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Intranight optical variability of blazars

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ABSTRACT

We present results of a multi-epoch intranight optical monitoring of 11 blazars consisting of six BL Lac objects and five radio core-dominated quasars (CDQs). These densely sampled and sensitive *R*-band CCD observations, carried out from 1998 November to 2002 May during a total of 47 nights with an average of 6.5 h per night, have enabled us to detect variability amplitudes as low as ~1 per cent on intranight time-scales. A distinction is found for the first time between the intranight optical variability (INOV) properties of the these two classes of relativistically beamed radio-loud active galactic nuclei (AGNs). BL Lacs are found to show a duty cycle (DC) of INOV of ~60 per cent, in contrast to CDQs, which show a much smaller INOV DC of ~20 per cent, the difference being attributable mainly to the weakly polarized CDQs. On longer time-scales (i.e. between a week to a few years) variability is seen from all the CDQs and BL Lacs in our sample. The results reported here form part of our long-term programme to understand the intranight optical variability characteristics of the four main classes of luminous AGNs, i.e. radio-quiet quasars (RQQs) and radio lobe-dominated quasars (LDQs), as well as CDQs and BL Lac objects.

Key words: galaxies: active – galaxies: jets – galaxies: photometry – quasars: general.

1 INTRODUCTION

Variability observations of active galactic nuclei (AGNs) on intranight time-scales can provide valuable clues to the physics of the innermost nuclear regions in these objects. Blazars (core-dominated quasars: CDQs, and BL Lac objects: BL Lacs) as a class of AGNs are characterized by the most violent variations at almost all wavelengths over a wide range of time-scales. Blazar properties are consistent with relativistic beaming, that is bulk relativistic motion of the jet plasma at small angles to the line of sight, which gives rise to strong amplification and rapid variability in the observer's frame. CDQs and BL Lacs are thought to be the beamed counterparts of high- and low-luminosity radio galaxies, respectively (e.g. Urry & Padovani 1995). The main difference between CDQs and BL Lacs lies in their emission lines, which are strong in CDQs, but weak, and in many cases, undetected, in BL Lacs. CDQ spectra can extend up to around GeV energies, whereas the spectra of BL Lacs can extend up to TeV energies. Though it is very likely that both CDQs and BL Lacs are dominated by non-thermal Doppler boosted jets, some important differences have been found between their apparent non-thermal properties, such as the magnetic field patterns in their parsec-scale jets (Gabuzda et al. 1992; but see Gopal-Krishna & Wiita 1993).

The intranight optical variability (INOV), or microvariability, of blazars has been an established phenomenon for over a dozen years (Miller, Carini & Goodrich 1989; Carini et al. 1991). Although the origin(s) of INOV in all AGNs is still uncertain, for blazars it is generally associated with the non-thermal Doppler-boosted emission from jets (Blandford & Rees 1978; Marscher & Gear 1985; Marscher, Gear & Travis 1992; Hughes, Aller & Aller 1992; Wagner & Witzel 1995). Still, alternative models, which invoke accretion disc instabilities or perturbations (e.g. Mangalam & Wiita 1993; for a review, see Wiita 1996) may also explain some INOV, particularly in radio-quiet quasars (RQQs) where any contribution from the jets, if they are at all present, is weak. Several studies of the INOV of blazars are available in the literature (e.g. Heidt & Wagner 1996; Dai et al. 2001; Romero et al. 2002; Xie et al. 2002). However, the unique feature of the present study is the deliberate focus on the comparison of the INOV properties of the two Doppler beamed AGN classes, namely CDQs and BL Lacs. Other results from this large programme, involving the nature of INOV in BL Lacs and RQQs (Gopal-Krishna et al. 2003, hereafter GSSW03), and a comparison of INOV between lobe-dominated radio-loud quasars (LDQs) and RQQs (Stalin et al. 2003a), have been published elsewhere.

2 SAMPLE, OBSERVATIONS AND REDUCTIONS

The sample of blazars used in this work consists of 6 BL Lac objects and 5 CDQs. All are bright, with apparent *B* magnitudes between

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Table 1. The sample of core-dominated quasars and BL Lacs monitored in the present programme.

Object	Other name	Type	RA(2000)	Dec.(2000)	B (mag)	M_B (mag)	z	α	per cent Pol* (opt)	$R^\dagger$
0219+428	3C 66A	BL	02 22 39.6	+43 02 08	15.71	−26.5	0.444	−0.19§	11.70	676.1
0235+164	AO 0235+164	BL	02 38 38.9	+16 37 00	16.46	−27.6	0.940	0.67	14.90	1949.8
0735+178	PKS 0735+17	BL	07 38 07.4	+17 42 19	16.76	−25.4	>0.424	−0.26§	14.10	3548.1
0851+202	OJ 287	BL	08 54 48.8	+20 06 30	15.91	−25.5	0.306	0.18§	12.50	2089.3
0955+326	3C 232	CDQ	09 58 20.9	+32 24 02	15.88	−26.7	0.530	−0.11§	0.53	549.5
1128+315	B2 1128+31	CDQ	11 31 09.4	+31 14 07	16.00	−25.3	0.289	−0.41	0.62	269.2
1215+303	B2 1215+30	BL	12 17 52.0	+30 07 01	16.07	−24.8	0.237	−0.17§	8.00	426.6
1216−010	PKS 1216−010	CDQ	12 18 35.0	−01 19 54	16.17	−25.9	0.415	−0.03§	6.90	218.8
1225+317	B2 1225+31	CDQ	12 28 24.8	+31 28 38	16.15	−30.0	2.219	0.01	0.16	182.0
1308+326	B2 1308+32	BL	13 10 28.7	+32 20 44	15.61	−28.6	0.997	−0.09§	10.20	512.9
1309+355	PG 1309+355	CDQ	13 12 17.7	+35 15 23	15.60	−24.7	0.184	−0.12	0.31	22.9

*Reference for optical polarizations: Wills et al. (1992).

†R is the ratio of the radio-to-optical flux densities as defined in the text.

§Reference for these radio fluxes: Kovalev et al. (1999); for others see text.

15.6 and 16.8, so that short exposures can still provide good signal-to-noise ratios. At most two of these, one CDQ (1225+317, with $z = 2.219$) and possibly one BL Lac (0735+178, with $z > 0.424$), lie at $z > 1$, so this sample provides a fairly even coverage of the redshift range up to $z = 1$ for each blazar subclass. Note that we have adopted a BL Lac classification for B2 1308+326, following the 1-Jy (Stickel, Fried & Kühr 1993) and Padovani & Giommi (1995) catalogues, even though it is classified as a CDQ in the Véron-Cetty & Véron (1998) catalogue. Also, for the BL Lac object PKS 0735+178 we have adopted a redshift $z = 0.424$, though formally the published value is $z > 0.424$ (see Véron-Cetty & Véron 1998). For each object we could find a measurement of the degree of optical polarization (Wills et al. 1992); it can be seen from Table 1 that for four out of the five CDQs the percentage polarization was <1 per cent at the time those measurements were made, and hence they can be assigned to the sub-class of low-polarization CDQs.

