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Further evidence for intra-night optical variability of radio-quiet quasars

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Abstract. Although well established for BL Lac objects and radio-loud quasars, the occurrence of intra-night optical variability (INOV) in radio-quiet quasars is still debated, primarily since only a handful of INOV events with good statistical significance, albeit small amplitude, have been reported so far. This has motivated us to continue intra-night optical monitoring of bona-fide radio-quiet quasars (RQQs). Here we present the results for a sample of 11 RQQs monitored by us on 19 nights. On 5 of these nights a given RQQ was monitored simultaneously from two well separated observatories. In all, two clear cases and two probable cases of INOV events were detected. From these data, we estimate an INOV duty cycle of ∼8% for RQQs which would increase to 19% if the 'probable variable' cases are also included. Such comparatively small INOV duty cycles for RQQs, together with the small INOV amplitudes (∼1%), are in accord with the previously deduced characteristics of this phenomenon.

Keywords : galaxies: active – galaxies: nuclei – galaxies: jets – quasars: general – BL Lacertae objects: general

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1. Introduction

The issue of the nature of the radio dichotomy of quasars continues to be debated (e.g. Kellermann et al. 1989; Miller, Peacock & Mead 1990; Becker et al. 1997; Ivezić et al. 2002; Cirasuolo et al. 2003; Laor 2003; Barvainis et al. 2005; White et al. 2007). From the distribution of QSOs over the radio-[OIII] plane, it was found that radio-loud objects occur exclusively at high [OIII] luminosities (Miller, Rawlings & Saunders 1993; Falcke, Gopal-Krishna & Biermann 1995; Xu, Livio & Baum 1999). Moreover, from recent H-band imaging of 15 intermediate redshift RQQs, using the Hubble Space Telescope (HST), their host galaxies are found to be typically 0.5-1 magnitude less luminous compared to the hosts of radio-loud quasars (RLQs) at similar redshifts (Hyvönen et al. 2007). This, in turn, might suggest a difference between the masses of their central black holes (see also Sikora, Stawarz & Lasota 2007). Preliminary evidence for difference in the central brightness profiles of the host galaxies of RLQs and RQQs has also been claimed (Capetti & Balmaverde 2007). Very recently, using a large database from the Sloan Digital Sky Survey (SDSS; Schneider et al. 2005) for an optically selected quasar sample with median $z = 1.47$ and a luminosity range of $-22 < M_i < -30$, Jiang et al. (2007) have shown that the radio-loud fraction of quasars increases with luminosity, but drops rapidly with redshift. Whilst all these observational trends are suggestive, their precise role in the core issue of the quasar radio dichotomy remains unclear.

According to a widely accepted scenario, powerful jets of relativistic particles are accelerated by the central engines of the radio-loud quasars (e.g. Begelman, Blandford & Rees 1984; Antonucci 1993; Urry & Padovani 1995). The detection of well resolved faint, extended radio structure associated with a number of radio-quiet quasars (Kellermann et al. 1994) indicates that the nuclei of RQQs, too, are probably capable of ejecting relativistic, albeit less powerful, jets. Supporting evidence comes from the detection of a relativistic jet in the VLBI observations of the RQQ PG 1407+263 (Blundell, Beasley & Bicknell 2003). Since INOV is now established as a common characteristic of jet-dominated AGN, such as BL Lacs (Miller, Carini & Goodrich 1989; Jang & Miller 1997), concerted efforts have been made to look for a similar signature of relativistic jet in RQQs as well (e.g. Gopal-Krishna, Sagar & Wiita 1993, 1995; Jang & Miller 1995, 1997; Anupama & Chokshi 1998; de Diego et al. 1998; Romero, Cellone & Combi 1999; Gopal-Krishna et al. 2000; Romero et al. 2002; Gopal-Krishna et al. 2003; Sagar et al. 2004; Stalin et al. 2004a, 2004b, 2005; Gupta & Joshi 2005; Carini et al. 2007). The picture emerging from these studies is that, compared to BL Lac objects, the INOV displayed by RQQs is much more modest, both in amplitude and duty cycle (e.g. Stalin et al. 2005; Carini et al. 2007). Also, there is a tendency for the INOV to be found in relatively nearby ($z < 1$) RQQs (e.g. Stalin et al. 2004a, b). Conceivably, this could be because the optical light received from distant ($z \sim 2$) quasars is strongly contaminated in the rest-frame by the thermal big-blue bump (Bachev, Strigachev & Semkov 2005).

The cause of the afore-mentioned marked difference between the INOV of BL Lacs and RQQs remains to be understood. Although the weaker and rarer INOV displayed by

RQQs can be understood in terms of a modest misalignment of their jets from the line-of-sight (Gopal-Krishna et al. 2003; Stalin et al. 2004a), the consistently small amplitude of the INOV exhibited by RQQs would also be in accord with its being associated with flaring hot spots on the accretion disk, as originally suggested by Wiita (1996) (see also Mangalam & Wiita 1993). In order to distinguish between the two competing scenarios for INOV, it is worthwhile to improve the statistics on the time scale, amplitude and duty cycle of INOV of RQQs. The present study represents our ongoing effort in that direction, with the added novelty that a part of the RQQ monitoring reported here was carried out *simultaneously* from two well separated observatories.

