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Jet opening angle and linear scale of launch region of blazars

Xiang Liu[1,2], Pengfei Jiang[1,3] and Lang Cui[1,4]

[1]Xinjiang Astronomical Observatory, CAS, 150 Science-1 Street, Urumqi 830011, China.
Email: liux@xao.ac.cn

[2]Qiannan Normal University for Nationalities, 558000 Duyun, China

[3]Graduate University of Chinese Academy of Sciences, Beijing 100049, China

[4]Key Laboratory of Radio Astronomy, Chinese Academy of Sciences, Nanjing 210008, China

Abstract. We explore the intrinsic jet opening angle (IJOA) of blazars, from the literature, we found that the blazar number density peaks around 0.5° of IJOA and declines quickly with increasing IJOA for flat spectrum radio quasars (FSRQs), while the number density has double peaks around 0.3° and 2.0° of IJOA for BL Lacs. We assume that the black hole accretion-produced jet may have the smaller IJOA (for its larger linear scale of launch region), and the BH spin-produced jet may have the larger IJOA (for its smaller launch region), such that the FSRQs are accretion dominated for their single peaked small IJOA, while the BL Lacs are either accretion or BH spin dominated for their double peaked IJOA.

Keywords. Galaxies: jets, quasars: general, BL Lacertae objects: general

1. Introduction

There are two jet-production mechanisms of active galactic nuclei (AGNs), namely black hole (BH) accretion produced jet by Blandford & Payne (1982) and the BH spin produced jet by Blandford & Znajek (1977). These jet formation mechanisms are also useful in the study of the black hole X-ray binaries (BHXBs). The jet in the low-hard state of the BHXBs is often observed, while it is much weaker in the high-soft state of the BHXBs. It was argued whether the radio power positively correlates to the BH spin parameter. Steiner *et al.* (2013) found a positive correlation between the jet power and the BH spin in BHXBs, but Russell *et al.* (2013) argued that there is no correlation with their data (concerning different jet power estimates).

Liu *et al.* (2016) suggested that there may have been two states in both AGNs and BHXBs: a high accretion state which will lead to a linear correlation between the jet power and the accretion power, such as in quasars, their jets are predominated by the BH accretion; a lower accretion state which will lead to a flatter power-law index (<1) of the jet power to accretion power, such as in low luminosity AGNs and also in the BHXBs (with the power-law index of 0.6). The flatter power-law indices are expected in the BH spin-jet model by Liu *et al.* (2016), which can be observed when the accretion rate is not sufficiently large. For the high-soft X-ray state of the BHXBs, there is only weak or no observable jet in relatively high accretion rate, the reason might be that their accretion rate is still not high enough to produce an accretion-jet. In the low X-ray state, it is often jetted, this gentle jet could be produced by the BH spin, but it may be smeared out or quenched in the high state by the higher accretion matter.

For AGNs, it is also argued that the bright gamma-ray emitting blazars could be powered by the supermassive BH spin at their center (Ghisellini *et al.* 2014). They found

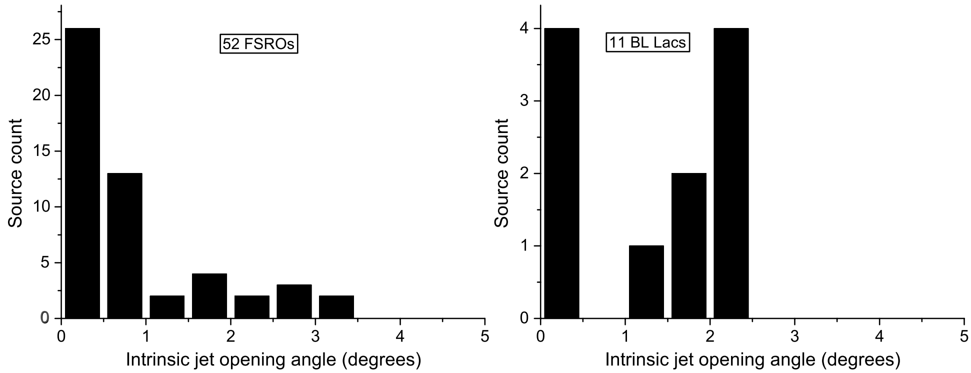

Figure 1. The intrinsic jet opening angles of 52 FSRQs (left) and 11 BL Lacs (right).

a nearly linear correlation between jet power and disk luminosity for their blazar sample. However, the linearity is also predicted in the accretion-jet model by Liu *et al.* (2016), as found in FRII quasars by van Velzen & Falcke (2013). Ghisellini *et al.* (2014) estimated the total jet power and the bolometric disk luminosity (10 times the BLR luminosity), found that the jet power is much larger than the disk accretion energy release (assuming 30% mass to energy efficiency), and suggested that the jet power is dominated by the BH spin in the blazars. As noted in Liu *et al.* (2016) linear correlation between jet power and disk luminosity is also a strong indicator of the accretion produced jet, and the disk luminosity in Ghisellini *et al.* (2014) might be underestimated (considering the uncertainty of the scaling relation of bolometric disk energy release to BLR luminosity).

