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Optical microvariability of southern AGNs*

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Abstract. We present results of a search for optical microvariability in a selected sample of 23 southern AGNs, which includes both radio-quiet and radio-loud objects. Microvariations were clearly detected in 60% of the radio-loud sources, with amplitudes from 2.2% up to 8% within a single night. Night-to-night variability with amplitudes of $\sim 20\%$ was also observed in the BL Lac object $0537-441$. On the contrary, no rapid variability was detected at all in 8 radio-quiet quasars. We have used microvariability data previously reported for northern objects along with our new results for southern AGNs in order to estimate duty cycles of each class of objects from the largest possible sample.

Most of the microvariability in radio-loud objects could be originating in interactions between relativistic shocks and features in the inner jets, although contributions from superluminal microlensing and accretion disk instabilities can be present in some sources. It is possible that the latter phenomenon is responsible for the microvariability observed in northern radio-quiet quasars. We suggest that the difference in the microvariability behaviour of radio and X-ray selected BL Lacs could be due to the effect of stronger magnetic fields in the latter group of objects, fields that can prevent the formation of features like density inhomogeneities and bends in the base of the jets by Kelvin-Helmholtz macroscopic instabilities.

Key words: galaxies: active — BL Lacertae objects: general — quasars: general — galaxies: photometry

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* Figures 1.2 to 1.23 are only available in the electronic version at http://www.edpsciences.com

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1. Introduction

Optical flux variations have been considered as a common characteristic of several types of AGNs almost since the original discovery of these objects (e.g. Smith & Hoffleit 1963). However, the existence of optical microvariability (i.e., flux changes at the level of a few percent over timescales from minutes to less than 10 hours) in some AGNs was not widely accepted until detailed monitoring campaigns were accomplished using modern CCD detectors in the late 1980s and the 1990s (e.g. Miller et al. 1989; Carini et al. 1990, 1991, 1992; Noble et al. 1997).

The origin of these microvariations, which can reach amplitudes up to 0.2 magnitudes within a single night (see, for instance, the recent review by Miller & Noble 1996), is not clearly established at present. Two broad kinds of intrinsic models have been proposed to account for the phenomenon (we notice that in some particular objects an extrinsic explanation involving superluminal gravitational microlensing is also possible, see Gopal-Krishna & Subramanian 1991 and Romero et al. 1995a). On the one hand there are models based on modified versions of the standard shock-in-jet scenario, which is widely used to interpret radio variability of blazars (Marscher & Gear 1985). In these models the microvariability is produced when a thin and relativistic shock strikes a feature (e.g. a particle density inhomogeneity or a bend) in the parsec-scale jet of the object (Marscher 1990; Qian et al. 1991; Gopal-Krishna & Wiita 1992; Marscher et al. 1992). On the other hand, there are models for microvariability that resort to the formation of instabilities on the surface of the accretion disk that is usually assumed to exist surrounding the central supermassive black hole in the AGN (e.g. Mangalam & Wiita 1993). The instabilities can generate short-lifetime perturbations like orbiting hot spots in the inner disk and Doppler and relativistic effects can induce very fast fluctuations of the observed optical flux.

High temporal resolution observations of different types of AGNs can be used for testing the models and probing the innermost regions of the sources.

In particular, microvariability observations of radio-quiet quasars (RQQSOs) can be useful to determine the contribution of the accretion disk instabilities to the overall rapid variability in radio-loud quasars (RLQSOs) and BL Lac objects. The reason is that RQQSOs are thought not to eject relativistic jets like those observed in radio-loud AGNs and, consequently, the presence of microvariability in their emission clearly points to disk activity (e.g. Gopal-Krishna et al. 1993b). Comparative studies of the incidence of microvariability in samples of both RQQSOs and radio-loud AGNs can be used to enlighten questions on the frequency of shock propagation and the microstructure of relativistic jets in the latter kind of objects.

Recent searches of intranight optical variability in RQQSOs have been carried out by Gopal-Krishna et al. (1993a,b, 1995), Sagar et al. (1996), and Rabbette et al. (1998). Studies of microvariability in samples of both RQQSOs and RLQSOs have been presented by Jang & Miller (1995, 1997). These studies, based almost entirely on samples formed by northern objects, seem to imply that the duty cycle (i.e., the fraction of time when an object displays microvariability) is very different for these two types of AGNs (see, however, de Diego et al. 1998).

