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Intranight optical variability of BL Lacs, radio-quiet quasars and radio-loud quasars

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ABSTRACT

We report monitoring observations of 20 high-luminosity active galactic nuclei (AGN), 12 of which are radio-quiet quasars (RQQs). Intranight optical variability (INOV) was detected for 13 of the 20 objects, including 5 RQQs. The variations are distinctly stronger and more frequent for blazars than for the other AGN classes. By combining these data with results obtained earlier in our programme, we have formed an enlarged sample consisting of 9 BL Lacs, 19 RQQs and 11 lobe-dominated radio-loud quasars (RLQs). The moderate level of rapid optical variability found for both RQQs and radio lobe-dominated quasars (LDQs) argues against a direct link between INOV and radio loudness. We supplemented the present observations of 3 BL Lacs with additional data from the literature. In this extended sample of 12 well observed BL Lacs, stronger INOV is found for the EGRET detected subset.

Key words: galaxies: active – BL Lacertae objects: general – galaxies: jets – galaxies: photometry – quasars: general.

1 INTRODUCTION

In a series of papers since 2003, we have reported results of a programme to search for intranight optical variability (INOV; see Wagner & Witzel 1995 for a review), often called microvariability, in a sample of 26 optically luminous active galactic nuclei (AGN), using the 104-cm Zeiss telescope of the Aryabhatta Research Institute of Observational Sciences (ARIES), Naini Tal, India (Gopal-Krishna et al. 2003, GK03; Stalin et al. 2004a, St04a; Sagar et al. 2004, Sa04; Stalin et al. 2004b, St04b; see also Stalin 2003). These objects belong to the four major classes of luminous AGN, namely, radio-quiet quasars (RQQs), radio-loud lobe-dominated quasars (LDQs), radio-loud core-dominated quasars (CDQs) and BL Lac objects (BLs). The sample selection was such that the four classes are reasonably well matched in the z–M_B plane, with z ranging from 0.17 to 2.2 and M_B ranging from −24.3 to −30.0 (taking $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0$).

The observations under this programme typically achieved convincing detectability of INOV at a level of 0.01–0.02 mag and spanned a total of 113 nights (720 h) between 1998 October and 2002 May. This work provided the first positive detection of INOV for RQQs, though modest evidence for such variations had been obtained earlier (e.g. Gopal-Krishna, Sagar & Wiita 1995; Sagar, Gopal-Krishna & Wiita 1996; Jang & Miller 1997; Gopal-Krishna et al. 2000). It was, moreover, found that except for BLs and high optical polarization CDQs (HP-CDQs), the amplitude of detected INOV is small ($\leqslant$3 per cent) and so is the INOV duty cycle (DC; $\sim$10–20 per cent), irrespective of the radio loudness. Further, for the BLs and HP-CDQs, for which a strong INOV was frequently observed, no correlation was found between the amplitude of INOV and long-term optical variability (St04b). We argued that these results are consistent with the hypothesis that even RQQs possess relativistic jets emitting optical emission on subparsec scales, but that we are observing them at moderately large angles to the jet direction so that any variations are neither amplified in magnitude nor compressed in time-scale as they are in BL Lacs (GK03; St04a). Wills (1996) also argued that RQQs do indeed possess jets, but that they propagate through denser gas close to the planes of the host galaxies and are thus quickly snuffed out. For BLs, we found no correlations between apparent brightness levels and INOV properties (St04b). This is in accord with a recent study, which indicates that microvariability of a blazar may be correlated with the presence of longer-term flux changes, rather than its apparent brightness level (Howard et al. 2004).

In this paper, we present the results of our optical monitoring for another 20 AGN belonging to all of the above mentioned four classes

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of luminous AGN. We then combine the present data for 3 BLs with similar high-quality light curves (LCs) for another 9 BLs taken from literature, to arrive at a representative sample of 51 intranight optical LCs for BL Lacs. This sample allows us to make a comparative study of the INOV properties of BL Lacs detected with the EGRET instrument on the *Compton Gamma-Ray Observatory* (Hartman et al. 1999), or otherwise found to emit high-energy γ-rays, and their counterparts that were not detected by EGRET (Section 4). Our conclusions are summarized in Section 5.

2 INTRANIGHT OPTICAL MONITORING

All AGNs chosen for this additional study had to be bright enough to allow a high temporal density for precision differential photometry using telescopes of a modest aperture. This led to a requirement that $m_B < 17$ mag. We also wanted to minimize the contamination problems that arise when the host galaxy contributes a significant portion of the visible light (e.g. Cellone, Romero & Combi 2000) and so restricted our sample to luminous AGNs (quasars), with $M_B < -23.5$ mag. For good visibility from India, the sources had to be at moderate positive declinations and within suitable ranges of right ascensions. Basic data on our sources is presented in Table 1. 12 of the sources are RQQs (using the usual criterion for the K-corrected ratio of 5 GHz to 2500 Å fluxes, $R^* < 10$), 4 are LDQs, 1 is a CDQ and 3 are BLs; their redshifts range from 0.22 to 1.97.

