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Central black hole mass determination for blazars*

Yuan Yu-Hai(袁聿海)[a)b)], Fan Jun-Hui(樊军辉)[b)†], and Huang Yong(黄 勇)[b)]

[a)] *Center for Experiment, Guangzhou University, Guangzhou* 510400, *China*

[b)] *Center for Astrophysics, Guangzhou University, Guangzhou* 510400, *China*

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In this paper, we use a method to determine some basic parameters for the γ-ray loud blazars. The parameters include the central black mass (M), the boosting factor (δ), the propagation angle (Φ), the distance along the axis to the site of the γ-ray production (d). A sample including 32 γ-ray loud blazars with available variability time scales has been used to discuss the above properties. In this method, the γ-ray energy, the emission size and the property of the accretion disc determine the absorption effect. If we take the intrinsic γ-ray luminosity to be λ times the Eddington luminosity, i.e. $L_\gamma^{\rm in} = \lambda L_{\rm Edd}$, then we have the following results: the mass of the black hole is in the range of $(0.59 - 67.99) \times 10^7 M_\odot$ ($\lambda = 1.0$) or $(0.90 - 104.13) \times 10^7 M_\odot$ ($\lambda = 0.1$); the boosting factor (δ) in the range of $0.16 - 2.09(\lambda = 1.0)$ or $0.24 - 2.86$ ($\lambda = 0.1$); the angle (Φ) in the range of $9.53^\circ - 73.85^\circ$ ($\lambda = 1.0$) or $7.36^\circ - 68.89^\circ$ ($\lambda = 0.1$); and the distance ($d/R_{\rm g}$) in the range of $22.39 - 609.36$ ($\lambda = 1.0$) or $17.54 - 541.88$ ($\lambda = 0.1$).

Keywords: galaxies, active-galaxies, BL Lacertae objects, general-galaxies
PACC: 9850R, 9850F, 9870Q

1. Introduction

Many blazars, including BL Lac objects (BLs), and flat-spectrum radio quasars (FSRQs), emit a large fraction of their bolometric luminosity in high-energy γ-rays, and have been detected by CGRO/EGRET (the energetic gamma ray experiment telescope in Compton gamma-ray observatory) at energies $E > 100\,{\rm MeV}$.[1−3] These blazars share some common properties, such as high γ-ray luminosity, violent variability on time scales from hours to days, not only at γ-rays, but also at other bands. So strong a variability implies that the γ-rays may come from the core of blazars.

It is generally believed that the emission of high energy γ-rays from AGNs (active galactic nuclei) depends on $\gamma - \gamma$ pair production process because there are a lot of soft photons around the central black hole. In 1995, Becker and Kafatos,[4] based on the x-ray field of an accretion disc, calculated the γ-rays optical depth, and found that the γ-rays should escape preferentially along the symmetric axis of the disc, due to the strong angular dependence of the pair production cross section. The phenomenon of $\gamma - \gamma$ 'focusing' is related to the main issue of $\gamma - \gamma$ transparency, which represents a minimum distance between the central black hole and the site of γ-ray production.[5−7] Therefore, the γ-rays are focused in a solid angle, $\Omega = 2\pi(1 - \cos\Phi)$, the apparent luminosity observed can thus be expressed as: $L_\gamma = \Omega D^2 F_\gamma (1+z)^{\alpha_\gamma - 1}$, where F_γ is the observed γ-ray energy flux, D the luminosity distance, z the redshift, α_γ the γ-rays spectral index. Because the observed γ-rays emitted from blazars demand that the jet should be almost pointing to us, the optical depth τ is not greater than unity. The γ-rays should come from a solid angle, Ω, instead of being isotropic. Hence, both the beaming and absorption effects must be considered when the properties of γ-ray blazars are discussed. The optical variability can supply some information about the γ-ray emission region. All these considerations suggest a method to estimate the basic parameters of γ-rays loud blazars, including the central black hole mass (M), the boosting factor (δ), the propagation angle (Φ) and the distance along the axis to the site of the γ-ray production (d).

Hereafter $H_0 = 75\,{\rm kms}^{-1}{\rm Mpc}^{-1}$, and $q_0 = 0.5$ are adopted throughout this paper.

