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OPTICAL MICROVARIABILITY OF BLAZARS

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ABSTRACT

We present the results of optical differential photometry of five blazars [PKS0219+428 (3C66A), PKS 0235+164 (AO 0235+16), H0414+019, PKS 0851+202 (OJ 287) and QSO 1807+698 (3C 371)] that were observed on 7 nights between November 05, 1997 and December 29, 1998, using the B and the V band filters. We have detected microvariations in four blazars (3C66A, AO 0235+16, H0414+019, and OJ 287). In addition, the light curve of AO 0235+16 has displayed a mini-flare when the brightness of this source was decreasing. Night-to-night variations have also been detected in 3C66A, H0414+019, and OJ 287. The results of our observations are discussed in the framework of accretion disk phenomena (magnetic flares or hot spots in accretion disks) and jet phenomena (plasma instabilities in jets).

Key words: galaxies: active-galaxies, individual [PKS0219+428 (3C66A), PKS0235+164 (AO 0235+16), H0414+019, PKS 0851+202 (OJ 287), QSO 1807+698 (3C 371)] – galaxies: photometry

I. INTRODUCTION

Optical flux variability has been considered as a common property of Active Galactic Nuclei (AGNs). The class of radio-loud AGNs called "blazars" includes BL Lacertae objects and quasars having flat radio spectra, rapid variability, high and variable polarization, and high brightness temperature. Blazars have displayed variability on all time scales ranging from minutes to years. The amplitude of the variability depends on the timescale of the observations. For example, large amplitude (more than a few magnitudes) variations have been detected in blazars on the timescales of years. Small amplitude (several hundredths of a magnitude) variations are very common in blazars, on the timescales of minutes to hours. Such variations are known as microvariations. Variations on the timescale of a day (intraday variability) have also been considered, by some authors, as microvariations (Jang & Miller 1995; Wagner & Witzel 1995 and references therein). It can be seen from the published literature that the observed microvariations are of three types: (i) discrete events (sudden decrease or increase in brightness), (ii) part of a longer duration variation (gradual decrease or increase in brightness), and (iii) discrete events superimposed on a longer duration variations. Also, it has been found that the amplitude of microvariations is usually larger during periods of major outbursts (Jia et al. 1998; Matsumoto et al. 1999; Nesci et al.; Ghosh et al. 2000b and references therein).

Different interpretations for microvariations have been suggested in the literature. Microvariations may result from vortices and magnetic flux tubes in the accretion disk (Abramowicz 1992), eclipsing of hot spots by the accretion disk, or differing lifetimes and luminosities of magnetic flares in the accretion disk (Wiita 1996). Microvariations may also come from shocks within the jet. Shocks in turbulent jets, due to compression of magnetic field in the shock, will produce variations of local emissivity that will lead to flares responsible for microvariations (Konigl & Choudhuri 1985; Hughes, Aller & Aller 1985; Jones 1988; Marscher 1996).

Even though different possible interpretations have been suggested, the mechanisms responsible for microvariations are still unclear and more observational effort is needed to study the patterns of microvariations that may help to shed further light on the emission processes and the structure of the emitting region. In this paper, we present the observed results of microvariability studies of five blazars. Section II describes the observations and data analysis. The results are given in Section III and Section IV presents the discussion and conclusions.

