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INVITED REPORT

Optical Variability of Blazars

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Abstract Variability is one of the characteristics of blazars. The rapid variability is superposed on the long term variations. In this talk, the variability on different time scales, such as intra-day(IDV), short-term (STV), and long-term (LTV) variations are presented for some sources. For objects with many observations, we have made periodicity analysis, the results show that the long-term variation periodicity is in a range of about 1.4 to 18 years from our consideration. Some possible mechanisms for different time scales are also discussed. The optical polarization is correlated with the variation amplitude.

Key words: Blazar-Active Galactic Nuclei (AGNs): variability – periodicity

1 INTRODUCTION

Over the years, two major classes of AGNs have been established. Roughly 85% of these are radio-quiet AGNs, with $B = \log \frac{F_{5\mathrm{GHz}}}{F_{2500\mathring{A}}} < 1.0$ (Kellermann et al. 1989) and the remaining $\sim$ 15% AGNs are radio-loud. A small subset of the radio-loud AGNs show often flux variability at almost complete electromagnetic spectrum and their emission is strongly polarized are known as blazars. The term "blazar" was first introduced by Ed Spiegel at the conference on BL lac objects in Pittsburg. BL Lacertae objects (BLs) and flat spectrum radio quasars (FSRQs) are collectively named as blazar. On observational point of view, there are some classifications for the extragalactic radio sources. such as, the optically violently variable quasars (OVVs) display variation amplitude of greater than 1.0 magnitude (Penston & Cannon, 1970), have steep optical spectra and are associated with compact variable radio sources which have flat radio spectra at GHz frequencies. Highly polarized quasars (HPQs) have optical polarization more than 3% (Moore and Stockman 1981). Core dominated quasars (CDQs) show ratio of the radio emissions from the core component to from the extended component being greater than unity ($R = \frac{L_{\mathrm{core}}}{L_{\mathrm{ext.}}} > 1.0$). Superluminal motion sources (SMs) show the velocity of the radio-component leaving its parent component being greater than the speed of light (the prototype is 3C 279). All OVVs, HPQs, CDQs, and SMs have flat radio spectrum, and are called flat spectrum radio quasars (FSRQs).

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A variable star BL Lacertae discovered by Hoffmeister (1929) was identified with the unusual radio source VRO 44.22.01 in 1968(see Macleod and Andrew (1968) and Schmidt(1968)). BL Lacertae have shown variation in radio band (Biraud & Veron 1968), linear polarization (Olsen 1969), optical radiation with continuous spectrum (neither emission nor absorption lines) (Oke et al. 1969) and relatively high degree of linear polarization (Visvanathan 1969). Later on, some other objects have also been found with similar properties and Strittmatter et al. (1972) suggested that objects similar to BL Lacertae comprise a class of BL Lacertae objects. Therefore, an object with following observational properties is called a BL Lacertae object (Stein et al. 1976), namely, (a) absence of emission lines in the core sources, (b) rapid variability at radio, infrared, and visual bands, (c) non-thermal continuum with most of the luminosity radiated at infrared wavelength, and (d) strong and rapidly varying polarization. However, for the high-frequency peaked BL Lacertae objects, they emit their bulk at much high frequencies, and in addition weak emission lines were found in BLs by Miller et al. (1978). In this sense, the first term should be changed into "absence of emission lines or with very weak emission lines (equivalent width $EW < 5\,\text{Å}$)". Therefore, blazars are an extreme subclass of AGNs, characterized by rapid and high amplitude variations, high and variable polarization, superluminal radio components, non-thermal continuum.