Basic information of these objects are given in Table 1. The values of the radio spectral index, α (with $S_\nu \propto \nu^\alpha$), given in Table 1 were usually determined from linear spectral fitting to the available *near-simultaneous* flux density measurements between 1 and 22 GHz reported by Kovalev et al. (1999); those not appended with § are based on linear fits to *non-simultaneous* flux measurements taken from NED.[1]

The observations were made using the 104-cm Sampurnanand telescope of the State Observatory, Naini Tal which is an RC system with a $f/13$ beam (Sagar 1999). The detectors used were a cryogenically cooled 1024 × 1024 CCD chip (prior to 1999 October) and a 2048 × 2048 chip (after 1999 October), both mounted at the Cassegrain focus. Each pixel of both the CCDs corresponds to a square of 0.38 arcsec on the sky, covering a total field of ∼12 × 12 arcmin^2 in the case of the larger CCD and ∼6 × 6 arcmin^2 in the case of the smaller CCD. Observations were almost always done using an R filter, as it was near the maximum response of the CCD system and thus allowed us to achieve good temporal resolution; however, on two nights quasisimultaneous observations were performed using R and I filters. To improve signal-to-noise ratio (S/N), observations were carried out in 2 × 2 binned mode. On each night only one QSO was monitored as continuously as possible and the typical sampling rate was about 5 frames per hour. The choice of the exposure time depended on the brightness state of the QSO, the moon's phase and sky transparency. The field containing the QSO was adjusted so as to have at least 2 (and usually 3) comparison stars within about a magnitude of the QSO on the CCD frame.

Preliminary processing of the images as well as photometry was done using the IRAF[2] software. Photometry of the QSO and the comparison stars recorded on the same CCD frame was carried out using the *phot* task in IRAF. The same circular aperture was used for the photometry of the QSO and the comparison stars for all the images acquired over the night. This optimum aperture was selected by considering a range of apertures starting from the median full width at half-maximum (FWHM) over the night for the photometry and choosing that aperture that produced the minimum variance in the star–star differential light curve (DLC) of the steadiest pair of comparison stars. Further details of the observations and reductions are presented elsewhere (Stalin 2002; Stalin et al. 2003b). DLCs of the AGN relative to the comparison stars as well as between all pairs of comparison stars (usually three, but in some cases, two) are constructed from the derived instrumental magnitudes. The DLCs of the AGN relative to the comparison stars are used to look for the presence of INOV in the AGN. The choice of more than one comparison star in the differential photometry enables us to identify QSO variability reliably, as any stars that themselves varied during the night can be identified and discarded. The position and apparent magnitudes of the comparison stars used in the differential photometry of our sample of blazars from the USNO catalogue[3] are given in Table 2. Note that the magnitudes of the comparison stars taken from this catalogue have uncertainties of up to 0.25 mag.

3 RESULTS

3.1 Differential light curves (DLCs)

DLCs are presented for those AGNs that have shown clear evidence of INOV in Fig. 1. We consider a source to be variable only if correlated variations (both in amplitude and time) are found in the DLCs of the AGN relative to all the comparison stars considered. All of the six BL Lacs in our sample showed

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[1] http://ned.ipac.caltech.edu/

[2] Image Reduction and Analysis Facility, distributed by NOAO, operated by AURA, Inc. under agreement with the US NSF.

[3] http://archive.eso.org/skycat/servers/usnoa

Table 2. Positions and apparent magnitudes of the comparison stars.

Source	Star	RA(2000) h m s	Dec.(2000) d m s	R mag	B mag
0219+428	S1	02 22 45.13	43 04 19.6	14.2	15.6
BL	S2	02 22 47.23	43 06 00.1	13.9	14.7
	S3	02 22 28.39	43 03 40.7	13.9	14.8
0235+164	S1	02 38 56.44	16 38 56.5	14.5	15.7
BL	S2	02 38 54.48	16 36 03.1	15.5	16.1
	S3	02 38 38.53	16 40 05.2	16.7	18.0
0735+178	S1	07 38 03.45	17 42 56.1	16.4	16.5
BL	S2	07 38 17.10	17 39 03.7	16.0	16.0
	S3	07 38 10.29	17 43 43.9	16.4	16.6
0851+202	S1	08 54 46.11	20 07 20.3	15.7	16.8
BL	S3	08 54 43.70	20 02 42.2	16.4	18.8
0955+326	S1	09 58 14.45	32 23 45.8	14.0	15.0
CDQ	S2	09 58 18.32	32 28 35.1	14.5	14.9
	S3	09 58 26.47	32 26 54.3	15.9	16.5
1128+310	S1	11 31 02.12	31 11 39.3	15.9	16.7
CDQ	S2	11 30 54.41	31 11 47.8	15.6	15.8
	S3	11 31 18.04	31 17 16.8	15.5	17.1
1215+303	S1	12 17 45.96	30 04 51.0	14.4	16.8
BL	S2	12 17 49.13	30 07 02.3	15.8	16.4
	S3	12 17 44.47	30 09 44.1	13.7	14.5
	S4	12 18 09.03	30 09 35.8	14.7	15.6
	S5	12 17 26.62	30 07 53.5	14.2	15.3
1216-010	S1	12 18 42.91	−01 19 24.8	15.4	16.2
CDQ	S2	12 18 45.07	−01 19 47.2	15.3	15.8
1225+317	S1	12 28 18.78	31 25 20.1	14.6	15.5
CDQ	S2	12 28 30.62	31 26 34.2	15.6	16.6
	S3	12 28 13.60	31 27 36.3	17.1	18.4
	S4	12 28 29.15	31 25 18.5	15.5	16.7
1308+326	S1	13 10 19.69	32 23 53.6	16.9	17.8
BL	S2	13 10 18.09	32 20 07.3	15.8	16.6
	S3	13 10 29.69	32 25 54.0	16.4	16.8
	S4	13 10 38.31	32 17 31.7	16.0	16.7
1309+355	S1	13 12 39.17	35 19 50.4	14.6	16.0
CDQ	S2	13 12 40.49	35 16 03.0	15.0	15.9
	S3	13 12 30.99	35 16 08.7	14.3	15.8

INOV on at least one night, whereas this was the case for only two of the five CDQs monitored (Table 3). For each variable AGN, we have statistically quantified the variability and have derived variability parameter, amplitude and time-scale of variability below.