In order to confirm these results and to extend the sample of observed AGNs to encompass a significant number of southern objects, we have observed 23 sources with declinations $\delta < -5°$. Our sample consists of both radio-quiet and radio-loud AGNs in such a way that the obtained results, along with those already gathered by Jang & Miller (1995, 1997), provide elements for a first all-sky statistics of the microvariability phenomenon. The purpose of this paper is to present our observational data as well as to discuss some general aspects of the phenomenon on the basis of the global sample. We emphasize that we deal here with microvariability (i.e., strictly intranight variability with timescales from minutes to a few hours) and not with the so-called intraday variability (IDV, timescales from hours to several days).

2. Observations and data reduction

The objects included in our program are listed in Table 1, along with their 1950.0 coordinates, redshifts, apparent visual magnitudes, and classification of AGN-type. They were selected from Véron-Cetty & Véron (1996), Drinkwater et al. (1997), and Padovani & Giommi (1995). All radio-quiet AGNs in our sample are QSOs with $R << 1$, where R is the ratio of radio (5 GHz) to optical (440 nm) flux densities. Radio-loud sources are highly polarized, flat-spectrum QSOs and BL Lac objects with $R > 1$. We have distinguished in the BL Lac group two subgroups: radio-selected sources (RBLs) and X-ray-selected sources (XBLs). The radio-through-X-ray spectral energy distributions are different for these subgroups (Sambruna et al. 1996, Brinkmann et al. 1996) and there is strong evidence for the existence of very different duty cycles for them at intraday timescales (Heidt & Wagner 1996, 1998). These differences are probably reflecting different physical conditions in the relativistic jets of the objects (see, for instance, Sambruna et al. 1996).

Table 1. Observed AGNs

Object	$\alpha_{1950.0}$	$\delta_{1950.0}$	z	m_V	Type
0537 − 441	05 37 21.1	−44 06 45.0	0.894	16.48	RBL
0637 − 752	06 37 23.25	−75 13 38.2	0.651	15.75	RLQ
1034 − 293	10 34 55.9	−29 18 27.0	0.312	16.46	RLQ
1101 − 232	11 01 11.1	−23 13 20.0	0.186	16.55	XBL
1120 − 272	11 20 34.2	−27 13 35.0	0.389	16.80	RQQ
1125 − 305	11 25 04.0	−30 28 14.0	0.673	16.30	RQQ
1127 − 145	11 27 35.6	−14 32 54.0	1.187	16.90	RLQ
1144 − 379	11 44 30.9	−37 55 31.0	1.048	16.20	RBL
1157 − 299	11 57 10.0	−29 55 10.0	0.207	16.40	RQQ
1244 − 255	12 44 06.7	−25 31 25.0	0.638	17.41	RLQ
1256 − 229	12 56 27.6	−22 54 28.0	?	17.30	RBL
1349 − 439	13 49 52.5	−43 57 55.0	?	16.37	RBL
1510 − 089	15 10 08.9	−08 54 48.0	0.360	16.54	RLQ
1519 − 273	15 19 37.3	−27 19 30.0	?	17.70	RBL
2005 − 489	20 05 46.6	−48 58 43.0	0.071	13.40	RBL
2155 − 304	21 55 58.3	−30 27 54.0	0.116	13.09	XBL
2200 − 181	22 00 27.0	−18 16 14.0	1.160	15.30	RQQ
2254 − 204	22 54 00.5	−20 27 43.0	?	16.60	RBL
2316 − 423	23 16 20.9	−42 23 14.0	0.055	16.00	XBL
2340 − 469	23 40 34.2	−46 56 42.0	1.970	16.40	RQQ
2341 − 444	23 41 08.2	−44 23 58.0	1.900	16.50	RQQ
2344 − 465	23 44 02.3	−46 29 10.0	1.890	16.40	RQQ
2347 − 437	23 47 57.5	−43 42 31.0	2.900	16.30	RQQ

RBL: radio-selected BL Lac, XBL: X-ray selected BL Lac
RLQ: radio-loud quasar, RQQ: radio-quiet quasar.