II. OBSERVATIONS AND DATA ANALYSIS

Five blazars [PKS0219+428 (3C66A), PKS 0235+164 (AO 0235+16), H0414+019, PKS 0851+202 (OJ 287) and QSO 1807+698 (3C 371)] were observed on 5 nights between November 05, 1997 and December 29, 1998, at the Bohyunsan Optical Astronomy Observatory (BOAO), South Korea. The source log and the log of observations are given in Tables 1 & 2, respectively. These optical observations were carried out at the F/8 Cassegrain focus of the 1.8 meter telescope of BOAO, using the B (4400 Å/ 1050 Å) coated filter with two CCD camera systems. A 1K CCD system (Tektronix back illuminated thinned chip) was used for the observations of four blazars (3C66A, AO 0235+164, H0414+ 019, and 3C371) and a 2K CCD system (anti-reflection coated and back illuminated thinned chip) was used to observe OJ287. Many bias frames were obtained before, during and after observations on each night to obtain nightly-mean bias value. Also many sky (evening and morning twilight sky) flats were obtained with a B filter and a median flat to remove the pixel to pixel quantum efficiency variations. The sky conditions were mostly nonphotometric and the seeing was around 2.0". Removal of cosmicray events, bias subtraction and flat-field corrections were carried out using the IRAF package. The IRAF/IMSHIFT program was used to align the images with respect to a reference frame. The IRAF/ APPHOT package was used for the aperture photometry of the stars and the blazar in the field. Light curves of all the stars, that are common in all the frames, were investigated. Two non-variable stars with magnitude similar to that of the blazar were selected and were used as the comparison stars. Photometric errors of the blazar and the two comparison stars were calculated using data obtained from APPHOT. If b_i, $s1_i$, and $s2_i$ are the photometric errors (obtained from the APPHOT) of the blazar, comparison star1, and star2, respectively, where i is the number of observations, then $s_i = \{(s1_i)^2 + (s2_i)^2\}^{0.5}$ and pi $= \{(b_i)^2 + (s_i)^2\}$. Final errors on s_i and b_i were computed by binning the two adjacent data points [$s_{1,2} = \{(s_1)^2 + (s_2)^2\}^{0.5}$, and $p_{1,2} = \{(p_1)^2 + (p_2)^2\}^{0.5}$. Similarly, the values of $s_{2,3}$,...., and $p_{2,3}$, ...were calculated].

OJ287 was also observed on two nights (March 4 and 5, 1998) from the Vainu Bappu Observatory (VBO), Kavalur, India. V-band observations of this blazar were carried out at the F/3.23 prime focus of the 2.34 m telescope using the UV coated and thinned Tektronics 1K CCD system. Many bias and flat field (in V band) frames were also obtained on each night using the same CCD system. The sky conditions were almost photometric and the seeing was around 2.0". Computations of differential magnitudes between OJ287 and the comparison stars were carried out using the DAOPHOT program (Stetson 1987, 1990). The errors in instrumental magnitudes were computed using the 'STAR ADD' program available in the DAOPHOT software package. The difference in the added and recovered instrumental magnitudes of the comparison stars was assumed to be the error in photometric measurement. These errors were com-

Table 1. Source log of five blazars

Source	Position (2000) R.A.	Position (2000) Dec	Redshift (z)	$m_v(B)^*$ (mag)
PKS 0219+428 (3C66A)	02 22 39.60	+43 02 07.8	0.444	15.83
PKS 0235+164 (AO 0235+16)	02 38 38.99	+16 36 59.4	0.940	16.46
1H0414+009	04 16 52.50	+01 05 23.0	0.278	16.78
PKS 0851+202 (OJ 287)	08 54 48.93	+20 06 30.5	0.306	14.39
QSO 1807+698 (3C 371)	18 06 50.78	+69 49 28.2	0.051	14.40

*Visual magnitude in the B band

Table 2. Log observations of five blazars

Source	HJD	MM/DD/ YY	Exposure time* (s)	Number of frames	Observatory
PKS 0219+428(3C 66A)	2450757/8	11/05/97	200-300	62	BOAO
PKS 0219+428(3C 66A)	2450758/9	11/06/97	200	52	BOAO
PKS 0235+164(AO 0235+16)	2450758	11/05/97	600	18	BOAO
1H 0414+009	2450761	11/08/97	200-300	80	BOAO
1H 0414+009	2450763	11/10/97	200-300	23	BOAO
PKS 0851+202(OJ 287)	2450876/7	03/04/98	600	16	VBO
PKS 0851+202(OJ 287)	2450877/8	03/05/98	600	16	VBO
PKS 0851+202(OJ 287)	2451177	12/29/98	500	22	BAO
QSO 1807+698(3C 371)	2450760/1	11/08/97	50-60	163	BOAO

*Exposure time per frame

pared with the formal errors obtained from the DAOPHOT analysis and it was found that the formal errors were smaller by a factor of 2. This factor of 2 was then added in quadrature to the 1σ formal errors for the blazar and the comparison stars, obtained from the DAOPHOT software package. Then the errors for each observed data set were computed for these objects. Details of the CCD system and data analysis are given in Ghosh et al. (2000a). The log of observations of OJ287 is also given in Table 2.

