A&A 440, 855–865 (2005)
DOI: 10.1051/0004-6361:20042370

Astronomy
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Astrophysics

# Intra-night optical variability of luminous radio-quiet QSOs

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Received 16 November 2004 / Accepted 13 May 2005

**Abstract.** We report the detection of intra-night variability in some radio-quiet quasi-stellar objects (RQQSOs) and one lobe-dominated radio-loud quasi-stellar object (LDQ). To study intra-night variability, we carried out photometric monitoring of seven RQQSOs and one LDQ in Johnson $V$-passband using 1.2 m optical/IR telescope at Gurushikhar, Mount Abu, India. Observations were made in nine nights during the first half of the year 2000; seven RQQSOs: 0748+291, 0945+438, 1017+280, 1029+329, 1101+319, 1225+317, 1252+020 and one LDQ: 1103-006 were observed. RQQSOs 0748+291, 1225+317 and LDQ 1103-006 have shown intra-night variations. In the case of 1017+280 (RQQSO) there is indication of intra-night variation on one night where as the observations on another night do not convincingly show the existence of intra-night variability. RQQSOs 0945+438, 1029+329, 1101+319 and 1252+020 have not shown any intra-night variations. We compiled intra-night variability data for radio-loud and radio-quiet AGNs from the literature for statistical analysis. It is found that some radio-quiet AGNs show intra-night variations with the maximum amplitude of variation being about 10%. On the other hand blazars at times show intra-night flux variability up to 100%. In the case of radio-loud AGNs (excluding blazars), the maximum amplitude of intra-night variation lies between the variability amplitude of radio-quiet AGNs and blazars i.e. the flux variation is close to 50%. The results indicate that the energy generation mechanism and the environment around the central engine in different classes of AGNs may be similar, if not identical. The standard model for radio-loud AGNs, where shocks are propagating down relativistic jets or models based on disturbances in accretion disks can also explain the micro-variability in RQQSOs.

**Key words.** galaxies: active

## 1. Introduction

There is a general consensus on the dichotomy of the quasar population: radio-loud ($R > 10$) and radio-quiet ($R < 10$) (where $R$ is the ratio of radio (6 cm) to the optical (440 nm) flux densities) (Kellerman et al. 1989). It is found that ∼10−15% of the quasars are in the radio-loud category. There is an additional distinction between radio-loud and radio-quiet AGNs: radio-loud sources occur in elliptical galaxies and radio-quiet are found to reside in galaxies dominated by disk.

Flux variability is a common property of AGNs. Blazars, in particular, show variation in the complete electromagnetic spectrum on all time scales ranging from minutes to years (e.g. Miller et al. 1989; Quinn et al. 1996; Heidt & Wagner 1996; Catanese et al. 1997; Lamer & Wagner 1998; Fan & Lin 1999; Kataoka et al. 1999; Peng et al. 2000; Petry et al. 2000; Ghosh et al. 2000; Pursimo et al. 2000; Fan et al. 2002; Gupta et al. 2002, 2004; Gupta & Joshi 2005; Sagar et al. 2004; Villata et al. 2004, and references therein).

Variability time scales can broadly be divided into three classes: (i) flux variability in few minutes to few hours is generally known as micro-variability or intra-night variability or intra-day variability; (ii) time scales ranging from days to weeks can be classified as short term variability; (iii) and the time scale ranging from months to years can be called long term variability.

The first report of micro-variability in AGNs can be found in Mathews & Sandage (1963), who observed a 0.04 mag change in 15 min in 3C 48. Subsequent to this there are several reports on the detection of rapid flux variations in optical region in AGNs (Mathews & Sandage 1963; Oke 1967; Racine 1970; Angione 1971; Bertaud et al. 1973; Miller 1980). However, these results were not taken seriously as such small amplitude variations might be due to instrumental errors. The first convincing case for optical micro-variability is reported for BL Lacertae using CCD detector by Miller et al. (1989). Since then extensive observations using CCDs have led to unambiguous confirmation of optical micro-variability for a large number of blazars (e.g. Miller et al. 1989; Carini et al. 1990; Carini & Miller 1992; Heidt & Wagner 1996; Noble et al. 1997; Ghosh et al. 2000; Romero et al. 2002; Sagar et al. 2004; Gupta & Joshi 2005, and references therein). All blazars that exhibit micro-variations are found to be radio-loud sources and it is believed that relativistic jets dominate their emission

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(Bregmann 1992). Presently, it is accepted that not only the blazars but many other radio-loud quasars exhibit intra-night variations (Jang & Miller 1995, 1997; Wagner & Witzel 1995; de Diego et al. 1998; Romero et al. 1999; Stalin et al. 2004, 2005, and references therein). However, detection of intra-night variations in radio-quiet AGNs has been elusive and little is known about their intra-night variability. There have been attempts by several groups to find intra-night variability in different sub-classes of radio-quiet AGNs (Jang & Miller 1995, 1997; Anupama & Chokshi 1998; de Diego et al. 1998; Romero et al. 1999; Petrucci et al. 1999; Gopal-Krishna et al. 2000, 2003; Stalin et al. 2004, 2005). In most of the cases, the reports on micro-variability are not convincing, although in a few RQQSOs as intra-night peak-to-peak variation of ~1% is reported (Gopal-Krishna et al. 2003; Stalin et al. 2004, 2005). The results reported by various groups have created some confusion on the intra-night variability in radio-quiet AGNs.

One of the important motivations to study variability in AGNs is to know the physical scales of the emitting regions. As it is quite difficult to resolve the nuclei of AGNs with current technology, a reasonable way to investigate the structure and physical conditions near the nucleus is to study micro-variations of flux and degree of polarization. It is believed that radio-quiet AGNs either do not have a relativistic jet (Antonucci et al. 1990) or harbor a very weak jet (Miller et al. 1993; Kellermann et al. 1994) and hence the effect of a jet is expected to be negligible. The presence of micro-variability in radio-quiet AGNs is, therefore, attributed to the disturbances of the accretion disk (e.g. hot spots or flaring). For radio-loud AGNs, both the shocked jet and disturbances of accretion disk may be responsible for micro-variability. Therefore comparison of micro-variations between radio-quiet and radio-loud AGNs could constrain some of the existing models. Micro-variability may be observed as discrete events or as part of a longer duration variation. The importance of micro-variability is that, if it is intrinsic to the source, it provides limits on the size of the emitting regions, providing a powerful tool to investigate both the physical structure of the central regions of AGNs and the processes responsible for the production of the extreme luminosities observed for these objects. The detection of micro-variability on a time scale of hours in radio-quiet AGNs is considered to be a powerful discriminator between accretion disks and relativistic jet models of these sources.

In the present study a sample of seven bright RQQSOs and one bright LDQ have been considered for the study of micro-variations. Observations were carried out during the period January–April 2000 (nine observing nights).

