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MASSES, DIMENSIONLESS KERR PARAMETERS, AND EMISSION REGIONS IN GeV GAMMA-RAY–LOUD BLAZARS

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ABSTRACT

We have compiled sample of 17 GeV γ-ray–loud blazars, for which rapid optical variability and γ-ray fluxes are well observed, from the literature. We derive estimates of the masses, the minimum Kerr parameters $a_{\min}$, and the size of the emission regions of the supermassive black holes (SMBHs) for the blazars in the sample from their minimum optical variability timescales and γ-ray fluxes. The results show that (1) the masses derived from the optical variability timescale (M_H) are significantly correlated with the masses from the γ-ray luminosity ($M_H^{\rm KN}$); (2) the values of $a_{\min}$ of the SMBHs with masses $M_H \geq 10^{8.3}\ M_\odot$ (three out of 17 objects) range from $\sim$0.5 to $\sim$1.0, suggesting that these SMBHs are likely to be Kerr black holes. For the SMBHs with $M_H < 10^{8.3}\ M_\odot$, however, $a_{\min} = 0$, suggesting that a nonrotating black hole model cannot be ruled out for these objects. In addition, the values of the size of the emission region, r*, for the two kinds of SMBHs are significantly different. For the SMBHs with $a_{\min} > 0$, the sizes of the emission regions are almost within the horizon ($2r_G$) and marginally bound orbit ($4r_G$), while for those with $a_{\min} = 0$ they are in the range (4.3–66.4)r_G, extending beyond the marginally stable orbit ($6r_G$). These results may imply that (1) the rotational state, the radiating regions, and the physical processes in the inner regions for the two kinds of SMBH are significantly different and (2) the emission mechanisms of GeV γ-ray blazars are related to the SMBHs in their centers but are not related to the two different kinds of SMBH.

Key words: black hole physics — BL Lacertae objects — galaxies: active — galaxies: nuclei

1. INTRODUCTION

It is well known that an active galactic nucleus (AGN) produces as much light as up to several trillion (10^{12}) stars in a volume that is significantly smaller than a cubic parsec. The working model for this AGN phenomenon is a "central engine" that consists of a hot accretion disk surrounding a supermassive black hole (SMBH; Peterson 1997, p. 32). However, searches for SMBHs in AGNs are difficult and complicated (see, e.g., Gebhardt et al. 2002a). As a consequence, so far only a little is known about the properties of SMBHs in AGNs, such as their masses, rotational states, and radiation mechanisms and the size of the radiating regions.

One of the most important properties of an SMBH is its mass. This, in general, is in the range $\sim 10^{6.5}$–$10^{9.5}\ M_\odot$ (e.g., Kormendy & Richstone 1995; Richstone et al. 1998). Various methods for estimating SMBH masses, such as that based on spatially resolved kinematics (see, e.g., Kormendy 2001), the reverberation mapping method (Blandford & McKee 1982; Netzer & Peterson 1997; Gebhardt et al. 2000b), and methods that rely upon variability in optical or X-ray wave bands (e.g., Abramowicz & Nobili 1982; Ho 1999), have been proposed.

Are SMBHs in AGNs Kerr black holes or Schwarzschild black holes? Elvis, Risaliti, & Zamorani (2002) have shown that the accretion process of an SMBH must on average be highly efficient: at least 15% of the accretion mass must be transformed into radiated energy. Thus, they further suggested that most SMBHs must be rapidly rotating. However, there is no direct observational evidence or quantitative results to confirm this suggestion.

Blazars are the best candidates with which to investigate the nature of SMBHs. They exhibit many unusual characteristics: They show continuum variability at all wavelengths, from γ-ray to radio. Large-amplitude, rapid optical variability is a well-known identifying characteristic of blazars. Abramowicz & Nobili (1982) proposed that this is likely produced in the vicinity of the central SMBH, and that the minimum timescale of the variations may be used to place constraints on the size of the emission region and to investigate the radiation mechanism in the inner region around the SMBH. They presented a relation between the minimum optical variability timescale, mass, rotational state (characterized by a dimensionless parameter known as the Kerr parameter), and size of the emission region. We have been engaged in efforts to search for short-timescale optical variations in blazars since the beginning of the 1990s (Xie et al. 1991b, 1998, 1999, 2001; Dai et al. 2001; Xie et al. 2002b).