2. Method

In this section, we follow the method used in our previous papers by Cheng[7] and Fan,[5] who obtained

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†E-mail: fjh@gzhu.edu.cn

the optical depth expression based on the work by Becker and Kafatos,[4]

$$\tau_{\gamma\gamma}(M_7, \Phi, d) = \frac{1}{3}(51-8\omega) \times \Phi^{2.5}\left(\frac{d}{R_{\rm g}}\right)^{-\frac{2\alpha_X+3}{2}} + kM_7^{-1}\left(\frac{d}{R_{\rm g}}\right)^{-2\alpha_X-3}, \quad (1)$$

where k is defined as:

$$k = 4.50\times10^9\frac{\Psi(\alpha_X)(2-\omega)(1+z)^{3+\alpha_X}}{(2\alpha_X+4-\omega)(2\alpha_X+3)} \times F'_{\rm O}\left[\frac{\left(\frac{R_{\rm O}}{R_{\rm g}}\right)^{2\alpha_X+4-\omega}-\left(\frac{R_{\rm ms}}{R_{\rm g}}\right)^{2\alpha_X+4-\omega}}{\left(\frac{R_{\rm ms}}{R_{\rm g}}\right)^{2-\omega}-\left(\frac{R_{\rm o}}{R_{\rm g}}\right)^{2-\omega}}\right] \times\left(\frac{E_\gamma}{4m_{\rm e}c^2}\right)^{\alpha_X}\times(1+z-\sqrt{1+z})^2. \quad (2)$$

M_7 is the black hole mass in units of $10^7 M_\odot$, $\Psi(\alpha_{\rm X})$, a function of x-ray spectral index, F'_0 the x-ray flux parameter in units of $\rm cm^{-2}s^{-1}$, $m_{\rm e}$ the electron mass, c the speed of light, $R_{\rm g} = \dfrac{GM}{c^2}$ the gravitational radius, E_γ the average energy of gamma-rays; and $R_{\rm o}$ and $R_{\rm ms}$, are respectively the outer and inner radii of the two-temperature accretion disc;[4] ω is a free parameter, $\omega = 3$ is for a two-temperature disc, while $\omega = 0$ is for a uniformly bright disc. Equation 1 shows that the optical depth depends on d, Φ and M.

If the variability timescale ($\Delta T_{\rm D}$ in units of day) can be observed, then d can be defined as

$$\frac{d}{R_{\rm g}} = 1.73\times10^3\frac{\Delta T_{\rm D}}{1+z}\delta M_7^{-1}, \quad (3)$$

where $\delta = \dfrac{1}{\Gamma(1-\beta\cos\Phi)}$ is the boosting factor. Based on the relativistic beaming model, the relation between the observed luminosity and the intrinsic one is

$$L_\gamma^{\rm obs} = \frac{\delta^{\alpha_\gamma+4}}{(1+z)^{\alpha_\gamma-1}}L_\gamma^{\rm in}. \quad (4)$$

The observed γ-ray flux $F_\gamma^{\rm obs}$ (in units of erg $\rm cm^{-2}s^{-1}$) can be expressed as a function of the intrinsic luminosity ($L_\gamma^{\rm in}$), the Doppler factor (δ), the luminosity distance (D), and the solid angle (Ω), written as:

$$F_\gamma^{\rm obs}(>100\,{\rm MeV}) = (1+z)^{1-\alpha_\gamma}\delta^{\alpha_\gamma+4}L_\gamma^{\rm in}/\Omega D^2. \quad (5)$$

We define the isotropic luminosity as $L_{\rm iso} = 4\pi D^2 F_\gamma^{\rm obs}(>100\,{\rm MeV})$, then

$$L_{\rm iso}^{45} = \frac{2.52\lambda\delta^{\alpha_\gamma+4}}{(1-\cos\Phi)(1+z)^{\alpha_\gamma-1}}M_7, \quad (6)$$

where $L_{\rm iso}^{45}$ (in units of 10^{45} ergs $\rm s^{-1}$) is the isotropic luminosity, λ a parameter which depends on the specific γ-ray emission model, and $L_\gamma^{\rm in} = \lambda L_{\rm Edd} = 1.26\times10^{45}\lambda M_7$ is adopted. From the above equations, we can obtain the Doppler factor δ

$$\delta = \left(\frac{L_{\rm iso}^{45}(1-\cos\Phi)(1+z)^{\alpha_\gamma-1}}{2.52\lambda M_7}\right)^{\frac{1}{\alpha_\gamma+4}}. \quad (7)$$

Then the distance can be defined as

$$d(\Phi, M, L_{\rm iso}) = AR_{\rm g}(1-\cos\Phi)^{\frac{1}{\alpha_\gamma+4}}, \quad (8)$$

where

$$A = 1.73\times10^3\triangle T_{\rm D}(1+z)^{-\frac{5}{\alpha_\gamma+4}}M_7^{-\frac{\alpha_\gamma+5}{\alpha_\gamma+4}} \times\left(\frac{L_{\rm iso}^{45}}{2.52\lambda}\right)^{\frac{1}{4+\alpha_\gamma}}. \quad (9)$$