Section 2 presents the details about target selection, in Sect. 3 we report the observations and data reduction techniques, in Sect. 4 the results of the present work and statistical analysis of the previous work are presented and in Sect. 5 our conclusions are given.

## 2. Target selection criterion

The radio-quiet QSOs and LDQ for the present study were selected from the lists of Véron-Cetty & Véron (2001). Detailed information of the seven RQQSOs and one LDQ and their dates of observations are listed in Table 1. Hubble constant $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$ and $q_0 = 0.5$ are assumed for determining $M_V$.

Simultaneous observation of the target source and a few comparison stars and the sky background allows to remove variations which may be due to fluctuations in either atmospheric transparency or extinction. Therefore, RQQSOs and LDQ were selected for observation in such a way as to have at least two comparison stars in the field of view of the camera with brightness comparable to the target source.

Carini et al. (1991) investigated whether a conspicuous galaxy component produces variations due to fluctuations in atmospheric seeing or transparency which are not intrinsic to the source. They showed that even for sources with significant underlying galaxy components, any spurious variations introduced by fluctuations in atmospheric seeing or transparency are typically smaller than the observational uncertainties. To further reduce this effect, we have selected sources which are optically bright (brighter than $M_V < -24.4$ mag) so that the fluctuations due to the underlying galaxy are minimal. The modest optical luminosities ($M_V > -24.4$ mag) lie close to the critical value below which the sources become like those of Seyfert galaxies (Miller et al. 1990). At these lower levels of AGN to galactic light ratios, false indications of variability produced by seeing variations that include different amounts of host galactic light within the photometric aperture become very probable (Cellone et al. 2000).

In our sample all the sources are brighter than $M_V \leq -24.4$ (vide. Table 1) thus minimizing the seeing effects. The host galaxy is expected to contribute less than 10% to the total flux of the luminous RQQSOs or the LDQ. The host galaxy is also expected to be encompassed within the aperture used for photometry.

## 3. Observations and data reduction

CCD photometric monitoring of seven RQQSOs and one LDQ were carried out in Johnson $V$-passband using a thinned back illuminated Tektronix 1K × 1K CCD detector at $f/13$ Cassegrain focus of 1.2 m Gurushikhar Telescope, Mount Abu, India. To improve the signal to noise ratio (S/N) on the CCD chip binning (2 × 2) was done while reading out the array. One super pixel projected on the sky corresponds to 0.634 arcsec in both the dimensions. The entire CCD chip covers ~5.4 × 5.4 arcmin$^2$ of the sky. Read out noise and gain of the CCD detector was 4 electrons and 10 electrons/ADU respectively. Throughout the observing run, the typical average seeing (FWHM of stellar image) was ~1.5 arcsec ranging from 1.2 to 1.8 arcsec. Several bias frames were taken intermittently in each observing night and sky flats in $V$-passband were taken during the twilight hours.

Image processing or initial processing (bias subtraction, flat-fielding and cosmic rays removal), photometric reduction or processing (instrumental magnitudes of stars and target RQQSOs or LDQ in the image frames) were done at Physical Research Laboratory, Ahmedabad, India and at Harish-Chandra Research Institute, Allahabad, India using IBM – 6000 RISC workstations and Pentium III computers.

**Table 1.** Complete log of $V$ band observations of seven radio-quiet QSOs and one lobe-dominated quasars from 1.2 m Gurushikhar Telescope at Mount Abu, India.

| IAU name* | Other name | $\alpha_{2000.0}$ | $\delta_{2000.0}$ | $z$ | $V$ | $M_V$ | Date of observations dd.mm.yyyy | Data points | Duration (h) |
|---|---|---|---|---|---|---|---|---|---|
| 0748+291 | QJ 0751+2919 | 07 51 12.3 | +29 19 38 | 0.912 | 16.14 | −27.9 | 13. 01. 2000 | 42 | 8.0 |
| 0945+438 | US 995 | 09 48 59.4 | +43 35 18 | 0.226 | 16.28 | −24.5 | 26. 02. 2000 | 26 | 5.5 |
| 1017+280 | Ton 34 | 10 19 56.6 | +27 44 02 | 1.918 | 15.69 | −29.8 | 14. 01. 2000 | 39 | 6.5 |
| 1017+280 | Ton 34 | 10 19 56.6 | +27 44 02 | 1.918 | 15.69 | −29.8 | 27. 02. 2000 | 55 | 6.1 |
| 1029+329 | CSO 50 | 10 32 06.0 | +32 40 21 | 0.560 | 16.00 | −26.7 | 05. 04. 2000 | 61 | 6.0 |
| 1101+319 | Ton 52 | 11 04 07.0 | +31 41 11 | 0.440 | 17.30 | −24.9 | 04. 04. 2000 | 47 | 6.4 |
| 1103−006 | PKS 1103−006 | 11 06 31.8 | −00 52 53 | 0.426 | 16.46 | −25.7 | 06. 04. 2000 | 48 | 5.7 |
| 1225+317 | b2 1225+317 | 12 28 24.8 | +31 28 38 | 2.219 | 15.87 | −30.0 | 07. 04. 2000 | 54 | 6.2 |
| 1252+020 | q 1252+020 | 12 55 19.7 | +01 44 12 | 0.345 | 17.30 | −24.4 | 09. 03. 2000 | 25 | 3.7 |

* Based on coordinates defined for 1950.0 epoch.

**Table 2.** Comparison star locations (relative to QSOs).

| QSO | Star 1 | | Star 2 | | Star 3 | |
|---|---|---|---|---|---|---|
| | $\Delta r''$ | PA$^0$ | $\Delta r''$ | PA$^0$ | $\Delta r''$ | PA$^0$ |
| 0748+291 | 128 | 352 | 93 | 332 | | |
| 0945+438 | 15 | 340 | 95 | 220 | | |
| 1017+280 | 208 | 38 | 107 | 311 | 135 | 78 |
| 1029+329 | 162 | 263 | 246 | 153 | | |
| 1101+319 | 167 | 169 | 201 | 20 | | |
| 1103−006 | 283 | 236 | 37 | 16 | | |
| 1225+317 | 142 | 242 | 196 | 334 | | |
| 1252+020 | 301 | 229 | 223 | 161 | | |

Standard routines in the IRAF package were used for the initial processing of the images. Median bias frames and flat-field images were constructed for each night which were used for bias and flat field correction. Instrumental magnitude of RQQSOs, LDQ and comparison stars in the RQQSOs and LDQ fields were determined by using DAOPHOT II software (Stetson 1987, 1992) and concentric aperture photometric technique. Aperture photometry was done with several concentric aperture radii: 3.5, 5.0, 7.0, 9.5 and 12.0 pixels. Though the data reduced with different aperture radii are found to be in good agreement, aperture radius of 7 pixels gives the best S/N and therefore the photometric magnitudes reported here are based on that aperture radius. Stars in different frames of the same source were matched by using DAOMATCH routine in DAOPHOT II package. The differential magnitudes were calculated for pairs of stars on the frame. Two comparison stars (non variable during our observing run) were used to generate the differential light curves of RQQSOs and LDQ. The positions of the comparison stars in RQQSOs and LDQ fields are listed in Table 2.