The nature of the central regions of blazars and other AGNs are still an open problem. The radiation of blazars at all wavelengths is predominantly non-thermal (e.g. Tagliaferri et al. (2003) and references therein). Optical photometric observations of blazars are important tools for constructing their light curves which can yield with valuable information about the mechanisms operating in these sources, with important implications for quasar modelling (see Fan et al. 1998a). The intensive monitoring of blazars in a night gives the variation on the time scales of minutes to hours and often called as intra-day variation (IDV). Monitoring of a specific blazars for several continuous nights can give the information about the short term outburst which can have time scales of few days to weeks. Blazars are interesting objects to observe for an extended periods of months to even few years which can give the long term flux variation behavior and will be helpful to predict for next outburst time. There are several groups all around the globe which are working on monitoring of these kinds in radio to NIR bands (e.g. Aller et al. 1999; Andruchow, et al., 2003; Babadzhanyants & Chernyshev 1999, Bai et al. 1998a, b; Balonek et al. 1998; Belokon & Babadzhanyants, 1999a, b, 2003 Ciprini, et al., 2003, 2004; Clements, et al. 2003; Dai et al., 2001; de Vries, et al. 2003; Dominici et al. 2004; Efimov & Shakhovskoy, 1998; Fan et al. 1998a, 2000, 2004; Gupta et al. 2002, 2004; Hanski et al. 2002; Heidt & Wagner 1996, 1998; Howard, et al., 2004; Katajainen et al. 1999; Kurtanidze, & Nikolashvili, 1999a, b, 2000; Miller et al. 1999; Nikolashvili et al. 1999a, b; Pursimo et al. 2000; Qian et al. 2000; 2002; Qian & Tao 2003, 2004; Raiteri et al. 1998a, b; 2001 Rector & Perlman 2003; Romero et al. 1999, 2000, 2002; Sillanpaa et al. 1996a, b; Steppe et al. 1995; Takalo et al. 1996,1998; Tagliaferri et al., 2003; Terasranta et al. 1999; Tosti et al. 1999; Valtaoja et al. 2000; Villata, et al. 1999, 2000, 2004; Webb et al. 1988; 1998; Xie et al. 1999,2004, Zhang, et al. 2000 etc. and reference therein).

Radio monitoring programme suggests that blazars are strongly beamed. Assuming an intrinsic origin of IDV, the brightness temperature of the variable component can be derived using the Rayleigh-Jeans law and the light travel time argument: $T_B K = 4.5 \times 10^{12} \times S[\mathrm{Jy}] \left(\frac{\lambda[\mathrm{cm}] D_L[\mathrm{Mpc}]}{t_{\mathrm{obs}}[\mathrm{day}](1+z)}\right)^2$. For the strong variations seen in most of the IDV sources, above equation yields brightness temperature of up to $10^{17} - 10^{21}\,\mathrm{K}$, far in excess of the inverse Compton limit of $10^{12}\,\mathrm{K}$. This fact seriously challenge existing models to explain blazar variability. Adopting an intrinsic origin for IDV, Qian et al. (1991) considered the propagation of a thin shock through the jet plasma in a cylindrical geometry with periodic boundaries. They found this model is capable of explaining the variations and the apparent high temperature by $T_B^{\rm app} = \gamma_s^2 \delta^3 T_B^{\rm true}$, where γ_s is the Lorentz factor of the shock. An alternative, collective emission (Benford 1992) caused by the scattering of an intense, relativistic electron beam from plasma waves, can avoid the violation of the inverse Compton limit. It is still unknown whether this process can produce broad-band (i.e., radio-optical) variations (see Kraus et al. 1999).