2. Observations

2.1 The source sample and the instruments used

The 11 optically bright RQQs monitored under this program were selected from the catalogue of Véron-Cetty & Véron (2001) following the usual criterion of K-corrected ratio of 5 GHz to 2500 Å fluxes, $R^* < 10$. The RQQs selected are bright enough ($m_B < 17$ mag) to attain an INOV detection threshold of $\sim$1-2% using a 1-2 meter class telescope equipped with a CCD detector used as an N-star photometer. Also, to minimize contamination due to the host galaxy (Cellone, Romero & Combi 2000), we limited our sample to intrinsically luminous AGNs with $M_B < -23.5$ mag (see also Stalin et al. 2004a). Further, the sources lie at sufficiently high declinations, ensuring good visibility from northern India. Tables 1 and 2 list the basic data for our sample. As described below, for 5 of these RQQs it was possible to carry out intra-night monitoring simultaneously from two observatories, in an attempt to minimize the possibility of spurious detection of low-amplitude variability, owing to factors like large intra-night seeing variations, passing clouds, or some unknown instrumental problems. Table 1 lists the basic data for the RQQs.

Part of the observations were carried out using the 104-cm Sampurnanand telescope (ST) located at Aryabhatta Research Institute of observational sciencES (ARIES), Naini Tal, India. It has a Ritchey-Chretien (RC) optics with a f/13 beam (Sagar 1999). The detector used was a cryogenically cooled 2048 × 2048 chip mounted at the Cassegrain focus. This chip has a readout noise of 5.3 e^-/pixel and a gain of 10 e^-/Analog to Digital Unit (ADU) in the usually employed slow readout mode. Each pixel has a dimension of 24 μm^2 which corresponds to 0.37 arcsec^2 on the sky, covering a total field of $13' \times 13'$. Observations were carried out in 2 × 2 binned mode to improve the S/N ratio. All the observations were carried out using R filter for which the CCD sensitivity is maximum. The seeing mostly ranged between $\sim 1.5''$ to $\sim 3''$, as determined using 3 fairly bright stars on the CCD frame and the plots of the seeing are provided for some of the nights in the bottom panels of Figs 1 and 2 (see Sec. 3).

The other telescope used by us is the 201-cm Himalayan Chandra Telescope (HCT)

Table 1. The sample of 11 optically luminous radio-quiet quasars monitored in the present study.

IAU Name	B	M_B	z	log $R^{*\dagger}$	IAU Name	B	M_B	z	log $R^{*\dagger}$
0043+039	16.00	−26.0	0.385	−0.7	1116+215	14.59	−25.3	0.177	−0.1
0100+020	15.97	−25.2	0.393	<−0.2	1244+026	18.30	−25.8	0.934	<0.1
0236−002	15.70	−25.4	0.261	<−0.8	1526+285	16.34	−25.8	0.450	−0.2
0514−005	15.87	−25.1	0.291	<−0.7	1629+296	17.08	−24.2	0.256	<−0.2
0748+295	15.97	−28.4	0.914	<−0.4	1630+377	16.62	−28.6	1.478	<−0.6
0824+098	15.50	−25.6	0.260	0.5					

†R^* is the K-corrected ratio of the 5 GHz to 2500 Å flux densities (Stocke et al. 1992) ; references for the radio fluxes are Véron-Cetty & Véron (2001), NVSS (Condon et al. 1998) and FIRST (Becker, White & Helfand 1995; Bauer et al. 2000) and the references therein. The absolute magnitude M_B is computed taking $H_0 = 50$ kms^{-1}Mpc^{-1}, $q_0 = 0$, and an optical spectral index $\alpha = 0.3$ (defined as $S \propto \nu^{-\alpha}$; Francis et al. 1991).

located at Indian Astronomical Observatory (IAO), Hanle, India which is also of the RC design with a f/9 beam at the Cassegrain focus[1]. The detector was a cryogenically cooled 2048 × 4096 chip, of which the central 2048 × 2048 pixels were used. The pixel size is 15 μm^2 so that the image scale of 0.29 arcsec/pixel covers an area of $10' \times 10'$ on the sky. The readout noise of CCD is 4.87 e$^-$/pixel and the gain is 1.22 e$^-$/ADU. The CCD was used in an unbinned mode. The observations were primarily made using R filter, except on 4 nights when V filter was used. The seeing ranged mostly between $\sim$1.0″ to $\sim$2.5″. The exposure time was typically 12-30 minutes for the ARIES observations and ranged from 3-6 minutes for observations from IAO, depending on the brightness of the source, phase of moon and the sky transparency for that night. The field positioning was adjusted so as to also have within the CCD frame 2-3 comparison stars within about a magnitude of the RQQ, in order to minimize the possibility of getting spurious variability detection (Cellone, Romero & Araudo 2007). For both the telescopes, the bias frames, taken intermittently, and twilight sky flats were obtained.

2.2 Data reduction

The preprocessing of images (bias subtraction, flat-fielding and cosmic-ray removal) was done by applying the regular procedures in IRAF[2] and MIDAS[3] softwares. The instrumental magnitudes of the RQQ and the stars in the image frames were determined by

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[1] http://www.iiap.res.in/~iao

[2] Image Reduction and Analysis Facility

[3] Munich Image and Data Analysis System

aperture photometry, using DAOPHOT II[4] (Stetson 1987). The magnitude of the RQQ was measured relative to the nearly steady comparison stars present on the same CCD frame (Table 2). This way, Differential Light Curves (DLCs) of each RQQ were produced relative to 2-3 comparison stars. For each night, the selection of optimum aperture radius was done on the basis of the observed dispersions in the star-star DLCs for different aperture radii starting from the median seeing (FWHM) value on that night to 4 times that value. The aperture selected was the one which showed minimum scatter for the steadiest DLC found for the various pairs of the comparison stars (Stalin et al. 2004a).