Simultaneous observations of the variable source and a few comparison stars and the sky background allowed us to remove variations which may be due to fluctuations in either the atmospheric transparency or the extinction. One may also find the gradual variation in differential magnitude as a function of zenith distance if the colour of the target source and the comparison stars differ very much. The data reported here were obtained during good photometric quality nights and also it was ensured that the zenith angle for observations did not exceed 60°. This reduces the colour dependence of the differential magnitude on zenith angle. Carini et al. (1992) examined the plots of differential magnitude between comparison stars of different colours versus airmass, and found that over a large range of airmass, the overall photometric accuracy was not affected significantly by the large colour difference in the sets of comparison stars, nor did it introduce systematic variations not intrinsic to the source. Also a closer look at the data did not indicate any signature of colour dependence with zenith distance.

## 4. Results

### 4.1. Differential Light Curves (DLCs)

DLCs of seven RQQSOs and one LDQ which were observed during nine nights in the $V$ passband are plotted in Figs. 1−9. In the following, we discuss the criteria to test the existence of variability. The individual bias-corrected and flat fielded images of targets were examined carefully to see if there was any background variation after initial processing of the images and image frames which showed gradual variation (say more than 2%) in CCD response were rejected. Lastly it is most important that the DLCs of any target should show good correlation so that there be no doubt about the variability of the source.

### 4.2. Variability detection criterion

We have followed the method outlined by Howell et al. (1988) to detect objectively the presence or absence of variability at a particular confidence level (say $3\sigma$ or above). In the present study, for the analysis of each source, two comparison stars (s1 and s2) were used and DLCs were generated. We estimate the rms error by fitting a straight line to the DLC of comparison stars (comparison star – check star) (s1 – s2) using the least square fit and estimate the deviation of the data points from the fitted straight line. The mean value of the standard deviation has been used as the measure of the observational error. The formal error for each data point is substantially smaller than the standard deviation ($\sigma$) of the comparison – check star data and therefore is a much more generous estimate of the true observational error than the formal errors (photon noise) detected

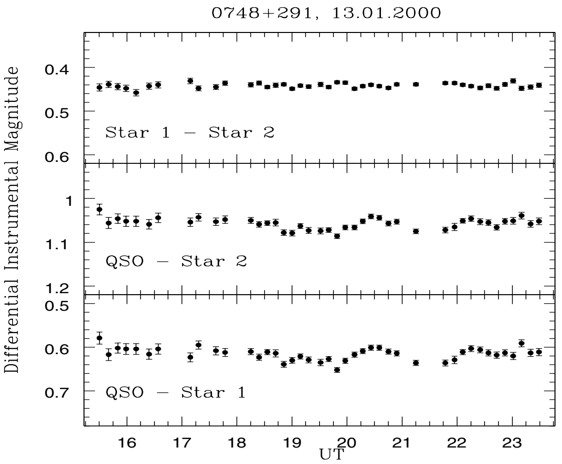

**Fig. 1.** The *V* band light curve of 0748+294 on the night of January 13, 2000.

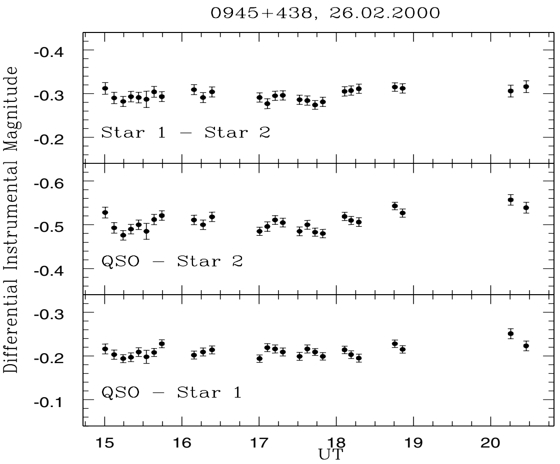

**Fig. 2.** The *V* band light curve of 0945+438 on the night of February 26, 2000.

by photometry software DAOPHOT II. In general the luminosity of the comparison stars is different to the target source. The value of the standard deviation estimated as above was scaled to the $\sigma^2_{v-s}$ by using Eq. (4) of Howell et al. (1988). The value of $\Gamma^2$ was calculated using Eq. (13) in Howell et al. (1988) which is used to scale the $\sigma^2_{s1-s2}$ to get $\sigma^2_{v-s}$. The scaled value of $\sigma^2_{v-s}$ was then used to assess the confidence level of the variability.

### *4.3. Notes on different sources*

**0748+294 (QJ 0751+2991).** This RQQSO, reported as the brightest new QSO in the first bright QSO survey (Gregg et al. 1996), was monitored on the night of February 14, 1999 in the optical *R* band by Gopal-Krishna et al. (2000) to search for micro-variability. In the seven hours of continuous monitoring of the source, they reported spikes (excursion of just one point) at two occasions and suggested the possible existence of micro-variability in the source. Observations of this source in six nights with average monitoring (~6.5 h per night) in *R* passband was again reported by Stalin et al. (2004) and they did not find micro-variability in this source but a spike of ~2% brightness excursion was seen on one occasion. However, Stalin et al. (2004) monitored this source for more than three years (December 14, 1998 to December 25, 2001) and on the basis of the data they have reported the existence of long term variation in the source.

We observed this source continuously for about eight hours (UT 15.669 to 23.336 h) during the night of January 13, 2000; data sampling was about 5 points per h and integration time for each frame was 500 s. DLCs were obtained with respect to two comparison stars, both the comparison stars being brighter than the source. Both the DLCs (QSO – star1 and QSO – star2) for the source 0748+291 are plotted in Fig. 1 which clearly indicate a brightness variation of about 4% during the time UT 18.553 – 22.569 h. As is clear from Fig. 1, the DLC for the comparison stars (star1 – star2) is quite steady whereas the DLCs for the source show appreciable variation during the period. To quantify the degree of variation, we estimated the variance from the DLC for the comparison stars assuming that the stars remained steady during the observing run. A straight line was fitted to the data (Δ mag against UT) and the deviations are estimated from the mean line. The rms noise (standard deviation) is estimated at 0.004 mag. This is scaled to the DLC of the (source – comparison) using the method stated above in Sect. 4.2 and the rms noise $\sigma$ is estimated at 0.005 mag. During the period UT 18.553 – 22.569 h, the rms variation of qso-comparisons are respectively 0.014 and 0.013 for qso – s1 and qso – s2. Thus the variance for DLCs of qso is more than $6\sigma$. This indicates detection of genuine micro variation in the source. If we consider peak-to-peak variation (≈0.05 mag) in the DLC of qso – star1, the variation is at a level of $10\sigma$, which further supports the existence of micro-variability in the source.