Our observations were carried out during several observing runs in April, July, September, and December 1997, and April 1998 with the 2.15-m CASLEO telescope at San Juan, Argentina. This instrument was equipped with a liquid-nitrogen-cooled CCD camera, using a Tek-1024 chip with a read-out-noise of 9.6 electrons and a gain of 1.98 electrons/adu. A focal–reducer provided a scale of 0.813 arcsec per pixel, and the useful field of view was ∼700 pix in diameter, or roughly 9 arcmin on the sky. Field frames were then sufficiently large as to contain at least 6 non-variable stars of apparent magnitude similar to the AGN-target magnitude. These stars were used during the data reduction procedure for comparison and control purposes (see below).

Microvariability observations were performed entirely using a Johnson's V filter with integration times between 30 and 500 s depending on the source brightness and the observing conditions. The signal-to-noise ratio at the central pixel of the AGN was fixed at a level such that the count rate was about 25% below the saturation limit in each case. A number of calibration frames (bias and flat-field images) were taken each night before the beginning of

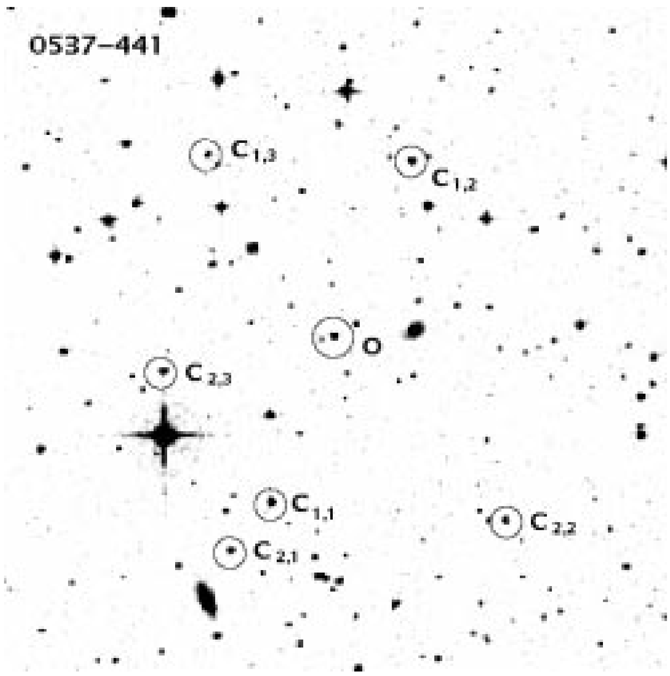

Fig. 1. CCD frame showing the field of 0537 − 441 (O) and stars used for comparison ($C_{1i},\ i = 1, 2, 3$) and control ($C_{2i},\ i = 1, 2, 3$). The image is 10 arcmin on each side; North is up and East to the left. Similar charts are available for all objects of the sample in the electronic version

the observations. The variability monitoring of each AGN lasted at least 3 hours in order to make our results directly comparable to those obtained by Jang & Miller (1995, 1997) for northern objects. As in their campaigns, several AGNs were observed during more than one night.

The data reduction was made following standard procedures with the IRAF software package running on a UNIX workstation. All object images were debiased and flat-fielded using the normalized dome flat images. Magnitude measurements of the AGNs were made relatively to non-variable field stars using the aperture photometry routine APPHOT. Differential lightcurves for each pair of objects in the frame were constructed and used for detecting variable stars or any anomalous behaviour (e.g. saturated stars). Two groups of well-behaved stars of similar magnitude to the target were determined for each AGN (usually three stars per group), and then an average magnitude was computed for each group in each frame. In Fig. 1 we show a finding chart for the first AGN listed in Table 1, where the object and the selected stars are marked. In the electronic version of this article this figure contains similar frames for all objects of our sample in order to allow future researchers to make comparative studies using the same groups of stars. One of the averaged groups was used for comparison ($< C_{1i} >$) and the other for control ($< C_{2i} >$), in such a way that the differential lightcurve for each AGN (O) is presented as $O- < C_{1i} >$, while $< C_{1i} > - < C_{2i} >$ provides a confident comparison curve. As in the Jang & Miller papers, the standard deviations (σ) of these latter curves are used as a measurement of the observational errors. The scatter σ supplies error estimates that are larger than the formal photometric errors and constitutes a more accurate determination of the actual errors along the entire variability monitoring of a given source. In most cases σ is at the level $0.001 - 0.003$ mag, and just in the worst cases occasionally reaches values of 0.01 mag.