Some objects have been claimed to display quasi-periodic variations in their light curves over different timescales. However, in general, the clear identification of periodic behavior has been very elusive due to the complexity of the optical lightcurves and the lack of databases large enough as to provide an adequate sampling over large period. Gamma-ray flares are also found correlated with the lower energy bands (e.g., the 1996 GeV/X-ray flares in 3C 279 (McHardy 1996), the GeV/optical flares in 1406–076 (Wagner et al. 1995), the TeV flare (Gaidos et al. 1996) and the similar optical flare in Mrk 421 (Xie et al. 1998). Observations show that the gamma-ray sources vary over time scales of hours to months in the gamma-ray regions, which set some constrain on the basic parameters of those gamma-ray sources (e.g., Cheng et al. 1999; Fan et al. 1999; Mattox, et al. 1997). The short time scales ranges are same in the gamma-ray, X-ray and optical bands shown in the above mentioned correlated cases. So, the short time scales detected in lower energy bands can be used to constrain the basic parameters of the gamma-ray loud sources as done by Dondi & Ghisellini (1995), Cheng et al. (1999), Fan et al. (1999), Fan & Cheng (2001), and Fan (2004). Therefore, the optical monitoring is an important clue for understanding the physical process of the sources not only in the optical band but also in other bands. Blazars have been monitored for a long time, compilations of optical data is available in (Fan & Lin 2000a; Fan et al. 2000b) and infrared data is in (Fan & Lin 1999a; Fan 1999a) bands. The infrared data are also available in http://xxx.lanl.gov/astro-ph/9908104 and http://xxx.lanl.gov/astro-ph/9910269. The long-term measurements make it possible for one to search for periodicity from the light curves and to discuss the long-term variability properties. Because of the characteristic of the astronomical measurements, we adopted the Jurkevich (Jerkevich 1971) and DCF (Discrete Correlation Function) (see Fan & Lin 2000b) methods to the available data in searching for the periods. In the paper, we will introduce the variations on different time scales (minutes to hours-$intra-day$, days to weeks-$short-term$ and months to years -$long-term$). The paper is structured as follows: in Sect. 2 we discuss the variation time scales, Sect. 3 covers the periodic analysis method, in Sect. 4 we report the variation property and in Sect. 5 the discussion of the present work.

2 VARIATIONS ON DIFFERENT TIME SCALES

2.1 Intra-day Variation (IDV)

During the past decades, the evidence for the existence of variability over hours to days has been established for blazars (Kinman 1975; Miller 1988; Carini & Miller 1992; Fan et al. 1998, 2004; Xie et al. 1988, 2004; Kurtanidze & Nikolashvili, 1999, 2003; Romero 2000; Takalo et al. 1998; Villata et al. 2002, 2004; Raiteri et al. 2002, 2003; Clements et al. 2003; Rector et al. 2003; Ciprini et al. 2003, 2004, etc). Such variations are called micro-variation or intra-day variation. We will call this kind of variation as IDV. Recently, some sources were reported to show this variations. Such as, a 0.5 mag. Variations in both R and V bands within a single night and a 1.2 mag. variation from night to night were observed from AO 0235+164 during a week long observation period by Romero et al. (2000), but they found no spectral index variation when the source showed large variation during their observational period. However, Raiteri et al. (2001) found a flattening spectral index when the source brightened. Very rapid brightness increasing by 1.3 magnitudes over 2.0 hours in the optical region was found from 0736+017 by Clements et al. (2003). In the WEBT BL Lacertae Campaign during July 16 to August 12, 2000, light curve showed very complicated fluctuation with different time scales (Villata et al. 2002). A rapid variation of 0.3 mag over 3 hours was also observed from BL Lacertae in our observation done in Oct. 2000 in Georgia (Fan et al. 2004). In the OJ-94 monitoring programme, very dense light curves displayed continuous variability on time scales from minutes to days (Takalo et al. 1999; Tosti et al. 1999; Pursimo et al. 2000).

2.2 Short-Term Variation

Observations also show that the blazars display variations on the timescales of days to weeks and even months, which can be called as short-term variation (STV). In the OJ-94 project, 3C 66A was selected as a comparison source for OJ 287 because it is relative quiescent blazar. However, it was in a bright state during the monitoring programme and displayed a 65-day period in its light curve (Lainela et al. 1999). Similar timescale variation was noticed from Mkn 501 which displayed a 23 day variation period in the X-ray and TeV gamma-ray bands (Kranich et al. 1999).