3. Results

The DLCs are shown in Figs. 1 and 2 for two station and single station monitoring, respectively, while Tables 3 and 4 summarize the observations for the present sample of RQQs monitored from two stations and a single station, respectively . For each night of observations these tables provide the object name, date of observation, telescope used (Table 4 only), filter(s) used, number of data points (N points), durations of observation, the measures of variability, C$_{eff}$ and ψ and an indicator of variability status . The classification 'variable' (V) or 'non-variable' (N) was decided using a parameter C$_{eff}$, basically defined following the criteria of Jang & Miller (1997). We define C for a given DLC as the ratio of its standard deviation, σ_T and $\eta\sigma_{err}$, where σ_{err} is the average of the rms errors of its individual data points and η was estimated to be 1.5 (Stalin et al. 2004a, 2004b, 2005; Gopal-Krishna et al. 2003; Sagar et al. 2004). However, our analysis for the present dataset yields $\eta = 1.3$ and we have adopted this value here. We compute C$_{eff}$ from the C values (as defined above) found for the DLCs of an AGN relative to different comparison stars monitored on a given night (details are given in Sagar et al. 2004). This has the advantage of using multiple DLCs of an AGN, relative to the different comparison stars. The source is termed 'V' for C$_{eff}$> 2.576, corresponding to a confidence level of 99%. We call the source to be 'probable variable' (PV) if C$_{eff}$ is in range of 1.950 to 2.576, corresponding to a confidence level between 95% to 99%. Finally, the peak-to-peak INOV amplitude is calculated using the definition (Romero, Cellone & Combi 1999)

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

with
D_{max} = maximum in the AGN differential light curve
D_{min} = minimum in the AGN differential light curve
$\sigma^2 = \eta^2 \langle \sigma^2_{err} \rangle$

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[4] Dominion Astrophysical Observatory Photometry software

Table 2. Positions and magnitudes of the RQQs and the comparison stars used in the present study*.

IAU Name	Object	RA(J2000)	Dec(J2000)	B (mag)	R (mag)	B-R (mag)
0043+039	RQQ	$00^h45^m47^s.23$	$+04^\circ10'23''.2$	16.50	15.59	0.91
	S1	$00^h45^m44^s.87$	$+04^\circ10'57''.9$	17.34	16.07	1.27
	S2	$00^h45^m44^s.16$	$+04^\circ13'26''.0$	17.76	15.21	2.55
	S3	$00^h45^m43^s.81$	$+04^\circ12'32''.1$	17.76	15.21	2.55
0100+020	RQQ	$01^h03^m12^s.98$	$+02^\circ21'10''.1$	17.39	17.02	0.37
	S1	$01^h03^m27^s.92$	$+02^\circ24'49''.4$	17.05	16.09	0.96
	S2	$01^h03^m28^s.26$	$+02^\circ20'19''.3$	17.99	16.52	1.47
	S3	$01^h03^m02^s.69$	$+02^\circ18'08''.1$	16.28	15.48	0.80
0236−001	RQQ	$02^h39^m22^s.84$	$-00^\circ01'19''.4$	15.76	15.07	0.69
	S1	$02^h39^m32^s.39$	$-00^\circ00'42''.2$	16.27	15.16	1.11
	S2	$02^h39^m38^s.60$	$-00^\circ04'24''.0$	16.31	15.61	0.70
0514−005	RQQ	$05^h16^m33^s.49$	$-00^\circ27'13''.5$	15.87	15.43	0.44
	S1	$05^h16^m27^s.61$	$-00^\circ30'54''.3$	15.25	14.52	0.73
	S2	$05^h16^m22^s.35$	$-00^\circ29'48''.0$	16.45	15.39	1.06
	S3	$05^h16^m21^s.11$	$-00^\circ31'04''.3$	15.48	14.64	0.84
0748+295	RQQ	$07^h51^m12^s.29$	$+29^\circ19'38''.4$	15.97	15.40	0.57
	S1	$07^h51^m06^s.02$	$+29^\circ16'13''.4$	17.04	15.06	1.98
	S2	$07^h51^m09^s.26$	$+29^\circ16'19''.0$	16.25	15.13	1.12
	S3	$07^h51^m02^s.54$	$+29^\circ19'24''.0$	15.61	14.56	1.05
0824+098	RQQ	$08^h27^m40^s.18$	$+09^\circ42'08''.3$	16.68	15.32	1.36
	S1	$08^h27^m51^s.44$	$+09^\circ45'21''.7$	16.84	16.02	0.82
	S2	$08^h27^m48^s.64$	$+09^\circ45'14''.4$	16.45	15.46	0.99
	S3	$08^h27^m44^s.30$	$+09^\circ45'05''.6$	16.28	15.44	0.84
1116+215	RQQ	$11^h19^m08^s.68$	$+21^\circ19'18''.1$	15.36	14.44	0.92
	S1	$11^h19^m19^s.08$	$+21^\circ26'20''.6$	15.42	14.21	1.21
	S2	$11^h19^m17^s.85$	$+21^\circ27'38''.2$	16.10	14.88	1.22
	S3	$11^h19^m24^s.62$	$+21^\circ25'08''.8$	15.54	14.35	1.19
1244+026	RQQ	$12^h46^m41^s.69$	$+02^\circ24'11''.9$	17.65	17.25	0.40
	S1	$12^h47^m02^s.84$	$+02^\circ25'20''.2$	17.10	16.04	1.06
	S2	$12^h46^m48^s.83$	$+02^\circ23'37''.5$	17.47	16.23	1.24
	S3	$12^h46^m48^s.43$	$+02^\circ20'41''.7$	17.09	16.04	1.05
1526+285	RQQ	$15^h28^m40^s.62$	$+28^\circ25'30''.0$	17.29	16.28	1.01
	S1	$15^h28^m13^s.06$	$+28^\circ27'51''.8$	18.03	15.88	2.15
	S2	$15^h28^m30^s.30$	$+28^\circ30'04''.2$	17.15	15.22	1.93
	S3	$15^h28^m55^s.02$	$+28^\circ25'12''.1$	18.09	16.03	2.06
1629+299	RQQ	$16^h31^m24^s.43$	$+29^\circ53'01''.7$	17.08	16.53	0.55
	S1	$16^h31^m31^s.70$	$+29^\circ50'01''.2$	16.97	15.07	1.90
	S2	$16^h31^m19^s.90$	$+29^\circ52'29''.2$	17.60	16.47	1.13
	S3	$16^h31^m18^s.42$	$+29^\circ52'18''.8$	17.88	16.39	1.49
1630+377	RQQ	$16^h32^m01^s.10$	$+37^\circ37'50''.1$	16.14	16.07	0.07
	S1	$16^h32^m06^s.40$	$+37^\circ39'18''.1$	16.67	15.49	1.18
	S2	$16^h32^m02^s.70$	$+37^\circ35'19''.9$	16.35	15.63	0.72
	S3	$16^h31^m39^s.98$	$+37^\circ36'03''.9$	15.72	15.28	0.44