**0945+438 (US 995).** Huang et al. (1990) studied the variability of this source using the data taken from Palomar plates for the period 1978 to 1981 (~3.5 year) and did not find any variability in the source. This source was also observed in near-infrared pass-bands ($JHK'$) during the period February 10, 1996 to December 27, 1997 by Enya et al. (2002) and they have reported the existence of long term variation which they were interested in. Search for micro-variability in this source in optical bands was done by different groups e.g. de Diego et al. (1998) in two nights, Stalin et al. (2004) in three nights, Stalin et al. (2005) in one night. de Diego et al. (1998) have reported the existence of micro-variability in the source but on the other hand Stalin et al. (2004, 2005) did not find any evidence of micro-variability. However, the existence of long term variation in the source has been reported by Stalin et al. (2004) the source dimmed by about 0.07 mag during February 26, 2000 and January 23, 2001.

We observed this source for more than 5 h during (UT 15.125–20.458 h) on the night of February 26, 2000. The integration time for each frame was 300 s. The DLCs are shown in Fig. 2. There is a break in observations during 18.9–20.2 h UT due to problems in the control system of the telescope. The DLC of comparison stars gives $\sigma$ at 0.011 and the scaled value

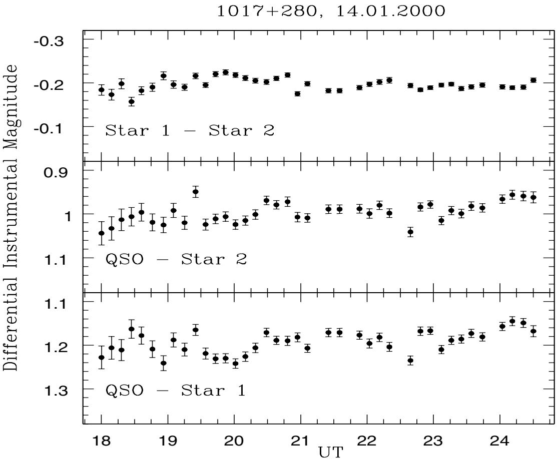

**Fig. 3.** The *V* band light curve of 1017+280 on the night of January 14, 2000.

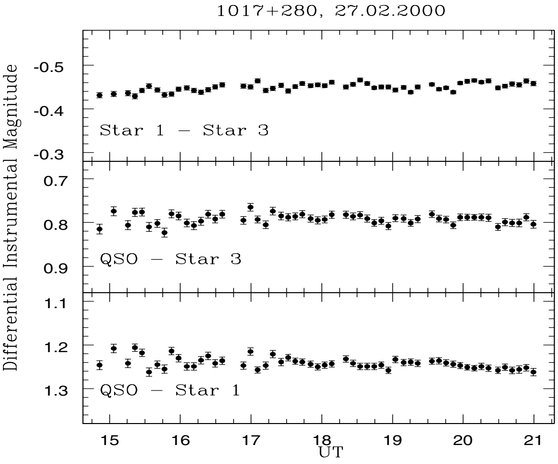

**Fig. 4.** The *V* band light curve of 1017+280 on the night of February 27, 2000.

is 0.010. The standard variation of qso-comparisons are respectively 0.011 and 0.018 for qso – s1 and qso – s2, and hence the mean variance is less than 2$\sigma$. The data appear quite noisy. Hence, the source has not shown any significant variation during the night.

**1017+280 (Ton34).** Stalin et al. (2004) have monitored this source to look for the existence of micro-variability and their observations in three nights in *R*-band did not show any clear evidence of micro-variability.

We observed this source on two nights, January 14 and February 27, 2000, for 6.5 and 6.0 h continuously. On January 14, 2000 the integration time for each image frame was 400 s whereas it was 300 s for the observing run on February 27, 2000. The DLCs are plotted in Figs. 3 and 4. During the night of January 14, the DLC of the comparisons is not stable during the period UT 18.003–21.586 h, but later on it is relatively stable. Hence, we consider only the data during the period of UT 21.886–24.503 h for further discussion. The standard deviation of comparison stars is estimated at 0.006 mag, the scaled value of $\sigma$ for DLCs of the source is 0.008. The standard deviation for DLCs of qso – s1 and qso – s2 are respectively 0.019 and 0.018. The mean variance for the DLCs of the source is more than 5$\sigma$. This indicates that the source is showing variability during the specific period of the night.

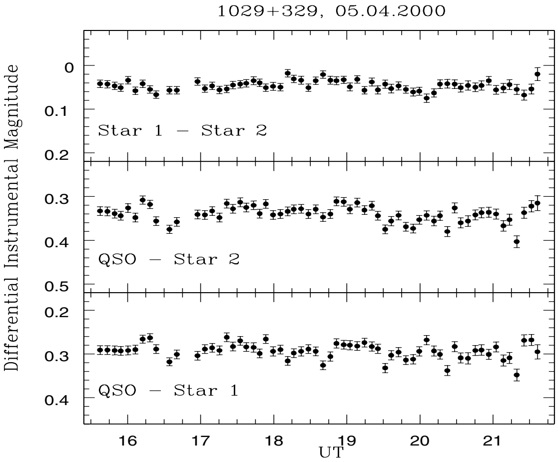

**Fig. 5.** The *V* band light curve of 1029+329 on the night of April 05, 2000.

In the night of February 27, 2000, the DLC of comparisons is quite stable; the $\sigma$ value is estimated as ~0.007, and the scaled value for the source DLC is 0.010. The standard variations for DLCs of qso are 0.011 and 0.011. Hence the variance is less than 2$\sigma$. Therefore, no variation is detected during the night.

**1029+329 (CSO 50).** This source was observed earlier by other groups in six nights (Gopal-Krishna et al. 2003; Stalin et al. 2004, 2005) and the existence of micro-variability was reported in two of the six nights. However, no significant long term variation in the span of two years was reported.

We observed this source continuously for about 6 h on the night of April 05, 2000. The integration time for each image frame was 300 s. The DLCs are plotted in Fig. 5. The $\sigma$ value for the DLC of the comparisons is estimated ~0.011 which is scaled to the same value as $\Gamma$ is close to 1; $\sigma$ values for qso – s1 and qso – s2 are respectively 0.017 and 0.018. The observed variance for the source is close to 2$\sigma$. Hence, no micro variability is detected.

**1101+319 (Ton 52).** Stalin et al. (2004) observed this source in four nights searching for micro-variability and reported the existence of micro-variability in one night; long term variation is also seen in the source.