Based on the above equations, $\tau_{\gamma\gamma}$ can be obtained,

$$\tau_{\gamma\gamma}(\Phi, M_7, L_{\rm iso}) = \left[9\times\Phi^{2.5}(1-\cos\Phi)^{-\frac{2\alpha_X}{2\alpha_\gamma+8}} + kM_7^{-1}A^{-\frac{2\alpha_X+3}{2}}(1-\cos\Phi)^{-\frac{2\alpha_X+3}{\alpha_\gamma+4}}\right]A^{-\frac{2\alpha_X+3}{2}}. \quad (10)$$

Therefore, we have four relations,[4,6]

$$\frac{d}{R_{\rm g}} = 1.73\times10^3\frac{\triangle T_{\rm D}}{1+z}\delta_7^{-1},\quad L_{\rm iso}^{45} = \frac{2.52\lambda\delta^{\alpha_\gamma+4}}{(1-\cos\Phi)(1+z)^{\alpha_\gamma-1}}M_7,$$

$$9\times\Phi^{2.5}\left(\frac{d}{R_{\rm g}}\right)^{-\frac{2\alpha_X+3}{2}} + kM_7^{-1}\left(\frac{d}{R_{\rm g}}\right)^{-2\alpha_x-3} = 1,$$

$$22.5\Phi^{1.5}(1-\cos\Phi) - 9\times\frac{2\alpha_X+3}{2\alpha_\gamma+8}\Phi^{2.5}\sin\Phi - \frac{2\alpha_X+3}{\alpha_\gamma+4}kM_7^{-1}A^{-\frac{2\alpha_X+3}{2}}(1-\cos\Phi)^{-\frac{\alpha_X+3}{2\alpha_\gamma+8}}\sin\Phi = 0. \quad (11)$$

For a source with available x-ray, γ-ray data, and short time scales, the mass of the black hole M_7, the boosting factor δ, the distance d, the propagation angle with respect to the axis of the accretion disc Φ, can be derived from the four equations, with $R_{\rm ms} = 6R_{\rm g}$, $R_0 = 30R_{\rm g}$, $E_\gamma = 1\,{\rm GeV}$ and $\omega = 3$ (a two-temperature disc) being used.

3. Observation data

We will use the variability timescales, so we only consider those γ-ray loud blazars with available short timescales variation. For different sources and/or different observation periods, the variability timescales correspond to different variation amplitudes, so we use the doubled timescales, $\Delta T_{\rm D} = (F_{\rm min}/\Delta F)\Delta T$, as the timescales, here $\Delta F = F_{\rm max} - F_{\rm min}$ is the variation of the flux over the time ΔT.[7]

Most of the γ-ray data come from Ref.[3], but $0829+046$ and $2005-489$ are taken from Ref.[8]. X-ray data come from Refs.[9–11]. Timescales come from Refs.[12–16]. We assume that the multi-band emission regions are co-spatial. For $0336-019$, $0440-003$, $0458-020$, $0827+243$, $1622-297$, and $1741-038$, there has been no available x-ray spectral index, so we use $\alpha_{\rm X} = 1.0$. For $0716+714$, whose redshift is not available, we use the average redshift, $z = 0.772$.

Table 1. Data for a sample of 32 gamma-ray loud blazars.