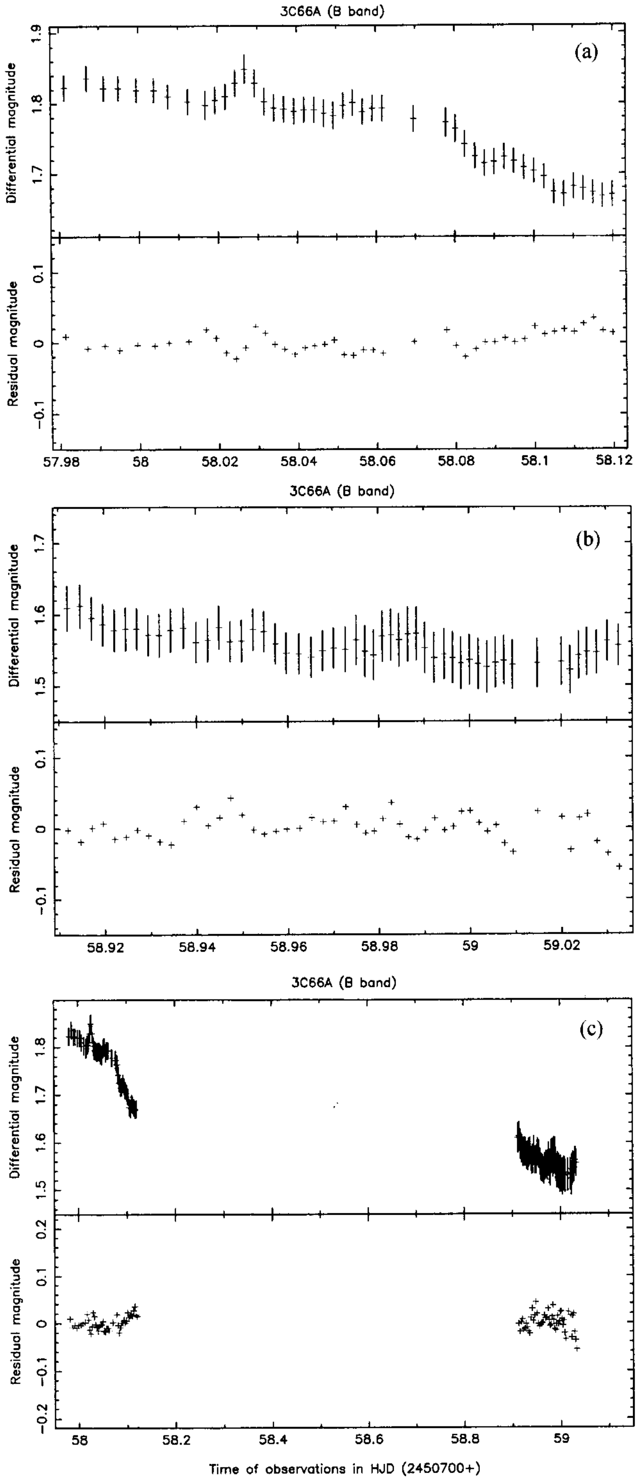

Fig. 1a. B band differential magnitude light curve of 3C66A (upper panel) that was observed on November 5, 1997. Lower panel shows the residual magnitude plot of the two comparison stars with respect to the mean of the residual magnitude, 1b. Same as Fig. 1a but for November 6, 1997, 1c. Same as Fig. 1a but for November 5 and 6, 1997.