We also observed this source for about 6 h on the night of April 04, 2000. The integration time for each image frame was 300 s. The DLCs are plotted in Fig. 6. From the plot it appears that the quality of the data is relatively poor and the data are noisy. The scaled $\sigma$ value of the comparison stars is estimated as 0.013. The $\sigma$ values for DLCs of qso are respectively 0.019 and 0.020 for qso – s1 and qso – s2. The variance for the DLCs of qso is close to 2$\sigma$, indicating the non-existence of micro-variability in the source.

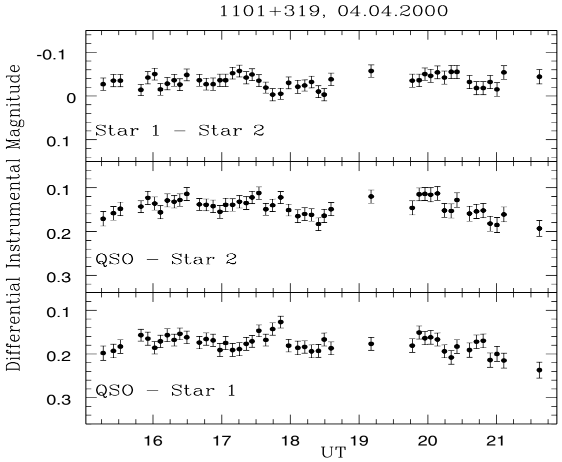

**Fig. 6.** The *V* band light curve of 1101+319 on the night of April 04, 2000.

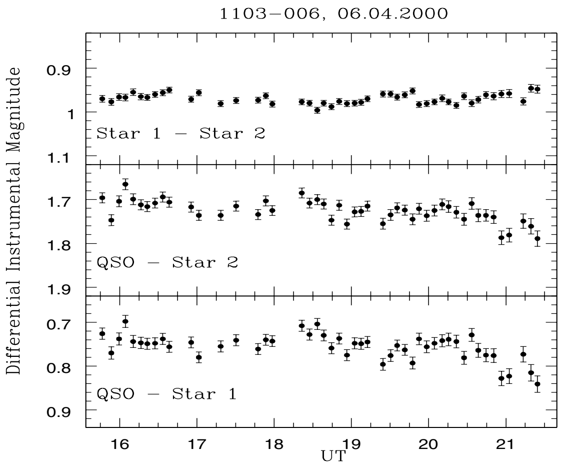

**Fig. 7.** The *V* band light curve of 1103-006 on the night of April 06, 2000.

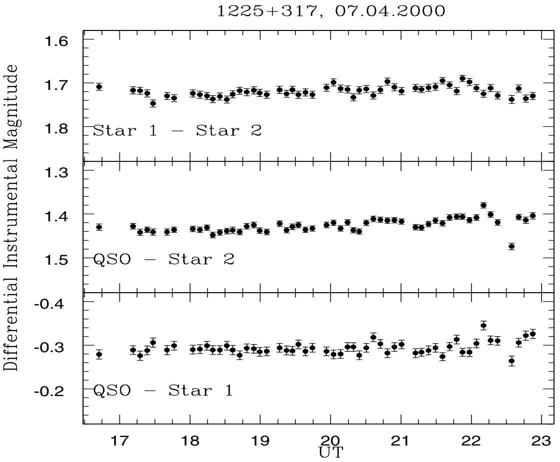

**Fig. 8.** The *V* band light curve of 1225+317 on the night of April 07, 2000.

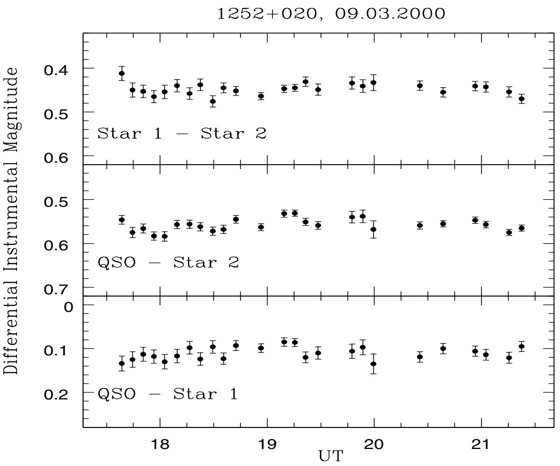

**Fig. 9.** The *V* band light curve of 1252+020 on the night of March 09, 2000.

**1103-006 (PKS 1103-006).** This is the only lobe-dominated quasar in our sample. The source was observed by Enya et al. (2002) in near infrared pass-bands *JHK′* to search for long term variability. Observations were made during the period February 12, 1996 to January 05, 1998. The source was found to show variation on the long term. This source was also observed by Stalin et al. (2004) during the period March 17, 1999 to March 22, 2002 (six nights) in the optical reported clear evidence of micro-variability in one night and also reported significant variation in the long term.

We observed this source for about 5.5 h on the night of April 06, 2000. The integration time for each image frame was 300 s. The DLCs are plotted in Fig. 7. The scaled value of $\sigma$ from the DLC of comparison stars is estimated as ~0.015. From the DLCs of the source, the standard deviations are 0.026 and 0.020 respectively for DLCs qso – s1 and qso – s2. Thus the variance for the source is about 3 times the variance of the standards, indicating the possible existence of intra-night variation.

**1225+317 (b2 1225+317).** There has been no systematic attempt to study this source for micro-variability. We monitored this source for about six hours (UT 15.669 to 23.480 h) during the night of April 07, 2000. The integration time for each image frame was 300 s. DLCs are plotted in Fig. 8. The $\sigma$ value based on the DLC of comparison stars is estimated as 0.011 which scales to 0.008 for source DLCs. DLCs for the source show standard deviations of 0.016 and 0.012 for qso – s1 and qso – s2 respectively. The variance for the DLC of qso is thus close to 3 times the $\sigma$ value, indicating the possible existence of micro variation. During the period UT 22.175–22.575 h the DLCs of qso – s1 and qso – s2 show a brightness variation of 0.081 mag and 0.094 mag respectively which is close to the $10\sigma$ level. Confirmation of such events require further monitoring of the source with larger S/N.

**1252+020 (q 1252+020).** This source was observed for five nights during March 22, 1999 to March 18, 2002 by Stalin et al. (2004). The source has shown micro-variability in two nights and significant long term variability is also reported.

This source was observed by us for about 3.5 h on the night of March 09, 2000. The DLCs are plotted in Fig. 9. The standard deviation based on the DLC of comparison stars scaled to the source DLC is estimated as 0.014. Standard deviations for the DLCs of the qso are respectively 0.014 and 0.014 for qso – s1 and qso – s2, indicating the absence of micro variation in the source.