3.1.1 Variability parameter ($C_{\rm eff}$)

To quantify the variability, we have employed a statistical criterion based on the parameter C, similar to that followed by Jang & Miller (1997), with the added advantage that for each AGN we have DLCs relative to multiple comparison stars. This allows us to discard any variability candidates for which the multiple DLCs do not show clearly correlated trends, both in amplitude and time. We define C for a given DLC as the ratio of its standard deviation, $\sigma_{\rm T}$, and the mean σ of its individual data points, $\eta\sigma_{\rm err}$. Here η is the factor by which the average of the measurement errors ($\sigma_{\rm err}$, as given by *phot*), should be multiplied. It has been argued in the literature that the final errors given by DAOPHOT/IRAF are often too small (Gopal-Krishna, Sagar & Wiita 1995; Garcia et al. 1999). We find $\eta = 1.50$ (Stalin 2002, GSSW03). The value of C_i for the ith DLC of the AGN has the corresponding probability, p_i, that the DLC is steady (non-variable), assuming a normal distribution. For a given AGN we then compute the joint probability, P, by multiplying the values of p_i for individual DLCs available for the AGN. The effective C parameter, $C_{\rm eff}$, corresponding to P, is given in Table 3 for each variable AGN (i.e. $C_{\rm eff} > 2.57$, corresponds to a confidence level of variability in excess of 99 per cent). We also note that for these AGN all the DLCs involving only comparison stars were found to show statistically insignificant variability. This is quantified by giving within parentheses the values of $C_{\rm eff}$ for the DLC involving two stable comparison stars.

3.1.2 Amplitude of variability (ψ)

For objects that are variable we define the variability amplitude as (Romero, Cellone & Combi 1999)

$$\psi = \sqrt{(D_{\rm max} - D_{\rm min})^2 - 2\sigma^2}, \qquad (1)$$

with

$D_{\rm max}$ = maximum in the quasar differential light curve,
$D_{\rm min}$ = minimum in the quasar differential light curve,
$\sigma^2 = \eta^2 \langle \sigma^2_{\rm err} \rangle$.

The variability amplitudes computed using equation (1) for objects which have shown INOV are given in Table 3 in per cent. Note that the smallest clearly detected amplitude of INOV in the present sample is 1 per cent.

3.1.3 Structure function

The structure function is frequently used to characterize variability properties such as time-scales and periodicities present in light curves. The first order structure function for a DLC containing N evenly spaced data points is defined as (Simonetti, Cordes & Heeschen 1985)

$$D^1_X(\tau) = \frac{1}{N(\tau)} \sum_{i=1}^{N} w(i)w(i+\tau)[X(i+\tau) - X(i)]^2 \qquad (2)$$

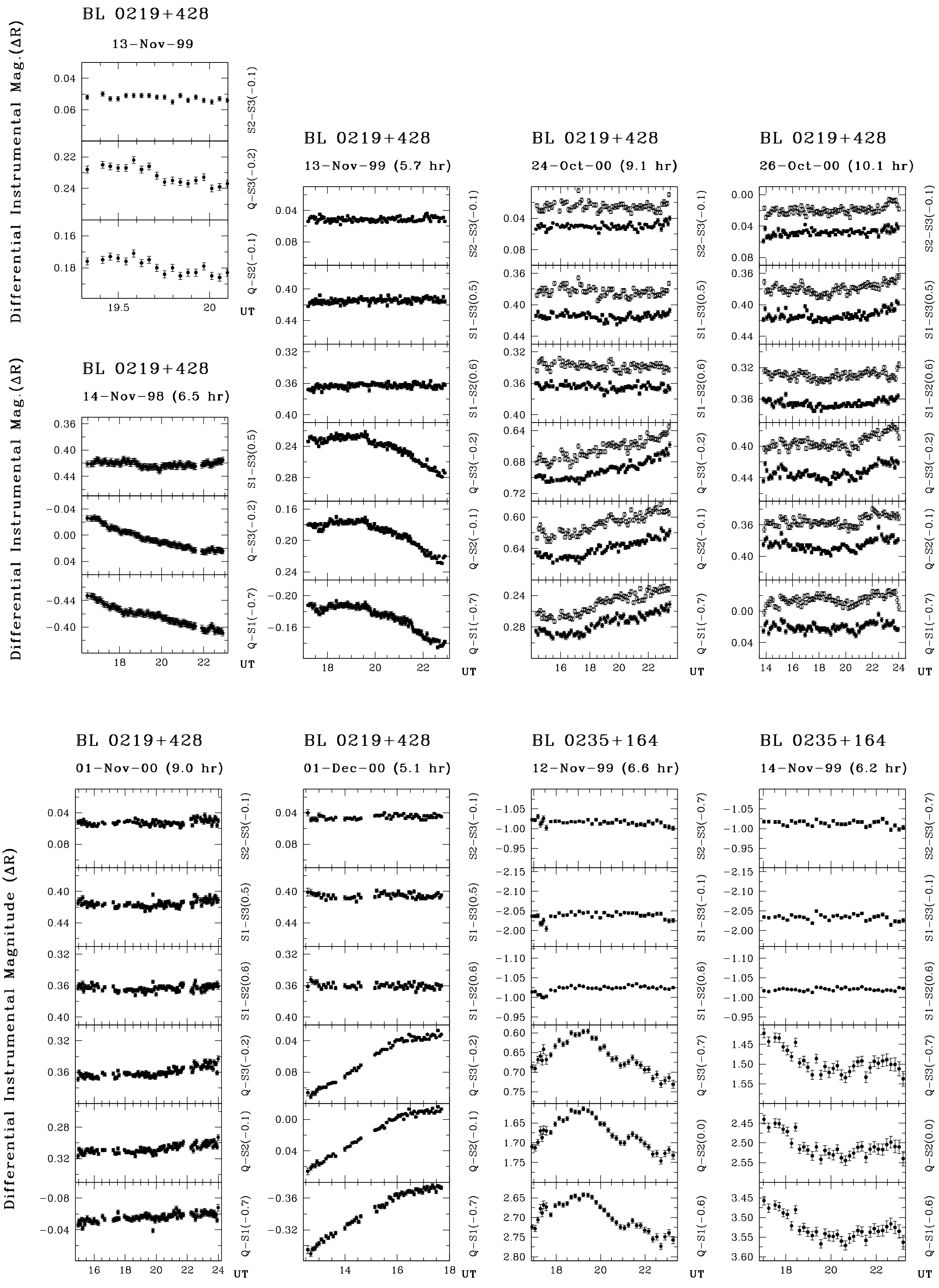
where τ = time lag, $N(\tau) = \sum w(i)w(i+\tau)$ and the weighting factor $w(i)$ is 1 if a measurement exists for the ith interval, 0 otherwise. The error in each point in the computed structure function is

$$\sigma^2(\tau) = \frac{8\sigma^2_{\delta X}}{N(\tau)} D^1_X(\tau), \qquad (3)$$

where $\sigma^2_{\delta X}$ is the measurement noise variance.

Since the samplings of our DLCs are quasi-uniform, we have determined structure functions using an interpolation algorithm. For any time lag τ, the value of $X(i+\tau)$ was calculated by linear interpolation between the two adjacent data points. A typical time-scale in the light curve (i.e. the time between a maximum and a minimum, or vice versa) is indicated by a local maximum in the structure function. In case of a monotonically increasing structure function, the source possesses no typical time-scale shorter than the total duration of observations. The plots of the structure function for objects which have shown definite microvariability are given in Fig. 2, and the inferred time-scales of variabilities are given in Table 3. The behaviour exhibited by these SF plots for our observations is of the following types.