III. RESULTS

Figs. 1-5 show the plots of differential magnitudes of the five blazars. The results of individual blazars are discussed below:

(a) PKS0219+428 (3C66A)

3C66A is a γ-ray blazar that has been detected both in GeV (Dingus et al. 1996; Mukherjee et al. 1997) and TeV (Neshpor et al. 1998 and references therein) γ-rays. This highly polarized (Mead et al. 1990) blazar has displayed short-term multifrequency (radio through γ-rays) variability (references can be seen in Ghosh et al. 2000a) and is known as an optically microvariable blazar (Carini, Noble & Miller 1998a). B band photometric observations of this source were carried out on two nights (November 5 and 6, 1997) at BAO (Table 2) and the results of differential magnitudes (mean magnitude of the two comparison stars minus the magnitude of the blazar) are plotted in Fig.1 a-b. It can be seen from Fig. 1a that a very short term (on the time scales of minutes) small amplitude (~0.06 magnitudes) variability is present in the light curve of 3C66A between 2450758.02 and 2450758.04 HJD. This may not be real, because the residual magnitudes of the comparison stars also displayed some variability during this interval of observations. However, there is a clear indication of a gradual decrease in brightness of this source during the interval of our observations. Between HJD 2450757.98 and 2450758.12 (~3.36 hours), the brightness of this blazar decreased by (0.17±0.023) magnitudes (~0.05 magnitudes per hour). However, the light curve of 3C66A (Fig. 1b) did not display any such variability on the night of November 06, 1997, but this blazar was in a relatively fainter state than the previous night (Fig. 1c). This figure also shows that the overall brightness of this blazar decreased at least by 0.3 magnitudes within a day.

(b) PKS 0235+164 (AO 0235+16)

AO 0235+16 is a highly polarized (Mead et al. 1990) optically violently variable blazar and an X-ray (Elvis et al. 1992; Ghosh & Soundararajaperumal 1995) and γ-ray emitting (Hartman et al. 1992; Hunter et al. 1993) source. This blazar has displayed optical microvariability

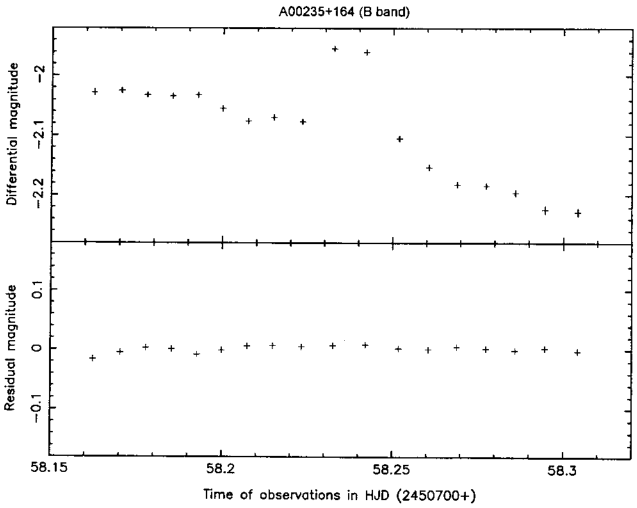

Fig. 2. Same as Fig. 1a but for PKS 0235+164 (AO 0235+16).

in its light curve (Noble & Miller 1996; Heidt & Wagner 1998; Ghosh et al. 2000a and references therein). Optical B band observations of AO 0235+16 were carried out on the night of November 05, 1997 (Table 2) under excellent sky conditions. The differential magnitude light curve of this blazar is shown in Fig. 2. It is clearly evident from this figure that the brightness of this source gradually decreased by more than (0.20± 0.01) magnitudes between HJD 2450758.16 and 2450758.31 (~3.6 hours) and this suggests a microvariability of 0.056 magnitude per hour. Note also in Fig. 2 that a short duration (~57 minutes) mini-flare {(~0.14±0.01) magnitude increase} is present in the light curve. This interesting event demonstrates that even when the source is gradually decreasing it can also briefly brighten. We shall discuss the significance of this in the next section.