The majority of the data was obtained at ARIES (formerly Uttar Pradesh State Observatory), Naini Tal, India, using the 104-cm Sampurnanand telescope, which is a Ritchey–Chretien 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. The 1k × 1k chip has a readout noise of 7 electrons and a gain of 11.8 electrons/Analog to Digital Unit (ADU), whereas the $2k \times 2k$ chip has a readout noise of 5 electrons (in the usually employed slow readout mode) and a gain of 10 electrons/ADU. Each pixel of both of these CCDs corresponds to 0.38×0.38 arcsec^2 on the sky, covering a total field of 12 × 12 arcmin in the case of the larger CCD and 6 × 6 arcmin in the case of the smaller CCD (Sagar 1999). An R Cousins filter was used for these observations. On each night only one AGN was monitored, as continuously as possible. The choice of exposure times depended on the brightness of the object, the phase of the moon and sky transparency. The field containing the AGN was adjusted so as to have within the CCD frame at least two (usually three or more) comparison stars within approximately a magnitude of the AGN; for nearly all objects, we were able to find at least one steady comparison star fainter, or <0.4 mag brighter, than the AGN, so as to obtain an equivalent signal-to-noise (S/N) ratio in the CCD frames. Seeing ranged from approximately 1.5 to approximately 3.5 arcsec.

Table 1. The sample of 20 optically luminous AGN monitored in the present work.

IAU Name	Type	B	M_B	z	$P_{\rm opt}$† (per cent)	log R^*‡
0003+158	LDQ	16.51	−25.7	0.450	0.65	2.6
0025+307	LDQ	15.79	−26.7	0.500	–	1.8
0043+039	RQQ	16.00	−26.0	0.385	0.27	−0.7
0806+315	BL	15.70	−25.0	0.220	–	1.7
0824+098	RQQ	15.50	−25.6	0.260	–	0.5
0832+251	RQQ	16.10	−25.5	0.331	–	0.1
0846+513	CDQ	16.28	−29.4	1.860	–	2.2
0850+440	RQQ	16.40	−26.1	0.513	–	<−0.5
0931+437	RQQ	16.47	−25.8	0.456	–	0.1
0935+416	RQQ	16.31	−29.6	1.966	–	<−0.7
0945+438	RQQ	16.28	−24.5	0.226	–	<−0.1
1029+329	RQQ	16.00	−26.7	0.560	–	<−0.6
1418+546	BL	16.17	−23.7	0.152	7.5	3.1
1422+424	RQQ	16.42	−25.1	0.316	–	<−0.4
1425+267	LDQ	15.78	−26.0	0.366	1.9	2.0
1444+407	RQQ	15.45	−25.7	0.267	0.4	−1.1
1522+101	RQQ	16.20	−28.4	1.324	0.3	<−0.7
1553+113	BL	15.00	−26.8	0.360	–	2.2
1631+395	LDQ	16.48	−27.8	1.023	1.1	1.6
1750+507	RQQ	15.80	−25.6	0.300	–	0.7

†References for optical polarization are Wills et al. 1992 and Berriman et al. 1990; – for no data available.

‡R^* is the K-corrected ratio of the 5-GHz radio to 2500-Å-band optical flux densities (Stocke et al. 1992); references for radio fluxes are Véron-Cetty & Véron 2001, NVSS (Condon et al. 1998) and FIRST (Becker, White & Helfand 1995; Bauer et al. 2000).

Four of the RQQs in the sample were monitored in a V Johnson passband using a cryogenically cooled Tektronix CCD detector (Tektronix, Inc., Beaverton, OR, USA) at the f/3.23 prime focus of the 2.34-m Vainu Bappu Telescope (VBT) of the Indian Institute of Astrophysics, at Kavalur, India (Table 2). The chip has 1024 × 1024 pixels of approximately 24×24 µm^2, with each pixel dimension corresponding to approximately 0.63 arcsec on the sky, so that the total area covered by a CCD frame is 10.75 × 10.75 arcmin. The readout noise was 4 electrons and the gain was 4 electrons/ADU. Typical seeing was around 2 arcsec.

One night of monitoring data for the RQQ 1422+424 reported here was carried out in a V Johnson passband using the Tektronix 1k × 1k CCD detector at the f/13 Cassegrain focus of the 1.2-m Gurushikhar Telescope (GSO) at Mount Abu, India (Table 2). Each pixel corresponds to 0.32 arcsec in each dimension and the entire chip covers approximately 5.4 × 5.4 arcmin of sky. The readout noise was 4 electrons and gain was 10 electrons/ADU. Typical seeing was ∼1.5 arcsec.

At all three telescopes, observations were carried out in 2 × 2 binned mode, in order to increase the S/N ratio; bias frames were taken intermittently and twilight sky flats were taken for processing of the data. Initial processing (bias subtraction, flat-fielding and cosmic ray removal) as well as photometric reductions were done in the usual manner employing standard routines in IRAF[1] software.

Instrumental magnitudes of the AGN and the stars in the images taken at Naini Tal were obtained using the routines available in the APPHOT package in IRAF. For these reductions, a crucial parameter, the circular aperture used for the photometry of the quasi-stellar object (QSO) and the comparison stars, varied from night to night. For each night an optimum aperture for the photometry was selected by considering a range of apertures starting from a minimum corresponding to the median seeing (FWHM) over the night; we chose the aperture that produced the minimum variance in the star to star differential light curve (DLC) of the steadiest pair of comparison stars. Additional details of the observation and reduction procedures are presented elsewhere (Stalin 2003; St04b).