**Table 3.** Log of radio-quiet AGNs monitored by various researchers looking for intra-night variability in the optical bands: Col. 1 – number of light curves (LCs) available; Cols. 2–4 – number of LCs available for the duration indicated at the top of the respective columns. The numbers in the brackets indicate the number of events when the source has been reported: non variable, possible variable, and variable; Col. 5 – source of the data (reference).

| No. of LCs | Radio quiet AGNs | | | Ref. |
|---|---|---|---|---|
| | duration ≤ 3 h | 3 h < duration ≥ 6 h | duration > 6 h | |
| 27 | 0(0, 0, 0) | 26(22, 2, 2) | 1(1, 0, 0) | 1 |
| 2 | 2(0, 0, 2) | 0(0, 0, 0) | 0(0, 0, 0) | 2 |
| 10 | 0(0, 0, 0) | 3(3, 0, 0) | 7(6, 1, 0) | 3 |
| 23 | 8(8, 0, 0) | 15(15, 0, 0) | 0(0, 0, 0) | 4 |
| 55 | 23(15, 7, 1) | 19(11, 8, 0) | 13(7, 6, 0) | 5 |
| 29 | 0(0, 0, 0) | 13(11, 0, 2) | 16(13, 0, 3) | 6, 7 |
| 20 | 6(4, 0, 2) | 8(5, 0, 3) | 6(5, 0, 1) | 8 |
| 8 | 0(0, 0, 0) | 2(2, 0, 0) | 6(3, 1, 2) | 9 |
| 174 | 39(27, 7, 5) | 86(69, 10, 7) | 49(36, 8, 6) | **Total** |

Ref. (1) Jang & Miller (1997); (2) Anupama & Chokshi (1998); (3) Romero et al. (1999); (4) Petrucci et al. (1999); (5) Gopal-Krishna et al. (2000); (6) Gopal-Krishna et al. (2003); (7) Stalin et al. (2004); (8) Stalin et al. (2005); (9) present study.

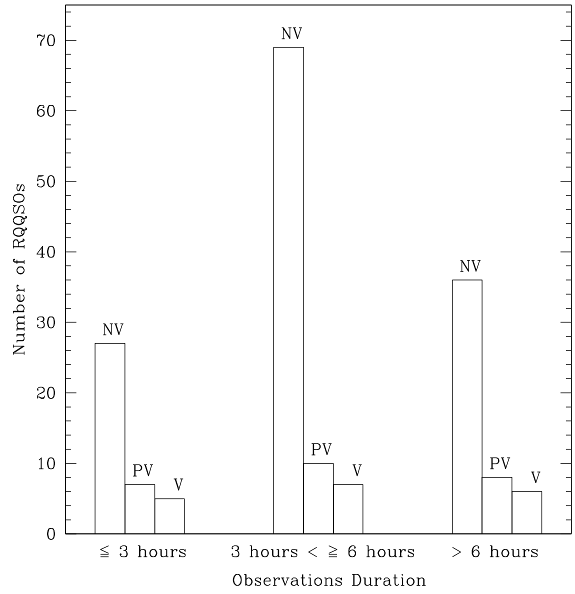

**Fig. 10.** Histogram of observing runs on radio-quiet AGNs. NV, PV and V denote the sources detected: non variable, possible variable and variable respectively.

### *4.4. Statistical analysis of intra-night optical variability of different classes of AGNs*

#### 4.4.1. radio-quiet AGNs

During the last decade several groups have done extensive searches for micro-variability in different subclasses of radio-quiet AGNs. The results based on the study made by various researchers is described briefly in the following.

A sample of 19 radio-quiet AGNs was studied by Jang & Miller (1995, 1997) for micro-variability. They presented DLCs for RQQSOs Ton 951 and Ton 1057 which show up to ~8% variation on time scales of an hour or so. However, both these sources are of modest luminosity ($M_B > -24.3$) and at these lower levels of luminosity, false indications of variability, due to varying seeing, cannot be ruled out (Cellone et al. 2000). Jang & Miller (1995, 1997) have reported 16% (3/19) sources showing micro-variability. Their statistical analysis show the existence of variability at a confidence level of 99%.

de Diego et al. (1998) monitored a sample of 34 sources, equally distributed between radio-quiet and core dominated radio-loud QSOs. They observed pairs of objects from both categories having reasonably matched redshifts and luminosities. Based on the variability behavior, they claim that there is no difference between radio-loud and radio-quiet QSOs. However, their data is rather scanty as each source was monitored only a few times per night and there was no attempt to systematically monitor sources continuously for a few hours (say for about three hours or more). So, the data lacks the continuity of a lengthy data sets. We have not considered these results in the statistical analysis in the present paper.

Rabbette et al. (1998) failed to detect intra-night variability in a sample of 23 high-luminosity RQQSOs. Their detection threshold was ~0.1 mag. Their data lacked the continuity of a long data set and was not used for statistical analysis in the present paper.

The search for rapid optical variability in two broad-absorption line QSOs (BALQSOs) was conducted by Anupama & Chokshi (1998) and they have reported detection of significant variation in both the QSOs.

Romero et al. (1999) observed a sample of 23 southern AGNs in which eight were RQQSOs and rest belong to the different subclasses of radio-loud AGNs. In their analysis, they used the scatter in the weighted average of six comparison stars to estimate photometric errors. None of their eight RQQSOs showed indications strong enough to support the existence of of intra-night variability.

A micro-variability study of 22 Seyfert 1 galaxies (relatively weak, radio-quiet AGNs) has been done by Petrucci et al. (1999). Their error estimation method is different from Romero et al. (1999). They took the weighted average of three or more comparison stars to define a virtual standard star and used structure-function analysis to look for micro-variability in these sources. However, they did not find micro-variability in any source in their sample.

**Table 4.** Log of radio-loud AGNs (excluding blazars) which were monitored by various researchers looking for intra-night variability in the optical bands. Details on the columns are as given in Table 3.

| No. of LCs | Radio loud AGNs (excluding blazars) | | | Ref. |
|---|---|---|---|---|
| | duration ≤ 3 h | 3 h < duration ≥ 6 h | duration > 6 h | |
| 19 | 1(0, 0, 1) | 17(5, 1, 11) | 1(1, 0, 0) | 1, 2 |
| 7 | 0(0, 0, 0) | 7(4, 0, 3) | 0(0, 0, 0) | 3 |
| 33 | 2(1, 0, 1) | 10(6, 0, 4) | 21(14, 0, 7) | 4 |
| 15 | 0(0, 0, 0) | 4(3, 0, 1) | 11(8, 1, 2) | 5 |
| 33 | 1(1, 0, 0) | 14(12, 2, 0) | 18(13, 0, 5) | 6 |
| 8 | 0(0, 0, 0) | 5(2, 0, 3) | 3(0, 0, 3) | 7 |
| 115 | 4(2, 0, 2) | 57(32, 3, 22) | 54(36, 1, 17) | **Total** |

(1) Jang & Miller (1995); (2) Jang & Miller (1997); (3) Romero et al. (1999); (4) Romero et al. (2002); (5) Sagar et al. (2004); (6) Stalin et al. (2004); (7) Stalin et al. (2005).