*Taken from United States Naval Observatory-B catalogue (Monet et al. 2003).

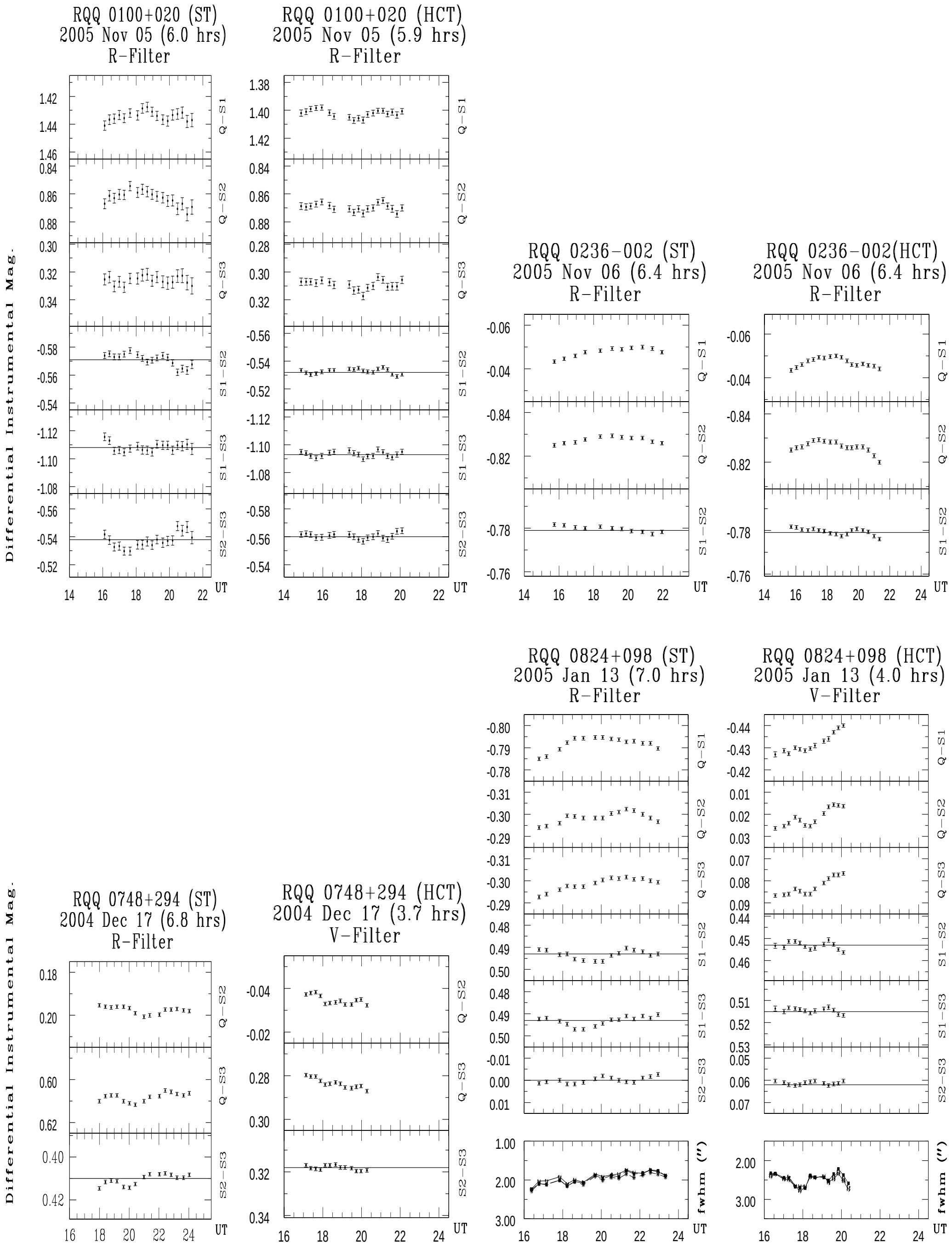


Figure 1. DLCs of radio-quiet quasars monitored simultaneously with the ST and HCT telescopes.