3. Results

The results of our observations are summarized in Tables 2-4. Tables 2 and 3 contain the information for radio-loud AGNs, while the results for radio-quiet objects are displayed in Table 4. In these tables Col. 1 lists the object name; Col. 2, the AGN classification; Col. 3, the date of observation; Col. 4, the observational error σ obtained from the standard deviation of the comparison differential lightcurve; Col. 5, the duration of each intranight observation. Column 6 gives the classification of each lightcurve according to a variable (V) – nonvariable (NV) scheme. We have adopted the same 99%-confidence criterion used by Jang & Miller (1997) to distinguish between V and NV sources. Both sets of data are, in this way, directly comparable. In Col. 7 of the tables we indicate the confidence level of the variability, when observed; C is defined as $\sigma_{\rm T}/\sigma$, where $\sigma_{\rm T}$ is the standard deviation of the target differential lightcurve. The adopted variability criterion requires that for a variable source $C \geq 2.576$. Finally, in Col. 8 we list the intranight variability amplitudes defined as (Heidt & Wagner 1996):

$$Y = \frac{100}{< D >}\sqrt{(D_{\max} - D_{\min})^2 - 2\sigma^2}\%, \quad (1)$$

where $D_{\max}$ and $D_{\min}$ are the maximum and the minimum of the differential lightcurve, respectively.

Among 15 radio-loud AGNs of our sample, 9 (60%) displayed microvariability with amplitudes from 2.2% up to ∼8%. Figures 2, 3, and 4 show lightcurves for two variable and one nonvariable radio-loud objects: the BL Lac 0537 − 441 (amplitudes ∼7.7% each night), and the flat-spectrum QSOs 1244 − 255 (with amplitudes of ∼ 6.8%) and 0637 − 752 (no variation detected). The short-term variations observed in 0537 − 441 are part of a larger outburst with timescales of ∼ 1 day and amplitudes of ∼ 20%. This can be clearly appreciated in Fig. 5, where we present the night-to-night behaviour.

The objects in Table 3 are classified as XBLs. As noted by Heidt & Wagner (1998) on the basis of an extensive study of intraday variability, this type of BL Lacs seems to display different duty cycles and variability amplitudes than radio-selected sources. These differences seem to be present also at microvariability timescales: just 1 out of 3 objects in our sample (33%) showed microvariations. The variable XBL is 1101 − 232 and its lightcurve is shown in

