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The relation between black hole masses and Lorentz factors of the jet components in blazars *

Ming Zhou[1,2,3] and Xin-Wu Cao[1,2]

[1] Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai 200030, China; *mzhou@shao.ac.cn; cxw@shao.ac.cn*
[2] Joint Institute for Galaxy and Cosmology (JOINGC) of SHAO and USMC, Shanghai 200030, China
[3] Graduate School of the Chinese Academy of Sciences, Beijing 100049, China

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Abstract We explore the relationship between black hole mass ($M_{\rm BH}$) and the motion of the jet components for a sample of blazars. The Very Long Baseline Array (VLBA) 2 cm Survey and its continuation: Monitoring of Jets in active galactic nuclei (AGNs) with VLBA Experiments (MOJAVE) have observed 278 radio-loud AGNs, of which 146 blazars have reliable measurements of their apparent velocities of the jet components. We calculate the minimal Lorentz factors for these sources from their measured apparent velocities, and their black hole masses are estimated with their broad-line widths. A significant intrinsic correlation is found between black hole masses and the minimal Lorentz factors of the jet components. The Eddington ratio is only weakly correlated with the minimal Lorentz factor, which may imply that the Blandford-Znajek (BZ) mechanism may dominate over the Blandford-Payne (BP) mechanism for the jet acceleration (at least) in blazars.

Key words: black hole physics — galaxies: active — galaxies: jets — galaxies: nuclei

1 INTRODUCTION

Relativistic jets have been observed in many radio-loud AGNs, which are believed to be formed very close to black holes. The currently most favored models of jet formation are BZ and BP mechanisms (Blandford & Znajek 1977; Blandford & Payne 1982). In these mechanisms, the power of a jet is extracted from the disk or black hole rotational energy. The disk-jet connection has been investigated by many authors in different ways (Rawlings & Saunders 1991; Falcke & Biermann 1995; Cao & Jiang 1999, 2001, 2002; Xie et al. 2007; Xie et al. 2008).

Some different approaches were proposed to estimate the masses of the black holes in AGNs, such as the gas kinematics near a black hole (see Ho & Kormendy 2000 for a review and references therein). The central black hole mass derived from the direct measurements of the gases moving near the hole is reliable, but unfortunately, it is only available for very few AGNs. For most AGNs, the velocities of the clouds in broad line regions (BLR) can be inferred from the widths of their broad emission lines. If the radius of the BLR is available, the mass of the central black hole can be derived from the broad-line width on the assumption that the clouds in the BLR are gravitationally bound and orbiting with Keplerian velocities (Dibai 1980). The radius of the BLR can be measured by using the reverberation-mapping method from the time delay between the continuum and line variations (Peterson 1993; Netzer

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& Peterson 1997). Long-term monitoring of the source is necessary for applying this method to derive the radius of the BLR, which leads to a small number of AGNs with measured black hole masses using this method. Alternatively, a tight correlation was found between the size of the BLR and the optical continuum luminosity, which can be used to estimate the size of the BLR in an AGN from its optical luminosity and then the black hole mass (e.g., Wandel, Peterson & Malkan 1999; Kaspi et al. 1996, 2000; Laor 2000).

The kinematic properties of the jet components in blazars were revealed by multi-epoch VLBI observations (e.g., Kellermann et al. 2004; Lister et al. 2005). In this paper, we use a large sample of blazars, of which the proper motions were well measured with VLBA, to explore the relationships between the jet speeds and physical properties of blazars, i.e., the black hole masses and Eddington ratios.

The cosmological parameters $\Omega_{\rm M} = 0.3$, $\Omega_\Lambda = 0.7$ and $H_0 = 70\ {\rm km\,s^{-1}\ Mpc^{-1}}$ have been adopted in this work.