2.3 Long-Term Variation

It was found that the light curves of blazars show variations over time scales of months to years, e.g., 3C 273 (Terrell & Olsen 1972), 3C 446 (Kinman 1975) and 3C 120 (Jurkevich 1971) etc. We call the variations over time scales of years as long-term variation (LTV). With the report of periodicity in OJ 287 (Sillanpaa et al. 1988), the OJ-94 project was proposed to detect the expected outburst of OJ 287, which was really observed (Sillanpaa et al. 1996a, b). Some other sources were also found to display LTVs (Liu et al. 1995; Fan et al. 1997, 1998, 2001a, 2002; Fan & Lin 2000a, b, Fan 1999, 2001; Raiteri et al. 2001; Ciprini et al. 2003, 2004). To search for LTVs, one should have a long time coverage of observations, therefore monitoring programme is important for periodicity analysis.

3 PERIODICITY ANALYSIS METHODS

For the periodicity analysis, there are several methods that we can use. However, the data compiled are not sampled evenly, the often used methods can not be used here. Fortunately there are some methods which can even work on nonuniform sampling data, are proposed. We will introduce two methods in the following.

3.1 Jurkevich Method

The Jurkevich method (Jurkevich 1971, also see Kidger et al. 1992; Fan et al. 1998a; Fan 1999b) is based on the expected mean square deviation and it is less inclined to generate spurious periodicity than the Fourier analysis used by other authors (e.g. Fan et al. 1997b). It tests a run of trial periods around which the data are folded. All data are assigned to m groups according to their phases around each trial period. The variance V_i^2 for each group and the sum V_m^2 of all groups are then computed. If a trial period equals the true one, then V_m^2 reaches its minimum. So, a "good" period will give a much reduced variance relative to those given by other false trial periods and with almost constant values. A further test is the relationship between the depth of the minimum and the noise in the "flat" section of the V_m^2 curve close to the adopted period. If the absolute value of the relative change of the minimum to the "flat" section is large enough as compared with the standard error of this "flat" section (say, five times), the periodicity in the data can be considered as significant and the minimum as highly reliable (Fan et al. 1998a).

3.2 Discrete Correlation Function Method

The discrete correlation function-DCF method is intended for analysis of the correlation of two data set. It is described in detail by Edelson & Krolik (1988) (also see Fan et al. 1998b). This method can indicate the correlation of two variable temporal series with a time lag. A positive peak of the DCF means correlation, which is stronger as the value of the peak approaches and exceeds one. A negative peak implies anti-correlation. This method can be applied to the periodicity analysis of a unique temporal data set. If there is a period, P, in the lightcurve, then the DCF should show clearly whether the data set is correlated with itself with time lags of $\tau = 0$ and $\tau = P$ (see Fan & Lin 2000b). We have implemented the method as follows.

Firstly, we have calculated the set of unbinned correlation (UDCF) between data points in the two data streams a and b, i.e. $UDCF_{ij} = \frac{(a_i-\bar{a})\times(b_j-\bar{b})}{\sqrt{\sigma_a^2\times\sigma_b^2}}$, where a_i and b_j are points in the data sets, $\bar{a}$ and $\bar{b}$ are the average values of the data sets, and σ_a and σ_b are the corresponding standard deviations. Secondly, we have averaged the points sharing the same time lag by binning the $UDCF_{ij}$ in suitably sized time-bins in order to get the DCF for each time lag τ: $DCF(\tau) = \frac{1}{M}\Sigma\, UDCF_{ij}(\tau)$, where M is the total number of pairs. The standard error for each bin is $\sigma(\tau) = \frac{1}{M-1}\{\Sigma\, [UDCF_{ij} - DCF(\tau)]^2\}^{0.5}$. The analysis results are listed in Table 1.

Table 1 Investigation results of periodicity of some selected blazars. The unit for periodicity is years except for those indicated.