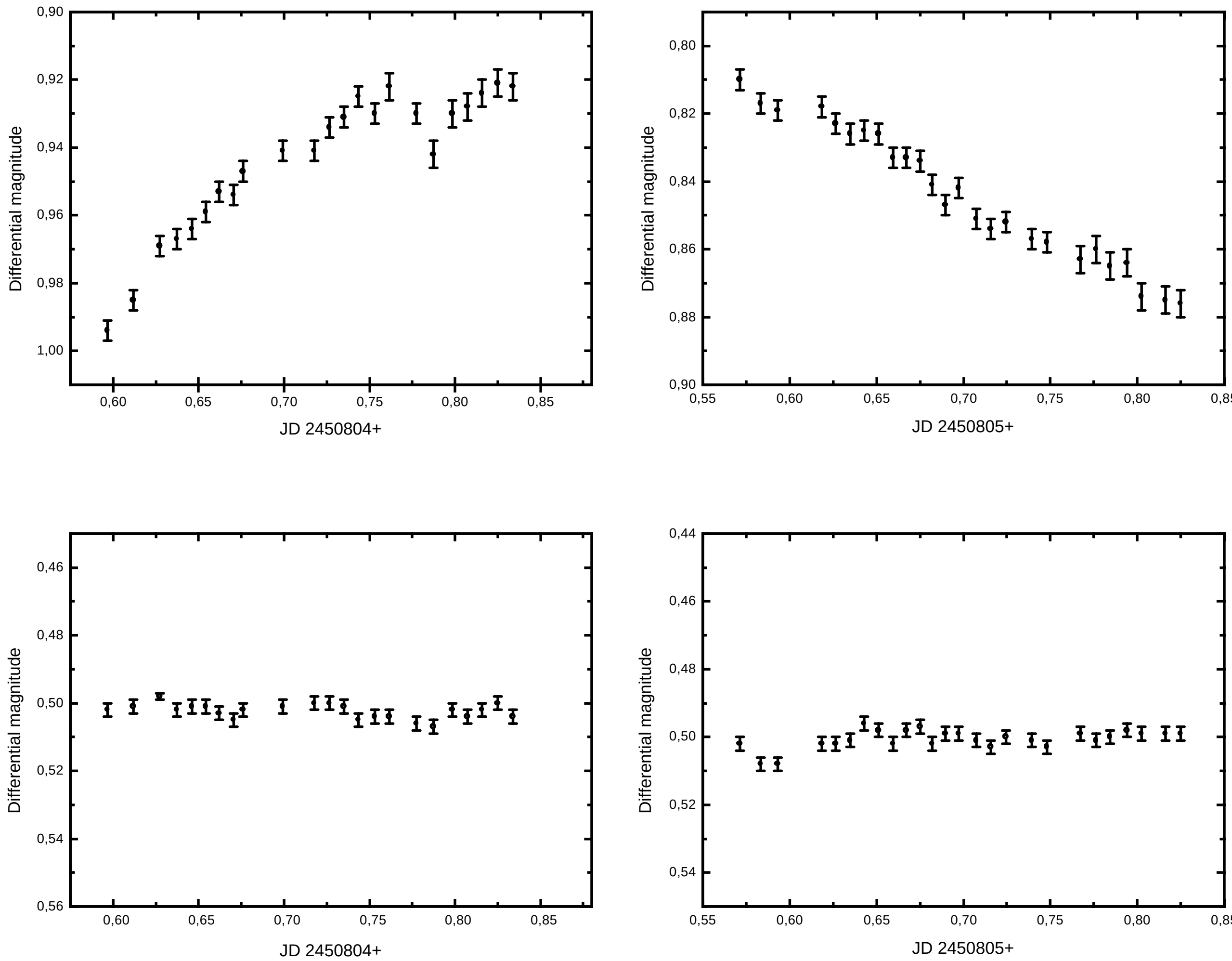

Fig. 2. Differential lightcurves for the radio-selected BL Lac object 0537 − 441 and for a comparison averaged star for the nights of December 21st and 22nd, 1997. The filled symbols represent (in all figures) the differences $O - < C_{1i} >$, whereas the open ones are $< C_{1i} > - < C_{2i} >$ (see Sect. 2 in the text). Error bars show the formal photometric errors (valid also for all figures)

Table 2. Results for radio-loud AGNs

Object	Type	Date	σ (mag)	Δt (hs)	Variable?	C	Y (%)
0537 − 441	BL Lac	12/21/97	0.002	5.7	V	9.45	7.7
		12/22/97	0.003	6.1	V	7.00	7.8
0637 − 752	QSO	12/21/97	0.001	5.6	NV	–	–
		12/22/97	0.002	5.8	NV	–	–
1034 − 293	QSO	04/24/97	0.002	4.7	V	9.60	4.1
1127 − 145	QSO	04/27/98	0.002	3.5	V	2.77	2.2
1144 − 379	BL Lac	04/27/97	0.013	4.8	V	4.36	7.8
1244 − 255	QSO	04/28/98	0.002	5.3	V	8.17	6.8
1256 − 229	BL Lac	04/24/980	0.003	6.6	NV	–	–
1349 − 439	BL Lac	04/24/98	0.002	3.1	V	9.62	3.0
1510 − 089	QSO	04/28/98	0.003	3.8	NV	–	–
		04/29/98	0.004	4.0	NV	–	–
1519 − 273	BL Lac	04/26/98	0.003	6.1	V	5.78	3.8
2005 − 489	BL Lac	04/26/97	0.004	3.0	NV	–	–
2254 − 204	BL Lac	09/20/97	0.005	7.2	V	2.60	3.3

Table 3. Results for X-ray selected BL Lac objects

Object	Type	Date	σ (mag)	Δt (hs)	Variable?	C	Y (%)
1101 − 232	XBL	04/29/98	0.002	5.3	V	3.0	3.6
2155 − 304	XBL	07/26/97	0.005	7.0	NV	–	–
		07/27/97	0.006	7.2	NV	–	–
2316 − 423	XBL	09/04/97	0.010	8.2	NV	–	–
		09/05/97	0.010	8.5	NV	–	–

Fig. 6. The observed variability amplitude (3.6%) is also lower than the average amplitude of radio-selected AGNs (5.2%). If we restrict our set of radio-loud objects to radio-selected ones (i.e., those in Table 2), we get that 8 out of 12 (67%) showed microvariability. The average amplitude for RBLs is 5.12%, while for RLQSOs it is 4.36%. The fraction of variable radio-loud AGNs in our sample is lower than that determined by Heidt & Wagner (1996) for RBLs at intraday timescales (~80%). Although these differences are suggestive, the very limited number of objects in our