2 SAMPLE

We start with a sample of radio-loud quasars and BL Lac objects with measured apparent velocities of jet components. The sample is compiled by searching the literature to include all blazars with available proper motion data of the jets. Most data are taken from several surveys, such as the original flux-limited MOJAVE-I sample and the extended MOJAVE-II sample [1]. We find that 278 sources have multi-epoch VLBI observations, of which 146 blazars have reliably measured apparent velocities. Their black hole masses are estimated with the broad-line widths and broad-line/continuum luminosities, which leads to 78 sources with measured black hole masses.

3 BLACK HOLE MASSES AND MINIMAL LORENTZ FACTORS

In order to estimate their $M_{\rm BH}$, we search the literatures for all the available measurements of the full width at half maximum (FWHM) for broad-lines Hα, Hβ, Mg II, C IV or Lyα lines, as well as the fluxes of these lines. For the sources without line flux data, we adopt their continuum fluxes instead. We find that one source in our sample has very narrow broad-lines (FWHM$<$ 1000 km s^{-1}), which is similar to typical narrow lines. Caution should be used when deriving black hole mass estimates from this source, since we cannot rule out the possibility that this line may be the narrow component emitted from the narrow line region (e.g., Gu et al. 2001). We therefore rule out this source. For most BL Lac objects, their broad-line emissions are too weak to be measured, and we estimate their $M_{\rm BH}$ with the empirical relation between $M_{\rm BH}$ and bulge luminosity $L_{\rm bulge}$. We list all the data of the sample in Table 1. Columns (1)–(2) represent the source's IAU name and redshift, respectively. In Column (3), we list the log of the minimal Lorentz factor of the jet. The lines used to estimate $M_{\rm BH}$ from their luminosity and the references are listed in Columns (4) and (5), respectively. The lines used to estimate $M_{\rm BH}$ from their widths and the references are listed in Columns (6) and (7), respectively. We list the estimated $M_{\rm BH}$ in Column (8). The data of the BL Lac objects in this sample are summarized in Table 2.

For blazars, the optical/UV continuum may be contaminated by the beamed synchrotron emission from the jets. Wu et al. (2004) compared the black hole masses obtained from a sample of radio-loud quasars with both the line and continuum, and they found that the masses obtained with line luminosity are systematically lower that those obtained with the continuum. In this work, the black hole masses $M_{\rm BH}$ are estimated by using the line width of either one of these lines: Mg II, Hβ or Hα and the line luminosities (or the optical/UV continuum, if the line luminosity is unavailable). McGill et al. (2008) analyzed a sample of 19 AGNs, of which all three lines were observed in optical wavebands, and they obtained a set of 30 internally self-consistent recipes for estimating $M_{\rm BH}$ from a variety of observables with different intrinsic scatters. Whenever more than one recipe is available for estimating the black hole mass, we always choose the one with the minimal intrinsic scatter (see McGill et al. 2008 for the

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[1] *http://www.physics.purdue.edu/astro/MOJAVE*