Gopal-Krishna et al. (2000) reported the results on micro-variability in a sample of 16 RQQSOs. They found 31% (5/16) to be probable or very probable micro-variable, 31% (5/16) RQQSOs showing spikes in their DLCs and the rest 38% (6/16) being non variable.

49 intra-night variability light curves were presented for 19 RQQSOs by Gopal-Krishna et al. (2003) and Stalin et al. (2004, 2005). They found peak-to-peak micro-variation of ~1% in 11 light curves of 8 RQQSOs. 11 RQQSOs did not show any intra-night variations.

To study the occurrence of micro-variability in radio-quite AGNs and their statistical behavior, we compiled the data on variability of different subclasses of radio-quiet AGNs from the literature, thus enlarging the data base. The statistics are expected to be more robust. The data are listed in Table 3 and the statistics in the form of histogram are plotted in Fig. 10. We find that nearly ~10% radio-quiet AGNs show intra-night variations.

### 4.4.2. radio-loud AGNs (non-blazars)

The study of micro-variability in optical wavebands of the radio-loud AGNs excluding blazars was carried out by several groups. The first systematic search for optical micro-variations in radio-loud QSOs was carried out by Jang & Miller (1995, 1997). They monitored 11 radio-loud QSOs on 20 nights and found 10 sources showing variation in the flux during at least in one night.

Romero et al. (1999) monitored a sample of 5 radio-loud QSOs over 7 nights and found 3 radio-loud QSOs showing a flux variation of ~2.2 to 8% within a single night. The other 2 radio-loud QSOs have not shown any significant variations during the observing run of 4 nights.

Romero et al. (2002) have reported observations of 16 EGRET radio-loud quasars (non blazars) in 33 nights during the period 1997 to 2000. Intra-night variations were reported for 12 nights in 7 radio-loud quasars. 9 radio-loud quasars did not show any intra-night variations.

In a recent paper, Sagar et al. (2004) have reported observations of 5 core dominated QSOs (CDQs) over 15 nights in *R*-band. They found one source showing variation on one night and another source showed variation on all the three nights when observations were made. The remaining sources did not display any intra-night variations in the observations of nine nights.

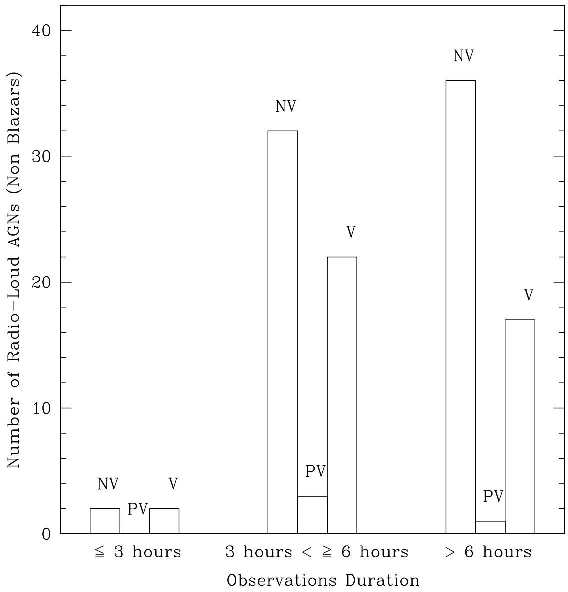

**Fig. 11.** Histogram of observing runs on radio-loud AGNs (non blazars). NV, PV and V denote the sources detected: non variable, possible variable and variable respectively.

In another set of recent papers, Stalin et al. (2004, 2005) reported optical monitoring of 5 radio-loud AGNs over 40 nights and have reported intra-night variations only on 11 nights and one source showed a possible intra-night variation on one night.

To investigate the general statistical behavior of micro-variability of radio-loud AGNs (excluding blazars), we compiled the data on variability (based on various monitoring program to study micro-variability) from the literature listed in Table 4. The data are plotted in the form of histogram in Fig. 11. We find that nearly ~35–40% radio-loud AGNs (non-blazars) show intra-night variations.

### 4.4.3. radio-loud AGNs (blazars)

The study of optical micro-variability of radio-loud AGNs (blazars) was done by several groups. The pioneering work in

**Table 5.** Log of radio-loud AGNs (blazars) which were monitored by various researchers looking for intra-night variability in the optical bands. Details on the columns are as given in Table 3.

| No. of LCs | Radio loud AGNs (blazars) | | | Ref. |
|---|---|---|---|---|
| | duration ≤ 3 h | 3 h < duration ≥ 6 h | duration > 6 h | |
| 2 | 0(0, 0, 0) | 2(0, 0, 2) | 0(0, 0, 0) | 1 |
| 4 | 0(0, 0, 0) | 4(0, 0, 4) | 0(0, 0, 0) | 2 |
| 9 | 8(6, 0, 2) | 1(0, 0, 1) | 0(0, 0, 0) | 3 |
| 32 | 13(3, 0, 10) | 17(6, 0, 11) | 2(1, 0, 1) | 4 |
| 4 | 0(0, 0, 0) | 0(0, 0, 0) | 4(0, 0, 4) | 5 |
| 9 | 5(0, 0, 5) | 3(1, 1, 1) | 1(1, 0, 0) | 6 |
| 24 | 2(1, 0, 1) | 6(2, 0, 4) | 16(3, 0, 13) | 7 |
| 25 | 0(0, 0, 0) | 11(7, 0, 4) | 14(1, 0, 13) | 8 |
| 4 | 0(0, 0, 0) | 2(0, 0, 2) | 2(1, 0, 1) | 9 |
| 113 | 28(10, 0, 18) | 46(16, 1, 29) | 39(7, 0, 32) | **Total** |

(1) Miller et al. (1989); (2) Carini et al. (1990); (3) Carini et al. (1991); (4) Carini et al. (1992); (5) Carini & Miller (1992); (6) Ghosh et al. (2001); (7) Romero et al. (2002); (8) Sagar et al. (2004); (9) Stalin et al. (2005).

blazar optical intra-night variability is by Miller et al. (1989), Carini (1990), Carini et al. (1990, 1991, 1992) and Carini & Miller (1992). The first clear evidence of optical intra-night variability in BL Lacertae was reported by Miller et al. (1989). Carini et al. (1990) have observed blazar OQ 530 in 4 nights (April 1–4, 1988), the source has shown micro-variability in all the four nights. Carini et al. (1991) observed the blazar AP Librae during nine nights during March–May 1989. On three nights intra-night variability were seen. Carini & Miller (1992) observed the blazar PKS 2155-304 for 4 continuous nights (Sep. 25–28, 1988), and micro-variability is seen in all these four nights. Carini et al. (1992) observed blazars OJ 287 and BL Lacertae for eighteen and fourteen nights respectively during (Nov. 1986–March 1989). Out of 32 nights observations micro-variability is reported for 18 nights. Carini (1990), based on the study of a sample of 20 blazars, reported that the probability of seeing a significant micro-variability exceeds 80% if a source is monitored continuously for more than 8 h.