Table 4. Results for radio-quiet quasars

Object	Type	Date	σ (mag)	Δt (hs)	Variable?	C	Y (%)
1120 − 272	QSO	04/27/98	0.003	3.7	NV	–	–
1125 − 305	QSO	04/28/97	0.004	5.9	NV	–	–
1157 − 299	QSO	04/28/98	0.002	5.0	NV	–	–
2200 − 181	QSO	07/26/97	0.003	6.5	NV	–	–
		07/27/97	0.003	7.2	NV	–	–
2340 − 469	QSO	09/04/97	0.006	7.5	NV?	1.7	3.3
		09/05/97	0.007	8.1	NV	–	–
2341 − 444	QSO	09/17/97	0.011	7.3	NV	–	–
2344 − 465	QSO	09/19/97	0.005	7.8	NV	–	–
2347 − 437	QSO	09/18/97	0.006	7.9	NV	–	–

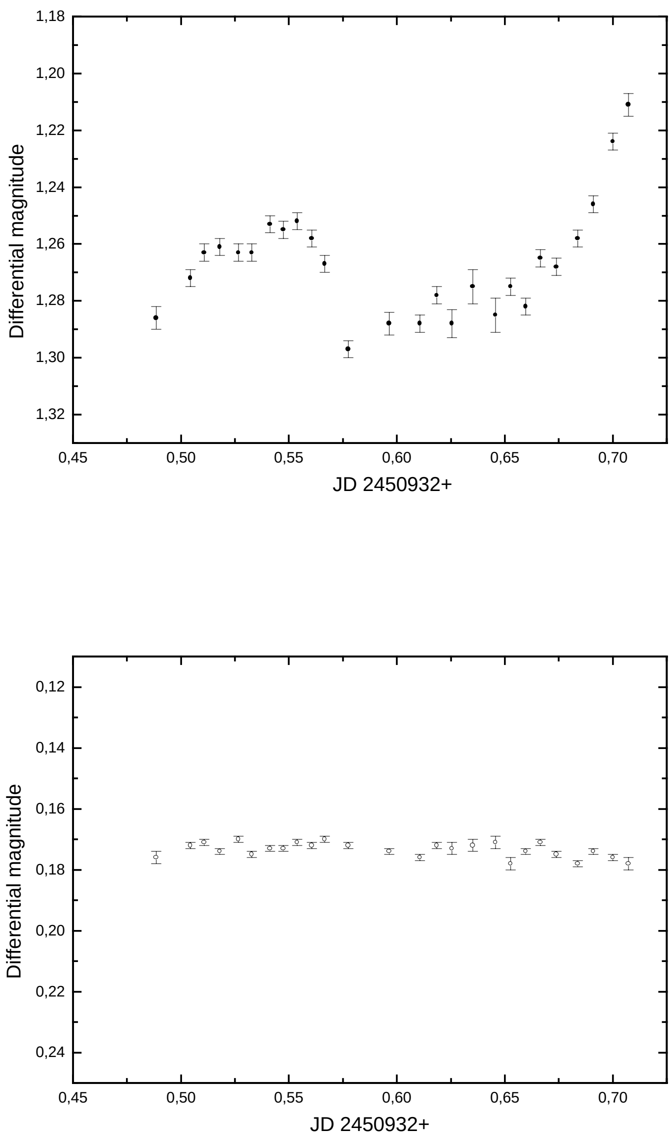

Fig. 3. Lightcurves for the RLQSO 1244 − 255 (filled symbols) and comparison (open symbols) obtained April 28th, 1998