Table 1 Data for Quasars

Source (1)	z (2)	$\log\gamma_{\rm min}$ (3)	Line (4)	Refs. (5)	Line (6)	Refs. (7)	$\log M_{\rm BH}/M_\odot$ (8)
0016+731	1.781	0.760	Mg II	L96	Lyα C IV Mg II	L96	8.93
0035+413	1.353	0.926	Mg II	SK93	Mg II	SK93	8.53
0106+013	2.107	1.461	C IV	B89	C IV	B89	8.83
0112−017	1.365	0.159	Mg II	B89	C IV	B89	7.85
0119+041	0.637	0.291	Hβ	JB91b	Hβ	JB91a	8.50
0133+476	0.859	0.350	Mg II	L96	Hβ	L96	8.30
0212+735	2.367	1.071	Mg II	L96	Lyα C IV Mg II	L96	8.48
0333+321	1.263	1.030	Mg II	B94	Mg II	S91	8.49
0336−019	0.852	1.006	Mg II	B89	Hβ	JB91a	8.78
0403−132	0.571	1.279	Hβ	M96	Hβ	S97	8.77
0420−014	0.915	0.933	Mg II	B89	Mg II	S97	8.84
0440−003	0.844	0.183	Mg II	B89	Hβ	JB91a	8.63
0605−085	0.872	1.367	Mg II	S93	Mg II	S93	8.43
0607−157	0.324	0.047	Hβ	H78	Hβ	H78	7.63
0736+017	0.191	1.082	Hβ	B96	Hβ	S97	8.23
0738+313	0.630	0.892	Hβ	B96	Hβ	JB91a	9.08
0804+499	1.432	0.552	Mg II	L96	C IV Mg II	L96	8.57
0836+710	2.180	1.550	Mg II	L96	Lyα C IV Mg II	L96	9.49
0850+581	1.322	0.903	Mg II	L96	Mg II	L96	9.67
0859−140	1.339	1.214	Mg II	B94	Mg II	S91	8.87
0906+015	1.018	1.288	Mg II	B89	Mg II	S97	8.63
0923+392	0.698	0.729	Mg II	L96	Hβ	L96	9.27
0945+408	1.252	1.230	Mg II	L96	C IV Mg II	L96	9.71
0953+254	0.712	1.063	Hβ	JB91b	Hβ	JB91a	8.73
1038+064	1.265	0.848	Mg II	B94	Mg II	S91	8.76
1055+018	0.888	0.398	Mg II	B89	Mg II	S97	8.45
1226+023	0.158	1.118	Mg II	B89	Hα	JB91a	8.76
1253−055	0.538	0.953	Mg II	W95	Hα	N79	8.53
1302−102	0.278	0.744	Mg II	B89	Hβ	M96	7.90
1334−127	0.539	1.247	Mg II	S93	Mg II	S93	8.36
1458+718	0.904	0.833	Mg II	L96	Hβ	L96	8.84
1502+106	1.839	1.249	Mg II	W86	C IV	S97	8.86
1504−166	0.876	0.608	Mg II	H78	Mg II	H78	8.84
1510−089	0.360	1.133	Mg II	W86	Hα	N79	8.22
1532+016	1.420	1.147	Mg II	B89	C IV Mg II	S97	8.73
1546+027	0.412	1.071	Mg II	B89	Hβ	S97	8.82
1611+343	1.401	1.197	Hβ	N95	Lyα C IV	W95	9.49
1633+382	1.807	1.380	Mg II	L96	Lyα C IV Mg II	L96	10.14
1637+574	0.751	1.118	Mg II	L96	Hβ	L96	8.68
1641+399	0.594	1.275	Mg II	L96	Hβ	L96	9.03
1642+690	0.751	1.222	Mg II	L96	Mg II	L96	8.49
1656+053	0.879	0.655	Hβ	B96	Mg II	S97	9.09
1739+522	1.379	0.961	C IV	L96	C IV	L96	8.20
1741−038	1.057	0.827	Mg II	S89	Mg II	S89	8.67
1828+487	0.692	1.110	Mg II	L96	Hβ	L96	8.66
1921−293	0.352	0.637	Hβ	JB91b	Hα	JB91a	8.38
1928+738	0.303	0.913	Hα	L96	Hβ	L96	8.76
2113+293	1.514	0.303	Mg II	S93	Mg II	S93	8.74
2121+053	1.941	1.165	Mg II	B94	Mg II	S91	8.60
2128−123	0.501	0.864	Hα	O02	Hβ	T93	9.16
2134+004	1.932	0.391	C IV	B89	C IV	B89	8.50
2145+067	0.999	0.407	Mg II	B94	Mg II	S91	8.61
2155−152	0.672	0.523	Mg II	S89	Hβ	S89	7.81
2201+315	0.298	0.848	Mg II	W95	Hα	JB91a	8.91
2216−038	0.901	0.748	Mg II	B94	Lyα C IV Mg II	W95 S91	8.89
2223−052	1.404	1.249	C IV	W95	Lyα C IV Mg II	W95 S97	8.54

Table 1 – Continued.