Name	P_1	P_2	Ref	P_3 Ref	P_4 Ref
0219+428	4.25±0.28		Fan et al. 2002	2.5 BB2003	65 days L1999
0235+164	2.95±0.15		Fan et al. 2002	5.7±0.5 R2002	
0735+178	14.2		Fan et al. 1997	13.8 QT2004	
0754+100	3.0±0.35	17.85	Fan et al. 2002		
0851+202	5.53±0.15	11.75±0.5	Fan et al. 2002	11.65 S1988	
1215+303	4.45±0.05	6.89±1.0	Fan et al. 2002		
1219+285	14.85±1.55		Fan et al. 2002	3.8 B2000	
1226+023	2.0	13.65±0.2	Fan et al. 2001	13.5 M2002	13.4 BB1993
1253−055	7.0		Fan 1999		
1308+326	1.4±0.3		Fan et al. 2002		
1514−241	2.0±0.2		Fan et al. 2002		
1807+698	2.70±0.15		Fan et al. 2002		
2155−304	4.6	7.0	Fan & Lin 2000		
2200+420	14.0		Fan et al. 1998		

B2000:Belokon et al. 2000; BB1993: Babadzhanyants & Belokon (1993) BB2003:Belokon & Babadzhanyants (2003); L1999: Lainela (1999); M2002: Manchanda (2002); QT2004: Qian & Tao, (2004); R2002: Raiteri et al. (2002); S1998: Sillanpaa et al. (1988).

4 VARIATION AND POLARIZATION

From the compilation (Fan et al. 2000b, Fan & Lin 2000a, b; Fan 1999a), we found that the largest variations are comparable in both the optical and infrared bands (see Table 2, in which

Col. 1 gives the name of the source, col. 2, the largest optical variation, col. 3 the largest infrared variation, and col. 4, the largest optical polarization). Largest variations at different wavelengths increase with decreasing wavelength. The variations are also correlated with the observed maximum optical polarization, which can be explained using the beaming model. $P^{ob} = \frac{(1+f)\delta_o^p}{1+f\delta_o^p} P^{in}$ is the observed polarization, where $P^{in} = \frac{f}{1+f}\frac{\eta}{1+\eta}$, is the intrinsic polarization in the source frame, which is the indication of magnetic field in the source and δ_o is the optical Doppler factor (see Fan et al. 1997a for details). Therefore, the observed polarization is associated with the magnetic field and the Doppler factor.

From the beaming model, which gives $S^{\rm ob} = (1+f\delta^p)S_{\rm unb} \equiv S_0 10^{-0.4m^{\rm ob}}$ and relation for polarization, we can obtain following relation

$$\log P(\%) = 0.4(\lambda - 1)\Delta m + \log P_{\rm min}. \qquad (1)$$

where $P(\%)$ is the polarization, λ is a parameter, and $\Delta\ m$ is the optical variation (Fan et al. 2001b).

Table 2 The Maximum Variation and Polarization of Blazars

Name (1)	$\Delta m_{\rm opt}$ (2)	$\Delta m_{\rm IR}$ (3)	$P_{\rm opt}(\%)$ (4)	Name (1)	$\Delta m_{\rm opt}$ (2)	$\Delta m_{\rm IR}$ (3)	$P_{\rm opt}(\%)$ (4)
0048–097	2.7	6.55	27.2	0109+244	3.07	1.58	17.3
0118–272	1.05	0.67	17	0138–097	1.52	1.69	29.3
0215+015	5.0	2.69	20	0219+428	3.3[a]	1.61	33.7[a]
0235+164	5.3	5.0	44	0323+022	1.3	0.97	10.4
0420–014	2.8	2.88	20	0422+004	2.2	3.25	22
0521–365	1.4	1.25	11	0537–441	5.4	3.0	18.8
0716+714	5.0		29.0	0735+178	4.6	2.47	36
0736+017	1.35	2.71	6	0754+100	3.16	1.88	26
0818–128	3.78	2.14	36	0823–223	1.41	2.32	11
0829+046	3.58	2.15	12	0851+202	6.0	3.87	37.2
0912+297	2.25	2.27	13	1101+384	4.6	2.03	16.0
1144–379	1.92	3.46	8.5	1147+245	1.0	1.34	13.0
1156+295	5.0	4.47	28	1215+303	3.3	1.05	14
1219+285	4.5[b]	2.46	12.8[c]	1253-055	6.7	4.57	44
1308+326	4.17	5.55	28	1418+546	4.8	1.59	24
1510–089	5.4	1.25	14	1514–241	3.0	2.64	8.0
1538+149	3.7	0.89	32.8	1641+395	3.0	3.16	35
1652+398	1.30	2.37	7.0	1727+502	2.1	0.82	6.0
1749+096	2.7	2.21	32	1807+698	2.0	1.02	12
1921–293	2.64	3.06	17	2005–489	0.53	0.31	2.0
2155–304	1.85	1.88	14.2	2200+420	5.31	2.93	23
2223–052	5.0	3.96	17.3	2240–260		1.66	15.1
2251+158	2.5	1.57	19	2254+074	3.27	1.36	21