2. The opening angle of jet in AGNs

Blazars are AGNs with relativistic jets oriented close to our line of sight. The very long baseline interferometry (VLBI) can resolve the inner jets or radio core at sub-milliarcsecond scales. As described in the BK model (Blandford & Konigl 1979, the core emission is the superposition of self-absorbed components which are moving in a conical channel. The core position can shift between different positions when viewed at different frequencies, so-called core-shift (e.g. Lobanov 1998; Pushkarev *et al.* 2012a).

The source intrinsic jet-opening angle (IJOA) can be estimated with $IJOA = JOA_{obs} \times sin\theta$, where the JOA_{obs} is observed (apparent) jet-opening angle and θ is jet viewing angle (Pushkarev *et al.* 2012a). The apparent opening angles have been determined by analyzing transverse jet profiles from the 2cm VLBA data in the image plane by using stacked images (Pushkarev *et al.* 2012b). The IJOAs were then estimated for 52 FSRQs and 11 BL Lacs (Finke 2019 and references therein). We have made a simple statistics for these opening angles in Finke (2019). The result is shown in Fig. 1, where we saw that the source count peaks around the small IJOA of 0.5° and declines quickly with increasing IJOA for FSRQs (left plot), while there are two peaks around 0.3° and 2.0° for BL Lacs (right plot). The IJOA of the BL Lacs is on average larger than that of the FSRQs. However, better statistics are needed to confirm this.

3. Possible connection between IJOA and jet formation mechanisms?

As mentioned, there are two jet-formation mechanisms, i.e. the BH accretion produced jet, and the BH spin produced jet. The former is fundamentally formed by the radiation pressure and the larger scale magnetic field from the accretion disk, in the scale of a few to tens of BH radii (Cao 2014). The latter is supposed to be formed from the BH ergosphere and its magnetosphere, in a scale of less than a few BH radii. Therefore, it is

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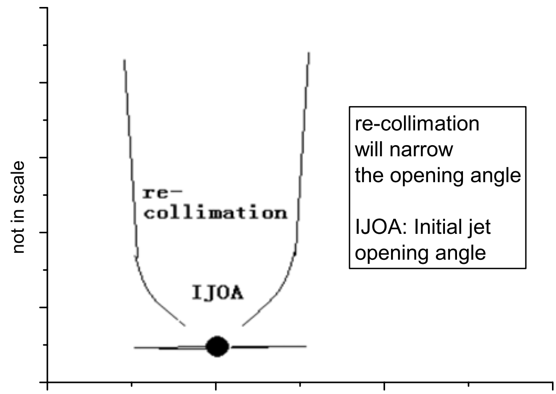

Figure 2. A cartoon of intrinsic jet opening angle and re-collimation in AGN.

expected that the linear scale of the jet launch region is much larger in the accretion-jet mechanism than that in the BH spin-jet mechanism, assuming a similar BH mass.

The jet, after formation, is also powered by the internal shocks in the shock-in-jet model (Marscher & Gear 1985; Marscher *et al.* 2002). The initial opening angle of jet base is usually parabolic (with larger opening angle), as shown in Fig. 2, and then re-collimated by the shocks afterwards to become a hyperbolic shape with a narrower opening angle (Hada *et al.* 2013). It is expected that the opening angles in the down-stream of jet for the blazars in Fig. 1, are smaller than the initial jet opening angles of launch region, but they could be positively correlated. With this idea, we expect that there is a connection between the IJOA and the jet formation mechanism, that the jet powers of FSRQs may be mainly formed by the accretion mechanism for their smaller IJOA (with the larger linear scale of jet launch region). In the meanwhile the jet powers of BL Lacs may be formed by either the accretion or the BH spin mechanism for their double peaks of the IJOA distribution. Further studies are required to test this assumption.

Acknowledgments

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References

Blandford, R. D., & Znajek, R. L., 1977, *MNRAS*, 179, 433
Blandford, R. D., & Payne, D. G., 1982, *MNRAS*, 199, 883
Blandford, R. D., & Konigl, A., 1979, *ApJ*, 232, 34
Cao, X., 2014, *ApJ*, 783, 51
Finke, J. D., 2019, *ApJ*, 870, 28
Ghisellini, G., Tavecchio, F., Maraschi, L., Celotti, A., & Sbarrato, T., 2014, *Nature*, 515, 376
Hada, K., Kino, M., Doi, A., *et al.*, 2013, *ApJ*, 775, 70
Liu, X., Han, Z. H., & Zhang, Z., 2016, *Astrophys. Space Sci*, 361, id9
Lobanov, A. P., 1998, *A&A*, 330, 79
Marscher, A. P., & Gear, W. K., 1985, *ApJ*, 298, 114
Marscher, A. P, Jorstad, S. G, Gómez, J.-L, *et al.*, 2002, *Nature*, 417, 625
Pushkarev, A. B., Hovatta, T., Kovalev, Y. Y., *et al.*, 2012a, *A&A*, 545, A113
Pushkarev, A. B., *et al.*, 2012b, *ArXiv e-prints*, 1205.0659
Russell, D. M., Gallo, E., & Fender, R. P., 2013, *MNRAS*, 431, 405
Steiner, J. F., McClintock, J. E., & Narayan, R., 2013, *ApJ*, 762, 104
van Velzen, S., & Falcke, H., 2013, *A&A*, 557, L7