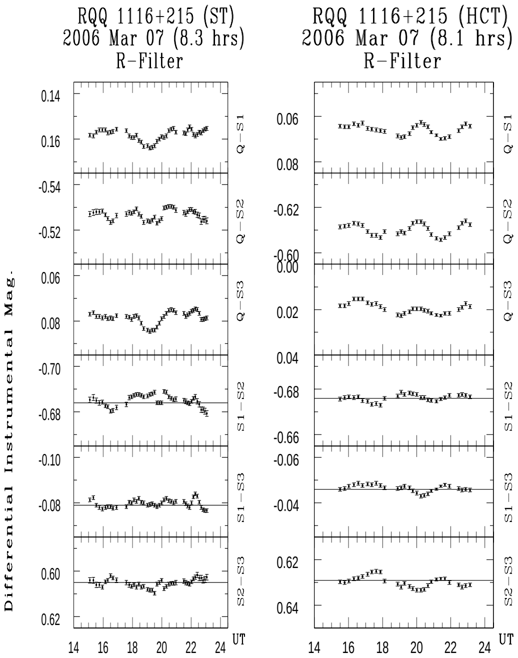


Figure 1. Continued.

Notes are given below for the RQQs showing INOV (or probable variables).

RQQ 0514−005: This RQQ has been monitored earlier on three nights by Stalin et al. (2004a) who did not detect INOV. In our monitoring on three nights, INOV was detected on the night of 2003 Nov 20, using the HCT (Fig. 2), with an amplitude $\psi \geq 1.5\%$. On another night, 2004 Nov 18, although correlated INOV with an amplitude $\psi \geq 1.2\%$ was seen in both QSO-star DLCs, the computed $C_{eff} = 1.73$ falls below the formal qualifying threshold value of 1.950 for 'PV' classification (see above).

RQQ 0824+098: This source was monitored by Gopal-Krishna et al. (2000) on one night for 3.3 hours when it showed a flare of ∼0.055 mag in just half an hour. Being a single point excursion, however, the variation was not considered by them as confirmed. Subsequently, the RQQ was monitored by Stalin et al. (2005) on one night when INOV was clearly seen, with an amplitude ψ ∼2.2%. We have monitored the source on 2005 Jan 13 using ST and HCT telescopes simultaneously and both sets of DLCs show a brightening by ∼1% over the time interval 16.5-20.0 UT (Fig. 1). The sky condition remained clear at both the observatories and the "seeing" was also fairly constant, as seen from the bottom panels. The small brightening seen from the two observatories is correlated both in amplitude as well as time, corresponds to $C_{eff} = 2.66$ for the HCT