Source (1)	z (2)	$\log\gamma_{\min}$ (3)	Line (4)	Refs. (5)	Line (6)	Refs. (7)	$\log M_{\rm BH}/M_{\odot}$ (8)
2230+114	1.037	0.950	C IV	W95	Lyα C IV Mg II	W95 S97	8.64
2251+158	0.859	1.187	Hβ	N95	Hβ	JB91a	8.87
2345−167	0.576	1.145	Hβ	JB91b	Hβ	JB91a	8.59
2351+456	1.986	1.452	Mg II	L96	Mg II	L96	9.22
0458−020	2.291	1.179	C IV	B89	$m_{\rm B}$	...	9.27
0730+504	0.720	1.236	Mg II	H97	$m_{\rm B}$	...	8.84
0748+126	0.889	1.317	Mg II	W86	$m_{\rm B}$	...	8.84
1012+232	0.565	1.012	Hβ	B96	$m_{\rm B}$	...	8.69
1127−145	1.187	1.133	Mg II	W86	$m_{\rm B}$	...	9.18
1145−071	1.342	0.433	C IV	W86	$m_{\rm B}$	...	8.61
1156+295	0.729	1.290	Hβ	B96	$m_{\rm B}$	...	9.19
1508−055	1.191	1.269	Mg II	W86	$m_{\rm B}$	...	8.97
1655+077	0.621	1.048	Mg II	W86	$m_{\rm B}$	...	7.91
1726+455	0.714	0.602	Mg II	H97	$m_{\rm B}$	...	8.59
1901+319	0.635	0.455	Hβ	G94	$m_{\rm B}$	...	8.80
2008−159	1.178	0.536	Mg II	W86	$m_{\rm B}$	...	9.56
2227−088	1.562	0.925	C IV	W86	$m_{\rm B}$	...	8.85

For sources without line luminosities, we use their optical continuum luminosities in the B band to estimate $M_{\rm BH}$.
References:B89: Baldwin et al. (1989); B94: Brotherton et al. (1996); B96: Brotherton (1996); G94: Gelderman et al. (1994); H78: Hunstead et al. (1978); H97: Henstock et al. (1997); JB91a: Jackson &Browne (1991); JB91b: Jackson & Browne (1991); L96: Lawrence et al. (1996); M96: Marziani et al. (1996); N79: Neugebauer et al. (1979); N95: Nerzer et al. (1995); O02: Oshlack et al. (2002); S89: Stickel et al. (1989); S91: Steidel et al. (1991); SK93: Stickel & Kühr (1993); S93: Stickel et al. (1993); S97: Scarpa et al. (1997); T93: Tadhunter et al. (1993); W95: Wills et al. (1995); W86: Wills et al. (1986).

Table 2 $\gamma_{\min}$ and $M_{\rm BH}$ for BL Lac

Source (1)	z (2)	$\log\gamma_{\min}$ (3)	$M_{\rm R}({\rm host})$ (4)	Refs. (5)	$\log M_{\rm BH}/M_{\odot}$ (6)
0829+046	0.180	1.037	–22.98	U00	8.49
1749+096	0.320	0.923	–22.68	U00	8.34
1807+698	0.051	0.480	–23.18	U00	8.59
2007+777	0.342	0.114	–22.96	U00	8.48
2200+420	0.069	0.813	–22.84	U00	8.42

Notes: Col. (1): IAU source name. Col. (2): Redshift. Col. (3): log of the minimal Lorentz factor of the jet. Col. (4): absolute R host galaxy magnitude. Col. (5): the references for Col. (4). Col. (6): the black hole masses.
References: U00: Urry et al. (2000).

