# Intranight Optical Variability of Radio-Quiet Weak Emission Line Quasars-IV

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Accepted —. Received —; in original form —

#### ABSTRACT

We report an extension of our program to search for radio-quiet BL Lac candidates using intra-night optical variability (INOV) as a probe. The present INOV observations cover a well-defined representative set of 10 'radio-quiet weak-emission-line quasars' (RQWLQs), selected from a newly published sample of 46 such sources, derived from the Sloan Digital Sky Survey (Data release 7). Intra-night CCD monitoring of the 10 RQWLQs was carried out in 18 sessions lasting at least 3.5 hours. For each session, differential light curves (DLCs) of the target RQWLQ were derived relative to two steady comparison stars monitored simultaneously. Combining these new data with those already published by us for 15 RQWLQs monitored in 30 sessions, we estimate an INOV duty cycle of ~ 3% for the RQWLQs, which appears inconsistent with BL Lacs. However, the observed INOV events (which occurred in just two of the sessions) are strong (with a fractional variability amplitude  $\psi > 10\%$ ), hence blazar-like. We briefly point out the prospects of an appreciable rise in the estimated INOV duty cycle for RQWLQs with a relatively modest increase in sensitivity for monitoring these rather faint objects.

**Key words:** galaxies: active – galaxies: photometry – galaxies: jet – quasars: general – (galaxies:) BL Lacertae objects: general – (galaxies:) quasars: emission lines

## 1 INTRODUCTION

Weak-line-quasars (WLQs), a rare subset of the quasar population, continue to be an enigma, in-spite of the substantial observational and theoretical effort invested in probing their nature (e.g., Plotkin et al. (2015): hereinafter P15; Meusinger & Balafkan (2014): hereinafter MB14). Exceptional weakness, even absence of emission lines, particularly in the rest-frame UV spectrum, is their principal abnormality vis-a-vis normal quasars (e.g., MB14; P15), as underscored initially by the discoveries of the WLQs: PG 1407+265 at z = 0.94 (McDowell et al. 1995) and SDSS J153259.96-003944.1 at z = 4.67 (Fan et al. 1999).

Since then over a hundred of WLQs have been found, mainly using the SDSS survey (York et al. 2000). Basically, these findings have given rise to two possible scenarios: (i) WLQs are (predominantly beamed) BL Lacs whose radiation is uncharacteristically weak in the radio band, or (ii) they are (unbeamed) quasars with an exceptionally weak broad emission-line region. While, some rare representatives of the first scenario may still be discovered among WLQs,

the weight of evidence has steadily shifted towards the second alternative which appears to be the norm. This inference for WLQs is based on several observables, such as radioloudness, optical polarization and continuum flux variability, all of which are found to be distinctly milder than those typical of BL Lacs (e.g., P15 and references therein; MB14). Furthermore, the rest-frame optical-UV broad-band spectra of WLQs are mostly found to be matching those of radio-quiet quasars (e.g., Lane et al. (2011); Diamond-Stanic et al. (2009); see Shemmer et al. (2009) for a similar inference based on the X-ray spectra). Likewise, recent optical polarimetric surveys of WLQs (e.g., Diamond-Stanic et al. 2009; Heidt & Nilsson 2011) have failed to reveal any robust example of radio-quiet BL Lac, in accord with earlier findings (e.g., Stocke et al. 1990; Jannuzi et al. 1994; Smith et al. 2007).

However, despite these negative indications, the first alternative is not entirely precluded and the possibility remains that at least a tiny population of radio-quiet BL Lacs may be lurking among WLQs (e.g., Londish et al. 2004; Collinge et al. 2005; Shemmer et al. 2006; Wu et al. 2012, MB14). Intensive searches aimed at picking any such exotic BL Lacs hold considerable astrophysical interest, since the discovery of even a single radio-quiet BL Lac

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would challenge the standard paradigm which posits that the jets of blazars (of which BL Lacs are a subset) emit predominantly synchrotron radiation over the (rest-frame) radio-to-infrared/optical waveband and their entire radiation appears predominantly relativistically beamed (e.g., Blandford & Rees 1978; Urry & Padovani 1995; Antonucci 2012). Here it is interesting to recall that although, compared to BL Lacs, RQWLQs are found to display much milder optical variability on month/year-like time scale (see, P15; MB14 and references therein), a few striking exceptions have been reported where a blazar-like large optical variability was observed on month/year-like time scale, betraying the presence of relativistically beamed synchrotron emission. Examples in these RQWLQs are PG 1407+265 at z = 0.94(Blundell et al. 2003) and J153259.96-003944 at z = 4.67 (Stalin & Srianand 2005). In PG 1407+265 there is indeed evidence that a relativistically beamed nonthermal jet appears intermittently in the radio/X-ray bands (Blundell et al. 2003; Gallo 2006). It may be recalled that weak parsec-scale relativistic jets have been detected, or inferred to exist in many radio-quiet quasars (RQQs)<sup>1</sup>, based on radio imaging and continuum flux variability on month/yearlike time scale (e.g., Ulvestad et al. 2005; Barvainis et al. 2005; Blundell & Beasley 1998; Kellermann et al. 1994; Czerny et al. 2008). Therefore, it would not be too surprising if weak relativistic jets were often present even in the subset of RQQs whose members exhibit uncharacteristically weak emission lines in the UV/optical (i.e., RQWLQs). A small fraction of such relativistic jets, oriented close to the line of sight, would then appear Doppler boosted, as indeed inferred, e.g., for the RQWLQ PG 1407+265 (see above).