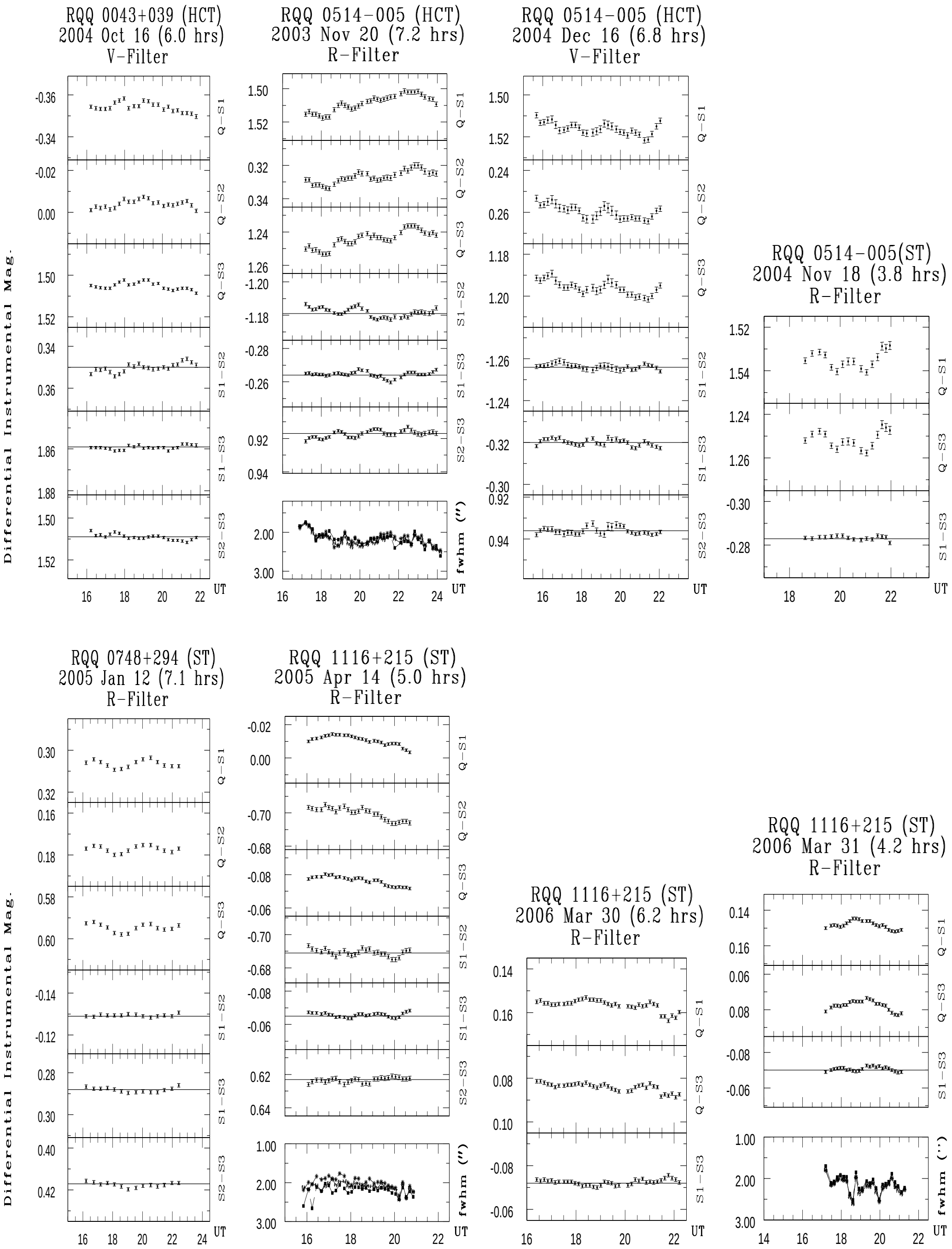
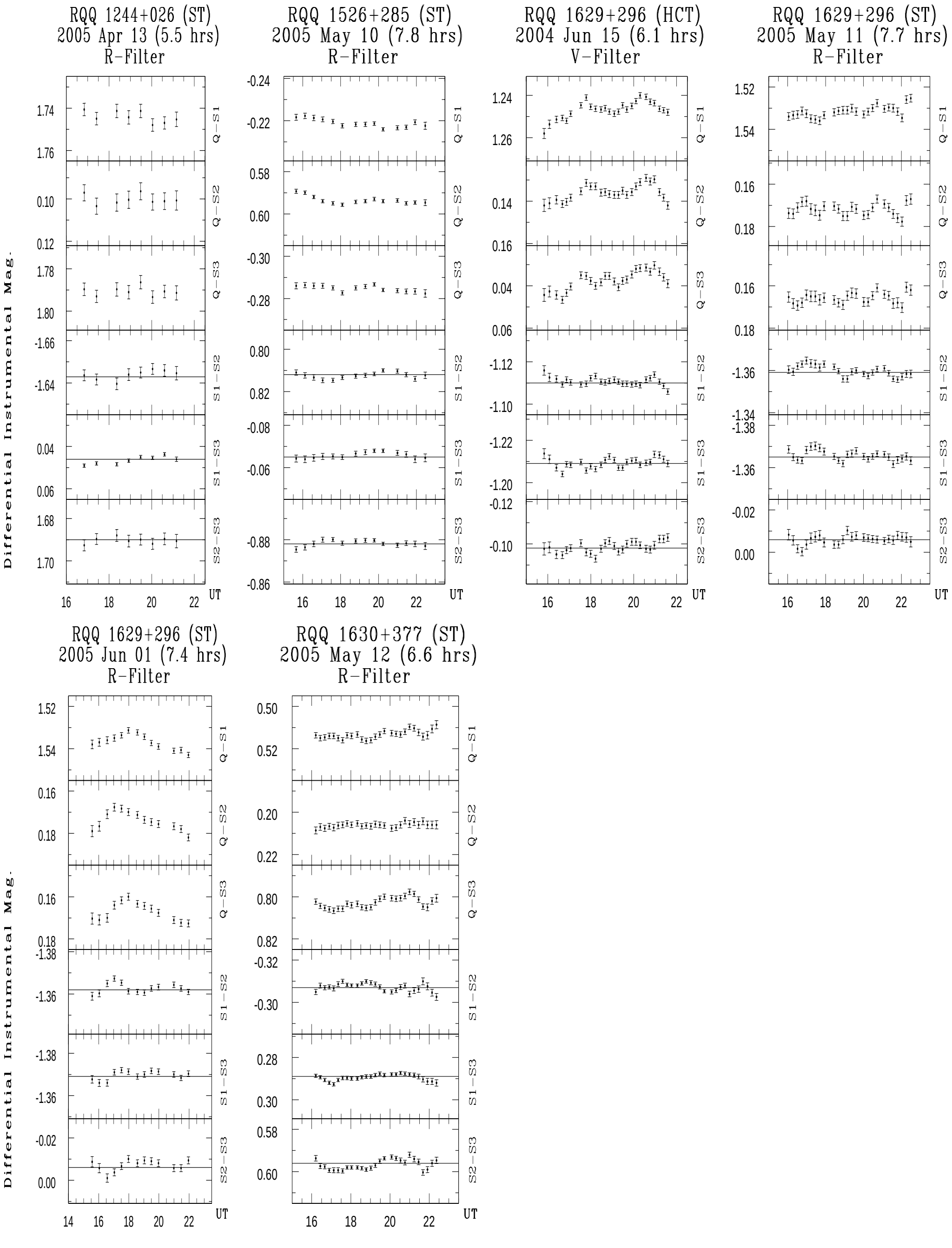


Figure 2. DLCs of radio-quiet quasars having single station monitoring.


RQQ 1244+026 (ST)
2005 Apr 13 (5.5 hrs)
R-Filter

RQQ 1526+285 (ST)
2005 May 10 (7.8 hrs)
R-Filter

RQQ 1629+296 (HCT)
2004 Jun 15 (6.1 hrs)
V-Filter

RQQ 1629+296 (ST)
2005 May 11 (7.7 hrs)
R-Filter

RQQ 1629+296 (ST)
2005 Jun 01 (7.4 hrs)
R-Filter

RQQ 1630+377 (ST)
2005 May 12 (6.6 hrs)
R-Filter

Figure 2. Continued.

light curves (Table 3; Fig. 1), qualifying it as a positive detection of INOV. Although C_{eff} = 2.12 found for the ST data alone would qualify this source as only a 'PV', taken together with the simultaneous HCT light curves, the ST data further strengthen the case for a positive detection of INOV.