Instrumental magnitudes of the AGN and stars in the image frames acquired at VBT and GSO were determined by using DAOPHOT II[2] (Stetson 1987) and employing aperture photometric

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[1] IMAGE REDUCTION AND ANALYSIS FACILITY, distributed by the National Optical Astronomy Observatories (NOAO), operated by AURA, Inc. under agreement with the US National Science Foundation (NSF).

[2] DOMINION ASTROPHYSICAL OBSERVATORY PHOTOMETRY software.

Table 2. Observation log and variability results.

IAU Name	Other Name	Type	Date	Filter	Telescope	N points	Duration (h)	Status*	C_{eff}	ψ (per cent)
0003+158	PKS	LDQ	03.11.00	R	ARIES	28	5.8	NV	–	–
			05.11.00	R	ARIES	32	7.0	V	3.1	1.8
0025+307	RXS	LDQ	13.10.98	R	ARIES	26	3.6	V	2.7	0.8
			01.11.98	R	ARIES	24	3.4	V	5.1	1.9
0043+039	PG	RQQ	21.10.98	R	ARIES	12	2.4	V	4.2	2.5
			05.11.98	R	ARIES	28	3.2	V	2.6	3.2
0806+315	B2	BL	28.12.98	R	ARIES	34	7.3	V	>6.6	14.5
0824+098	1WGA	RQQ	27.12.98	R	ARIES	58	8.2	V	4.3	2.2
0832+251	PG	RQQ	25.12.98	R	ARIES	24	4.7	V	4.3	2.0
			14.01.99	R	ARIES	63	7.3	NV	–	–
			10.12.99	R	ARIES	31	6.7	NV	–	–
0846+513	0846+51	CDQ	30.12.98	R	ARIES	37	7.1	V	2.8	5.6
0850+440	US 1867	RQQ	17.02.99	R	ARIES	37	7.7	NV	–	–
0931+437	US 737	RQQ	20.02.99	R	ARIES	24	4.5	NV	–	–
0935+416	PG	RQQ	27.03.99	R	ARIES	15	2.7	NV	–	–
0945+438	US 995	RQQ	15.01.99	V	VBT	10	2.2	NV	–	–
1029+329	CSO 50	RQQ	13.03.99	V	VBT	57	5.4	NV	–	–
1418+546	OQ 530	BL	28.03.99	R	ARIES	31	5.6	V	4.0	2.0
1422+424	RXS	RQQ	03.04.99	R	ARIES	39	7.2	NV	–	–
			14.04.99	V	VBT	40	4.1	NV	–	–
			07.03.00	R	ARIES	15	3.9	NV	–	–
			08.03.00	V	GSO	28	3.0	V	2.9	3.6
1425+267	B2	LDQ	06.05.99	R	ARIES	31	5.8	V	2.8	3.2
1444+407	PG	RQQ	15.04.99	V	VBT	28	2.9	NV	–	–
1522+101	PG	RQQ	11.04.99	R	ARIES	36	6.6	NV	–	–
1553+113	PG	BL	05.05.99	R	ARIES	20	3.6	V	>6.6	2.3
			06.06.99	R	ARIES	40	7.1	NV	–	–
1631+395	KUV	LDQ	04.06.99	R	ARIES	28	5.7	V	2.9	2.7
			30.05.00	R	ARIES	12	3.5	NV	–	–
1750+507	IRAS	RQQ	03.06.98	R	ARIES	44	4.7	NV	–	–
			06.06.98	R	ARIES	15	1.6	NV	–	–
			08.06.99	R	ARIES	34	6.1	V	>6.6	2.0

*V = variable; NV = non-variable.

techniques. The best S/N ratio was found for data reduced with a 7.0 pixel radius and it is thus used for our analysis.

The positions and the B and R magnitudes (taken from the United States Naval Observatory-B catalogue[3] (Monet et al. 2003) for the comparison stars used in our analysis are given in Table 3. Note that the magnitudes of the comparison stars taken from this catalogue have uncertainties of up to 0.25 mag, though errors for individual objects are not provided.

3 RESULTS OF INTRANIGHT MONITORING

Fig. 1 presents the DLCs for all the nights on which significant variability was detected for any AGN in the present sample. It can be seen that in these data, variability of the order of 0.01 mag over the course of a few hours can be detected. A log of the observations and the main results are given in Table 2. For each night of observations of every object, this table provides the number of data points (N points), the duration, an indicator of the variability status, as well as two quantitative measures of the variability, C_{eff} and ψ (see below).

The parameter C_{eff} is defined, basically following Jang & Miller (1997), for a given DLC as the ratio of the standard deviation of all its data points, σ_T, to the averaged standard deviation for its individual data points, $\sigma = \eta\sigma_{\text{err}}$. Here η is the factor by which the average of the measurement errors (σ_{err}, as given by PHOT) should be multiplied; we find $\eta = 1.50$ (Stalin 2003, St04b). We compute C_{eff} from the C_i values (defined as the ratio of the standard deviation of ith DLC to the mean σ of its individual data points multiplied by the factor η) determined for the DLCs of an AGN relative to different comparison stars, measured on a single night (see Sa04 for details). A value of $C_{\text{eff}} > 2.57$ corresponds to a confidence level of variability in excess of 0.99 and is the criterion we use to assign variability to a QSO. We note that for these AGN all the DLCs involving only their comparison stars were found to show statistically insignificant variability, using the same statistical criterion.