As already discussed widely in the literature, rapid optical variability on hour-like time scale, termed Intra-Night Optical Variability (INOV), can be a fairly reliable discriminator between the AGN whose optical jets are relativistically beamed towards us (i.e., blazar-like), and their misaligned (hence unbeamed) counterparts (e.g., Goyal et al. 2013, and references therein). Specifically, the AGNs showing strong INOV( $\psi > 3\%$ ) are nearly always blazars and the duty cycle of such strong INOV is around 50% for a monitoring duration of around 4-6 hours (e.g., Goyal et al. 2013; Carini et al. 2007; Stalin et al. 2004a; Gopal-Krishna et al. 2003). Since the INOV data on RQWLQs did not exist, we have attempted to bridge this gap by initiating a program of intra-night monitoring of RQWLQs. The results obtained so far under this program are reported in 3 papers (Gopal-Krishna et al. (2013): Paper I, Chand et al. (2014): Paper II, Kumar et al. (2015): Paper III). Recently, a similar program has also been undertaken by Liu et al. (2015). Together, these two INOV programs encompass 18 RQWLQs, of which 15 RQWLQs are covered in our program. This admittedly rather limited dataset has shown that INOV is a rare occurrence among RQWLQs (duty cycle  $\sim 5\%$ ), as also found for radio-quiet quasars and radio lobe-dominated quasars (e.g., Goyal et al. 2013; Carini et al. 2007). However, the estimate of INOV duty cycle for RQWLQs may

likely be revised upwards once a matching sensitivity is achieved for monitoring these relatively faint objects (see Paper III). Thus, the main goal of our ongoing INOV program is two-fold: (i) to characterise the INOV behaviour of RQWLQs, and (ii) to make a systematic search for any blazar-like INOV events among RQWLQs, granting that such events might be quite rare.

# 2 THE SAMPLE OF RADIO-QUIET WLQS

Since a major goal of our program is to characterise the INOV properties of RQWLQs, it is desirable to monitor RQWLQ samples selected from different catalogs, given that individual catalogs are expected to suffer from different sets of systematic and hence rare objects, such as WLQs, picked up in them may not represent identical populations. Spurred by the initial discoveries of a few individual cases of WLQs, the huge and rapidly growing SDSS database began to be deployed to make systematic searches for WLQs (e.g., Collinge et al. 2005; Diamond-Stanic et al. 2009). In Papers I, II, III we reported INOV observations of 15 bona-fide RQWLQs monitored in 30 sessions, each lasting for minimum 3 hrs (median duration 4.2 hr). That well-defined set of RQWLQs was drawn from the list of 86 RQWLQs published by Plotkin et al. (2010) who had classified them as "high-confidence BL Lac candidate", primarily because the emission line equivalent-widths are small (Wr < 5Å) and the 4000Å break, if present, is less than 40%. Additional selection criteria imposed by us were: (i) the object should be brighter than  $R \sim 18.5$  mag and (ii) its image should not appear confused/distorted due to a neighboring object. This is specially relevant for our type of observations which involve taking a sequence of CCD exposures and then doing aperture photometry to derive the light-curve of the monitored target, relative to at least two steady stars seen in the target's vicinity on each CCD frame. Such "differential light curves" (DLCs) have become the preferred mode adopted in INOV studies almost universally (e.g., Miller et al. 1989). Lastly, we note that each of the 15 RQWLQs is consistent with zero proper motion, confirming their extragalactic nature (Paper III).