EGRET observations show that some blazars are GeV γ-ray–loud blazars. Because the emitting regions and the physical processes in the close vicinity of SMBHs are still unknown, where and how these γ-rays are emitted is still somewhat mysterious. The γ-ray emission offers new constraints on the SMBHs from another aspect. Dermer & Gehrels (1995) have presented a method to estimate lower limits on SMBH masses using γ-ray emission fluxes.

In a previous work, we studied the masses of SMBHs using their minimum optical variability timescales and γ-ray fluxes (Xie et al. 2002a). The results for the five γ-ray–loud blazars for which masses were estimated with both methods are reasonable. The masses estimated by the minimum optical variability timescales (upper limits on the

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masses) are slightly greater than those estimated using the Dermer-Gehrels method (lower limits on the masses).

In this work, we further investigate the masses of SMBHs in GeV γ-ray blazars. A sample of 17 GeV γ-ray–loud blazars, most of which are included in our observational program, was compiled from the literature. We estimated the masses of the SMBHs in these blazars using their minimum optical variability timescales, based on the two alternative assumptions that these SMBHs are either Kerr black holes with the maximum possible rotation rate or Schwarzschild black holes, with no rotation. Lower limits on the masses are estimated by the Dermer-Gehrels method using γ-ray fluxes. The SMBHs' rotation parameters and emission regions for these objects are also studied.

The sample is described in § 2. The masses of the SMBHs estimated using the different methods are presented in § 3. The dimensionless Kerr parameters are studied in § 4. A discussion and conclusions are presented in § 5.

2. SAMPLE DESCRIPTION

Our example includes 17 γ-ray–loud blazars for which rapid optical variability and γ-ray fluxes are well observed. The main properties of these objects have been compiled from the literature and are listed in Table 1 as follows: column (1) gives the IAU name, column (2) the object type, column (3) the redshift of the source, columns (4) and (5) the logarithm of the minimum timescale for optical variability in units of seconds and references therefor, columns (6) and (7) the bolometric luminosity of each object in ergs per second and the relevant reference, column (8) the Doppler factor δ, and columns (9) and (10) the γ-ray flux ($F_\gamma > 100$ MeV) in units of 10^{-6} photons cm^{-2} s^{-1} at the lowest and highest state, respectively. The γ-ray data for each source are taken from the Third EGRET Catalog (Hartman et al. 1999), and *K*-corrections have been taken into account.

3. THE MASSES OF SMBHs IN GeV GAMMA-RAY BLAZARS

3.1. *Upper Mass Limit*

Large-amplitude, rapid optical variability is a well-known identifying characteristic of blazars. Abramowicz & Nobili (1982) proposed that it is likely produced in the vicinity of an SMBH in the nuclei of such objects and that the minimum timescale of the variations ($\Delta t_{\rm min}$) may be used to place constraints on the size of the emission region and the SMBH's mass, that is,

$$\Delta t_{\rm min} = 0.98 \times 10^{-5} \tau [M_H/(1\ M_\odot)]\ {\rm s}\ , \tag{1}$$

where τ is a dimensionless parameter that depends on the location of the region that provides the time variation ($r_* = r/r_G$) and on the rotation parameter a:

$$\tau \equiv \pi (r_*^{3/2} + a)\ . \tag{2}$$

The dimensionless rotation parameter characterizes the rotation of the SMBH: when $a = 0$ the hole does not rotate, and when $a = 1$ the hole rotates at the maximum possible rate. The quantity r_* characterizes the location of the region that causes the time variations. The locations of the horizon, marginally bound orbit, and marginally stable orbit for a nonrotating black hole are given by $r_* = 2$, $r_* = 4$, and $r_* = 6$, respectively; for a black hole rotating at the maximum speed, all three locations are given by $r_* = 1$. Since the inner edge of the disk can be as close as the marginally bound orbit $r_{\rm mb}$, τ must obey $\tau > \tau_{\rm min}$, where

$$\begin{aligned} \tau_{\rm min}(a) &= \pi[(r_{*,{\rm mb}})^{3/2} + a] \\ &= \pi\{[2 - a + 2(1-a)^{1/2}]^{3/2} + a\}\ . \end{aligned} \tag{3}$$

From equation (3), we can see that $\tau_{\rm min} = 2\pi$ for an $a = 1$ black hole and $\tau_{\rm min} = 8\pi$ for an $a = 0$ black hole. If $\tau < 2\pi$, observations would exclude the possibility of the black hole model (Abramowicz & Nobili 1982); in the case that $2\pi < \tau < 8\pi$, nonrotating black holes are ruled out.