(i) Sources with SF that display no plateau even at long time lag. The interpretation is that any characteristic time-scale, τ, is longer than the duration of the light curve and therefore the longest time



BL 0219+428 13-Nov-99

BL 0219+428 14-Nov-98 (6.5 hr)

BL 0219+428 13-Nov-99 (5.7 hr)

BL 0219+428 24-Oct-00 (9.1 hr)

BL 0219+428 26-Oct-00 (10.1 hr)

BL 0219+428 01-Nov-00 (9.0 hr)

BL 0219+428 01-Dec-00 (5.1 hr)

BL 0235+164 12-Nov-99 (6.6 hr)

BL 0235+164 14-Nov-99 (6.2 hr)

Figure 1. Differential *R*-band light curves for the BL Lacs and core-dominated quasars. The name of the object, the date and duration of observation are given on the top of each panel. The upper panel(s) give the DLC of the pair(s) of comparison stars whereas the subsequent lower panels are the DLCs of the quasar relative to the comparison stars. Note the different scales for many of the sources. *I*-band DLCs are shown as open symbols for two nights for BL 0219+428.

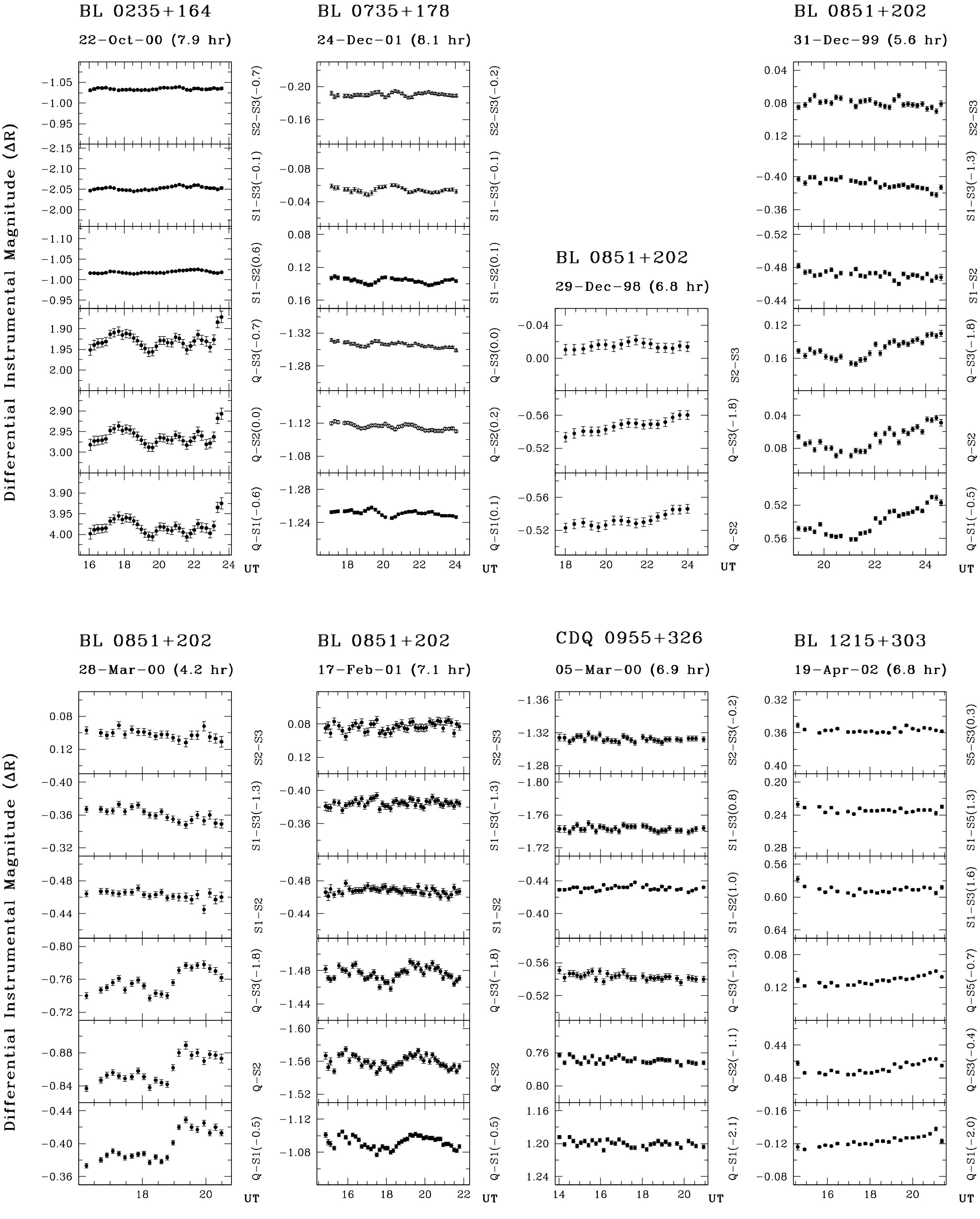


Figure 1 – *continued*

lag available represents only a lower limit to any characteristic time-scale of variation.

(ii) Sources with SF that shows two plateaux. This indicates the presence of two time-scales, which may possibly be related to different physical processes.

(iii) Sources that exhibit one plateau followed by a dip in the structure function. The plateau is interpreted as the variability time-scale and the dip as a period of a possibly cyclic signal in the light curve; these possible periods are denoted by *P* in Table 3.