We quantify the actual variation of the QSO on a given night using the error corrected amplitude of variability, ψ, as defined by Romero, Cellone & Combi (1999),

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

with $D_{\max}$ ($D_{\min}$) the maximum (minimum) in the quasar DLC and σ the corrected error value described in the previous paragraph. Details are given in St04b.

The structure function (SF) is frequently used to characterize variability properties such as time-scales and periodicities present in the LCs. We have also computed the SFs for our data set in the fashion discussed in some detail in Sa04 and St04b. Basically, a

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[3] http://www.nofs.navy.mil/data/fchpix

Table 3. Positions and magnitudes of the comparison stars.

IAU name	Star	RA(2000)	Dec.(2000)	B (mag)	R (mag)
0003+158	S1	$00^{\rm h}06^{\rm m}08^{\rm s}.42$	$+16^{\circ}09'54''.4$	16.31	15.32
	S2	$00^{\rm h}06^{\rm m}06^{\rm s}.20$	$+16^{\circ}10'46''.3$	17.17	15.71
	S3	$00^{\rm h}06^{\rm m}05^{\rm s}.97$	$+16^{\circ}12'15''.6$	16.89	15.49
0025+307	S1	$00^{\rm h}28^{\rm m}25^{\rm s}.59$	$+31^{\circ}03'19''.0$	15.57	14.11
	S2	$00^{\rm h}28^{\rm m}15^{\rm s}.86$	$+31^{\circ}03'09''.8$	15.57	13.89
0043+039	S1	$00^{\rm h}45^{\rm m}39^{\rm s}.87$	$+04^{\circ}10'02''.0$	16.95	15.50
	S2	$00^{\rm h}45^{\rm m}44^{\rm s}.87$	$+04^{\circ}10'57''.9$	17.34	16.09
	S3	$00^{\rm h}45^{\rm m}44^{\rm s}.16$	$+04^{\circ}13'26''.0$	17.76	15.21
0806+315	S1	$08^{\rm h}09^{\rm m}06^{\rm s}.08$	$+31^{\circ}22'19''.3$	16.52	15.09
	S2	$08^{\rm h}09^{\rm m}18^{\rm s}.58$	$+31^{\circ}22'20''.7$	16.54	15.11
	S3	$08^{\rm h}09^{\rm m}14^{\rm s}.89$	$+31^{\circ}20'18''.7$	17.65	15.92
0824+098	S1	$08^{\rm h}27^{\rm m}39^{\rm s}.18$	$+09^{\circ}41'13''.5$	16.60	15.03
	S2	$08^{\rm h}27^{\rm m}44^{\rm s}.30$	$+09^{\circ}45'05''.6$	16.28	15.44
0832+251	S1	$08^{\rm h}35^{\rm m}26^{\rm s}.47$	$+24^{\circ}57'12''.2$	18.86	16.62
	S3	$08^{\rm h}35^{\rm m}47^{\rm s}.24$	$+24^{\circ}57'19''.0$	16.56	15.72
0846+513	S1	$08^{\rm h}50^{\rm m}14^{\rm s}.07$	$+51^{\circ}06'21''.9$	17.27	16.11
	S3	$08^{\rm h}50^{\rm m}19^{\rm s}.88$	$+51^{\circ}09'00''.0$	17.34	18.67
0850+440	S1	$08^{\rm h}53^{\rm m}28^{\rm s}.75$	$+43^{\circ}46'22''.8$	18.37	16.08
	S2	$08^{\rm h}53^{\rm m}48^{\rm s}.92$	$+43^{\circ}48'28''.1$	18.03	16.39
	S3	$08^{\rm h}53^{\rm m}39^{\rm s}.97$	$+43^{\circ}46'15''.4$	18.72	16.46
0931+437	S1	$09^{\rm h}34^{\rm m}46^{\rm s}.90$	$+43^{\circ}32'05''.9$	15.75	14.42
	S2	$09^{\rm h}35^{\rm m}01^{\rm s}.19$	$+43^{\circ}27'43''.4$	15.72	15.24
0935+416	S1	$09^{\rm h}38^{\rm m}40^{\rm s}.37$	$+41^{\circ}26'11''.3$	16.11	15.32
	S3	$09^{\rm h}39^{\rm m}02^{\rm s}.53$	$+41^{\circ}30'37''.9$	16.27	15.47
0945+438	S1	$09^{\rm h}49^{\rm m}28^{\rm s}.88$	$+43^{\circ}37'54''.4$	15.30	14.35
	S3	$09^{\rm h}49^{\rm m}06^{\rm s}.74$	$+43^{\circ}29'08''.2$	17.18	15.27
	S4	$09^{\rm h}48^{\rm m}58^{\rm s}.30$	$+43^{\circ}55'11''.8$	17.28	16.14
1029+329	S1	$10^{\rm h}32^{\rm m}10^{\rm s}.68$	$+32^{\circ}36'08''.1$	16.37	15.02
	S2	$10^{\rm h}32^{\rm m}07^{\rm s}.49$	$+32^{\circ}37'28''.2$	17.35	15.33
1418+546	S1	$14^{\rm h}20^{\rm m}02^{\rm s}.31$	$+54^{\circ}25'25''.3$	16.28	15.58
	S2	$14^{\rm h}19^{\rm m}46^{\rm s}.29$	$+54^{\circ}26'43''.4$	16.11	15.51
	S3	$14^{\rm h}19^{\rm m}39^{\rm s}.75$	$+54^{\circ}21'56''.1$	16.74	15.44
1422+424	S1	$14^{\rm h}25^{\rm m}03^{\rm s}.56$	$+42^{\circ}14'41''.8$	16.27	15.67
	S2	$14^{\rm h}25^{\rm m}09^{\rm s}.20$	$+42^{\circ}17'21''.8$	18.14	16.81
	S3	$14^{\rm h}25^{\rm m}11^{\rm s}.09$	$+42^{\circ}17'51''.2$	15.97	15.39
1425+267	S1	$14^{\rm h}27^{\rm m}47^{\rm s}.53$	$+26^{\circ}35'14''.9$	15.21	13.65
	S2	$14^{\rm h}27^{\rm m}30^{\rm s}.07$	$+26^{\circ}36'05''.5$	15.59	14.01
1444+407	S1	$14^{\rm h}16^{\rm m}54^{\rm s}.96$	$+40^{\circ}36'51''.9$	15.68	14.10
	S2	$14^{\rm h}46^{\rm m}55^{\rm s}.62$	$+40^{\circ}36'16''.6$	17.04	14.99
1522+101	S1	$15^{\rm h}24^{\rm m}03^{\rm s}.25$	$+09^{\circ}58'15''.2$	16.99	15.03
	S2	$15^{\rm h}24^{\rm m}07^{\rm s}.32$	$+10^{\circ}01'02''.9$	17.12	15.56
1553+113	S1	$15^{\rm h}55^{\rm m}35^{\rm s}.71$	$+11^{\circ}09'33''.2$	16.11	15.11
	S3	$15^{\rm h}55^{\rm m}51^{\rm s}.81$	$+11^{\circ}12'28''.7$	16.55	15.45
1631+395	S1	$16^{\rm h}33^{\rm m}01^{\rm s}.57$	$+39^{\circ}20'49''.4$	17.20	15.90
	S3	$16^{\rm h}32^{\rm m}54^{\rm s}.19$	$+39^{\circ}21'19''.8$	17.91	16.48
1750+507	S1	$17^{\rm h}51^{\rm m}07^{\rm s}.39$	$+50^{\circ}45'03''.5$	20.11	19.55
	S2	$17^{\rm h}51^{\rm m}06^{\rm s}.32$	$+50^{\circ}44'33''.9$	16.38	14.81
	S3	$17^{\rm h}51^{\rm m}37^{\rm s}.59$	$+50^{\circ}43'56''.5$	15.70	14.80

