respectively. We can say that after the redshift effect is excluded, there is still a correlation between L_{bol} and L_{BLR} for FSRQs and BL Lacs, respectively.

From above, it is obvious that either for FSRQs or BL Lacs, there exists significant trend between L_{bol}^{obs} and L_{BLR}. Therefore this lends support to the disk-jet symbiosis. However, it is clear that the trends of FSRQs or BL Lacs are different from each other, either from statistics or from visual inspection of Fig. 1. The two correlations show

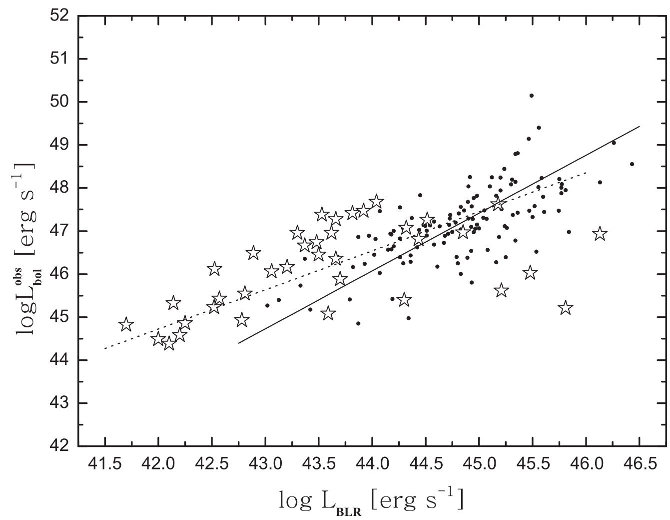

Fig. 1. The $L_{bol}^{obs} \sim L_{BLR}$ relation for sample I. The filled circles and stars illustrate FSRQs and BL Lacs, respectively. The dashed and the solid lines are fitting lines for FSRQs and BL Lacs, respectively.

different slopes. We then do not treat all the blazars as a whole population below, as what has been done in previous works.

3. The correlation between the L_{bol}^{int} and L_{BLR}

The blazars, by their nature, are strongly beamed objects. The observed emissions from them are Doppler boosted and this enhancement needs to be removed in the study of disk-jet connection(see Du et al., 2013).The de-beamed, intrinsic luminosity L_{bol}^{int} can be obtained as (Sikora et al., 1997; Jarvis and McLure, 2002), and (Maraschi and Tavecchio, 2003)

$$L_{bol}^{int} = \frac{L_{bol}^{obs}}{\delta^2} \quad (3)$$

where δ is the Doppler factor. By definition, the Doppler factor δ is given as

$$\delta \equiv \frac{1}{\Gamma(1 - \beta cos\theta)} \quad (4)$$

and another important parameter, the Lorentz factor Γ is defined as

$$\Gamma \equiv \frac{1}{\sqrt{1 - \beta^2}} \quad (5)$$

here θ is the angle between the jet orientation and the line of sight and $\beta = v/c$, v is the velocity of the emitting material. Blazars, which are believed to have very small θ, have the relation $\delta \sim \Gamma$ (e.g. Maraschi and Tavecchio, 2003). Therefore δ can serve as the indicator of how fast the jet of blazars is.

There are various methods to obtain the δ factor (see e.g. Du and Bai, 2012 or Liodakis and Pavlidou, 2015a for a brief review). Different methods are believed to be statistically equivalent to each other. However, for some sources the measurements of δ using different methods might differ substantially (Hovatta et al., 2009; Liodakis and Pavlidou, 2015a), therefore it is desirable to include δ obtained using one single method for a sample.

To obtain the de-beamed blazar sample, we compile two subsamples from sample I, the sample IIA of 30 FSRQs and sample IIB of 25 BL Lacs. In the two samples, every source has the value of the Doppler factor, δ, searched from the literatures, in addition to data provided in sample I. The data of sample IIA and IIB are in Tables 3 and 4, respectively. For the sample IIA, the Doppler factors are variability Doppler factors, denoted as δ_A, using equipartition assumption for calculation (Readhead, 1994; Lähteenmäki et al., 1999) and