The present set of 10 RQWLQs, for which INOV results are reported here, was drawn by us from the list of 46 WLQs published recently in MB14. In order to select WLQs they employed machine learning data mining techniques to the huge database of guasars in the SDSS/DR7 pipeline (DR-7, Abazajian et al. 2009), followed by manual inspection of the spectra of individual sources. This led them to a final sample of 365 quasars with weakly detected emission lines (as a consistency check, MB14 found all these WLQs to have their counterparts in the SDSS/DR7 guasar catalog of Shen et al. (2011)). From this sample, MB14 extracted a well-defined sub-sample of 46 WLQs, termed as 'WLQ-EWS' with the mean redshift of 1.48, by imposing rest-frame equivalentwidth thresholds: EW(Mg II) < 11Å and EW(C IV) < 4.8Å, which represent  $3\sigma$  deviations below the mean of the (lognormal) EW distribution of the corresponding emission line, for their sample of 365 WLQs. Additional selection criteria imposed by us are (i) the radio-loudness parameter R < 10. or equivalently, a non-detection in the FIRST survey, which amounts to a somewhat conservative upper limit of  $\sim 1 \text{ mJy}$ 

 $<sup>^1\,</sup>$  Radio-loudness is usually parametrized by the ratio (R) of flux densities at 5 GHz and at 2500Å in the rest-frame, and R <10 for radio-quiet quasars (e.g. see, Kellermann et al. 1989).

IAU Name <sup><i>a</i></sup>	R.A.(J2000) (h m s)	Dec(J2000) (°′′′′)	R-mag	$z^{b}$	R <sup>c</sup>	PM (msec/yr)	Telescope <sup>d</sup> used
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$J081250.79 + 522531.0^*$	08 12 50.80	+ 52 25 31.0	18.30	$1.1532 \pm 0.0011$	2.75	0	ST
J083232.37+430306.1	$08 \ 32 \ 32.37$	+ 43 03 06.1	17.95	$1.3136 \pm 0.0007$	ND	0	DFOT
J094726.72+443526.5	$09 \ 47 \ 26.72$	+ 44 35 26.5	18.18	$1.2887 \pm 0.0007$	ND	0	DFOT
J110539.59+315955.6	$11 \ 05 \ 39.59$	+ 31 59 55.6	18.46	$1.7824 \pm 0.0012$	ND	0	DFOT
J113413.48+001042.0	$11 \ 34 \ 13.48$	+ 00 10 42.0	18.46	$1.4857 \pm 0.0007$	ND	0	DFOT
J124514.04 + 563916.1	$12 \ 45 \ 14.04$	+ 56 39 16.1	18.47	$0.6139 \pm 0.0004$	ND	0	DFOT
J125219.47+264053.9*	$12 \ 52 \ 19.47$	+ 26 40 53.9	17.72	$1.2883 \pm 0.0007$	4.51	0	DFOT
J134052.43 + 074008.1	$13 \ 40 \ 52.43$	+ 07 40 08.1	17.95	$1.0773 \pm 0.0004$	ND	$5.66 {\pm} 2.24$	DFOT
J142943.60+385932.0*	$14 \ 29 \ 43.60$	+ 38 59 32.0	17.56	$0.9279 \pm 0.0005$	ND	0	DFOT
J161245.68+511817.3*	16 12 45.68	+ 51 18 17.3	17.73	$1.5942 \pm 0.0010$	ND	0	DFOT

Table 1. The set of 10 RQWLQs observed in the present study.

 $^a\,$  The sources marked by \* have also been covered in our earlier publication (Paper I).

<sup>b</sup> All the redshifts are from Hewett & Wild (2010), except for J134052.43+074008.1,

whose redshift is taken from Shen et al. (2011).

<sup>c</sup> R is ratio of flux densities at 5 GHz and at 2500Å in the rest-frame, (e.g., Kellermann et al. 1989);

ND=non-detection in the FIRST survey (see text).

<sup>d</sup> DFOT=Devasthal Fast Optical Telescope; ST=Sampurnanand Telescope.

at 1.4 GHz for point-like sources (Becker et al. 1995); (ii) Rmagnitude < 18.5 and (iii) a proper motion consistent with zero (Monet et al. 2003), so that any Galactic objects are excluded. Proper motion is found to be zero for each source, excepting J134052.43+074008.1 which has a proper motion (PM) of  $5.66 \pm 2.24$  milli-arcsec/yr. We consider this to be consistent with zero proper motion, and treat this source as extragalactic, particularly in view of the fact that its SDSS spectrum clearly exhibits the Mg II emission line (with a rest-frame equivalent width of  $\sim 9.7$ Å and  $z \sim 1.077$ , see the catalog of Shen et al. (2011); also Londish et al. (2004)). Application of these selection criteria led us to a well-defined set of 12 RQWLQs, after rejecting J151554.81+251334 on account of its location in a crowded optical field (see above). Here we report INOV observations of 10 out of these 12 RQWLQs, the remaining two sources, J001444.02–000018.5 and J232214.72-103725.1 fall outside the 8-17 hr right ascension range covered in the present observations. Particulars of the observed 10 RQWLQs are given in Table 1. We note that 4 of them have also been covered earlier in our INOV program (Paper I) and those 4 sources are marked with an asterisk in Table 1.