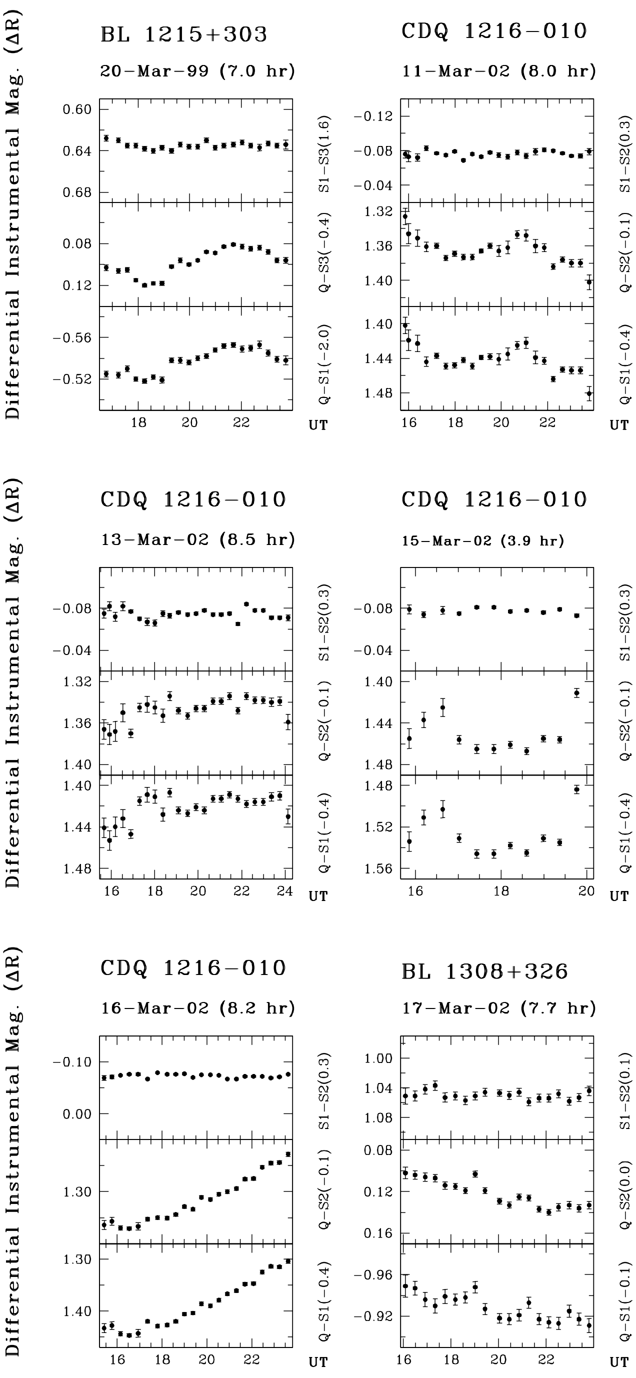


Figure 1 – *continued*

3.2 Long-term optical variability (LTOV)

Our observations also provide information on the LTOV. The number of epochs covered range between three and seven. For the six BL Lacs in our sample the total time-spans covered range between about two to three years. Similarly, year-like time coverage is available for four of our five CDQs; for the CDQ 1216−010 the overall time-spans are much shorter (∼1 week). Interestingly, even in this case, LTOV is convincingly detected just as in the case of the remaining CDQs and BL Lacs in our sample. The smallest amplitude of LTOV was found in the CDQ 1225+317; a ∼2 per cent brightening within a year between 2000 April and 2001 April. It is noteworthy that this CDQ has not only the highest redshift ($z = 2.219$) but also the lowest optical polarization ($P_{\rm opt} = 0.16$ per cent) in our sample. Also a ∼2 per cent brightening is noticed in 1216−010 within 48 h.

The LTOV results are summarized in the last column of Table 3, where the differences in the nightly means from those of the previous observations are tabulated. Consequently, for an object, the last column is left blank at the first epoch of its observations. We also give comments on the LTOV of individual sources below.

4 NOTES ON THE VARIABILITY OF INDIVIDUAL SOURCES

BL 0219+428. This is the best observed blazar in our sample, with seven epochs of monitoring with durations between five and ten hours, over the period from 1998 November to 2000 December. Fig. 1 shows the DLCs for the six of these epochs when INOV was seen. On two of these epochs in 2000 October, we also have *I*-band monitoring in addition to the default *R*-band monitoring. On both of those nights the INOV in *I* and *R* bands is found to be strongly correlated. The overall INOV amplitudes on the six nights range between 2 and 8 per cent. On 1999 November 13 and 2000 December 1, fairly abrupt changes in the slope of the DLCs were seen during the 5 to 6 hours of continuous monitoring, and the INOV amplitudes recorded on these two nights are also the largest observed for this object (Table 3). Another remarkable feature is that on 1999 November 13 at 19.6 UT a 1.5 per cent downward ‘glitch’ occurred within a time span of less than 10 min, followed by the onset of steady fading. An expanded version of this part of the DLC is shown in the top panel of column 1 in Fig. 1. The SF plots for the six nights are smoother than usual, although significant flattenings are apparent on the nights of 2000 November 1 and 2000 October 26, indicating time-scales of around 4 h (Fig. 2). Both brightening and fading were noted in this BL Lac’s LTOV. The blazar faded by 0.70 mag during our first three epochs of observations (between 1998 November 14 and 2000 October 24). This was followed by a brightening of 0.34 mag within a week that encompassed two additional nights of study. The object had dimmed by 0.06 mag when observed 23 d later on 2000 November 24 and was found to have brightened by 0.35 mag when observed for the last time on 2000 December 1.

BL 0235+164. This well-known BL Lac object was monitored on five epochs between 1998 November and 2000 October. The DLCs of the first and last epochs are quite noisy, owing to the less sensitive CCD chip in the former case and faintness of the object in the latter case. On each of the remaining three DLCs, INOV is clearly seen against all three comparison stars, with amplitudes ranging between 7.6 per cent and 12.8 per cent (Fig. 1). The derived SFs for the two nights in 1999 November have good S/N and in both cases a flattening is noticed corresponding to time-scale of around 3 h (Fig. 2). INOV monitoring of this object has also been recently reported by Xie et al. (2001). A particularly interesting feature of the DLCs on 1999 November 12 is the rapid brightening of this object by about 2 per cent within about 22 min (which corresponds to only about 11 min in the rest frame). This BL Lac also showed significant LTOV, with changes in both directions during the period of slightly under 2 yr during which we observed it. It had initially brightened by 0.67 mag between the first two epochs of observations (1998 November 13 and 1999 November 12) followed by a dramatic 0.83 mag fading in two days (1999 November 12 to 1999 November 14). Additional fading by 0.45 mag was noticed when it was observed a year later on 2000 October 22. This was again followed by a fading of 0.35 mag in the following week (between 2000 October 22 and

Table 3. Log of INOV and LTOV observations of CDQs and BL Lacs. In the case of INOT, the variability parameter (C_{eff}), amplitude (ψ), characteristic time-scale (τ) and Period (P) of variability are also given. The number within parentheses in the C_{eff} column denotes the value for the DLC involving two stable comparison stars.