IAU Name	z	F_X	α_X	Ref	F_γ	α_γ	Ref	ΔT	L^{48}_{iso}	Ref
0202+149	1.202	0.06	0.68	Don01	23.6	2.23	Har99	24	0.1297	Mil78
0208-512	1.003	0.627	1.04	Fos98	134.1	1.99	Har99	168.000	0.5718	Don95
0219+428	0.444	1.558	1.6	Fos98	25.3	2.01	Har99	30.000	0.0181	Don95
0235+164	0.94	1.7	1.59	Fos98	65.1	1.85	Har99	48.000	0.2600	Don95
0336-019	0.852	0.253		Fos98	177.6	1.84	Har99	2.4	0.5783	Wil71
0440-003	0.844	0.109		Fos98	85.9	2.37	Har99	2.64	0.1825	Wil71
0458-020	2.286	0.1		And96	31.7	2.45	Har99	144.000	0.7419	Don95
0521-365	0.055	2.12	1.89	Don01	31.9	2.63	Har99	72.000	0.0001	Don95
0528+134	2.06	0.951	0.54	Fos98	147.1	2.46	Har99	48.000	2.6259	Don95
0537-441	0.896	0.8	1.04	Fos98	91.1	2.41	Har99	24.000	0.2148	Don95
0716+714		1.346	1.77	Fos98	45.7	2.19	Har99	1.920	0.0931	Don95
0735+178	0.424	0.248	1.34	Fos98	29.3	2.6	Har99	28.800	0.0095	Don95
0827+243	0.939	0.34		Fos98	68.5	2.42	Har99	1.32953	0.1790	Xie04
0829+046	0.18	0.4	3.26	Don01	14.3	2.3	Chi95	24.000	0.0011	Don95
0836+710	2.17	0.819	0.42	Fos98	33.4	2.62	Har99	24.000	0.6288	Don95
0851+202	0.306	1.063	1.5	Fos98	15.8	2.03	Har99	1.08	0.0050	Xie022
0954+658	0.367	0.158	0.96	Fos98	47.2	2.12	Har99	48.000	0.0200	Giu02
1101+384	0.031	37.333	2.1	Fos98	27.1	1.57	Har99	1.920	0.0001	Don95
1127-145	1.187	0.659	3.06	Sie98	38.3	2.7	Har99	6	0.1382	Wil71
1156+295	0.729	0.44	2.3	Don01	50.9	1.98	Har99	11.040	0.1087	Don95
1219+285	0.102	0.409	1.24	Fos98	53.6	1.73	Har99	1.71276	0.0024	Xie04
1226+023	0.158	12.074	0.89	Fos98	48.3	2.58	Har99	24.000	0.0018	Fan05
1253-055	0.536	1.246	0.83	Fos98	267.3	1.96	Har99	48.000	0.2986	Don95
1510-089	0.361	0.718	0.9	Fos98	29	2.47	Har99	57.600	0.0077	Don95
1622-297	0.815	0.08		And96	276.5	2.07	Har99	4.850	0.7049	Fan05
1633+382	1.814	0.258	0.53	Fos98	107.5	2.15	Har99	48.000	1.6200	Don95
1741-038	1.046	2.213		Fos98	36	2.42	Har99	240.000	0.1221	Qia95
2005-489	0.071	5.333	1.94	Fos98	15.1	2.2	Chi95	1.92	0.0002	Don95
2155-304	0.117	45.583	1.34	Fos98	30.4	2.35	Har99	3.300	0.0008	Fan05
2200+420	0.069	0.936	1.92	Fos98	39.9	2.6	Har99	11.000	0.0003	Fan04
2230+114	1.037	0.73	1.51	Don01	51.6	2.45	Har99	48.000	0.1668	Fan05
2251+158	0.859	1.082	0.62	Fos98	116.1	2.21	Har99	1.920	0.2973	Don95

All the data are listed in Table 1, in which Col.1 gives the IAU name, Col.2 the redshift, Col.3 the flux density of x-rays in units of μJy, Col.4 the spectral index of x-rays, Col.5 the reference of x-ray data, Col.6 the flux density at γ-ray band, in units of 10^{-8}photon cm^{-2} s^{-1}, Col.7 the spectral index at γ-ray band, Col.8 the reference of γ-ray data, Col.9 the timescales in units of hours, and Col.10 the reference of timescales.

4. Result and discussion

As we do not know the intrinsic γ-ray luminosity, we assume that it is close to the Eddington luminosity, say $\lambda L_{\rm Edd}$. In this paper, $\lambda = 0.1$ and $\lambda = 1.0$ are used. Using the data listed in Table 1, we can estimate the four parameters (M_7, Φ, d, δ). The results are listed in Table 2, in which Col.1 gives the name,

Table 2. Calculation Results for a sample of 32 gamma-ray loud blazars.