## 2.1 The Photometric Monitoring

The monitoring was done in the SDSS r-band using the 1.3m optical telescope (DFOT <sup>2</sup>) (Sagar et al. 2011), except for one source, J081250.79+522531.0 which was monitored using the 1.04-m Sampurnanand Telescope (ST) located at Nainital, India. Each time, a given source was monitored for a minimum duration of 3 hours. Table 3 provides the log of the monitoring sessions.

The 1.3-m DFOT is a fast beam (f/4) optical telescope with a pointing accuracy better than 10 arcsec (rms). It is equipped with a 512k  $\times$  512k Andor CCD camera having a pixel size of 16 micron and a plate scale of 0.63 arcsec

per pixel. The CCD covers a field of view of  $\sim 5$  arcmin on the sky. It is cooled thermo-electrically to -90 degC and is read out at 1 MHz speed. The corresponding system noise is 6.1 e- (rms) and the gain is 1.4 e-/Analog to Digital Unit (ADU).

The 1.04-m ST is equipped with a  $2k \times 2k$  liquidnitrogen cooled CCD camera having square pixels of 24 micron and a plate scale of 0.37 per pixel. The CCD covers a square field-of-view of about 13 arcmin on a side. Operating at 27 kHz, the gain and readout noise of the CCD are  $10e^$ per Analog-to-Digital Unit (ADU) and  $5.3e^-$ , respectively.

The exposure time for each science frame was set to about 5-7 minute, yielding a typical SNR above 25-30. The typical seeing (FWHM) during our observations is close to 2 arcsec. Since in the sample selection, care was taken to ensure the availability of at least two, but usually more, comparison stars on each CCD frame, within about 1 mag of the target RQWLQ, it became possible to identify and discount any comparison star(s) which showed a hint of variability during the monitoring session.

#### 2.2 The Data Reduction

The pre-processing of the raw images (bias subtraction, flatfielding, cosmic-ray removal and trimming) was done using the standard tasks available in the Image Reduction and Analysis Facility IRAF<sup>3</sup>. The instrumental magnitudes of the observed RQWLQs and their chosen comparison stars in the CCD frames were determined by aperture photometry (Stetson 1992, 1987), using the Dominion Astronomical Observatory Photometry II (DAOPHOT II algorithm)<sup>4</sup>. To select the aperture size (FWHM) for photometry, we first determined the "seeing" for each frame by averaging the observed FWHMs of 5 moderately bright stars in the frame.

<sup>&</sup>lt;sup>3</sup> IMAGE REDUCTION AND ANALYSIS FACILITY (HTTP://IRAF.NOAO.EDU/).

<sup>&</sup>lt;sup>4</sup> Dominion Astrophysical Observatory Photometry.

We then took the median of these averaged values over all the frames recorded in the session. The aperture diameter was set equal to 2 times the median FWHM.

To derive the Differential Light Curves (DLCs) of the target RQWLQ monitored in a given session, we selected two steady comparison star present within each CCD frame, on the basis of their proximity to the target, both in apparent location and brightness. Particulars of the comparison stars used for the various sessions are given in Table 2. Note that the g - r color difference for our 'quasar-star' and 'star-star' pairs is always < 1.5, with a median value of 0.5 (Table 2, column 7). Analyses by Carini et al. (1992) and Stalin et al. (2004a,b), show that for color difference of this order, the changing atmospheric attenuation during a session produces a negligible effect on the DLCs.

# **3 STATISTICAL ANALYSIS**

C-statistic (e.g., Jang & Miller 1997) is the most commonly used and the one-way analysis of variance (ANOVA) (de Diego 2010) the most powerful test for verifying the presence of variability in a DLC. However, we did not employ either of these tests because, de Diego (2010) has questioned the validity of the C-test by arguing that the C-statistics does not have a Gaussian distribution and the commonly used critical value of 2.567 is too conservative. On the other hand, the ANOVA test requires a rather large number of data points in the DLC, so as to have several points within each sub-group used for the analysis. This is not feasible for our DLCs which typically have no more than about 30-45 data points. So, we have instead used the F-test which is based on the ratio of variances, F= variance(observed)/variance(expected) (de Diego 2010; Villforth et al. 2010), with its two versions : (i) the standard F-test (hereafter  $F^{\eta}$ -test, Goyal et al. (2012)) and (ii) scaled F-test (hereafter  $F^{\kappa}$ -test, Joshi et al. (2011)). The  $F^{\kappa}$ -test is preferred when the magnitude difference between the object and comparison stars is large (Joshi et al. 2011). Onward Paper II, we have only been using the  $F^{\eta}$ -test because our objects are generally quite comparable in brightness to their available comparison stars. An additional gain from the use of the  $F^{\eta}$ -test is that we can directly compare our INOV results with those deduced for other major AGN classes (Goyal et al. 2013). An important point to keep in mind while applying the statistical tests is that the photometric errors on individual data points in a given DLC, as returned by the algorithms in the IRAF and DAOPHOT softwares are normally underestimated by the factor  $\eta$  which ranges between 1.3 and 1.75, as estimated in independent studies (e.g., Gopal-Krishna et al. 1995; Garcia et al. 1999; Sagar et al. 2004; Stalin et al. 2004b; Bachev et al. 2005). Recently, using a large sample, Goyal et al. (2013) estimated the best-fit value of  $\eta$  to be 1.5, which is adopted here. Thus, the  $F^{\eta}$  – statistics can be expressed as:

$$F_1^{\eta} = \frac{\sigma_{(q-s1)}^2}{\eta^2 \langle \sigma_{q-s1}^2 \rangle}, \quad F_2^{\eta} = \frac{\sigma_{(q-s2)}^2}{\eta^2 \langle \sigma_{q-s2}^2 \rangle}, \quad F_{s1-s2}^{\eta} = \frac{\sigma_{(s1-s2)}^2}{\eta^2 \langle \sigma_{s1-s2}^2 \rangle} (1)$$

where  $\sigma_{(q-s1)}^2$ ,  $\sigma_{(q-s2)}^2$  and  $\sigma_{(s1-s2)}^2$  are the variances of the 'quasar-star1', 'quasar-star2' and 'star1-star2' DLCs and  $\langle \sigma_{q-s1}^2 \rangle = \sum_{i=0}^N \sigma_{i,err}^2 (q-s1)/N, \langle \sigma_{q-s2}^2 \rangle$  and  $\langle \sigma_{s1-s2}^2 \rangle$  are the mean square (formal) rms errors of the individual data

points in the 'quasar-star1', 'quasar-star2' and 'star1-star2' DLCs, respectively.  $\eta$  is the scaling factor (=1.5) as mentioned above.

The  $F^{\eta}$ -test is applied to a given DLC (say, q-s) by calculating the F value using Eq. 1, and then comparing it with the critical value,  $F_{\nu_{qs}}^{(\alpha)}$ , where  $\alpha$  is the significance level set for the test, and  $\nu_{qs}$  is the degree of freedom (N - 1) of the 'quasar-star' DLC. The two values we have set for the significance level are  $\alpha = 0.01$  and 0.05, which correspond to confidence levels of greater than 99 and 95 per cent, respectively. If the computed F value exceeds the corresponding critical value  $F_c$ , the null hypothesis (i.e., no variability) is discarded to the respective level of confidence. Thus, a RQWLQ is marked as *variable* ('V') for a given session, if the computed F-values for both its DLCs are  $\geq F_c(0.99)$ , which corresponds to a confidence level  $\geq$  99 per cent, and is termed *non-variable* ('NV') if either of the two DLCs is found to have an F-value  $\leq F_c(0.95)$ . The remaining cases are classified as *probably variable* ('PV').

The inferred INOV status of the DLCs of each RQWLQ, relative to the two comparison stars, are presented in Table 3 for each monitoring session. In the first 4 columns, we list the name of the RQWLQ, the date and duration (T) of its monitoring and the number of data points (N) (which is the same for both DLCs of the RQWLQ). The next two columns list the computed *F*-values for the two DLCs and their INOV status, based on the  $F^{\eta}$ -test. Column 7 gives our averaged photometric error  $\sigma_{i,err}(q-s)$  of the data points in the two 'quasar-star' DLCs. Typically, it lies between 0.02 and 0.06 mag (without the  $\eta$  scaling mentioned above).

## 4 DISCUSSION AND CONCLUSIONS

This paper extends our program aimed at the first systematic characterisation of the INOV properties of "radioquiet weak-line quasars" (RQWLQs). This program began about four years ago and differential light-curves (DLCs) of 15 bona-fide RQWLQs, monitored in 30 sessions of  $\geq$ 3 hours each, have been reported in 3 papers, as summarized in Papers III. To derive the differential light curves, we basically followed the analysis procedure and statistical test, very similar to those adopted in Goyal et al. (2013)for determining the INOV properties of AGN of different classes. Based on the 30 monitoring sessions, of which two showed INOV (for the RQWLQs J090843.25+285229.8 and J140710.26+241853.6), an INOV duty cycle of  $\sim 5\%$  was estimated for RQWLQs (Paper III). The procedure followed for this has been outlined in Paper I (see, also, Romero et al. 1999). If we now add to these 30 DLCs the 18 DLCs presented here (none of which shows a significant INOV), the estimate of INOV duty cycle drops to  $\sim 3.2\%$  which is comparable to the INOV duty cycles found for radio-quiet quasars and radio lobe-dominated quasars, also by applying the  $F^{\eta}$ -test (Goyal et al. 2013). However, we note that the estimated INOV duty cycle for RQWLQs is probably an underestimate since the present set of 10 RQWLQs has been selected on the criterion of weakly detected emission lines, instead of a featureless (i.e., BL Lac type) optical/UV spectrum (Sect. 2: MB14).