monotonically rising SF indicates that the source shows no temporal structure on time-scales shorter than the duration of the LC, while the beginning of a plateau in the SF signifies a time-scale for the variability and a dip in the SF may be indicative of a periodic component. Fig. 2 shows the SFs for five objects on the nights when they were rather strongly variable, with $\psi > 0.03$ mag.

We now give brief comments on a few of the sources that showed INOV.

(i) RQQ 0043+035 varied on both the nights it was observed; on the first night it brightened by ~0.02 mag in ~1 h. On the second night, approximately 2 weeks later, the data were relatively noisy; none the less, a brightening by approximately ~0.03 mag over 2 h is clearly detected. The SF for this night shows a time-scale of roughly 1.5 h (Fig. 2).

(ii) BL 0806+315: on the single night this BL Lac was monitored for approximately 7 h, a fading by approximately 0.15 mag was detected. The SF indicates that no time-scale shorter than the monitoring duration is present (Fig. 2).

(iii) CDQ 0846+513 is the only CDQ in the present sample. A fluctuation of ~0.05 mag can be seen on its DLC. The SF shows hints of periodicities of approximately 2 and 4.5 h (Fig. 2); however, the data train is much too short to justify claiming them as actual periodicities. As this is a gravitationally lensed quasar (e.g. Maoz et al. 1993), much of its variability may be extrinsic, produced by microlensing.

(iv) RQQ 1422+424 showed variability on just one of the 4 nights it was monitored. The DLC in Fig. 1 shows a quasi-oscillatory pattern, with an amplitude of ~0.04 mag. The SF suggests a time-scale of ~1 h (Fig. 2).

(v) LDQ 1425+267 showed a weak flare of ~0.02 mag near 19.6 Universal Time (UT) on the single night it was monitored. The SF hints at a time-scale of ~4 h (Fig. 2).

In order to obtain more significant estimates of the INOV DC, we have combined the results for the 12 RQQs, 4 LDQs and 3 BLs in this sample with the extensive monitoring data presented for these AGN classes in our earlier work (Sa04, St04a). It may be recalled that for a given class of objects, the DC is defined as the weighted fraction of its DLCs that show INOV, where the contribution of an individual DLC to this fraction is weighted inversely by the duration of that DLC in the frame of the emitter (Romero et al. 1999; GK03; Sa04; St04a,b). Using these enlarged samples based on our observations, we estimate DCs of 22, 22 and 63 per cent for RQQs, LDQs and BLs, respectively.