Considering the effects of relativistic beaming, from equation (1) one can derive

$$M_H = 1.02 \times 10^5 \tau^{-1} \frac{\delta}{1+z} \Delta t_{\rm min}^{\rm obs}\ M_\odot\ , \tag{4}$$

where δ is the Doppler factor and z is the redshift. According to the argument presented in Xie et al. (1991b), the Doppler factor should be

$$\delta \geq (\eta^{\rm obs}/\eta^{\rm intrins})^{1/(4+\alpha)}\ , \tag{5}$$

where η is the inferred efficiency of the conversion of accreted matter into energy for a spherical, homogeneous, non–relativistically beamed region (see Fabian & Rees 1979) and α is the spectral index in the optical band.

For each object, upper limits for the mass of an $a = 1$ (M_H) and an $a = 0$ (M_H^*) SMBH can be derived from equation (3) by substituting the corresponding values for $\tau_{\rm min}$ (2π and 8π, respectively) and using the measured values for δ and the redshift. These values for the masses are listed in columns (11) and (12) of Table 1.

3.2. *Lower Mass Limit*

For a black hole accretion model, the luminosity of the object sets a lower limit on the possible timescale of flux variations, if one assumes that the luminosity is less than or equal to the Eddington luminosity (Elliot & Shapiro 1974). When the main interaction of the emergent radiation flux with the infalling gas is through electron scattering and the energy of most of the emergent photons $h\nu \ll m_e c^2$, the Thomson cross section $\sigma_{\rm T}$ applies, and the luminosity L of the object satisfies the inequality

$$L \leq L_{\rm Edd} = 4\pi G M m_p c/\sigma_{\rm T}\ . \tag{6}$$

For high-energy γ-ray emission, $\epsilon = h\nu/m_e c^2 \gg 1$, Klein-Nishina effects on the Compton scattering cross section must be considered when inferring Eddington-limited masses, and the Compton scattering cross section $\sigma_{\rm KN}$ is

$$\sigma_{\rm KN} \simeq \tfrac{3}{8}\sigma_{\rm T}\epsilon^{-1}(\ln 2\epsilon + \tfrac{1}{2})\ . \tag{7}$$

One may note that equation (7) is valid only for a single energy. But the Third EGRET Catalog (Hartman et al. 1999) lists the photon flux $F(\epsilon_l, \epsilon_u)$ integrated between photon energies of 100 MeV and 5 GeV (i.e., $\epsilon_l \simeq 196$, $\epsilon_u \simeq 10^4$). Taking this into account, the effective cross section $\sigma_{\rm KN}$ in equation (7) becomes $\sigma_{\rm KN}^* = (\epsilon_u - \epsilon_e)^{-1} \int_{\epsilon_e}^{\epsilon_u} \frac{3}{8}\sigma_\tau \epsilon^{-1}(\ln 2\epsilon + \frac{1}{2}) d\epsilon$. In this case, the γ-ray