Another pertinent point is that the presence of weak emission lines in the SDSS spectra of all the 10 RQWLQs

Table 2. Basic parameters and	observing dates (	18 sessions	) for the $10$ l	RQWLQs and th	eir comparison stars.
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IAU Name	Date	R.A.(J2000)	Dec.(J2000)	g	r	g- $r$
	dd.mm.yyyy	(h m s)	(°′″)	(mag)	(mag)	(mag)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
J081250.79 + 522531.0	24.12.2014	$08\ 12\ 50.79$	$+52 \ 25 \ 31.0$	18.30	18.05	0.25
S1		$08 \ 13 \ 29.57$	$+52 \ 27 \ 56.3$	20.14	18.60	1.54
S2		$08 \ 13 \ 20.70$	$+52 \ 23 \ 27.8$	18.36	17.80	0.56
J081250.79+522531.0	25.12.2014	08 12 50.79	$+52\ 25\ 31.0$	18.30	18.05	0.25
S1		08 13 20.70	+52 23 27.8	18.36	17.80	0.56
S2	00 11 0015	08 13 21.90	$+52\ 24\ 58.8$	19.23	17.81	1.42
J083232.37+430306.1	08.11.2015	08 32 32.37	+43 03 06.1	18.12	17.95	0.17
S1		08 32 34.56	+43 01 34.9	18.57	17.08	1.49
S2 J083232.37+430306.1	09.11.2015	$08 \ 32 \ 24.30$ $08 \ 32 \ 32.37$	$+43 \ 03 \ 10.4$ $+43 \ 03 \ 06.1$	$17.54 \\ 18.12$	$16.94 \\ 17.95$	$0.60 \\ 0.17$
S1	09.11.2015	$08\ 32\ 32.37$ $08\ 32\ 40.67$	+43 03 00.1 +43 04 39.3	17.96	17.53 17.54	0.17
S1 S2		08 32 40.01	+43 04 35.3 +43 03 10.4	17.50 17.54	16.94	0.42
J083232.37+430306.1	10.11.2015	08 32 32.37	+43 03 06.1	18.12	17.95	0.17
S1	10.11.2010	08 32 40.67	+43 04 39.3	17.96	17.54	0.42
S2		08 32 34.56	+43 01 34.9	18.57	17.08	1.49
J083232.37+430306.1	01.02.2016	08 32 32.37	+43 03 06.1	18.12	17.95	0.17
S1		08 32 40.67	+43 04 39.3	17.96	17.54	0.42
S2		08 32 34.56	+43 01 34.9	18.57	17.08	1.49
J083232.37 + 430306.1	02.02.2016	08 32 32.37	+43 03 06.1	18.12	17.95	0.17
S1		$08 \ 32 \ 46.22$	$+43 \ 02 \ 41.7$	18.93	17.48	1.45
S2		$08 \ 32 \ 34.56$	$+43 \ 01 \ 34.9$	18.57	17.08	1.49
J083232.37 + 430306.1	03.02.2016	$08 \ 32 \ 32.37$	$+43 \ 03 \ 06.1$	18.12	17.95	0.17
S1		$08 \ 32 \ 40.67$	$+43 \ 04 \ 39.3$	17.96	17.54	0.42
S2		$08 \ 32 \ 34.56$	$+43 \ 01 \ 34.9$	18.57	17.08	1.49
J094726.72 + 443526.5	18.12.2015	$09\ 47\ 26.72$	$+44 \ 35 \ 26.5$	18.23	18.17	0.06
S1		$09 \ 47 \ 17.61$	$+44 \ 35 \ 05.6$	19.35	18.14	1.21
S2		$09 \ 47 \ 38.95$	$+44 \ 34 \ 29.1$	19.06	17.76	1.30
J110539.59+315955.6	02.02.2016	$11\ 05\ 39.59$	+31 59 55.6	18.64	18.48	0.16
S1		11 05 42.26	$+32\ 02\ 21.8$	17.94	17.40	0.54
S2	00.04.0016	11 05 50.05	+32 00 56.9	18.61	17.23	1.38
J113413.48+001042.0	03.04.2016	11 34 13.48	$+00\ 10\ 42.0$	18.72	18.44	0.28
S1 S2		11 34 22.50	$+00\ 10\ 34.5$	19.16	17.75	1.41
52 J124514.04+563916.1	04.02.2016	$11 \ 34 \ 09.65$ $12 \ 45 \ 14.04$	$+00\ 11\ 12.9$ +56\ 39\ 16.1	$18.04 \\ 18.57$	$17.64 \\ 18.44$	$0.40 \\ 0.13$
S1	04.02.2010	$12 \ 45 \ 14.04$ $12 \ 44 \ 54.50$	+56 39 10.1 +56 36 45.3	18.57	18.44 18.19	0.13
S1 S2		$12 \ 44 \ 51.84$	+56 39 38.4	17.65	17.31	0.34
J125219.47+264053.9	05.04.2016	$12 \ 52 \ 19.47$	+26 40 53.9	17.94	17.70	0.24
S120215.41   204000.5	00.04.2010	12 52 13.41 12 52 14.26	+26 39 11.5	18.43	17.15	1.28
S2		12 52 23.82	+26 41 42.6	16.71	16.43	0.28
J134052.43+074008.1	02.04.2016	13 40 52.43	+07 40 08.1	18.08	17.95	0.13
S1		$13 \ 41 \ 02.94$	+07 38 32.9	18.20	16.71	1.49
S2		13 40 51.00	+07 40 02.6	19.07	17.72	1.35
J142943.64+385932.2	10.05.2016	$14 \ 29 \ 43.64$	+38 59 32.2	17.56	17.55	0.01
S1		$14 \ 29 \ 49.95$	+39  00  15.6	17.30	16.54	0.76
S2		$14 \ 29 \ 59.94$	+39  00  49.8	17.50	16.13	1.37
J161245.67 + 511816.9	03.04.2016	$16\ 12\ 45.67$	+51  18  16.9	17.93	17.76	0.17
S1		$16\ 12\ 38.59$	$+51 \ 19 \ 48.4$	16.50	16.14	0.36
S2		$16\ 12\ 30.03$	$+51 \ 17 \ 10.4$	18.85	17.39	1.46
J161245.67 + 511816.9	13.04.2016	$16\ 12\ 45.67$	+51  18  16.9	17.93	17.76	0.17
S1		$16\ 12\ 50.46$	$+51 \ 19 \ 41.1$	18.36	17.71	0.65
S2		16 12 39.38	+51 19 23.5	18.76	17.68	1.08
J161245.67+511816.9	11.05.2016	16 12 45.67	+51 18 16.9	17.93	17.76	0.17
S1		16 12 30.03	$+51\ 17\ 10.4$	18.85	17.39	1.46
S2		16 12 30.58	$+51 \ 20 \ 07.3$	17.97	17.37	0.60