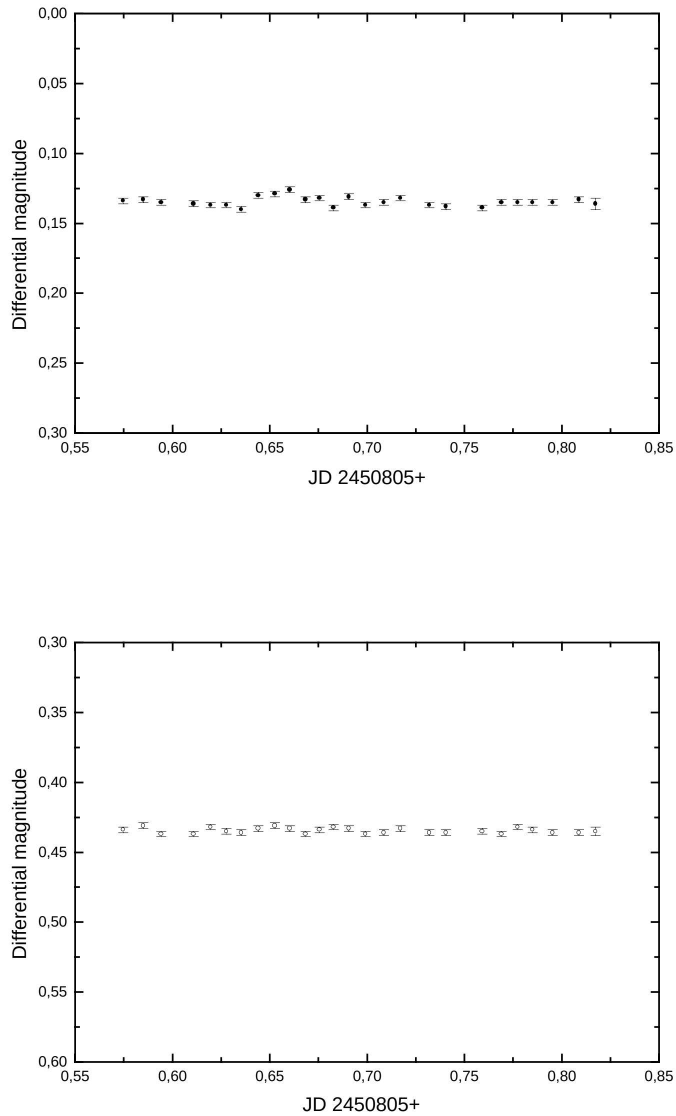

Fig. 4. Lightcurves for the nonvariable RLQSO 0637−752 (filled symbols) and comparison (open symbols) obtained December 22nd, 1997

samples makes necessary more observations in order to draw any statistically significant conclusion.

One of the XBLs included in our selection is the well-known BL Lac PKS 2155 − 304. Optical microvariability with timescales as short as one hour has been found in this object by Carini & Miller (1992) and Paltani et al. (1997). Heidt et al. (1997), however, did not detect any variation on timescales shorter than one day and have suggested that this object could pass through relatively frequent quiet stages at microvariability level. Our results, which span two consecutive nights without detecting any kind of variation, lend additonal support to this conjecture.

None of the 8 RQQSOs observed during our campaign have displayed variability strong enough to be classified as a variable source. Just in one case, the first night of

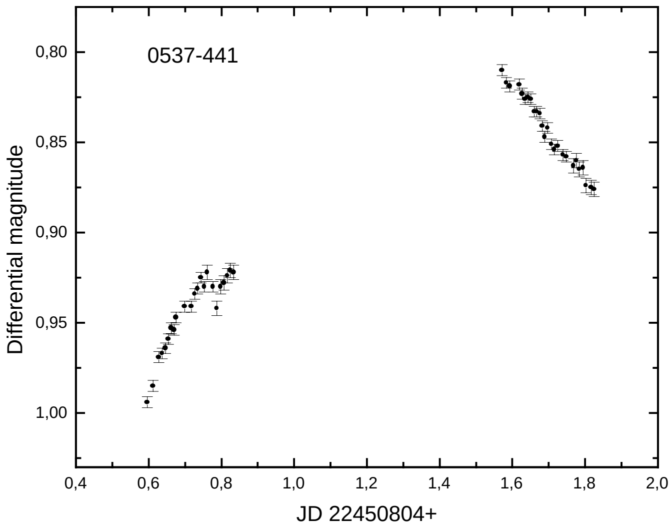

Fig. 5. Two-nights differential lightcurve for 0537 − 441

observation of 2340 − 469, there seem to be some microfluctuations in the differential lightcurve at the level of ∼ 3.3%. However, the confidence for this variability is just $C = 1.7$, so that the source formally classifies as NV. This QSO will be included in future monitorings in order to confirm whether it presents real variability or not. In Fig. 7 we show its lightcurve with average comparison star for the night of April 9th, 1997. Additionally, in Fig. 8, we show cross comparisons with different individual stars for that night. In no case can the object be classified as formally variable according to the adopted variability criterion.