4 STATISTICS OF INOV IN BL LACS USING ENLARGED DATA SETS

Although INOV of blazars has been clearly established for approximately 15 yr (Miller, Carini & Goodrich 1989; Carini 1990), only recently has enough data been accumulated to allow a reliable description of its frequency and amplitude, and to examine if various AGN classes exhibit different INOV behaviour. In order to increase the sample of LCs, we have combined the results for BLs in this paper with those reported in Sa04 and in other papers taken from the literature from 1990 to 2003 reporting intranight optical monitoring of BLs (as classified in the Véron-Cetty & Véron catalogue, 2001). Note that the object 0537−441 may also be classified as a CDQ (see Maraschi et al. 1985); however, we have considered it to be a BL in our analysis. While it is possible that our literature search is less than complete, we believe that our selection of BL Lac monitoring data is both extensive and representative. We have neither included in our sample data from papers where results are presented for just a single BL, nor where the duration of the LC is shorter than 4 h. These criteria led to the selection of 51 LCs with durations ranging between 4 and 10 h (median = 6.5 h). These LCs correspond to 12 BLs (Table 4), reported in 4 papers: present work (3 LCs, R filter); Sa04 (26 LCs, R filter); Romero et al. 2002 (19 LCs, V filter); Ghosh et al. 2001 (3 LCs, B filter). For the present purpose, we do not distinguish between data taken using the different filters. It may be noted that the rms error of individual data points is typically ~0.003 mag for all the 51 LCs considered.

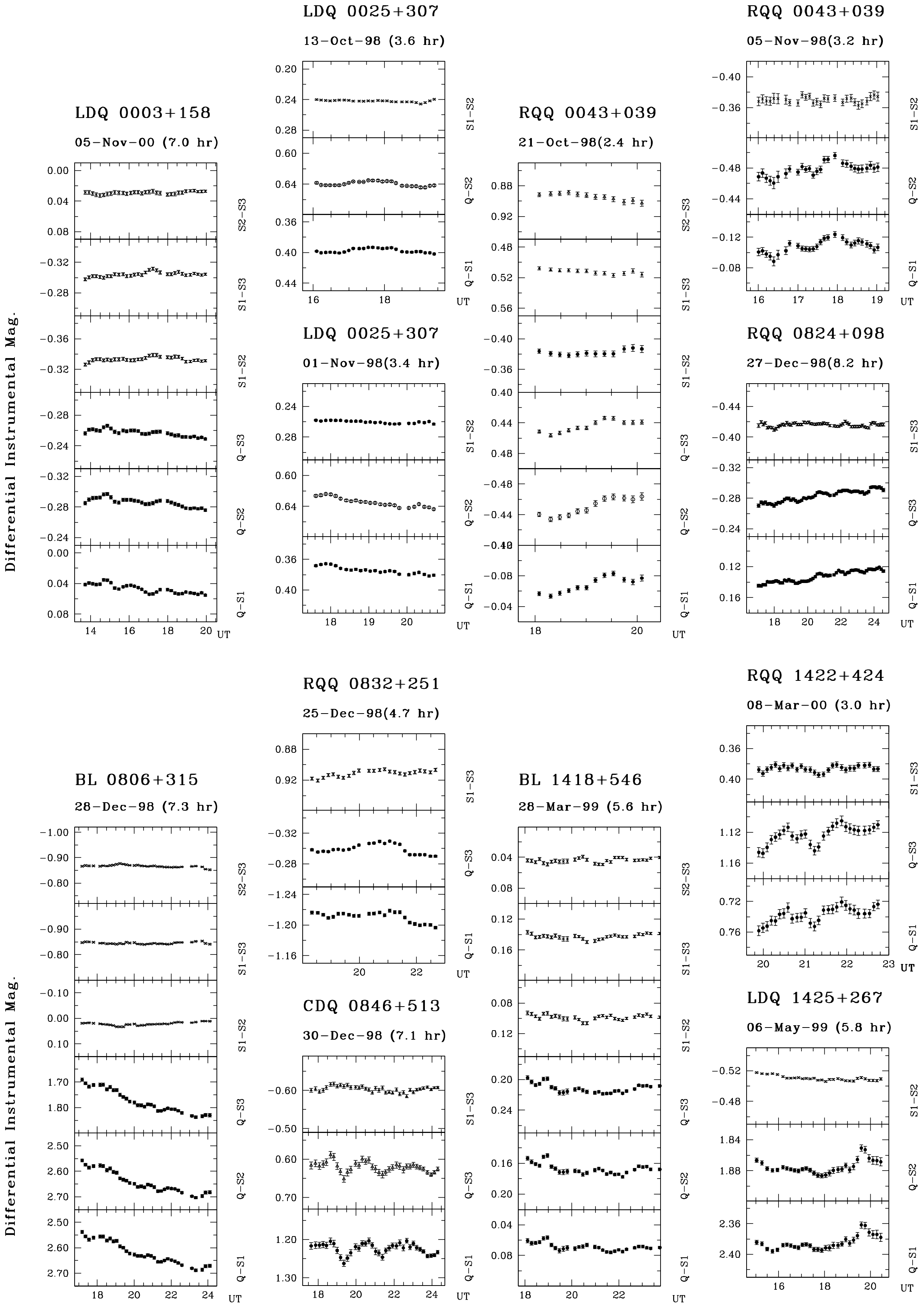

Figure 1. Differential light curves (DLCs) for the quasars on nights with a positive detection of intranight optical variability (INOV). The name of the quasar, the date and the duration of the observation are given at the top of the data of each night. The upper panels give the DLCs for the various pairs of comparison stars available and the subsequent panels give the quasar-star DLCs, as defined in the labels on the right side.