(c) 1H 0414+009

This is an X-ray selected BL Lac object (detail references can be seen in Ghosh & Soundararajaperumal 1995 and also in Kubo et al. 1998). Mead et al. (1990) detected 6.4±0.8 % optical B band polarization of this blazar, and rapid x-ray variability, on the time scale of hours, has also been detected (Giommi et al. 1990; Sambruna et al. 1993). However, no information is available, in the literature, about the optical microvariability of H0414+009, which is not a well observed blazar. We observed this source on two nights (November 8 and 10, 1997) in the B band. The differential magnitude light curves of H0414+009 are shown in Figs. 3a,b. An apparent microvariability is observed in this source but this is most probably due to sky variations. The lower panels of these figures display the residual magnitude plots of the two comparison stars that also show apparent variations. However, Fig. 3c

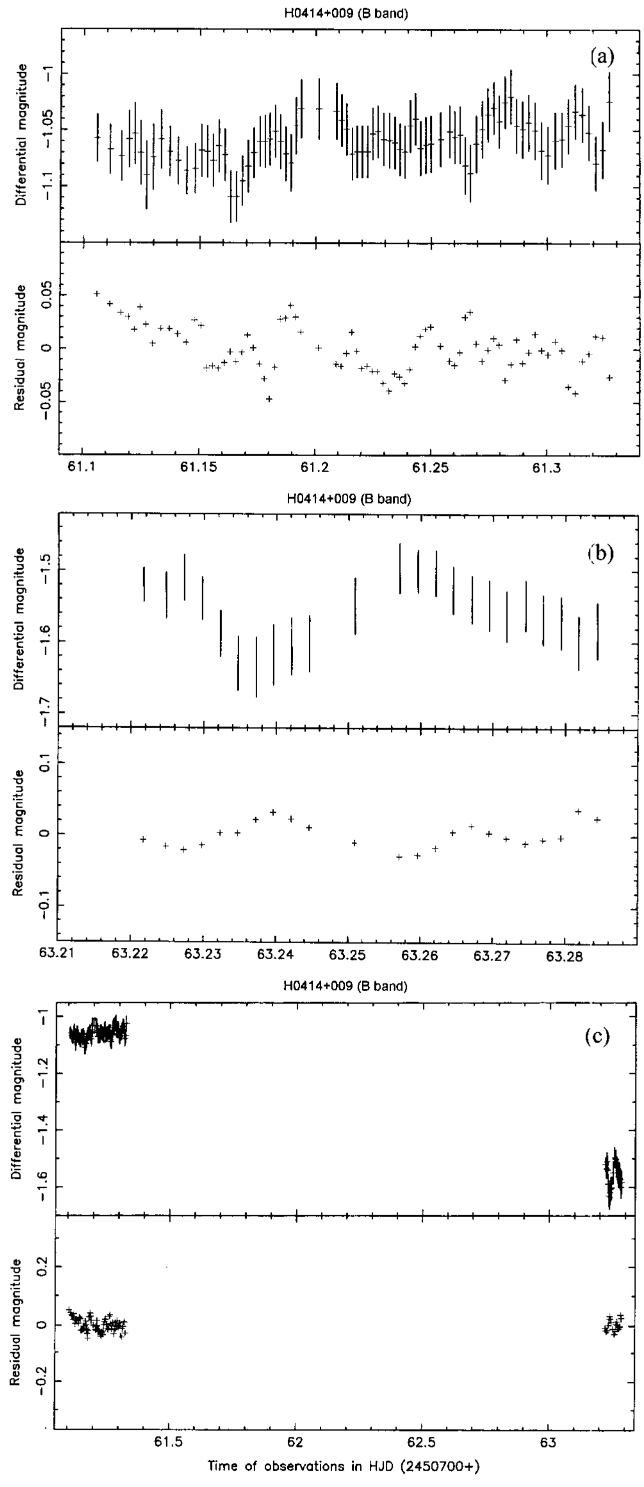

Fig. 3a. Same as Fig. 1a but for 1H 0414+009 observed on November 8, 1997, 3b. Same as Fig. 3a but for November 10, 1997, 3c. Same as Fig. 3a but for November 8 and 10, 1997.