RQQ 1116+215: This source was monitored by us on total of four nights. On one night, observations could be made simultaneously using the ST and HCT (Table 3). On two nights of monitoring (i.e. on 2005 Apr 14 and 2006 Mar 31), when it could be observed using ST alone, it showed a variation in amplitude by ∼1% (Fig. 2) and is designated a 'PV' on both the nights, since the variation is significant at confidence level of 95% (Table 4; Fig. 2). On these nights, sky at the observatory was clear and the "seeing" was fairly constant, as seen from the bottom panels (Fig. 2). Unfortunately, on the night of simultaneous two-station monitoring, the sky conditions were not good, as the one or the other site had thin clouds throughout the observing run.

Table 3. Observation log and variability results for two station (simultaneous) monitoring.

IAU Name	Date yy.mm.dd	Filter ST, HCT	N points ST, HCT	Duration(h) ST, HCT	C_{eff} ST, HCT	ψ% ST, HCT	Status[‡] ST, HCT
0100+020	05.11.05	R, R	20, 21	6.0, 5.9	0.18, 0.38	1.22, 1.0	N, N
0236−002	05.11.06	R, R	13, 19	6.4, 6.4	1.27, 1.80	0.5, 0.8	N, N
0748+295	04.12.17	R, V	17, 15	6.8, 4.0	1.35, 1.78	0.5, 0.7	N, N
0824+098	05.01.13	R, V	17, 15	7.0, 4.0	2.12, 2.66	0.9, 1.0	PV, V
1116+215	06.03.07	R, R	46, 31	8.3, 8.1	1.63, 1.78	0.8, 0.7	N, N

[‡] V = variable; N = non-variable; PV = probable variable

Table 4. Observation log and variability results for single station monitoring.

IAU Name	Date yy.mm.dd	Telescope	Filter	N points	Duration(h)	C_{eff}	ψ%	Status[‡]
0043+039	04.10.16	HCT	V	25	6.0	1.50	0.7	N
0514−005	03.11.20	HCT	R	39	7.2	2.70	1.5	V
	04.11.18	ST	R	18	3.8	1.73	1.2	N
	04.12.16	HCT	R	34	6.8	1.02	1.1	N
0748+295	05.01.12	ST	R	16	7.1	1.07	0.5	N
1116+215	05.04.14	ST	R	30	5.0	2.37	1.0	PV
	06.03.30	ST	R	40	6.2	1.75	0.8	N
	06.03.31	ST	R	26	4.2	2.05	0.8	PV
1244+026	05.04.13	ST	R	10	5.5	0.27	0.4	N
1526+285	05.05.10	ST	R	16	7.8	0.67	0.5	N
1629+299	04.06.15	HCT	V	28	6.1	1.78	1.5	N
	05.05.11	ST	R	28	7.7	0.42	0.9	N
	05.06.01	ST	R	15	7.4	1.34	1.2	N
1630+377	05.05.12	ST	R	29	6.6	0.31	0.6	N

[‡] V = variable; N = non-variable; PV = probable variable

4. Discussion

The duty cycle (DC) of INOV has been computed according to the procedure given in Romero, Cellone & Combi (1999)

$$DC = 100 \frac{\sum_{i=1}^{n} N_i (1/\Delta t_i)}{\sum_{i=1}^{n} (1/\Delta t_i)} \% \tag{2}$$

where $\Delta t_i = \Delta t_{i,obs}(1+z)^{-1}$ is the duration of monitoring session of a source on the ith night, corrected for the cosmological redshift z. Note that since the sources have not been monitored for the same duration on each night, the computation is weighted by the duration of monitoring Δt_i. N_i was set equal to 1 if INOV was detected, otherwise $N_i = 0$. The computed duty cycle of INOV for the present sample is DC = 8%. Note that in case of INOV detection from simultaneous monitoring, the data used for calculation is the one for which the duration is longer. Note also that DC increases to 19% if the two cases of probable variability (i.e. RQQ 1116+215 observed on 2005 Apr 14 and 2006 Mar 31) are included (Table 4). These estimates are consistent with the previous results for RQQs (see Sec. 1). In contrast, it was found that for BL Lac objects monitored for longer than about 4 hours, INOV with amplitudes in excess of 3% occurs with a duty cycle DC ~50% (e.g. Gopal-Krishna et al. 2003; Sagar et al. 2004). Thus, the observations reported here further strengthen the view that INOV of RQQs is a comparatively rare phenomenon and the variability amplitude remains below 3%. Simultaneous two-station monitoring of such quasars would be a worthwhile effort. An added motivation for this comes from the detection of near-infrared flares from the central source of our Galaxy, SgrA*, on time scale of ~10 minutes; these flares might be powered by annihilation of magnetic field near the inner edge of the accretion disk around the supermassive black hole in SgrA* (Trippe et al. 2007; Eckart et al. 2006).