Object	Date	No. of points	Duration (h)	INOV status*	C_{eff} AGN(star)	ψ (per cent)	τ (h)	P (h)	LTOV (Δm)
0219+428	14.11.98	118	6.5	V	6.0 (0.5)	5.4	> 6.5		
BL	13.11.99	123	5.7	V	> 6.6(1.2)	5.5	> 5.9		+0.25
	24.10.00	73	9.1	V	5.8 (1.5)	4.3	> 9.1		+0.45
	26.10.00	82	10.1	V	3.5 (1.4)	3.2	4.9		−0.26
	01.11.00	103	9.0	V	2.9 (1.1)	2.2	3.9		−0.08
	24.11.00	71	5.1	NV					+0.06
	01.12.00	59	5.1	V	>6.6 (1.1)	8.0	> 5.1		−0.35
0235+164	13.11.98	36	4.4	–	–	–	–	–	
BL	12.11.99	39	6.6	V	>6.6 (1.1)	12.8	3.6		−0.67
	14.11.99	34	6.2	V	3.2 (1.1)	10.3	3.4		+0.83
	22.10.00	39	7.9	V	2.6 (1.4)	7.6			+0.45
	28.10.00	29	6.8	–	–	–	–	–	+0.35
0735+178	26.12.98	49	7.8	NV					
BL	30.12.99	65	7.4	NV					−0.45
	25.12.00	43	6.0	NV					−0.70
	24.12.01	43	7.3	V	2.8 (2.0)	1.0	> 8.1		+0.43
0851+202	29.12.98	19	6.8	V	2.8 (0.4)	2.3	> 6.8		
BL	31.12.99	29	5.6	V	6.5 (1.1)	3.8	3.0		+0.60
	28.03.00	22	4.2	V	5.8 (0.8)	5.0	1.2		−0.93
	17.02.01	48	6.9	V	2.7 (0.7)	2.8	2.0	3.8	−0.70
0955+326	19.02.99	36	6.5	NV					
CDQ	03.03.00	37	6.3	NV					−0.05
	05.03.00	34	6.9	PV	2.2 (0.6)	0.7			0.00
1128+315	18.01.01	31	5.7	NV					
CDQ	09.03.02	27	8.2	NV					−0.14
	10.03.02	28	8.3	NV					0.00
1215+303	20.03.99	21	7.0	V	5.5 (0.9)	3.5	4.2		
BL	25.02.00	28	5.9	NV					+0.19
	31.03.00	27	5.0	NV					+0.13
	25.04.01	29	6.5	–	–	–	–	–	+0.21
	19.04.02	23	6.8	V	4.9 (1.3)	1.8	> 6.8		−0.11
1216−010	11.03.02	22	8.0	V	3.2 (0.9)	7.3	1.8	3.2	
CDQ	13.03.02	24	8.5	V	2.6 (1.5)	3.8	1.2	2.2	−0.02
	15.03.02	11	3.9	V	3.9 (0.9)	5.5	1.0	2.2	+0.11
	16.03.02	22	8.2	V	6.6 (1.4)	14.1	> 8.2		−0.14
1225+317	07.03.99	49	6.6	NV					
CDQ	07.04.00	23	6.0	NV					0.00
	20.04.01	34	7.4	NV					−0.02
1308+326	23.03.99	17	6.0	–	–	–	–	–	
BL	26.04.00	16	5.6	NV					+0.21
	03.05.00	19	6.7	–	–	–	–	–	0.00
	17.03.02	19	7.7	V	3.1 (0.6)	3.4	1.2,4.4		−1.90
	20.04.02	14	5.8	NV					+0.44
	02.05.02	15	5.1	NV					−0.03
1309+355	25.03.99	39	6.7	NV					
CDQ	01.04.01	32	4.6	NV					+0.10
	02.04.01	41	5.2	NV					0.00

*V = variable, NV = not variable, PV = probably variable.

2000 October 28). This blazar had thus shown very large peak to peak LTOV during our observations: 1.63 mag within a year.

BL 0735+178. This BL Lac object was observed on four nights between 1998 December and 2001 December. Although the data quality was generally good, on no occasion was a clear detection of INOV made, though there is marginal evidence for variations on 2001 December 24 (Fig. 1). This behaviour is in clear contrast to that found here for the remaining five BL Lacs in our sample. Still, substantial LTOV was noted in this BL Lac. It showed significant brightening by 1.15 mag over the course of our first three epochs of observations within two years. The blazar had faded by 0.43 mag from that peak over the next year when last monitored on 2001 December 24.

BL 0851+202. A recent detection of INOV of this well known BL Lac object has been reported by Ghosh et al. (2000). We monitored this object on four nights between 1998 December and 2001 February and found it to show INOV on all four nights (Fig. 1). On each night features can be seen in the SF, corresponding to

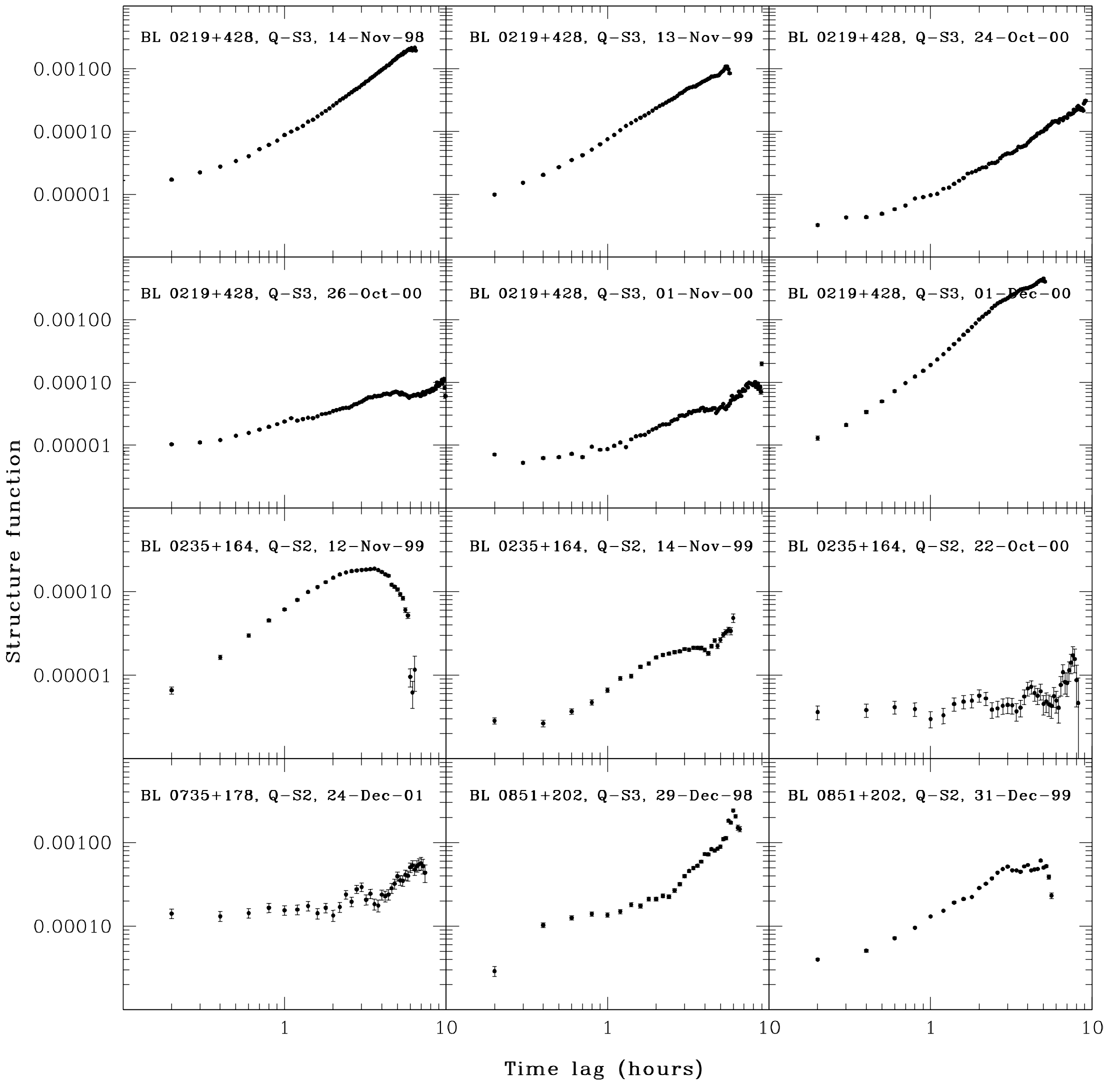


Figure 2. First-order structure function of BL Lacs and CDQs which have shown INOV on the marked epoch against the indicated comparison star.

time-scales between 1.5 and 3.0 h (Fig. 2). In addition, a 'periodicity' of ~3.8 h is present in the SF for the night of 2001 February 17 (Fig. 2; Table 3); however, we note that this corresponds to only two peaks in the light curve (Fig. 1) and so need not be a genuine (quasi)periodicity. The most remarkable feature on the DLC on 2000 March 28 is a ~4 per cent jump in brightness against all three comparison stars within about an hour (at around 19 UT), which is also borne out in the SF analysis. This blazar also showed very large amplitude LTOV: it faded by 0.6 mag in a year between 1998 December 29 and 1999 December 31. However it then brightened during our remaining three epochs of observations. A total brightening of 1.63 mag was observed between 1999 December 31 and 2001 February 17.