Heidt & Wagner (1996) studied optical intra-night variability in a sample of 34 radio-selected BL Lac objects from a 1 Jy catalog. Observations were carried out from June 1990 to September 1993; each blazar was observed over seven continuous nights, 3 times each night with a time interval of 2 h. In 28 out of 34 BL Lac objects (82%) intra-night variability was detected and 75% of the variable BL Lacs changed significantly over a time scale < 6 h. As this data lacks continuity of lengthy data sets, we have not considered these results in the statistical analysis in the present paper.

About 140 intra-night light curves of a large sample of blazars were generated in a series of papers by a Chinese group (Ref. Bai et al. 1998, 1999; Dai et al. 2001; Xie et al. 1999, 2001, 2002, 2004; Fan et al. 2001, 2004; Qian & Tao 2004). Observations were made in more than two visual pass-bands and on a particular night two or more blazars were observed. All the blazars in the sample showed micro-variations in several nights. The data in these papers also lacks the continuity of long sets and hence are not considered for further discussion and the statistical analysis in the present paper.

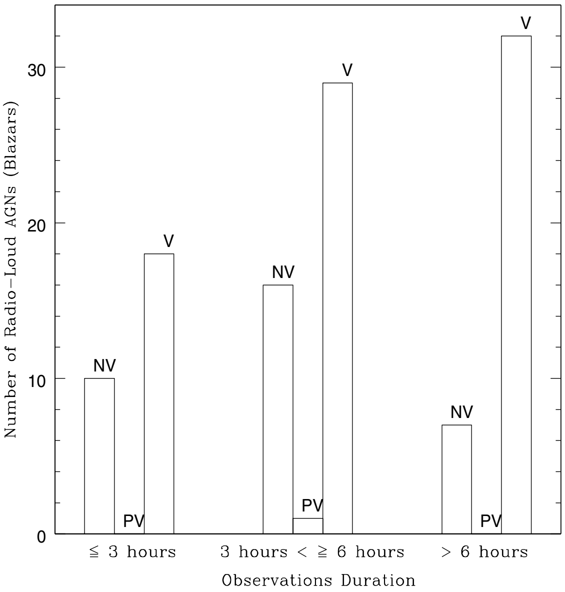

**Fig. 12.** Histogram of observing runs on radio-loud AGNs (blazars). NV, PV and V denote the sources detected: non variable, possible variable and variable respectively.

Ghosh et al. (2001) have made observations of five blazars over seven nights from November 05, 1997−December 29, 1998. Micro-variations were seen in four blazars.

Romero et al. (2002) have reported observations of 4 EGRET blazars on 24 nights during the period 1997 to 2000. Intra-night variations were reported for 18 nights in 3 blazars. One blazar was observed on 2 nights but has not shown any intra-night variations.

Sagar et al. (2004) and Stalin et al. (2005) have recently done an extensive search for intra-night optical variability in blazars. They observed nine BL Lac objects over 35 nights. All the sources showed intra-night variations at least on one night of observations. Out of 35 nights of observation, intra-night variations are seen in 20 nights.

We compiled the data from the literature on micro-variability of blazars (based on monitoring of radio-loud AGNs (blazars)) to study the statistics. The data are listed in Table 5 and presented in the form of a histogram in Fig. 12. The data indicate that the occurrence of micro-variation on blazars in time scale of less than 6 h is ∼60–65%. If the blazar is observed for more than 6 h then the possibility of intra-night variability detection is about 80–85%.

## 5. Conclusions

The new observations of RQQSOs reported here indicate clear evidence for the existence of optical intra-night variability in the luminous RQQSOs. The compiled data of all classes of AGNs, divided in three subgroups, show the presence of intra-night variability in all the subclasses of AGNs.

The most popular model to explain micro-variations is the shock-in-jet model (e.g. Blandford & Konigl 1979; Scheuer & Readhead 1979; Marsher 1980; Hughes et al. 1985; Marsher 1992; Marscher & Gear 1985; Valtaoja et al. 1988; and Qian et al. 1991). An important signature of the relativistic particle jets ejected by black holes is that their light is seen to fluctuate even on the time scale of less than an hour. This model is rather well accepted to explain micro-variability in radio-loud AGNs. The clear evidence of micro-variations in RQQSOs reported here can be explained as relativistic particle jets ejected by the central engine of RQQSOs. However, probably most jets are quenched at the incipient stage, due to severe inverse-Compton losses inflicted by the intense photon field in the vicinity of the black hole. Thus, there appears to be no fundamental difference in the central engines of radio-quiet and radio-loud AGNs.

The micro-variability reported here in the RQQSOs can also be supported by an alternative standard model having numerous flares or hot spots on the accretion disk surrounding the central engine which can produce the micro-variations in quasars (e.g. Wiita et al. 1991, 1992; Chakrabarti & Wiita 1993; Mangalam & Wiita 1993).

From the compiled catalog of micro-variation studies of radio-quiet and radio-loud AGNs, we find that both classes of AGNs show micro-variations. The frequency of occurrence of micro-variations is least in radio-quiet AGNs, highest in blazars and radio-loud AGNs (excluding blazars) fall between these two extreme classes. Radio-quiet AGNs exhibit micro-variations with a maximum amplitude of about 10% or less whereas radio-loud AGNs (excluding blazars) show micro-variations with an amplitude of variation reaching 50% of the normal flux level with the frequency of occurrence being more than radio-quiet AGNs. On the other hand blazars show extreme micro-variations with a maximum amplitude of variation reaching to ∼100% of the normal flux level. Genearlly ≈10% and 35–40% radio-quiet AGNs and radio-loud AGNs (non-blazars) show intra-night variations. For any blazar, if observed continuously for less than 6 h and more than 6 h, the chances of seeing micro-variations are ≈60–65% and 80–85% respectively.

These results indicate that the energy generation mechanism and the environment around the central engine in different classes of AGNs may be similar, if not identical. The standard models that explain the micro-variability in radio-loud AGNs viz. shock-in-jet models and accretion disk-based models can also explain the micro-variability behavior of RQQSOs.

*Acknowledgements.* We thank the anonymous referee for his/her constructive critical comments that helped to improve this paper. We are grateful to Profs. J. H. Fan and J. S. Bagla for reading the manuscript and making useful suggestions. The research work at the Physical Research Laboratory is funded by the Department of Space, Government of India. The Department of Atomic Energy, Government of India supported the research work at the Harish-Chandra Research Institute and at the Tata Institute of Fundamental Research. IRAF is distributed by NOAO, USA.

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