IAU Name	M_7 ($\lambda=0.1$)	M_7 ($\lambda=1.0$)	Φ ($\lambda=0.1$)	Φ ($\lambda=1.0$)	$d/R_{\rm g}$ ($\lambda=0.1$)	$d/R_{\rm g}$ ($\lambda=1.0$)	δ ($\lambda=0.1$)	δ ($\lambda=1.0$)	Type
0202+149	10.47	6.85	11.08	12.01	173.99	191.42	1.16	0.84	FSRQ
0208-512	104.13	67.99	23.01	25.03	64.75	70.40	1.12	0.79	FSRQ
0219+428	28.75	19.03	25.49	45.18	90.19	50.87	0.87	0.65	BL
0235+164	42.19	27.58	42.85	46.42	140.61	150.67	1.66	1.17	BL
0336-019	2.55	1.65	33.24	24.72	101.80	214.04	2.75	1.91	FSRQ
0440-003	2.45	1.63	18.36	28.90	163.90	92.07	1.96	1.44	FSRQ
0458-020	48.89	32.74	24.10	26.11	219.35	237.82	1.70	1.23	FSRQ
0521-365	67.18	46.33	16.97	10.46	17.54	34.37	0.24	0.16	FSRQ
0528+134	9.76	6.43	34.33	37.12	332.23	367.68	2.86	2.08	FSRQ
0537-441	15.77	10.55	30.61	22.24	88.35	187.51	1.53	1.09	BL
0716+714	2.53	1.69	68.89	73.85	171.58	181.99	2.79	1.98	BL
0735+178	27.19	18.53	18.83	12.94	35.03	72.14	0.65	0.46	BL
0827+243	1.01	0.66	42.85	31.85	138.82	290.48	2.78	1.99	FSRQ
0829+046	45.70	31.02	68.43	72.30	43.10	45.05	0.67	0.48	BL
0836+710	2.88	1.89	36.50	39.44	541.88	609.36	2.84	2.09	FSRQ
0851+202	1.32	0.88	29.83	32.62	117.30	123.91	1.32	0.93	BL
0954+658	42.68	28.03	8.75	9.53	28.27	30.81	0.48	0.34	BL
1101+384	2.31	1.48	37.74	68.58	67.58	39.29	0.59	0.43	BL
1127-145	4.07	2.78	45.64	49.05	230.44	245.35	2.38	1.74	FSRQ
1156+295	10.79	7.09	39.13	42.39	66.29	71.37	1.55	1.10	FSRQ
1219+285	2.38	1.54	9.22	9.99	57.28	61.51	0.61	0.43	BL
1226+023	13.55	9.12	9.68	10.61	105.32	114.82	0.48	0.35	FSRQ
1253-055	37.63	24.35	14.80	11.23	60.22	131.27	1.01	0.71	FSRQ
1510-089	36.91	24.70	7.36	11.70	77.41	42.70	0.47	0.35	FSRQ
1622-297	5.93	3.90	14.33	23.17	127.03	70.79	1.96	1.43	FSRQ
1633+382	12.93	8.35	16.81	18.36	405.34	451.54	2.13	1.54	FSRQ
1741-038	93.15	62.31	28.28	30.61	87.90	95.22	0.97	0.70	FSRQ
2005-489	2.34	1.58	28.28	30.61	66.56	70.43	0.61	0.43	BL
2155-304	2.51	1.69	40.68	28.28	69.83	142.26	0.82	0.57	BL
2200+420	13.95	9.61	12.94	24.41	39.22	22.39	0.37	0.29	BL
2230+114	37.34	25.29	55.72	59.75	70.28	74.80	1.54	1.11	FSRQ
2251+158	0.90	0.59	30.45	24.72	236.59	502.00	2.79	2.04	FSRQ

Col.2 the intrinsic luminosity, in units of 10^{48}erg/s, Col.3 the black hole mass in units of $10^7 M_\odot (\lambda = 0.1)$, Col.4 the black hole mass in units of $10^7 M_\odot (\lambda = 1.0)$, Col.5 the propagation angle, $\Phi(\lambda = 0.1)$, Col.6 the propagation angle, Φ $(\lambda = 1.0)$, Col.7 the distance $d/R_{\rm g}$, where the γ-rays are produced, $(\lambda = 0.1)$, Col.8

the distance $d/R_{\rm g}$, ($\lambda = 1.0$), Col.9 the boosting factor for $\lambda = 0.1$, Col.10 the boosting factor for $\lambda = 1.0$, and Col.11 the classification.

4.1. Black hole mass

In blazars, the central black holes play a very important role in the observational properties and attract great attention. The black hole mass might shed some light on the evolution of AGNs[5] and there are many methods to measure its important properties. In the present method, the black hole mass is constrained by the optical depth of the $\gamma-\gamma$ pair production. One difference between our procedure and others is that we assume that the γ-rays are from a cone, as opposed to being emitted isotropically. In our method, there is a minimum value of the optical depth τ, which depends on the central black hole mass, as shown in Fig.1. So the black hole mass can be determined.

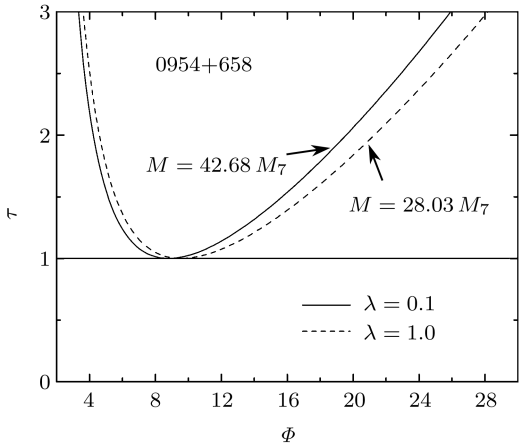


Fig.1. Illustration of dependence of the optical depth τ on the propagation angle Φ for a certain black hole mass of 0954+658.