monitored here (Sect. 2) does not preclude a BL Lac nature for at least some of them. As pointed out by Collinge et al. (2005), the faint emission lines could even be contributed by H II regions in the host galaxy. Secondly, BL Lac signatures can be transitory; even the prototypical BL Lac itself has shown emission lines in its optical spectrum, at a level above the standard threshold defined for BL Lacs (Vermeulen et al. 1996). The non-detection of optical linear polarization above 2 - 3% level is another well known argument used to discount a blazar interpretation of RQWLQs (e.g., Stocke et al. 1990; Jannuzi et al. 1994; Smith et al. 2007, Section 1). However, again, this by itself does not exclude the presence of a tiny subset of BL Lacs among RQWLQs, given that a large polarization variability is a hallmark of BL Lacs (Angel & Stockman 1980). One may recall some independent studies (e.g., Fugmann 1988; Jannuzi et al. 1989) demonstrating that there is a good chance ( $\sim 40\%$ ) that at a given epoch, even a bona-fide blazar may not show a high optical polarization (i.e., above 3-4% level). All these considerations provide an impetus to extend searches for the elusive radio-quiet (or radio-weak) BL Lac objects, since their existence can be a crucial ingredient to development of a comprehensive theoretical understanding of the AGN jets. Intra-night monitoring offers a useful practical tool to address this issue and even a modest enhancement in the sensitivity is likely to boost the efficacy of this approach substantially.