clearly demonstrates that this blazar varied by more than 0.5 magnitude during the total interval of our observations, indicating an intranight variability (0.25 magnitude variations per day) for this blazar. This intranight variability may be translated to microvariability of ampli-

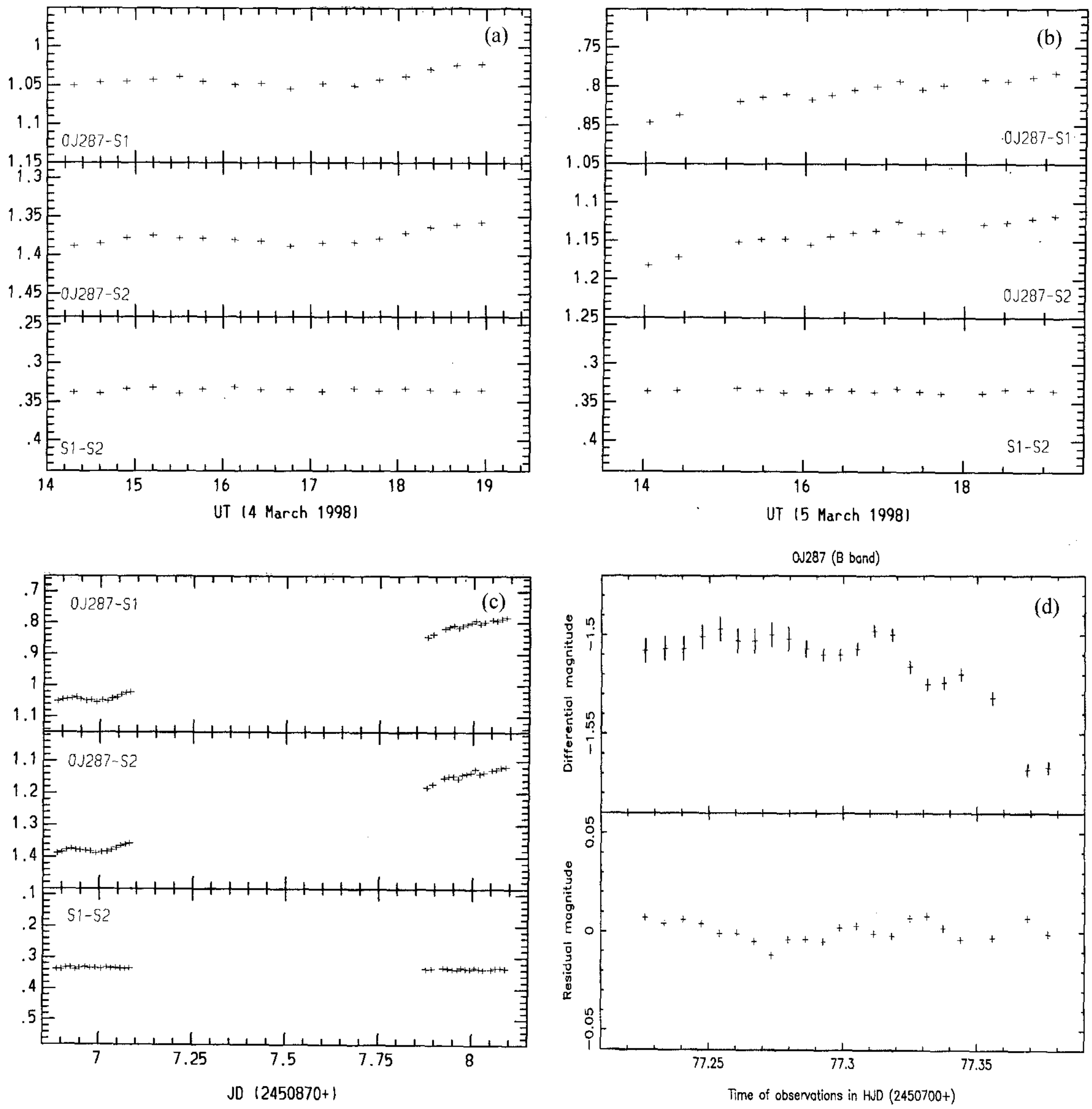

Fig. 4a. V band differential magnitude light curve of PKS 0851+202 (OJ 287) observed on March 4, 1998. Upper panel shows the differential magnitude between OJ 287 and comparison star 1. Middle panel is same as the upper panel, but for the comparison star 2. Lowest panel shows the differential magnitude plot of the two comparison stars, 4b. Same as Fig. 4a but for March 5, 1998, 4c. Same as Fig. 4a but for March 4 and 5, 1998, 4d. Same as Fig. 1a but for OJ 287 observed on December 29, 1998.