CDQ 0955+326. The only one of the three nights of monitoring this quasar which showed possible indications of variability was 2000 March 5. Against all three comparison stars, the quasar showed a steady decline of about 0.5 per cent over 6.9 h (Fig. 1). Some LTOV of this quasar can be ascertained from our three epochs of observations which cover a span of about one year. The quasar brightened by 0.05 mag within a year between 1999 February 19 and 2000 March 3 and was found to remain at essentially the same level when observed two days later.

CDQ 1128+315. No INOV was detected. Our three epochs of observations span about a year. Between 2001 January 18 and 2002 March 9 the quasar brightened by 0.14 mag; it remained at the same brightness level over the next 24 h.

BL 1215+303. This BL Lac object was monitored on five nights, of which only four nights were considered for INOV as the data on the remaining one night are of moderate quality. On 1999 March 20 the BL Lac showed clear evidence of variability with peak-to-peak amplitude of ~4 to 5 per cent with a 2 per cent change noticed within ~0.5 h. On 2002 April 19 the DLCs showed a steady brightening of 2 per cent over the 6.8 h of observations (Fig. 1). On 1999 March 20, the SF derived from 7.0 h of observations shows a steady rise with a turnover corresponding to a time-scale of 4.2 h; no such SF turnover is present on 2002 April 19 (Fig. 2; Table 3). The five epochs of monitoring observations of this BL Lac covered a temporal baseline of over three years (from 1999 March 20 to 2002 April 19). The quasar exhibited LTOV by fading progressively during the first four epochs, becoming fainter by 0.53 mag between 1999 March

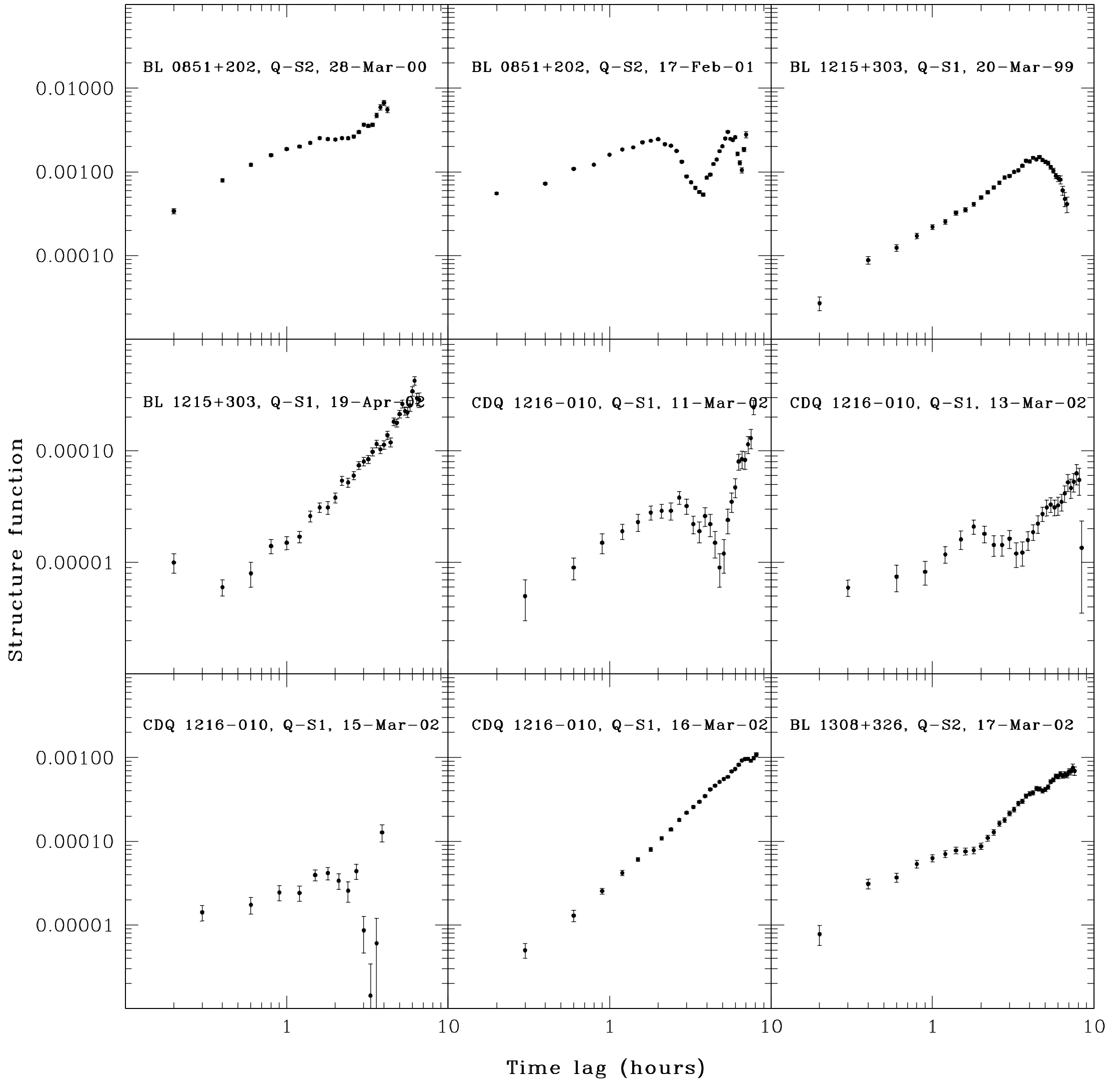


Figure 2 – *continued*

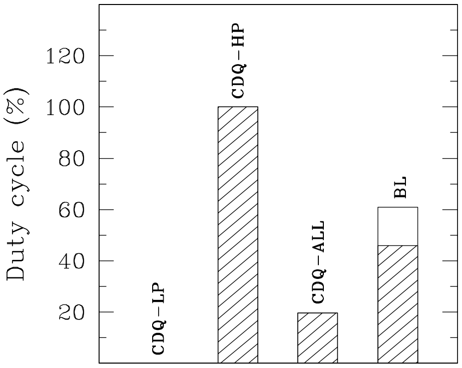


Figure 3. Duty cycles for various classes of blazars and for different amplitude ranges: shaded for $\psi > 3$ per cent; open for $\psi < 3$ per cent.

20 and 2001 April 25. By 2002 April 19 it had brightened again by 0.11 mag.