a: Babadzhanyants et al. 1993; b: Belokon & Babadzhanyants 2003; c: Efimov & Shakhovskoy 1998.

5 DISCUSSION

For the light curves of blazars, we have compilations for BL Lac objects in the optical and infrared bands (Fan & Lin 1999; 2000a; Fan 1999). The data bases can be used to discuss the variability properties over different time scales, the correlated variations and to search for periodicity signatures in the light curves. When the both methods are adopted to those optical data, the both methods give consistent results. The results are presented in Table 1. It is interesting to notice that there is a common period of $\sim$ 1.0 year, which is likely from the effect of the Sun on the measurements. From observations, people found that there are some correlated variations, such as the radio and optical outbursts in AO 0235+164 (Takalo et al. 1998), the gamma-ray and the optical outbursts in 1406-076 and 0420-014(Wagner et al. 1995a, b), the optical and radio variations in 0109+224 (Ciprini et al. 2004). Also, the about 14.0 year period in the optical band is also found in the X-ray region in 3C 273 by Manchanda (2002).

The implication of the different time scales is the main aim of the observers. Although the real situation is not clear yet, some arguments are really useful for one to understand the intrinsic nature of blazars and some other AGNs.

$Intra-day\ variation$ It can give an upper limit to the mass of the central black hole if the time scale indicates the innermost stable orbit period. The inner most stable orbit depends on the black hole and the accretion disk. $r = \frac{6GM}{c^2}$ for thin accretion disks surrounding a Schwarzschild black hole, $r = \frac{4GM}{c^2}$ for thick accretion disks surrounding a Schwarzschild black hole, and the radius of the event horizon of a Kerr black hole of mass M and an angular momentum parameter a, $r = 1.48 \times 10^5(1+\sqrt{1-a^2})\frac{M}{M_\odot}$. The period is $p = \frac{2\pi r}{c}$. The mass can be obtained from the period determined from the light curves.

Considered as a simple causality argument, the IDV time scale perhaps shed some light on the size of the emitting region since the variability cannot be faster than the light-crossing time of the emitting volume. Thus the observed variability time scale gives an upper limit to the size, $R \leq c\Delta t_{var.}$ or $R \leq c\delta\Delta t_{var.}$ if the emitting volume moves at relativistic velocity.

$Short-term\ variation$ There are two sources that are reported to show STV in their light curves. For Mkn 501, it is 23-day period in the TeV and X-ray light curves. It may be possibly related to the orbital motion of the relativistic jet emerging from the less massive black hole. Due to the orbital motion around the center-of-mass, the Doppler factor for the emission region is a periodical function of time (Rieger & Mannheim 2000, 2003, Rieger 2004 this proceeding). For 3C 66A, its 65-day period, implies that a shock wave moves along a helical path in a relativistic jet. Therefore the period can be explained by the changing viewing angle. The model can explain why the periodicity can be detected during the bright state but not in the faint state of the 3C 66A (Lainela et al. 1999).