TABLE 1

Observational Data and Results for17 Blazars

Source (1)	Type[a] (2)	z (3)	$\log \Delta t_{\rm min}^{\rm obs}$ (4)	Ref. (5)	$\log L_{\rm bol}$ (6)	Ref. (7)	δ (8)	F_γ(low) (9)	F_γ(high) (10)	$\log M_H$ (11)	$\log M_H^*$ (12)	$\log M_H^{\rm KN}$ (13)	$\log M_L^{\rm KN}$ (14)	$\log \tau_{\max}$ (15)	$a_{\min}$ (16)	r^* (17)
0219+428.......	BL	0.444	3.73	1	47.2	7	3.0	0.121 ± 0.039	0.254 ± 0.058	8.3	7.7	7.2	6.9	1.86	0.00	8.1
0235+164.......	BL	0.940	4.45	2	47.8	7	2.2	0.105 ± 0.036	0.598 ± 0.080	8.7	8.1	8.4	7.6	1.11	0.8	2.2
0420−014.......	FSRQ	0.915	4.65	3	48.1	10	3.0	0.133 ± 0.063	0.854 ± 0.455	9.0	8.4	8.2	7.3	1.45	0.00	4.3
0537−441.......	BL	0.896	4.66	1	47.5	7	2.2	0.221 ± 0.060	1.223 ± 0.196	8.9	8.3	8.2	7.5	1.53	0.00	4.9
0716+714.......	BL	0.3	3.68	4	46.2	10	2.0	0.098 ± 0.049	0.480 ± 0.117	8.1	7.5	6.9	6.2	1.98	0.00	9.7
0735+178.......	BL	0.424	3.62	1	47.6	7	4.0	0.195 ± 0.052	0.362 ± 0.122	8.3	7.7	6.9	6.6	2.17	0.00	13.0
0851+202.......	BL	0.306	4.0	5	46.4	7	1.9	0.098 ± 0.044	0.159 ± 0.070	8.4	7.8	6.7	6.4	2.42	0.00	19.1
1101+384.......	BL	0.031	3.26	6	45.7	7	1.9	0.089 ± 0.036	0.267 ± 0.068	7.7	7.1	5.3	4.9	3.23	0.00	66.4
1156+295.......	FSRQ	0.729	4.70	3	47.0	3	1.8	0.082 ± 0.020	1.612 ± 0.396	8.9	8.3	8.5	7.2	1.23	0.50	2.9
1219+285.......	BL	0.102	3.58	7	45.3	7	1.4	0.067 ± 0.025	0.522 ± 0.137	7.9	7.3	6.4	5.5	2.29	0.00	15.7
1253−055.......	FSRQ	0.538	3.68	1	48.3	10	5.1	0.075 ± 0.036	2.624 ± 0.105	8.4	7.8	8.3	6.9	0.91	1.0	1.4
1510−089.......	FSRQ	0.361	3.49	8	46.9	10	3.0	0.116 ± 0.061	0.571 ± 0.212	8.0	7.4	6.9	6.3	1.94	0.00	9.2
1514−241.......	BL	0.049	2.95	7	44.5	7	1.3	0.190 ± 0.063	0.382 ± 0.188	7.2	6.6	4.9	4.6	3.15	0.00	58.7
1652+398.......	BL	0.033	3.80	1	45.3	7	1.2	0.176 ± 0.049	0.313 ± 0.127	8.1	7.5	5.8	5.4	3.07	0.00	51.9
2155−304.......	BL	0.116	2.95	9	46.8	7	3.6	0.082 ± 0.036	0.316 ± 0.080	7.6	7.0	5.8	5.2	2.67	0.00	28.1
2200+420.......	BL	0.069	3.23	1	45.0	7	1.2	0.092 ± 0.040	0.415 ± 0.121	7.5	6.9	5.3	4.7	2.99	0.00	45.9
2230+114.......	FSRQ	1.037	4.60	3	48.2	10	3.2	0.167 ± 0.048	0.711 ± 0.201	9.0	8.4	8.2	7.5	1.76	0.00	6.9

Note.—Logarithmic masses are given in solar units.

[a] (BL) BL Lacertae object; (FSRQ) flat-spectrum radio quasar.

References.—(1) Xie et al. 1999; (2) Moles et al. 1985; (3) Xie et al. 1991a; (4) Qian, Tao, & Fan 2002; (5) Xie et al. 2001; (6) Xie et al. 1998; (7) Xie et al. 1991b; (8) Xie et al. 2002b; (9) Paltani et al. 1997; (10) Xie et al. 2003.

luminosity L_γ of the object must satisfy a new inequality,

$$L_\gamma \leq 4\pi G M m_p c/\sigma^*_{\rm KN} . \tag{8}$$

On the basis of similar considerations, Dermer & Gehrels (1995) obtained an expression for the minimum mass of a black hole, in units of $10^8\ M_\odot$, which is given by

$$M_8^{\rm KN} \geq \frac{3\pi d_L^2(m_e c^2)}{2(1.26\times 10^{46})\ {\rm ergs\ s^{-1}}}\frac{F(\epsilon_l,\epsilon_u)}{1+z}\ln[2\epsilon_l(1+z)] , \tag{9}$$