details). We therefore use the broad-line emission instead of the optical/UV continuum to estimate $M_{\rm BH}$, provided their line luminosities are available. When more than one empirical correlation is applicable, we use one of following relations in order:

$$\log M_{\rm BH} = 6.384 + 2\log\left(\frac{{\rm FWHM}_{\rm Mg\ II}}{1000{\rm km\ s}^{-1}}\right) + 0.55\log\left(\frac{L_{\rm H\alpha}}{10^{44}{\rm erg\ s}^{-1}}\right), \tag{1}$$

$$\log M_{\rm BH} = 6.711 + 2\log\left(\frac{{\rm FWHM}_{\rm Mg\ II}}{1000{\rm km\ s}^{-1}}\right) + 0.56\log\left(\frac{L_{\rm H\beta}}{10^{44}{\rm erg\ s}^{-1}}\right), \tag{2}$$

$$\log M_{\rm BH} = 6.711 + 2\log\left(\frac{{\rm FWHM}_{\rm Mg\ II}}{1000{\rm km\ s}^{-1}}\right) + 0.56\log\left(\frac{L'_{\rm H\alpha}}{10^{44}{\rm erg\ s}^{-1}}\right), \tag{3}$$

$$\log M_{\rm BH} = 6.930 + 2\log\left(\frac{{\rm FWHM}_{\rm H\alpha}}{1000{\rm km\ s}^{-1}}\right) + 0.56\log\left(\frac{L_{\rm H\beta}}{10^{44}{\rm erg\ s}^{-1}}\right), \tag{4}$$

$$\log M_{\rm BH} = 6.747 + 2\log\left(\frac{\rm FWHM_{H\beta}}{\rm 1000km\,s^{-1}}\right) + 0.55\log\left(\frac{L_{\rm H\beta}}{\rm 10^{44}erg\,s^{-1}}\right), \qquad (5)$$

$$\log M_{\rm BH} = 6.420 + 2\log\left(\frac{\rm FWHM_{H\beta}}{\rm 1000km\,s^{-1}}\right) + 0.56\log\left(\frac{L_{\rm H\alpha}}{\rm 10^{44}erg\,s^{-1}}\right), \qquad (6)$$

$$\log M_{\rm BH} = 6.747 + 2\log\left(\frac{\rm FWHM_{H\beta}}{\rm 1000km\,s^{-1}}\right) + 0.55\log\left(\frac{L^{'}_{\rm H\beta}}{\rm 10^{44}erg,\,s^{-1}}\right), \qquad (7)$$

$$\log M_{\rm BH} = 6.747 + 2\log\left(\frac{\rm FWHM_{C\ IV}}{\rm 1000km\,s^{-1}}\right) + 0.55\log\left(\frac{L^{'}_{\rm H\beta}}{\rm 10^{44}erg\,s^{-1}}\right) + \log 0.5, \qquad (8)$$

$$\log M_{\rm BH} = 6.990 + 2\log\left(\frac{\rm FWHM_{Mg\ II}}{\rm 1000km\,s^{-1}}\right) + 0.518\log\left(\frac{L_{5100}}{\rm 10^{42}erg\,s^{-1}}\right), \qquad (9)$$

$$\log M_{\rm BH} = 7.026 + 2\log\left(\frac{\rm FWHM_{H\alpha}}{\rm 1000km\,s^{-1}}\right) + 0.518\log\left(\frac{L_{5100}}{\rm 10^{42}erg\,s^{-1}}\right), \qquad (10)$$

$$\log M_{\rm BH} = 7.026 + 2\log\left(\frac{\rm FWHM_{C\ IV}}{\rm 1000km\,s^{-1}}\right) + 0.518\log\left(\frac{L_{5100}}{\rm 10^{42}erg\,s^{-1}}\right) + \log 0.5, \qquad (11)$$

where $M_{\rm BH}$ is in units of $M_\odot$; $L^{'}_{\rm H\alpha}$ and $L^{'}_{\rm H\beta}$ are estimated from $L_{\rm Ly\alpha}$, $L_{\rm C\ IV}$ or $L_{\rm Mg\ II}$ by their relative rations (Gaskell, Shields & Wampler 1981; Francis et al. 1991); and L_{5100} is nuclear luminosity λL_λ at $\lambda = 5100\,$Å.

We also estimate $M_{\rm BH}$ using Equations (9), (10) and (11) for the black holes with continuum luminosities, of which the masses can also be estimated with line luminosities. We compare the black hole masses with these two different methods in Figure 1. It is indeed found that the masses estimated with line luminosities are systematically lower that those estimated with continuum luminosities, which is consistent with Wu et al. (2004)'s conclusion.