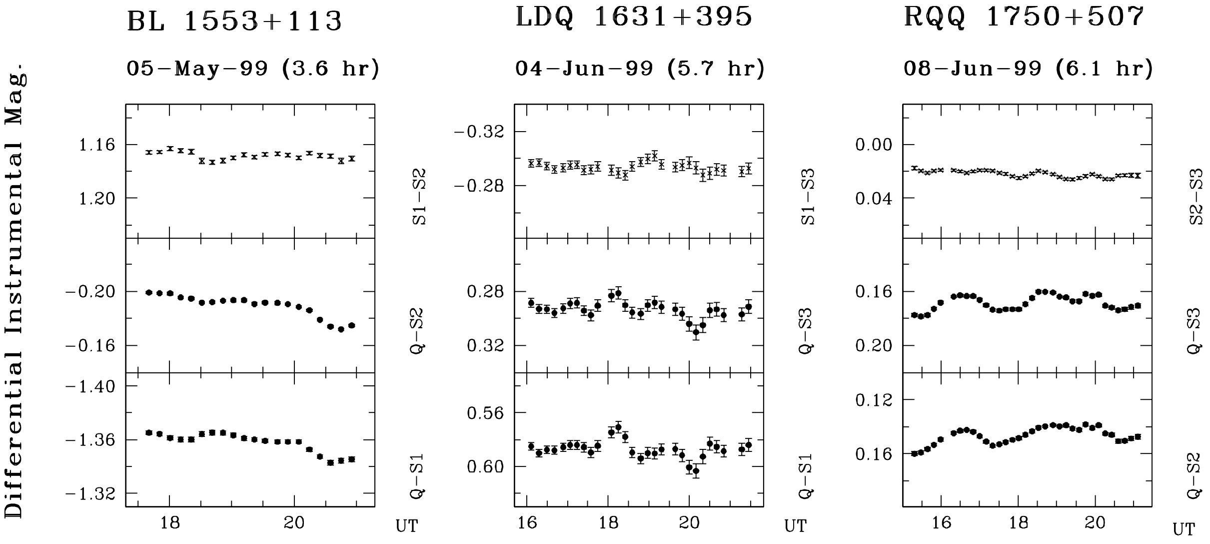

Figure 1 – *continued*

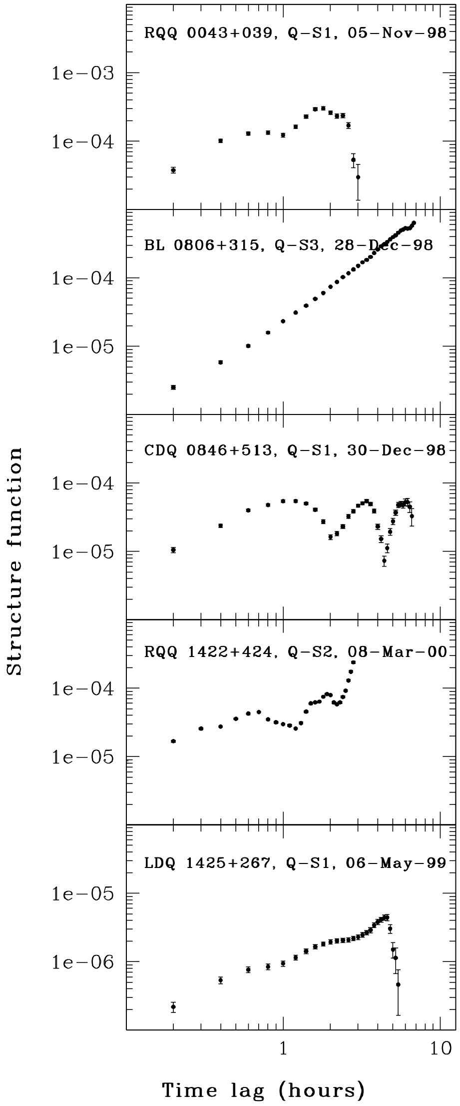

Figure 2. Structure functions (SFs) for the five most strongly variable quasar light curves (LCs). The object, DLC descriptor and date label each of the panels.

In Fig. 3, we present the distributions of the INOV amplitude, ψ, for two subsets of the 51 (high quality) LCs. These subsets are derived by applying the criterion whether or not the LC refers to a BL detected in γ-rays with EGRET (Hartman et al. 1999) and/or at TeV energies (Chadwick et al. 1999). Henceforth, such BLs will be referred to by the common name EGRET-BLs. Likewise, BLs not detected at γ-ray energies will be called non-EGRET-BLs. A Kolmogorov–Smirnov (K–S) test performed on the two ψ distributions rejects the null hypothesis that the two distributions are identical; its probability in only 0.038. Thus, EGRET-BLs appear to show stronger INOV as compared with non-EGRET-BLs, though both the number of nights of observations per object and the total number of objects is too small to allow this to be a firm conclusion at this stage. If confirmed using larger samples, this would suggest a stronger Doppler beaming for EGRET-BLs. Possible physical scenarios for this difference are mentioned in Section 5.

5 CONCLUSIONS

We have presented new observations of intranight optical monitoring for 20 powerful AGN, including 3 BL Lacs, 5 radio-loud quasars (RLQs) and 12 RQQs. INOV is detected in all three classes of AGN, consistent with the results reported in our earlier papers (GK03; Sa04; St04a,b). By combining the present data with the observations reported in our earlier papers (GK03; Sa04; St04a), we could assemble a larger AGN sample consisting of 19 RQQs, 9 BL Lacs and 16 RLQs (after excluding the high optical polarization quasar 1216−010 from the radio core-dominated RLQs in our sample).