Our results for the central black hole masses are in the range of $(0.59 - 67.99) \times 10^7 M_\odot$ ($\lambda = 1.0$) or $(0.90 - 104.13) \times 10^7 M_\odot$ ($\lambda = 0.1$), which are consistent with the results given by others. For the BL 0235+164, we obtain $M = 42.19 M_7$ ($\lambda = 0.1$), which is in good agreement with the result $M = 40 M_7$ by Roy.[17] For 3C279, we have $(24.35 - 37.63) M_7$, which is consistent with the result by Hartman,[18] who obtained an accreting black hole of $10^8 M_\odot$, and that by Becker[4] who also obtained $M = 10^{8-9} M_\odot$. For 3C273, our result $M = (0.88 - 1.32) \times 10^8 M_\odot$ is consistent with that by Kriss,[19] who obtained $7 \times 10^8 M_\odot$, and that by Peterson,[20] who obtained $9 \times 10^8 M_\odot$ through reverberation-mapping. For 0521-365, our result is $M = (4.63 - 6.72) \times 10^8 M_\odot$, which is consistent with the result by Barth.[21]

The central black hole masses are very important in understanding the properties of AGNs including the emission mechanism and the evolution process. Many researchers have used various methods to calculate or determine the masses of the black holes[5,22−44] although the masses determined using different methods do not show a consensus.

As for the study of the relationship between BLs and FSRQs, there are some proposals, such as the gravitational enhancement, core-boosted emissions and evolution effects. However, as mentioned in Ref.[45], any proposals should explain the similarity in the continuum between BLs and FSRQs and the difference between their emission lines. From the mass determination in the present work, we find that the average masses are $M = 11.78 \pm 11.63 M_7$ for BLs, and $M = 17.61 \pm 21.08 M_7$ for FSRQs. The results are also shown in Fig.2. A K-S test indicates that the

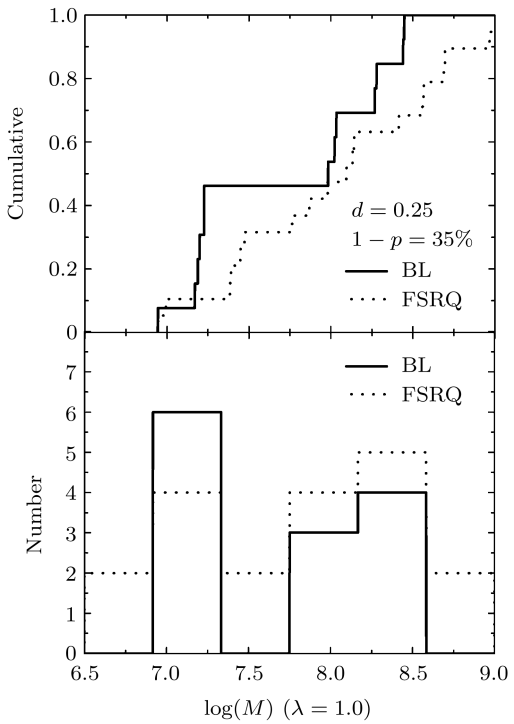


Fig.2. The distribution of central black hole mass M and the K-S test result for BL Lacertae objects and flat spectrum radio sources.

distribution of black holes in BLs and FSRQs are consistent (at a 35.2% confidence). If we use $\omega = 0$, and $\lambda = 1.0, 0.1, 0.01$, then we can obtain $M = 9.53 \pm 9.50 M_7$ ($\lambda = 1.0$), $M = 14.30 \pm 14.29 M_7$ ($\lambda = 0.1$),

$M = 21.44 \pm 21.49M_7$ ($\lambda = 0.01$) for BLs; and $M = 13.72 \pm 16.53M_7$ ($\lambda = 1.0$), $M = 20.59 \pm 24.81M_7$ ($\lambda = 0.1$), $M = 30.92 \pm 37.28M_7$ ($\lambda = 0.01$) for FSRQs.

It is very interesting that the long-term periodicity distributions for the BL Lacerate objects and the flat spectrum radio quasars come from the same parent distribution which is 68%.[27] If the long-term periods are associated with the central construction, then the similar period distribution suggests a similar central construction, for instance the central black hole masses. Based on our sources, we collect some long-term periods from Refs.[27,46–51], to compare with our results, and obtain $\log(\mathrm{M}) = (-0.063 \pm 0.04)P + (8.45 \pm 0.37)$ (here, M is central black hole mass, in units of $M_\odot$, P is the long-term periodicity, in units of yr), $p = 83\%$, see Fig.3.

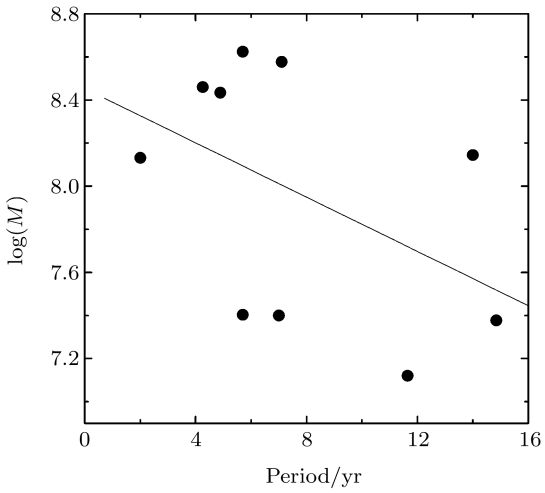


Fig.3. Relationship between the long-term periods and the black hole masses.