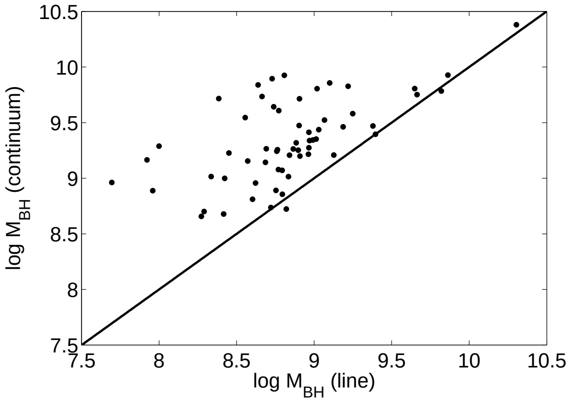

Fig. 1 Comparison of the black hole masses estimated with two different approaches.

For the BL Lac objects in this sample, we use the empirical relation between the host galaxy's absolute magnitude in the R-band $M_{\rm R}$ and $M_{\rm BH}$ proposed by Bettoni et al. (2003),

$$\log M_{\rm BH} = -0.50 M_{\rm R} - 3.00, \qquad (12)$$

to estimate their black hole masses.

Although the apparent velocities of the jet components were measured by VLBI observations, the intrinsic speeds of the jet components are still unavailable, as the viewing angles of the jets are unknown for most sources in this sample. However, we can derive the minimal Lorentz factors from the observed apparent velocities of the jet components using:

$$\gamma_{\rm min} = (1+\beta_{\rm app}^2)^{0.5}, \tag{13}$$

and then analyze their relationships with other physical quantities pertaining to the sources. For the sources with more than one measured moving component, we always select the one moving fastest, as we intend to explore the acceleration mechanism of the jets in blazars (see Cohen et al. 2007 for the detailed discussion).

4 RESULTS

In Figure 2, we plot the relation between black hole masses $M_{\rm BH}$ and the minimal Lorentz factors $\gamma_{\rm min}$ of the jets. The linear regression gives

$$\log\gamma_{\rm min} = 0.31\log M_{\rm BH} - 1.80\,. \tag{14}$$

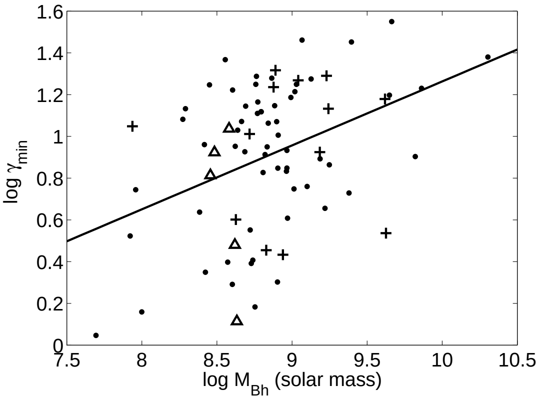

Fig. 2 Relationship between the black hole mass and the minimal Lorentz factor of the jet. The filled circles represent quasars whose $M_{\rm BH}$ is estimated by line luminosities, while the triangles represent BL Lac objects. The crosses represent quasars whose $M_{\rm BH}$ is estimated by continuum luminosities.

A significant correlation is found between these two quantities at 99.6 percent confidence (Spearman rank correlation analysis), and the correlation coefficient is 0.33. It should be noted with caution that this correlation may be caused by the common dependence on redshift. In Figure 3, we plot the relationship between redshift z and the minimal Lorentz factor $\gamma_{\rm min}$. Only a weak correlation is found at 93.6 percent confidence between these two quantities. We perform the Spearman partial rank correlation analysis (Macklin 1982), and we find that the partial correlation coefficient is 0.27 after subtracting the common redshift dependence. The significance of the partial rank correlation is 2.39, which is equivalent to the deviation from a unit variance normal distribution if there is no correlation present (see Macklin 1982 for the details). A summary of the results of partial rank correlation analysis is listed in Table 3.