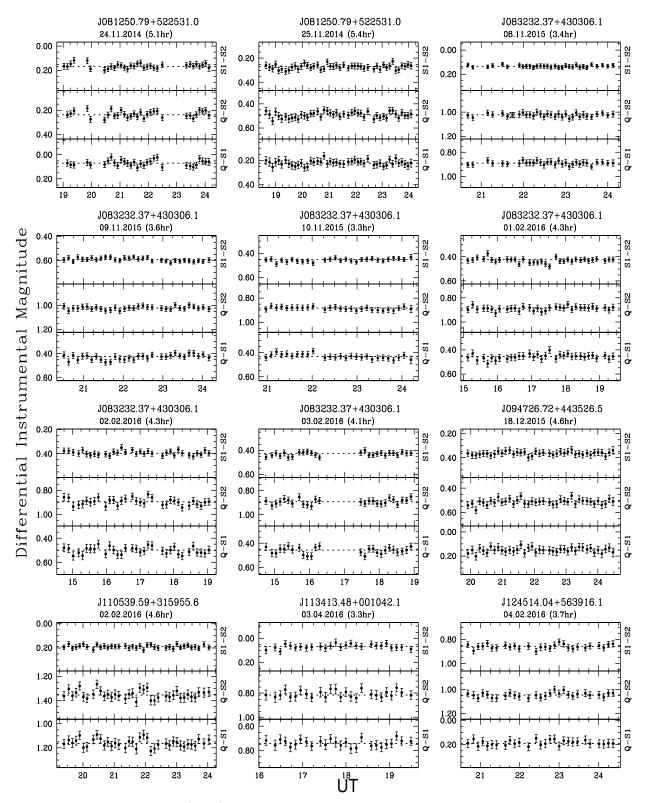
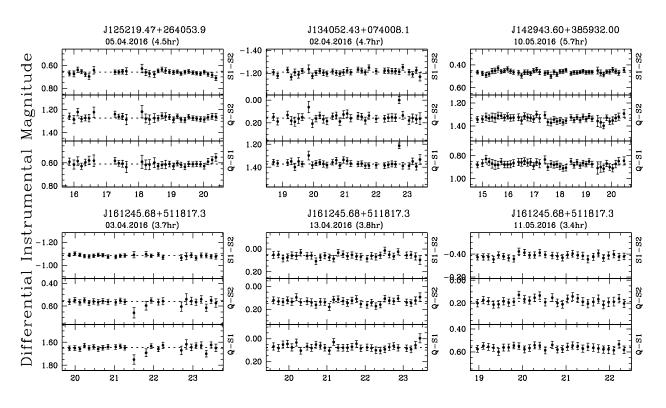


Figure 1. Differential light curves (DLCs) in R-band, for our sample of 10 RQWLQs. The name of the RQWLQ along with the date and duration of its monitoring session are given at the top of each panel. In each panel, the upper DLC is derived using the two 'non-varying' comparison stars, while the lower two DLCs are the 'quasar-star' DLCs, as defined in the labels on the right side. Any likely outlier points (at >  $3\sigma$ ) in the DLCs are marked with crosses and such points are excluded from the statistical analysis. The number of such points does not exceed to for any of the DLCs.

Table 3. Observational details and INOV results for the sample of 10 RQWLQs monitored in 18 sessions.

RQWLQ	Date	Т	Ν	F-test values	INOV status <sup>a</sup>	$\sqrt{\langle \sigma_{i,err}^2 \rangle}$
(1)	dd.mm.yyyy	hr		$F_{1}^{\eta}, F_{2}^{\eta}$	$F_{\eta}$ -test	(q-s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
J081250.79+522531.0	24.11.2014	5.10	32	1.35, 1.57	NV, NV	0.04
J081250.79 + 522531.0	25.11.2014	5.45	45	0.23, 0.33	NV, NV	0.04
J083232.37 + 430306.1	08.11.2015	3.43	31	0.13, 0.15	NV, NV	0.04
J083232.37 + 430306.1	09.11.2015	3.66	31	0.35, 0.16	NV, NV	0.03
J083232.37 + 430306.1	10.11.2015	3.23	27	0.27, 0.12	NV, NV	0.03
J083232.37 + 430306.1	01.02.2016	4.26	33	0.24, 0.17	NV, NV	0.04
J083232.37 + 430306.1	02.02.2016	4.30	33	0.36, 0.39	NV, NV	0.05
J083232.37 + 430306.1	03.02.2016	4.15	26	0.39, 0.29	NV, NV	0.04
J094726.72 + 443526.5	18.12.2015	4.56	39	0.18, 0.28	NV, NV	0.04
J110539.59 + 315955.6	02.02.2016	4.65	37	0.35, 0.38	NV, NV	0.06
J113413.48 + 001042.0	03.04.2016	3.34	26	0.25, 0.24	NV, NV	0.06
J124514.04 + 563916.1	04.02.2016	3.68	28	0.16, 0.20	NV, NV	0.05
J125219.47 + 264053.9	05.04.2016	4.52	31	0.16, 0.19	NV, NV	0.06
J134052.43 + 074008.1	02.04.2016	4.69	34	0.66, 0.54	NV, NV	0.05
J142943.64 + 385932.2	10.05.2016	5.68	45	0.20, 0.24	NV, NV	0.05
J161245.68 + 511817.3	03.04.2016	3.73	25	0.52, 0.33	NV, NV	0.04
J161245.68 + 511817.3	13.04.2016	3.85	32	0.27, 0.21	NV, NV	0.05
J161245.68+511817.3	11.05.2016	3.36	29	0.13,0.22	NV, NV	0.05

 $^{a}$ V=variable, i.e., confidence level  $\geq 0.99;$  PV=probable variable, i.e., 0.95-0.99 confidence level; NV=non-variable, i.e., confidence level < 0.95. Variability status identifiers based on quasar-star1 and quasar-star2 pairs are separated by a comma.



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Figure 2. Same as Figure 1.

# ACKNOWLEDGMENTS

G-K thanks the National Academy of Sciences, India for the award of a NASI Senior Scientist Platinum Jubilee Fellowship.

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