Based on our sources, we collected some black hole masses from Refs.[40–42], and compare with our results, then we have the result as shown in Fig.4. In this paper, we assume that most of the x-rays come from the accretion disc. But if most of the x-ray radiation come from the jet, then we assume $X_{\mathrm{acc}} = 1\% \times X_{\mathrm{jet}} \approx 1\% \times X_{\mathrm{tot}}$($X_{\mathrm{acc}}$, X_{jet}, X_{tot} represents the x-rays from accretion disc, jet and the total respectively). We thus have $M = 29.68 \pm 34.48M_7$ ($\lambda = 1.0$), $M = 44.6 \pm 51.89M_7$ ($\lambda = 0.1$) for FSRQs; and $M = 17.29 \pm 17.02M_7$ ($\lambda = 1.0$), $M = 29.68 \pm 34.47M_7$ ($\lambda = 0.1$) for BLs. Based on the results, we find that most of the x-rays come from the jet.

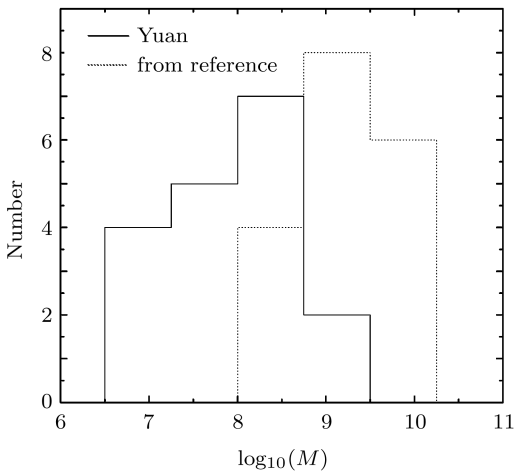


Fig.4. The distributions of black hole masses.

4.2. Doppler factor

There are several methods[5,13,25,52–54] that can be used to calculate the Doppler (boosting) factor. In the present work, we apply the optical depth, which depends on the Doppler factor, δ, to γ-ray sources by demanding that the optical depth due to pair-production should be low enough for γ-rays to escape, so that δ is a lower limit. Our results cover $0.16 - 2.09(\lambda = 1.0)$ and $0.24 - 2.86(\lambda = 0.1)$. From Table 2 and Fig.5, we can find that BLs and FSRQs

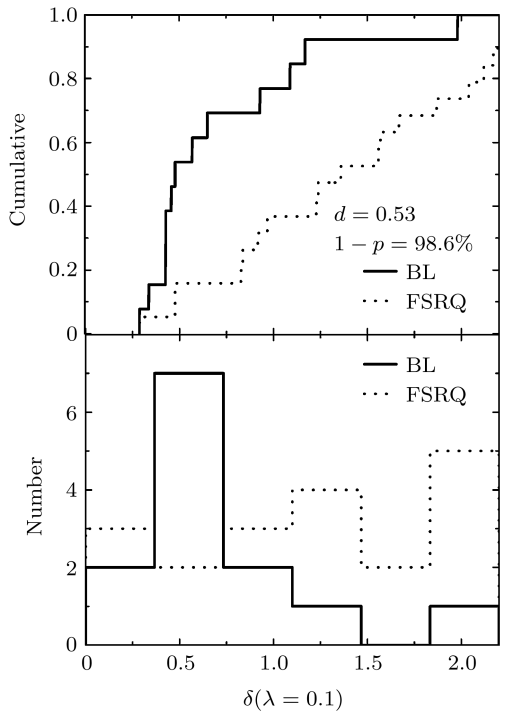


Fig.5. The distribution of δ and the K-S test results for the BL Lacertae objects and the flat spectrum radio sources.

show a great difference between their average Doppler factors, with $\delta = 0.71 \pm 0.48$ for BLs and $\delta = 1.24 \pm 0.63$ for FSRQs. A K-S test result shows $p = 0.014$, which implies that BLs and FSRQs might have different Lorentz factor distributions.

We collect some results from Refs.[27] and [55], to compare with our results, as shown in Fig.5. In our model, the radiation in a cone has been used, but in others, the radiation is isotropic.