We also perform a correlation analysis on the sources in the restricted redshift range $0.1 < z < 2.1$ (see Fig. 4). For this subsample of 72 sources, a correlation at 97.6 percent confidence is still present between $\gamma_{\rm min}$ and $M_{\rm BH}$, while almost no correlation between $\gamma_{\rm min}$ and z is found (at 55.2 percent confidence). It appears that the correlation between $\gamma_{\rm min}$ and $M_{\rm BH}$ is an intrinsic one, not caused by the common redshift dependence.

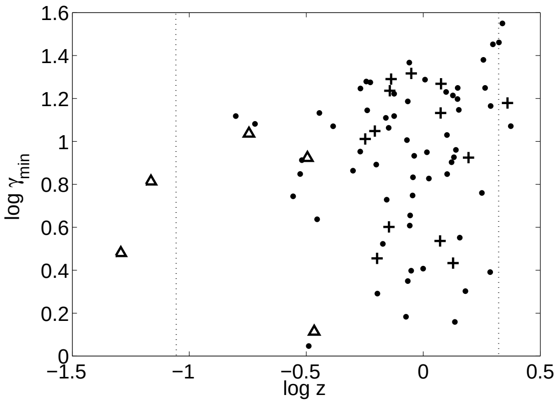

Fig. 3 Minimal Lorentz factor of the jet versus redshift plane for our sample (symbols as in Fig. 2). The restricted redshift range, $0.1 < z < 2.1$, is indicated by the dotted lines.

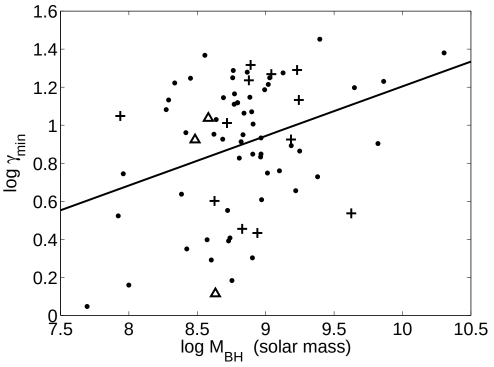

Fig. 4 The same as Fig. 2, but for the subsample within the restricted redshift range.

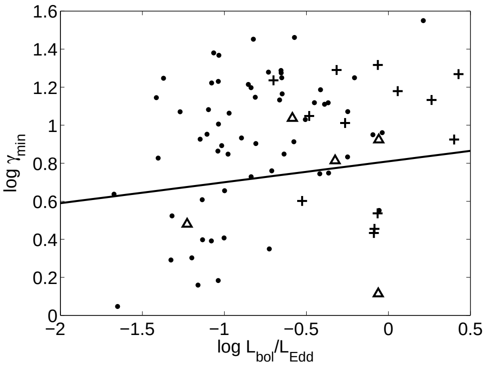

Fig. 5 Relationship between the Eddington ratio and the minimal Lorentz factor of the jet (symbols as in Fig. 2).

Table 3 Spearman Partial Rank Correlation Analysis of the Sample

Sample	N	Correlated variables: A,B	Variable: C	$r_{\rm AB}$	$r_{\rm AB,C}$	significance
All	78	$M_{\rm BH}$,$\gamma_{\rm min}$	z	0.33	0.27	2.39
		z,$\gamma_{\rm min}$	$M_{\rm BH}$	0.21	0.07	0.61
		$M_{\rm BH}$, z	$\gamma_{\rm min}$	0.46	0.42	3.85
		$L_{\rm bol}/L_{\rm Edd}$,$\gamma_{\rm min}$	z	0.21	0.18	1.52
Within $0.1 < z < 2.1$	72	$M_{\rm BH}$,$\gamma_{\rm min}$	z	0.27	0.25	2.14
		z ,$\gamma_{\rm min}$	$M_{\rm BH}$	0.09	–0.02	-0.17
		$M_{\rm BH}$, z	$\gamma_{\rm min}$	0.41	0.40	3.47

Here $r_{\rm AB}$ is the rank correlation coefficient of the two variables, and $r_{\rm AB,C}$ is the partial rank correlation coefficient. The significance of the partial rank correlation is equivalent to the deviation from a unit variance normal distribution if there is no correlation present.