where $F(\epsilon_l, \epsilon_u)$ is the integrated photon flux in units of 10^{-6} photons $\rm cm^{-2}\ s^{-1}$ between photon energies ϵ_l and ϵ_u in units of 0.511 MeV, d_L is the luminosity distance, and z is the redshift of the source. Here we have also defined $d_L = 2cf(z)/H_0$, where $f(z) = 1 + z - (1 + z)^{1/2}$, appropriate to a $q_0 = \frac{1}{2}$ cosmology with $\Lambda = 0$, as did Dermer & Gehrels (1995). The lower limits for the masses obtained from equation (9) in a cosmological model with $\Lambda = 0$ and $H_0 = 75$ km $\rm s^{-1}$ $\rm Mpc^{-1}$ are listed in columns (13) and (14) of Table 1 for high- and low-state γ-ray fluxes, respectively. Equation (9) was derived for the case of isotropic radiation by steady, Eddington-limited accretion. But the current models for γ-ray production in blazars are based on beamed emission (e.g., Dondi & Ghisellini 1995). However, we note that some of the arguments in favor of the beamed γ-ray model have not considered Klein-Nishina effects on the Compton scattering cross section. If one considers these effects, the present EGRET γ-ray observations show that the evidence for the beaming effect in GeV γ-ray blazers is weak (Dermer & Gehrels 1995). To check this conclusion, from equations (1) and (8), and assuming that the minimum variability timescales in the two bands are the same for GeV γ-ray sources, we deduce a corrected form of the basic Elliot-Shapiro (1974) formula for a Kerr black hole (assuming $a = 1$):

$$\log \Delta t_{\rm min} \geq \log L_\gamma - 45.18 . \tag{10}$$

We show in Figure 1 the Elliot-Shapiro relation between $\Delta t_{\rm min}$ and L_γ for our sample, where L_γ is the high-state luminosity and $\Delta t_{\rm min}$ has been divided by $1 + z$. Also shown (*dotted line*) is the relation defined by equation (10). We

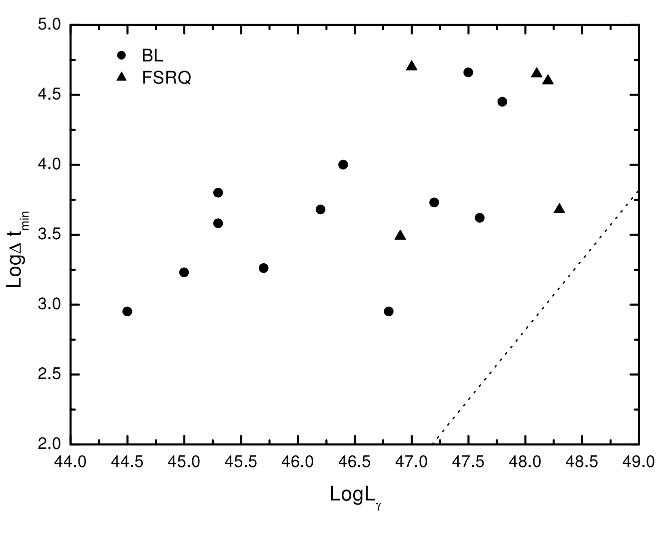

FIG. 1.—Plot of $\log \Delta t_{\rm min}$ vs. $\log L_\gamma$. The dotted line corresponds to the corrected form of the basic Elliot-Shapiro formula, $\log \Delta t_{\rm min} = \log L_\gamma - 45.18$ for a Kerr black hole ($a = 1$ is assumed in this case), where Klein-Nishina effects have been taken into account.