The INOV DCs derived for this sample are: 63 per cent for BL Lacs, 18 per cent for RLQs and 22 per cent for RQQs. Thus, the INOV DCs for both RQQs and RLQs (five of which are CDQs) are similar and much smaller than that for BL Lacs. This supports our earlier result that the mere presence of a powerful radio synchrotron jet does not lead to an enhanced INOV (GK03; St04a). The observed similarity in the INOV of RQQs and non-blazar RLQs, both in terms of DC and ψ, further suggests that the RQQs also eject relativistic jets. Their jets are, however, probably quenched while crossing the innermost micro-arcsecond scale, possibly through heavy inverse Compton (IC) losses in the vicinity of the central engine (GK03).

Table 4. Consolidated list of the BL Lacs in the extended sample.

IAU name	m_B	M_B	z	$P^*_{\rm opt}$ (per cent)	log $R^{*\dagger}$	EGRET[‡]
0219+428	15.71	−26.5	0.444	11.7	2.8	Yes
0235+164	16.46	−27.6	0.940	14.9	3.4	Yes
0414+009	16.86	−24.6	0.278	2.8	2.2	No
0537−441	17.00	−27.0	0.894	10.5	3.8	Yes
0735+178	16.76	−25.4	>0.424	14.1	3.5	Yes
0806+315	15.70	−25.0	0.220	–	1.7	No
0851+202	15.91	−25.5	0.306	12.5	3.3	Yes
1215+303	16.07	−24.8	0.237	8.0	2.6	No
1308+326	15.61	−28.6	0.997	10.2	2.8	No
1418+546	16.17	−23.7	0.151	7.5	3.1	No
1553+113	15.00	−26.8	0.360	–	2.2	No
2155−304	13.36	−25.9	0.116	4.9	1.5	TeV

[*] References for optical polarizations are Wills et al. (1992), Impey & Tapia (1988) and Marcha et al. (1996); – implies no data available.

[†] R^* is the K-corrected ratio of the 5 GHz radio to 2500-Å-band optical flux densities (Stocke et al. 1992); reference for radio fluxes is Véron-Cetty & Véron (2001).

[‡] Reference for EGRET detections is Hartman et al. (1999); for TeV detection is Chadwick et al. (1999).

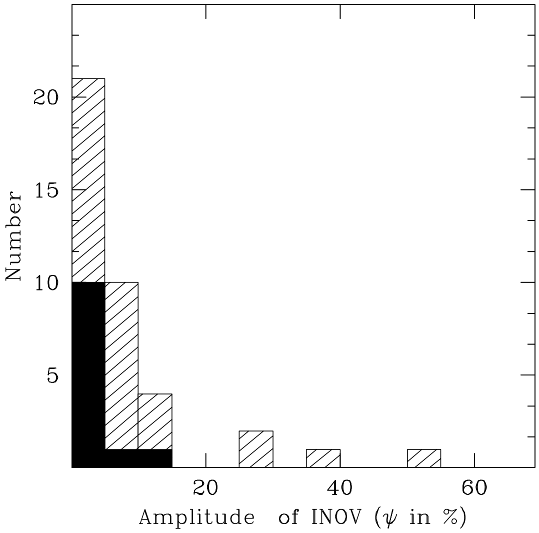

Figure 3. Distributions of intranight optical variability (INOV) amplitude (ψ), for 39 light curves (LCs) of the 6 EGRET (hatched) and 12 LCs of the 6 non-EGRET (black) BLs.

A similar conclusion has also been reported recently from radio variability studies of RLQs and RQQs (Barvainis et al. 2004).

Further, we have formed an enlarged sample of BLs with intranight monitoring duration >4 h, by combining the 3 LCs reported here with 48 taken from the literature (Section 4). The DC of INOV for this entire sample of 51 LCs of BL Lacs is found to be 68 per cent.

Dividing this sample of 51 LCs by the criterion of detection of γ-rays (Table 4), we find that the γ-ray detected BLs show somewhat stronger INOV, the formal confidence being 0.962 using the K–S test (Fig. 3). It is tempting to speculate about the possible origin of this difference. The synchrotron self-Compton (SSC) model for the origin of γ-rays posits that the γ-rays are produced by IC scattering of the synchrotron photons themselves off the relativistic jet electrons (e.g. Maraschi, Ghisellini & Celloti 1992; Bloom & Marscher 1996). The external Compton (EC) models invoke IC scattering of photons originating outside the jet, typically from the accretion disc around the central black hole (e.g. Dermer, Schlickeiser & Mastichiadis 1992), or disc photons reprocessed by matter above the disc but outside the jet (e.g. Sikora, Begelman & Rees 1994; Blandford & Levinson 1995). A variant of the EC model, the mirror model, utilizes jet photons reflected or reprocessed by clouds external to the jet (Ghisellini & Madau 1996).

In the IC scenario involving external seed photons for γ-ray loud blazars, one expects the emission cone to be particularly sharp (Dermer 1995), raising the likelihood of detecting stronger and more rapid INOV (GK03). Hence, our current preliminary results provide additional support to the EC model. None the less, more extensive, multiband intranight monitoring observations of blazars are clearly needed. For the non-blazar AGN, the amplitude of INOV continues to be found to be small (<3 per cent), emphasizing the need for even more sensitive monitoring programmes.

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