The bolometric luminosity ($L_{\rm bol}$) is estimated by assuming $L_{\rm bol} \approx 10L_{\rm BLR}$ (e.g., Liu et al. 2006). For some sources without measured broad-line luminosities, we estimate the bolometric luminosities from the optical continuum luminosities using the relationship $L_{\rm bol} \approx 9\lambda L_{\lambda,\rm opt}$ ($\lambda = 5100\,$Å) (Kaspi et al. 2000). We plot the relationship between the Eddington ratio ($L_{\rm bol}/L_{\rm Edd}$) and $\gamma_{\rm min}$ of the jets in Figure 5. The linear regression gives

$$\log\gamma_{\rm min} = 0.11\log L_{\rm bol}/L_{\rm Edd} + 0.87. \tag{15}$$

We find that only a weak correlation between $L_{\rm bol}/L_{\rm Edd}$ and $\gamma_{\rm min}$ (at 93.5 per cent confidence) is present.

5 DISCUSSION

We find an intrinsic correlation between the black hole masses and the minimal Lorentz factors of the jet components for a sample of blazars, while no significant correlation between the Eddington ratios and the Lorentz factors is present for the same sample. Our main statistical results will not be altered, even if those black holes with masses estimated with continuum luminosities are removed. Our statistical results provide useful clues to the mechanisms of jet formation and acceleration in blazars.

It is believed that the growth of massive black holes in the centers of galaxies is dominantly governed by mass accretion in the AGN phases (e.g., Soltan 1982; Yu & Tremaine 2002). The massive black holes will be spun up through accretion, as the black holes acquire mass and angular momentum simultaneously though accretion. The spins of massive black holes may also be affected by the mergers of black holes. A rapidly rotating new black hole will be present after the merger of two black holes, only if the binary's larger member already spins quickly and the merger with the smaller hole is consistently near prograde, or if the binary's mass ratio approaches unity (Hughes & Blandford 2003). The comoving space density for heavier black holes is much lower than that for lighter black holes (e.g., see the black hole mass function in Yu & Tremaine 2002), which means that the probability of merging for two black holes with similar masses is lower than for heavier black holes. This implies that the spins of heavier black holes are mainly regulated by accretion rather than mergers. Thus, it is natural to expect (in a statistical sense) that the heavier black holes have higher spin parameters a than their lower mass counterparts. Volonteri et al. (2007) studied how the accretion from a warped disc influences the evolution of black hole spins and concluded that within the cosmological framework, one indeed expects most supermassive black holes in elliptical galaxies to have on average higher spins than black holes in spiral galaxies, where random, small accretion episodes (e.g., tidally disrupted stars, accretion of molecular clouds) might have played a more important role. The jets can be accelerated to higher speeds by the heavier black holes, because they are spinning more rapidly (Blandford & Znajek 1977). The intrinsic correlation between black hole masses and the minimal Lorentz factors of the jet components found in this work is consistent with the Blandford-Znajek mechanism. The properties of accretion disks are related to the dimensionless accretion rates $\dot{m}$ ($\dot{m} = \dot{M}/\dot{M}_{\rm Edd} \propto L_{\rm bol}/L_{\rm Edd}$). No significant correlation between $L_{\rm bol}/L_{\rm Edd}$ and $\gamma_{\rm min}$ is found, which implies that the jet acceleration may not be related to the properties of the accretion disk, which may imply that the jet formation is not sensitive to the disk structure. This is, of course, quite puzzling, and should be verified by future work with a larger blazar sample. Our statistical results imply that the BZ mechanism may dominate over the BP mechanism for jet acceleration in blazars.

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