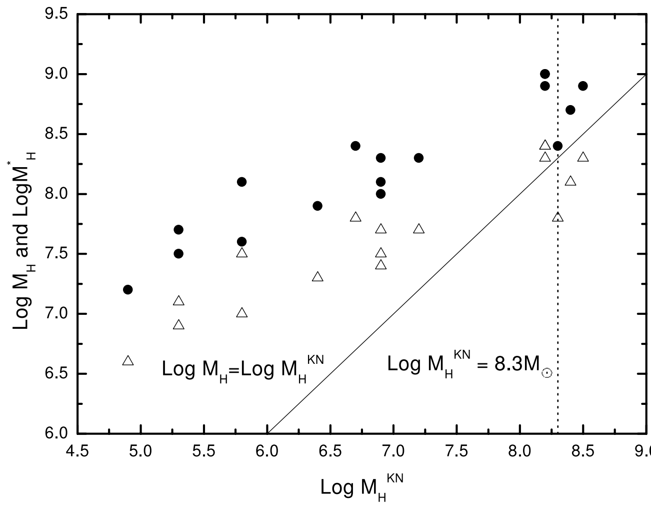

FIG. 2.—Plot of $\log M_H$ and $\log M_H^*$ vs. $\log M_H^{\rm KN}$. The circles represent $\log M_H$, and the triangles represent $\log M_H^*$. The solid line is $\log M_H = \log M_H^{\rm KN}$, and the dotted vertical line is $\log M_H^{\rm KN}(M_\odot) = 8.3$. See text for a definition of the three different masses.

observe that the observed properties of our 17 sources, besides lying in the sub-Eddington region of the plane, are well correlated (correlation coefficient $r = 0.85$, with a chance probability $p \simeq 6.5 \times 10^{-5}$), suggesting that $\delta_\gamma > 1$ is not required by these data. On the basis of this analysis, we conclude that we are indeed allowed to use equation (8) (in which beaming is not included) to estimate the Eddington-limited mass of SMBHs in blazars using current EGRET γ-ray data (Dermer & Gehrels 1995).

3.3. *Results*

If an SMBH is rotating at the possible maximum rate, one would expect that $M_H > M_H^{\rm KN}$, and if it is not rotating, $M_H^* > M_H^{\rm KN}$. Figure 2 shows M_H and M_H^* versus $M_H^{\rm KN}$ for the 17 objects in our sample. From this figure, we find that (1) for the three objects with $\log M_H^{\rm KN}(M_\odot) \geq 8.3$, $M_H > M_H^{\rm KN}$ but $M_H^* < M_H^{\rm KN}$, suggesting the assumption that these objects are nonrotating is unreasonable and they are likely to be rapidly rotating; (2) for the objects with $\log M_H^{\rm KN}(M_\odot) < 8.3$, both M_H and M_H^* are greater than $M_H^{\rm KN}$, implying that the nonrotating model cannot be ruled out; (3) both M_H and M_H^* are significantly correlated with $M_H^{\rm KN}$, suggesting that mass estimates from the optical variability timescale seem to be reliable.

4. DIMENSIONLESS ROTATIONAL PARAMETERS AND THE EMISSION REGIONS

The rotational state and the size of the emission region are very important for understanding the nature of the energy mechanism of SMBHs and for revealing the physical processes near SMBHs. Equation (4) relates the minimum optical variability timescale, mass, rotational state (characterized by a dimensionless parameter), and size of the emission region. This offers us a way to investigate the state and emission region of an SMBH.

Since M_H is the upper mass limit of an SMBH and $M_H^{\rm KN}$ is the lower limit, we can estimate an upper limit on τ by using the value of $M_H^{\rm KN}$ in equation (4):

$$\tau_{\rm max} = 1.02 \times 10^5 \frac{1}{M_H^{\rm KN}} \frac{\delta}{1+z} \Delta t_{\rm min}^{\rm obs} . \qquad (11)$$

The value of $a_{\rm min}$ is given by solution of the equation

$$\log \tau_{\rm max} = \log \tau_{\rm min}(a) \qquad (12)$$

(Abramowicz & Nobili 1982), where $\tau_{\rm min}(a)$ is given by equation (3). From equations (2), (3), (11), and (12), we can derive the values of $\tau_{\rm max}$ and $a_{\rm min}$ and the corresponding size of the emission region (r^*). The results are listed in columns (15), (16), and (17) of Table 1.

From Table 1, one can note that for the three objects with $a_{\rm min} > 0$, the masses estimated using the Dermer-Gehrels method range from $10^{8.3}$ to $10^{8.5}$ $M_\odot$, while they range from $10^{4.9}$ to $10^{8.2}$ $M_\odot$ for those SMBHs with $a_{\rm min} = 0$. This suggests that most SMBHs with masses $\geq 10^{8.3}$ $M_\odot$ should be Kerr black holes.