tude 0.01 magnitude per hour.

(d) PKS 0851+202 (OJ 287)

PKS0851+202 (OJ 287) is a superluminal source (Porcas 1987), a γ-ray blazar (Hartman 1998) and an intranight optical and infrared variable source (Brindle 1996; Bai et al. 1998, 1999; Raiteri et al. 1998). It has also displayed long-term optical variations that have been explained in the framework of a binary black hole model (Valtonen, Lehto & Pietila 1999 and references therein). We observed this source on three nights between March and December 1998 in B and V bands (Table 2). Differential magnitudes of OJ 287 are plotted in Figs. 4a-c. From these figures we find that OJ 287 displayed weak microvariability on all the three nights. Fig. 4d shows the intranight variability (0.30 magnitude variations per day) for this blazar.

(e) QSO 1807+698 (3C 371)

3C371 is one of the rare blazars to have observational detection of an optical jet (Nilsson et al. 1997). This blazar has displayed rapid flux variability at radio, optical, ultraviolet and x-ray wavelengths (detail references are given in Carini, Noble, & Miller 1998b). Recently, Carini, Noble, & Miller (1998b) have detected optical microvariability (in the range from 0.02 to 0.03 magni-

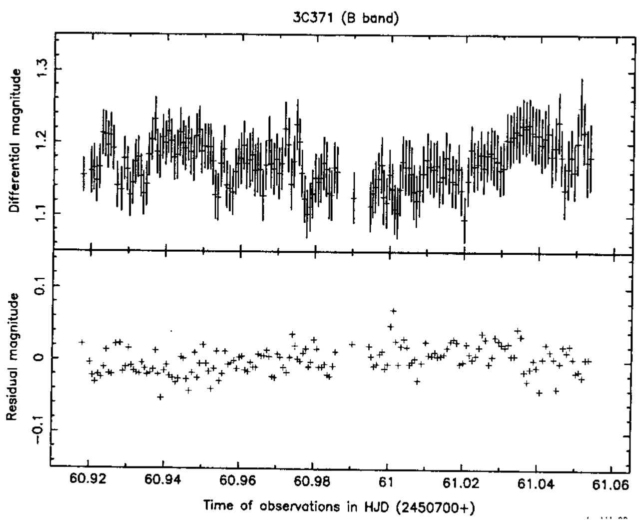

Fig. 5. Same as Fig. 1a but for QSO 1807+698 (3C371) observed on November 8, 1997.

tude per hour in V band) in 3C371. We observed this source on November 8, 1997, in B band and the observed differential magnitude light curve is shown in Fig. 5. Even though the light curve shows weak microvariability of this blazar, this variability may be due to the sky variations.

IV. DISCUSSION AND CONCLUSIONS

From the results of microvariability of the five blazars we find that both 3C66A and AO 0235+16 displayed microvariability of amplitude 0.05 magnitudes per hour. Also a mini-flare (peak amplitude 0.14±0.01 magnitudes over a period of 57 minutes) was detected in AO 0235+16 when the brightness of this source was decreasing. The brightness of 3C66A decreased, by at least 0.3 magnitudes within a day. Within the observational uncertainties we could not detect microvariability of 1H 0414+009 but this blazar varied by 0.5 magnitudes within two days. If we assume that this observed variation is due to gradual change of the source over a period of two days, this result indicates that most probably 1H 0414+009 displayed microvariability, at least, by 0.01 magnitudes per hour. Weak microvariability was detected on all the three nights in OJ 287. Also, this source varied by 0.3 magnitudes over a period of a day. During the interval of our observations we could not detect brightness variations of 3C 371. However, this blazar has displayed rapid variability on timescales of minutes to hours in the V band (Carini, Noble, & Miller 1998). In summary, out of five observed blazars, we have detected microvariability in four blazars (3C66A, AO 0235+16, 1H 0414+009, and OJ 287).

