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A relation of jet power to the central black hole and its accretion

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Abstract. We have developed an integrated jet power formula in the context of the Blandford-Znajek and Blandford-Payne models, and applied this model to the Foschini sample. The result suggests that there is a positive correlation of the jet power versus the product of the disk luminosity and black hole mass within each type of source, and the different linear correlation slopes imply that the disk emissivity efficiency and/or the SMBH spin are quite different for FSRQs, BL Lacs and $\gamma - NLS\,1s$.

1 Introduction

It is generally believed that galaxies harbor super-massive black holes (SMBH). It is reported that SMBHs co-evolve only with bulges, they do not correlate with either galaxy disks or dark matter halos (Kormendy et al. 2011a,b). Masses of SMBHs can be well constrained if they have bulges, but the spins of SMBHs are not well constrained. In the early time of co-evolution, a SMBH could spin up through merging and accretion processes at high redshift z > 1, and then spin down from z < 1 by episodic random accretion (Wang et al. 2009; Volonteri et al. 2013). The masses and spins of SMBHs are also crucial for understanding the AGN phenomena; most theories and simulations suggest that it is the accretion and/or spin of black holes that produce the highly relativistic jets in AGNs (recently for X-ray binaries, see Steiner, McClintock & Narayan 2013; Russell, Gallo & Fender 2013). The SMBH spin is difficult to measure since its general relativistic effects emerge in the very vicinity of the event horizon of the SMBH. However, the accretion of black holes could be measured through multiwave emission and jets in radio loud AGN, with the mechanisms of e.g., Blandford and Znajek (1977, hereafter BZ) and Blandford and Payne (1982, hereafter BP).

In the circumstances of the BZ and BP models, one could find an integrated framework to explain the multiwave emission data, e.g. the jet power with respect to the BH parameters and accretion rate. We investigate this area further below.

2 Jet power

In the BZ and BP models, generally the accretion induced jet power is stronger than the spin induced jet power, and there is a relation in the BZ model: $P_h \sim 0.3(a/M)^2 P_d$. Where P_h is the power released from the black hole, the P_d is the power from the accretion disk, a is the angular momentum and M is the mass of the black hole.

So the jet power from both the disk and the hole can be

$Pj = P_d + P_h = P_d(1 + 0.3(a/M)^2)$, (1)

here the second term (spin power) is always smaller than the first term (accretion power), for we know that $a \leq M$ in electromagnetic disk. So we first want to search for a form of the accretion induced jet power.

In the Newtonian approximation (this is suitable to a distance beyond a few Schwarzschild radii (see Meier 2012), a typical scale where a jet may be formed), the binding energy of unit mass in a Keplerian orbit is $GM/2r$, where G is the gravitational constant. For an accretion mass of ΔM per unit time, the binding energy P_D is

$P_D = \Delta M/s \times (GM/2r) = G\dot{m}M^2/2r$, (2)

where $\dot{m}$ is accretion rate defined by $\Delta M/M$. Therefore, in this expression, the jet power is proportional to the accretion rate and the mass squared of the black hole, in a finite distance r from the black hole. Observed jet power is related to the P_D with $P_j = \eta P_D$, η is the disk emissivity efficiency.

To test this formula, we searched for suitable AGN samples which have information on jet power, accretion rate and BH mass. The Foschini (2011) sample has such information on radio loud AGN, consisting of flat spectrum radio quasars (FSRQ), BL Lac objects (BL), and Fermi detected narrow line Seyfert 1 galaxies ($\gamma - NLS\,1$). In that paper, the black hole mass did not show a good linear correlation with the jet power, with BL Lacs deviating from a linear positive correlation a lot, see figure 1. In our model, the jet power is not simply correlated with BH mass itself, but it is correlated with accretion rate $\dot{m}$ and BH mass squared in equation (2). We test our model with the Foschini sample, noting that the accretion rate is proportional to L_d/L_E with the relation of $L_d/L_E = 5.51 \times 10^{-13}\dot{m}M/r$, where L_d is the disk lumi-