CDQ 1216−010. This highly polarized CDQ was monitored on four nights during March 2002 and clear INOV was detected on all the four nights against both comparison stars (Fig. 1). The SF for 2002 March 16 shows a linear rise all the way to the time lag of ~8 h. On each of the earlier three nights a 'periodicity' signal of ~3 to 4 h is seen in the SF (Fig. 2; Table 3). This quasar was observed over a time baseline of only 6 d; none the less, the source is found to show significant internight variability. The quasar brightened by 0.02 mag between the first two epochs (2002 March 11 and 2002 March 13) followed by 0.11 mag fading during the next two days. It once again had brightened (by 0.14 mag over the next 24 h) when first observed on 2002 March 16; it continued to brighten throughout that night.

CDQ 1225+317. This most distant quasar in our sample did not show any evidence of INOV in our three roughly equally spaced epochs of observations over a span of two years (between 1999 March 7 and 2001 April 20). However, it showed LTOV, wherein a ~2 per cent brightening was noticed in a year between 2000 April and 2001 April. One might attribute this lack of detection to a combination of only three nights of observation and the high redshift, which means that we were examining a relatively short period in the rest frame of the CDQ.

BL 1308+326. This BL Lac object was monitored on six epochs between 1999 March and 2002 May; however, it was sufficiently bright for the purpose of INOV detection on just the last three epochs, which fall in 2002 March, April and May. INOV was detected only on the night of 2002 March 17 showing a gradual fading by about 2 per cent (Fig. 1), as well as possible very short-term variations. The SF shows a plateau corresponding to a time-scale of about 1.5 h (Fig. 2). Large-amplitude LTOV was seen. The quasar was relatively faint during the initial three epochs of our observations. A fading of 0.21 mag was found within the first year (1999 March 23 and 2000 April 26) and it was found in the same level when observed a week later on 2000 May 3. However the quasar had brightened by 1.9 mag when observed about 2 yr later on 2002 March 17. It faded once again in about a month by 0.44 mag and then brightened by 0.03 mag over 12 d when observed for the last time on 2002 May 2.

CDQ 1309+355. This quasar was observed for three epochs and showed no INOV, although it did exhibit LTOV. Between the first two epochs, separated by about two years, the quasar decreased in brightness by 0.10 mag, and remained at the same brightness level over the next 24 h.

4.1 Duty cycle (DC) of intranight optical variability

Duty cycles of INOV were calculated following the definition of Romero et al. (1999). Since most AGNs do not display variability on each night, duty cycles are best estimated not as a fraction of the variable objects found within a given class, but as the ratio of the time over which objects of the class are seen to vary to the total observing time spent on monitoring the objects in the class. It is thus given as

$$DC = 100\frac{\sum_{i=1}^{n} N_i(1/\Delta t_i)}{\sum_{i=1}^{n}(1/\Delta t_i)} \text{ per cent,} \tag{4}$$

where $\Delta t_i = \Delta t_{i,\mathrm{obs}}(1+z)^{-1}$ is the duration (corrected for cosmological redshift) of the ith monitoring session of the source out of a total of n sessions for the selected class, and N_i equals 0 or 1, depending on whether the object was non-variable or variable, respectively, during Δt_i. Results for the different classes (CDQ-LP: low-polarization CDQs; CDQ-HP: high-polarization CDQs; CDQ-ALL: CDQs; BL: BL Lacs) are shown as histograms in Fig. 3. The shaded portions refer to the subsets showing large variability ($\psi >$ 3 per cent), while the blank portions refer to the INOV detections of lower amplitudes; the cases of probable INOV are not included in these histograms.

The results presented here allow for the first time a comparison of the DC of INOV for the three blazar classes, namely BL Lacs; high-polarization CDQs, CDQ-HP; and low-polarization CDQs, CDQ-LP (although our sample contains just one CDQ-HP, 1216-010 (Table 1), a significant statement about it is possible, since it was monitored on four nights with an average duration of 7.1 h per night). In fact, the comparisons can now be made for ranges of variability amplitudes, which we take as $\psi < 3$ per cent and $\psi > 3$ per cent. In GSSW03 we presented a similar comparison for RQQs and BL Lac objects monitored in our program. We see that the DC for INOV detection is high both for BL Lacs (61 per cent) and for the CDQ-HP source (100 per cent), but much lower for the CDQ-LP sources. Thus, there appears to be a close link between the INOV and the polarized component of optical emission (which is commonly attributed to shocks in the relativistic non-thermal jets). While this pattern is highly suggestive, we must caution that a more definitive claim would require that the classification of the blazars into the two polarization classes be based on measurements made simultaneous to the optical flux monitoring and that the number of CDQ-HP sources be increased.

Further, it is interesting to note from Fig. 3 that not only do the BL Lacs and CDQ-HP exhibit high DC of INOV but also the probability of observing large amplitude INOV ($\psi > 3$ per cent) is high (DC $\simeq$ 0.5) and probably very similar to the probability of small-amplitude INOV ($\psi < 3$ per cent), when we note that our lower limit for clear detections of INOV is $\psi \simeq 1$ per cent.

Any successful model of INOV should be able to explain this rather unexpected behaviour found here for the blazars.

5 CONCLUSIONS

The observations reported here present the first systematic study of the INOV characteristics of the two Doppler beamed AGN classes, CDQs and BL Lacs, although studies of individual sources of these types have been made over the past decade (e.g. Noble et al. 1997). We monitored both classes of blazars in our sample with equally high sensitivities and for comparable time durations; the mean monitoring duration for BL Lacs was 6.5 h over 31 nights, while for CDQs it was 6.7 h over 16 nights.

The major result of this observational programme is our finding that the duty cycles of INOV detection for weakly polarized CDQs and BL Lacs are strikingly different. BL Lacs show a high DC of ~60 per cent, in contrast to CDQs-LP for which the DC is found to be 0 per cent as none of them showed INOV at the level of 1 per cent. Including the one case of probable variable (0955+326 on 2000 March 5) raises this DC to 6 per cent only. This value is nominally lower than the DCs we have found for RQQs and LDQs (~15 per cent; Stalin et al. 2003a; GSSW03). At the same time, we find a close resemblance, both in amplitude and duty cycle of INOV, between the one CDQ-HP in our sample and the BL Lacs. Thus it appears that the mere presence of a prominent (and hence presumably Doppler boosted) radio core does not guarantee INOV; instead, the more crucial factor appears to be the optical polarization of the core emission. Such highly polarized emission is normally associated with shocks in a relativistic jet, so this may not be surprising. Of course the number of sources in our sample is not large, and moreover the polarization measurements were made long before the intranight optical monitoring reported here. Both these shortcomings need to be overcome in subsequent studies in order to place the present results on a firmer basis.

For most of the sources that do show INOV, some type of time-scale of a few hours (observer's frame) is frequently detected. Although, in a few cases, the structure function indicates the presence of several hour 'periodicities', we stress that these may well correspond to the time gap between multiple flares (or perturbations on bigger, slower flares). None of the light curves are long enough to actually detect putative real periodicities (or quasiperiodicities) of longer than 1 or 2 h. Probing such phenomena would require continuous monitoring through coordinated observations by many observatories, well separated in longitude, or by a space observatory.

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