We have mentioned in Section I that basically there are two interpretations regarding the origin of microvariations in blazars. The first suggests an accretion disk origin (magnetic flares or hot spots in accretion disk) and the second, plasma instabilities in the jet or shock interactions in the jet. Here we like to discuss our observed results in the framework of these two scenarios. Microvariations detected in four blazars (3C66A, AO 0235+16, 1H 0414+009, and OJ 287) clearly demonstrate that these variations were due to a gradual decrease or increase in brightness of these sources, rather than discrete variations (sudden decrease or increase in brightness). Also, we have detected a miniflare which may be a discrete event superimposed on the gradual variations of brightness of AO 0235+16 (Fig. 2). Discrete events may be explained by the accretion disk phenomena (magnetic flares or eclipsing of hot spots in the accretion disk) or by the instabilities in the jet, however it is difficult to explain the gradual variations (gradual decrease or increase) of brightness of blazars by these phenomena. Only if these gradual variations are the rising or declining part of the flare profiles, can these variations be explained by the magnetic flares of the accretion disk or by the plasma instabilities in the jet. We now ask if the observed microvariations can be due to the accretion disk or jet phenomena. According to the standard blazar model, the jet of a blazar is beaming to the observer (Urry & Padovani 1995 and references therein). In this scenario, jet phenomena will be highly Doppler boosted (by a factor of $\delta^{3+\alpha}$, where δ is the Doppler boosting factor and α is the spectral index) than the accretion disk phenomenon. This means that, at the source frame, the accretion disk phenomenon has to be $\delta^{3+\alpha}$ times brighter than the jet phenomenon to appear almost equal brightness at the observer's frame. The value of α in the optical band for AO 0235+16 (also for blazars in general) is around 1.0 (Ghosh et al. 2000a and references therein) and the value of δ for AO 0235+16 is larger than 80 (Fujisawa et al. 1999). Using these values of δ and α for AO 0235+16, we find that the accretion disk phenomenon (magnetic flares or hot spots) has to be brighter by > 4.1×10^7 than the jet phenomenon (plasma instabilities), at the source frame. If magnetic energy ($B^2/8\pi$) is the source of energy for magnetic flares or hot spots in the accretion disk, then the magnetic field in the accretion disk has to be 3.2×10^4 times greater than the magnetic field of the jet, assuming that the MHD plasma instabilities in the jet may also be able to explain the observed microvariations in AO 0235 + 16. Fitting different models to multifrequency spectra, or to the flare profiles, has lead to an estimate of the magnetic field in the jet of ~0.5-2.0 G (Sambruna et al. 1999; Wang et al. 1999 and references therein). This indicates that the magnetic field in the accretion disk has to be ~(1.7-7.0) × 10^4 G. Presently we are not sure whether or not such high magnetic field is present in the accretion disks of blazars. However, recent time dependent electron acceleration model with relatively low magnetic fields (~0.5-2.0 G) in the jets can fit well the observed multifrequency spectra and the flare profiles, at different frequencies, of blazars (Kusunose, Takahara, & Li 2000 and references therein). If the observed microvariations in blazars are the rising or declining part of the short or long duration flares, it may be suggested that (based on the recent time dependent electron acceleration models of blazars) the microvariations may be due to the variations of distribution of electrons injected with different periods of time of electron accelerations, in the acceleration region of the jets of blazars.

Obviously, it is still not clear which physical mechanism(s) in jet is(are) responsible for the origin of the observed microvariations in blazars. To better understand the physics of microvariations in blazars, multi-site continuous multifrequency observations of these objects are essential to find out whether or not the gradual microvariations are the rising or declining part of the flare profiles.

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