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References

Antonucci, R., 1993 ARA&A, 31, 473
Anupama, G. C., & Chokshi, A., 1998, ApJ, 494, L147
Bachev, R., Strigachev, A., & Semkov, E., 2005, MNRAS, 358, 774
Barvainis, R., Lehár, J., & Birkinshaw, M., et al., 2005, ApJ, 618, 108

Bauer, F. E., Condon, J. J., Thaun, T. X., & Broderick, J. J., 2000, ApJS, 129, 547
Becker, R. H., White, R. L., & Helfand, D. J., 1995, ApJ, 450, 559
Becker, R. H., Gregg, M. D., & Hook, I. M., et al., 1997, ApJ, 479, L93
Begelman, M. C., Blandford, R. D., & Rees, M. J., 1984, RvMP, 56, 255
Blundell, K. M., Beasley, A. J., & Bicknell, G. V., 2003, ApJ, 591, L103
Capetti, A., & Balmaverde, B., 2007, astro-ph/0704.2100
Carini, M. T., Noble, J. C., Taylor, R., & Culler, R., 2007, AJ, 133, 303
Cellone, S. A., Romero, G. E., & Combi, J. A., 2000, AJ, 119, 1534
Cellone, S .A., Romero, G. E., & Araudo, A. T., 2007, MNRAS, 374, 357
Cirasuolo, M., Celotti, A., Magaliocchetti, M., & Danese, L., 2003, MNRAS, 346, 447
Condon, J. J., Cotton, W. D., & Greisen, E. W., et al., 1998, AJ, 115, 1693
de Diego, J. A., Dultzin-Hacyan, D., Ramírez, A., & Benítez, E., 1998, ApJ, 500, 69
Eckart, A., Baganoff, F. K., & Schödel, R., et al., 2006, A&A, 450, 535
Falcke, H., Gopal-Krishna, & Biermann, P. L., 1995, A&A , 298, 395
Francis, P. J., Hewett, P. C., & Foltz, C. B., et al., 1991, ApJ, 373, 465
Gopal-Krishna, Sagar, R., & Wiita, P. J., 1993, MNRAS, 262, 963
Gopal-Krishna, Sagar, R., & Wiita, P. J., 1995, MNRAS, 274, 701
Gopal-Krishna, Gupta, A. C., Sagar, R., Wiita, P. J., Chaubey, U. S., & Stalin, C. S., 2000, MNRAS, 314, 815
Gopal-Krishna, Stalin, C. S., Sagar, R., & Wiita, P. J., 2003, ApJ, 586, L25
Gupta, A. C., & Joshi, U. C., 2005, A&A, 440, 855
Hyvönen, T., Kotilainen, J. K., & Örndahl, E., et al., 2007, A&A, 462, 525
Ivezić, Ž., Menov, K., & Knapp, G. R., et al., 2002, AJ, 124, 2364
Jang, M., & Miller, H. R., 1995, ApJ, 452, 582
Jang, M., & Miller, H. R., 1997, AJ, 114, 565
Jiang, L., Fan, X., & Ivezić, Ž., et al., 2007, ApJ, 656, 680
Kellermann, K. I., Sramek, R., Schmidt, M., Shaffer, D. B., & Green, R. F., 1989, AJ, 98, 1195
Kellermann, K. I., Sramek, R. A., Schmidt, M., Green, R. F., & Shaffer, D. B., 1994, AJ, 108, 1163
Laor, A., 2003, ApJ, 590, 86
Mangalam, A. V., & Wiita, P. J., 1993, ApJ, 406, 420
Miller, H. R., Carini, M., & Goodrich, B., 1989, Nature, 337, 627
Miller, L., Peacock, J. A., & Mead, A. R. G., 1990, MNRAS, 244, 207
Miller, P., Rawlings, S., & Saunders, R., 1993, MNRAS, 263, 425
Monet, D. G., Levine, S.E., & Canzian. B., et al., 2003, AJ, 125, 984
Romero, G. E., Cellone, S. A., & Combi, J. A., 1999, A&AS, 135, 477
Romero, G. E., Cellone, S. A., Combi, J. A., & Andruchow, I., 2002, A&A, 390, 431
Sagar, R., 1999, Curr. Sci., 77, 643
Sagar, R., Stalin, C. S., Gopal-Krishna, & Wiita, P. J., 2004, MNRAS, 348, 176
Schneider, D. P., Hall, P. B., & Richards, G. T., et al., 2005, AJ, 130, 367
Sikora, M., Stawarz, Ł, & Lasota, J.-P., 2007, ApJ, 658, 815
Stalin, C. S., Gopal-Krishna, Sagar, R., & Wiita, P. J., 2004a, MNRAS, 350, 175
Stalin, C. S., Gopal-Krishna, Sagar, R., & Wiita, P. J., 2004b, JApA, 25, 1
Stalin, C. S., Gupta, A. C., Gopal-Krishna, Wiita, P. J., & Sagar, R., 2005, MNRAS, 356, 607
Stetson, P. B., 1987, PASP, 99, 191
Stocke, J. T., Morris, S. L., Weymann, R. J., & Foltz, C. B., 1992, ApJ, 396, 487
Trippe, S., Paumard, T., & Ott, T., et al., 2007, MNRAS, 375, 764
Urry, C. M., & Padovani, P., 1995, PASP, 107, 803

Véron-Cetty, M.-P., & Véron, P., 2001, A&A, 374, 92
White, R. L., Helfand, D. J., & Becker, R. H., et al., 2007, ApJ, 654, 99
Wiita, P. J., 1996, Blazar Continuum Variablity, eds H. R. Miller et al., ASP Conf. Ser., Vol. 110, ASP, San Fransisco, 42
Xu, C., Livio, M., & Baum, S., 1999, AJ, 118, 1169