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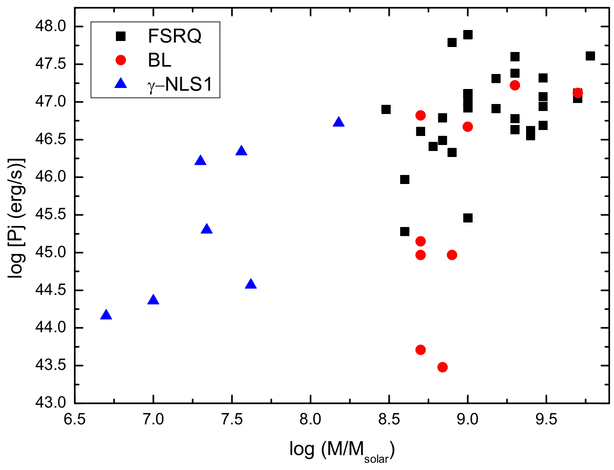

Figure 1. The radio jet power versus the black hole mass in the Foschini sample.

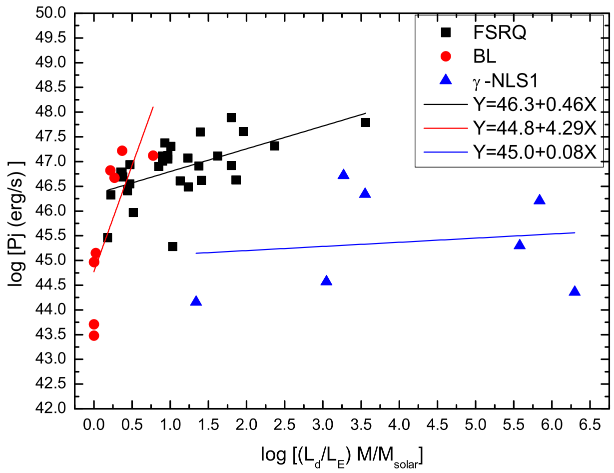

Figure 2. The radio jet power versus the product of disk luminosity and black hole mass.

nosity and L_E is the Eddington luminosity. Taking this relation into equation (2), r is cancelled, and we have

$$P_j = \eta G\dot{m}M^2/2r = 9\times10^{11}G\eta(L_d/L_E)M, \quad (3)$$

here we find that the jet power is related to the disk emissivity efficiency η, disk luminosity L_d/L_E and BH mass M. It is shown that the jet power is not proportional to the product of disk luminosity (in Eddington luminosity) and BH mass (in solar mass) for different types of AGN, but seems to have a linear (in logarithm) correlation within each type of source (except NLS1s are marginally correlated), in figure 2.

This non-correlation in figure 2 between different types of source implies either the disk emissivity efficiency η is quite different for different types of source, or a spin contribution to jet power has to be considered, that the BL Lacs may have higher η than FSRQs, and the $\gamma - NLS1s$ have further low η, or that the SMBHs of BL Lacs may spin faster than FSRQs, and the SMBHs of $\gamma - NLS1s$ may spin slowly.

From a different sample, van Velzen & Falcke (2013) observed a tight correlation between the optical luminosity and the radio lobe luminosity. These authors argued that the spin of FRII sources is not important for powering AGN jets. The FRII sources consist of quasars and radio galaxies, the spin of their SMBHs could be slower than the spin of BL Lacs in our result, so that the spin of FRIIs could make little contribution to their total jet power.

3 Discussion

The non-correlation in figure 2 seems to suggest that the emissivity efficiency η of the binding energy is quite different for different type sources in the Foschini sample, or that the SMBHs of BL Lacs may have highest spins, the SMBHs of FSRQs spin relatively slow, and the SMBHs of $\gamma - NLS1s$ spin more slowly, although this spin scenario has some conflict with a general view of the SMBH spin evolution as noted in the introduction (which might not be necessarily true).

Finally we note, in both BZ and BP models, a large scale magnetic field (B-field) is required for producing the collimated jets, but observationally to detect such a regular B-field around the jet base is difficult, e.g., see a discussion on the results from VLBA observations (Gómez et al. 2011). The B-field was not accommodated in our model equations, since we thought its energy was already included in the total gravitational energy released in equation (3), unless a jet is mainly created around the event horizon of a central black hole, which is the spin-dominated jet power, as seen in the second term of equation (1).

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