The estimated size of the emission regions for the three objects with $a_{\rm min} > 0$ are in the range $(1.4\text{–}2.9)r_G$, almost within the scope of the horizon ($2r_G$) and marginally bound orbit ($4r_G$). However, for the other 14 sources with $a_{\rm min} = 0$, the emission regions are in the range $(4.3\text{–}66.4)r_G$, extending beyond the marginally stable orbit ($6r_G$). These results seem to suggest that for different kinds of SMBHs, the emission regions are significantly different.

5. DISCUSSION AND CONCLUSION

Estimates of the masses, the minimum Kerr parameters $a_{\rm min}$, and the size of the emission regions of supermassive black holes for a sample of 17 blazars have been derived from their minimum optical variability timescales and γ-ray fluxes. Our results show the following: (1) For the three objects with masses $M_H^{\rm KN} \geq 10^{8.3}$ $M_\odot$, $M_H > M_H^{\rm KN}$ but $M_H^* < M_H^{\rm KN}$, suggesting the assumption that these objects are nonrotating is unreasonable and they are likely to be Kerr black holes; the minimum Kerr parameters for these objects range from 0.5 to 1.0, and the estimated sizes of the emission regions are in the range $(1.4\text{–}2.9)r_G$, almost within the scope of the horizon ($2r_G$) and marginally bound orbit ($4r_G$). (2) For the 14 objects with masses $M_H^{\rm KN} < 10^{8.3}$ $M_\odot$ ($10^{4.9}$–$10^{8.2}$ $M_\odot$), both M_H and M_H^* are greater than $M_H^{\rm KN}$, implying that a nonrotating model cannot be ruled out; the minimum Kerr parameters are zero, and the estimated sizes of the emission regions are in the range $(4.3\text{–}66.4)r_G$, going beyond the marginally stable orbit ($6r_G$). (3) Both M_H and M_H^* are significantly correlated with $M_H^{\rm KN}$.

It is generally believed that most SMBHs are rapidly rotating (e.g., Elvis et al. 2002). The results of this work show that, indeed, the most massive SMBHs, that is, those with $M_H \geq 10^{8.3}$ $M_\odot$, are likely to be Kerr black holes, with $a_{\rm min}$ values in the range 0.59–1.0. This is quite consistent with the result of Elvis et al. (2002), who suggested that most SMBHs must be rapidly rotating on the basis of the integrated spectrum of the X-ray background and spectral energy distribution of quasars. For the SMBHs with $M_H < 10^{8.3}$ $M_\odot$, however, $a_{\rm min} = 0$, suggesting that a nonrotating black hole model is not ruled out for these less massive black holes. On the other hand, since the $a_{\rm min}$ values we have derived are lower limits on a, we cannot exclude the possibility that some of these less massive black holes are also rotating.

It is quite interesting that the sizes of the emission regions in the two kinds of SMBH are significantly different. This suggests that the size of the emission region is quite related to the rotational state, and it may imply that the emission mechanisms for the two kinds of SMBH may be different. Assuming that an SMBH is a maximal Kerr black hole, the innermost edge of the disk does not necessarily coincide with the marginally stable orbit but can be much closer to the black hole: as close, in fact, as the marginally bound orbit. As a consequence, the region responsible for the observed variability can be smaller than the least stable circular orbit. This condition could be violated if the fluctuations were produced, for example, by some plasma instability in a small region in or above the accretion disk or in a jet that momentarily releases energies comparable to the overall energy. In addition, a Kerr SMBH may also emit energy via the powerful Blandford-Znajek mechanism (Blandford & Znajek 1977) in a region that is closely adjacent to the SMBH. In a Schwarzschild SMBH, the radiation is generated at a stable orbit far away from the black hole horizon. Thus, a Kerr SMBH may emit energy via a more powerful and more efficient mechanism than a Schwarzschild SMBH does. The emission rates, especially at high energies (such as γ-rays), are significantly different. For a Kerr SMBH, the emitted γ-ray flux in its local frame should be greater than that for a Schwarzschild SMBH. Thus, masses estimated by the Dermer-Gehrels method for the two kinds of SMBH should be significantly different. As can bee seen from Table 1, this is in fact the case. These results may imply that the masses, the rotational state, the radiating regions, the physical processes in the inner regions, and even the radiation mechanisms for the two kinds of SMBH are significantly different.

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