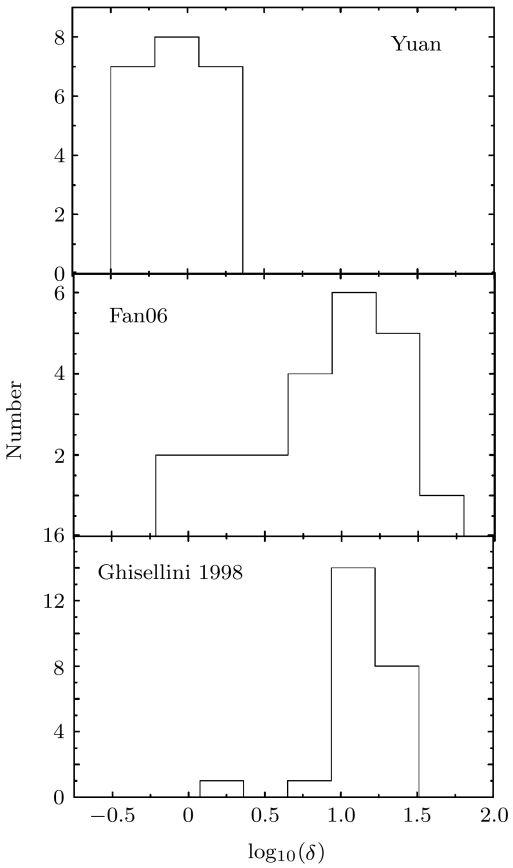


Fig.6. The distribution of doppler factors.

4.3. Propagation angle and distance

Our calculations show that the propagation angle (Φ) is in the range of $9.53 - 73.85$ ($\lambda = 1.0$) or $7.36 - 68.89$ ($\lambda = 0.1$), which is consistent with those by Fan (2005).[5] From Fig.7, we find that there is a great difference between the results for BLs and FSRQs, with $p = 0.51$.

Our results show that $d/R_{\rm g}$ (distance, in units of $R_{\rm g}$) in the range of $22.39 - 609.36$ ($\lambda = 1.0$) or $17.54 - 541.88$ ($\lambda = 0.1$). From Fig.8, we see that there is a difference between the results for BLs and FSRQs, with $p = 0.041$.

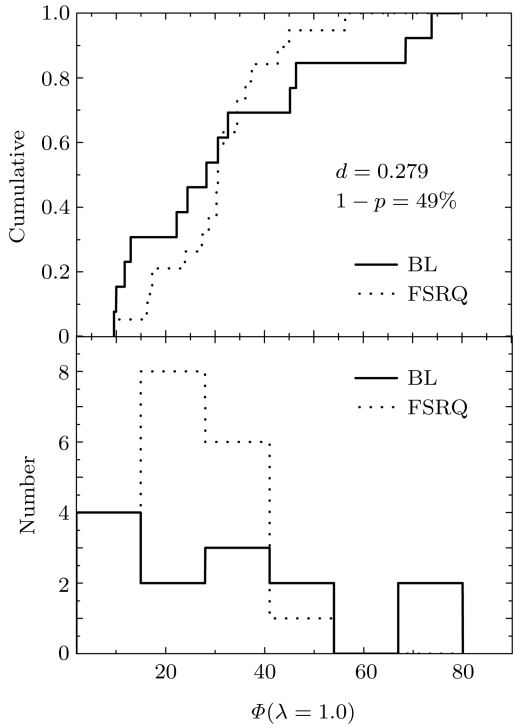


Fig.7. The distribution of Φ and the K-S test results for the BL Lacertae objects and flat spectrum radio sources.

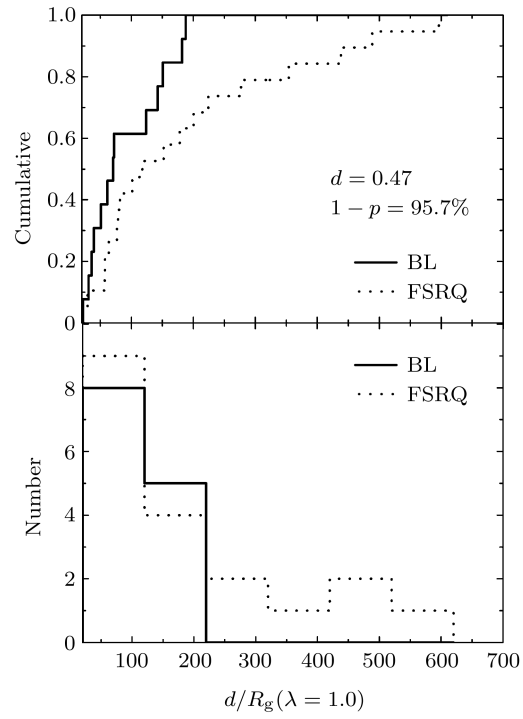


Fig.8. The distribution of $d/R_{\rm g}$ and the K-S test results for the BL Lacertae objects and flat spectrum radio sources.

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