$Long-term\ variation$ For the long-term periodicity of variations, there are several explanations. the binary black hole model, the helical jet model, the slim disk model, and the effect of external perturbations to the accretion disk. (e.g. Sillanpaa et al. 1988; Meyer & Meyer-Hofmeister 1984; Horiuchi & Kato 1990; Abraham & Romero 1999; Fan et al. 1997b, 1998a, 2000c; Villata & Raiteri 1998, 1999; Romero et al. 2000c, 2004; Torrell et al. 2003; Rieger & Mannheim 2000; 2003; Rieger 2004). It is clear that this kind of variations in AGNs are associated with the binary black hole systems. And this system was really found by Komossa et al. (2003), who found a binary black hole system in a Seyfert galaxy. However, it should be kept in mind that the present binary black hole system is perhaps too simple. In OJ 287, the optical outburst is not always consistent with radio activity.

Begelman et al. (1980) have considered binary black hole models for active galactic nuclei with orbit periods of the order of 10 yr. They pointed out that the geodetic precession period in a black hole binary system generally exceeds 10^4 yr. Thus it is impossible that the $\sim$10 yr period is caused by the precession of a relativistic jet on and off the line of the sight. In the binary black hole model of Sillanpaa et al. (1988), the tidal perturbations of sufficient strength create global disturbances in the disk and cause a flow of matter into the center of the disk. They consider that two mass points (black holes) are initially in an elliptic orbit. The larger mass point is surrounded by a self-gravitational disk of matter which is tidally perturbed by the smaller mass point. The disk lies in the orbital plane of the binary, and it rotates in the same sense as the binary. Using simulation (inputting the ratio of the masses of two black holes, M_1, M_2 and the disk mass, m_d, of the primary black hole, $\frac{M_2}{M_1+M_d}$, the eccentricity e, the semimajor axis of the binary orbit a, and the radius of the main disk r, the last three parameters are correlated), one can get the variation pattern and the mass of the smaller black hole can also be estimated by the short time scale, $M \sim 10^6 M_{\odot} \Delta t(\mathrm{min})$. In this sense, one can estimate M_1. But there is a problem, why is the short time scale caused by the smaller black hole?

If the long-term variation period is caused by a slim disk, then the period can be expressed as $P = 9.0\ \mathrm{yr}\delta(\frac{\alpha}{0.1})^{-0.62}\ (\frac{M_{\mathrm{BH}}}{10^6 M_{\odot}})^{1.37}$. But this method gives less massive black hole mass ($\sim 10^7\, M_{\odot}$) (Fan 1999).

Abraham & Romero (1999) and Romero et al. (2000c) proposed a way to explain the long-term period. They assumed that the inner jet and the innermost parts of the accretion disk that surrounds the primary black hole are coupled in such a way that a precession of the disk induces a precession of the jet. A secondary black hole in a close non-coplanar orbit can exert a tidal perturbation on the disk that can result in the near-rigid body precession of its innermost region. But the masses can not be determined uniquely.

For the masses of the central black holes, there are many authors who have tried to determine them (e.g., Barth et al. 2002, 2003; Woo & Urry, 2003; Bian & Zhao 2004, Cao 2002; Fan et al. 1999; Liang & Liu 2003; Rieger & Mannheim 2000, 2003, 2004; Romero et al. 2000; Wu, et al 2002).

The variation of the blazars is important to the understanding of the intrinsic physics in these sources. Our analysis show that the long-term variation time scales are in the range of 1.4 to 18 years. The short- and long-term variations are found associated with a binary system and the sources with long-term variations can be the candidates of binary systems and are encouraged to be observed using X-ray detectors and VLBI technique. The variation is found to be correlated with the polarization, simultaneous photometric and polarization observations are helpful for the understanding of the nature of the polarization in blazars.

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