4. Microvariability duty cycles

The observations presented in this paper can be used, along with the similar results obtained for northern objects by Jang & Miller (1995, 1997), to determine the microvariability duty cycles on the basis of a relatively large sample. Considering both sets of observations we have high-quality CCD variability data for 53 AGNs (23 southern and 30 northern objects). This sample is formed by 27 RQAGNs, 23 RL objects, and 3 XBLs. 74% of the radio-selected sources have displayed microvariations at the 99% confidence level within a single night. On the contrary, just 11% of the RQAGNs have shown variability under the same circumstances. This confirms that both AGN-types form distinct classes from the point of view of their microvariability (Miller & Noble 1996). In Fig. 9 we present an histogram where these results are summarized.

We can enlarge the RQ-sample by including the 13 objects monitored by Gopal-Krishna et al. (1993a,b, 1995) and Sagar et al. (1996) (we do not consider here the variable source 0838+359 because it is not a strict RQQSO). Taking into account the results of their observations the fraction of variable RQ objects is not significantly modified: 6 out of 40 (15%) sources present strong evidence of microvariability in their lightcurves (see Fig. 10).

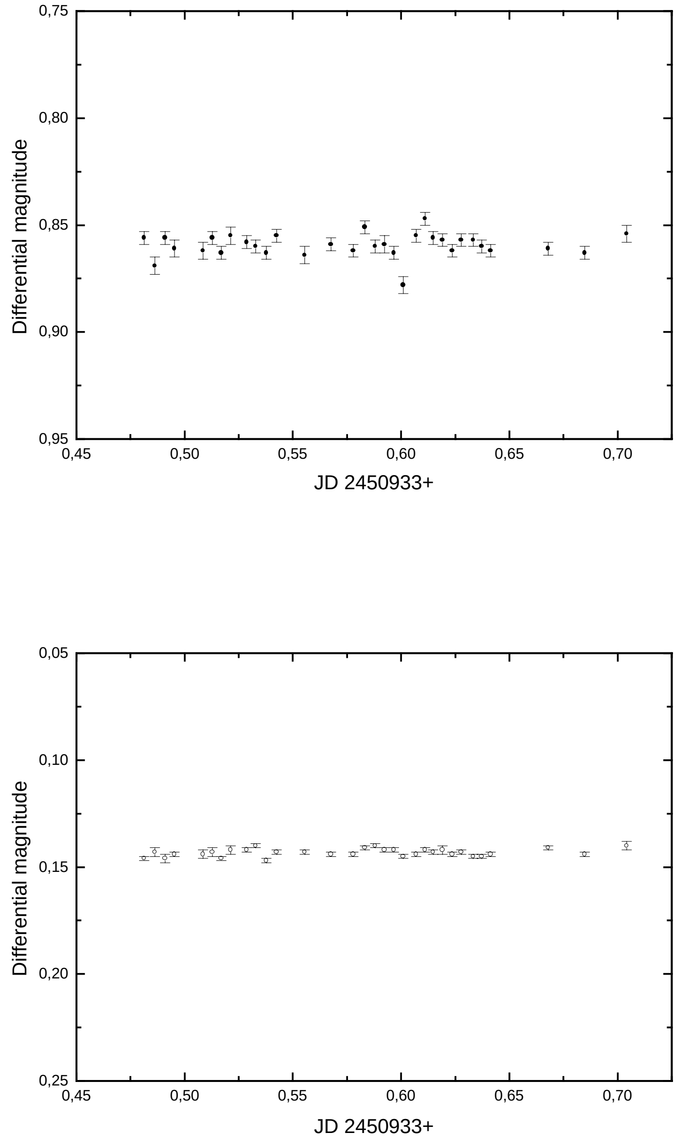

Fig. 6. Lightcurves for the XBL 1101 − 232 (filled symbols) and comparison (open symbols) obtained April 29th, 1998

Several of the objects included in the Jang & Miller sample are not really QSOs, but rather Seyfert 1 (S1) galaxies. If we differentiate this group of lower luminosity sources from the rest of the sample we find that 7 out of 9 RLS1s (77.8%) displayed variability whereas just 2 out of 12 RQS1s (16.7%) showed similar behaviour.

Since some variable AGNs do not display variability all the time, duty cycles are best estimated not as the fraction of variable objects within a given class, but as the ratio of the time at which objects of the class are effectively varying to the total observing time for objects in that class. In this way we are taking into account the fact that there are nights in which usually variable AGNs do not present

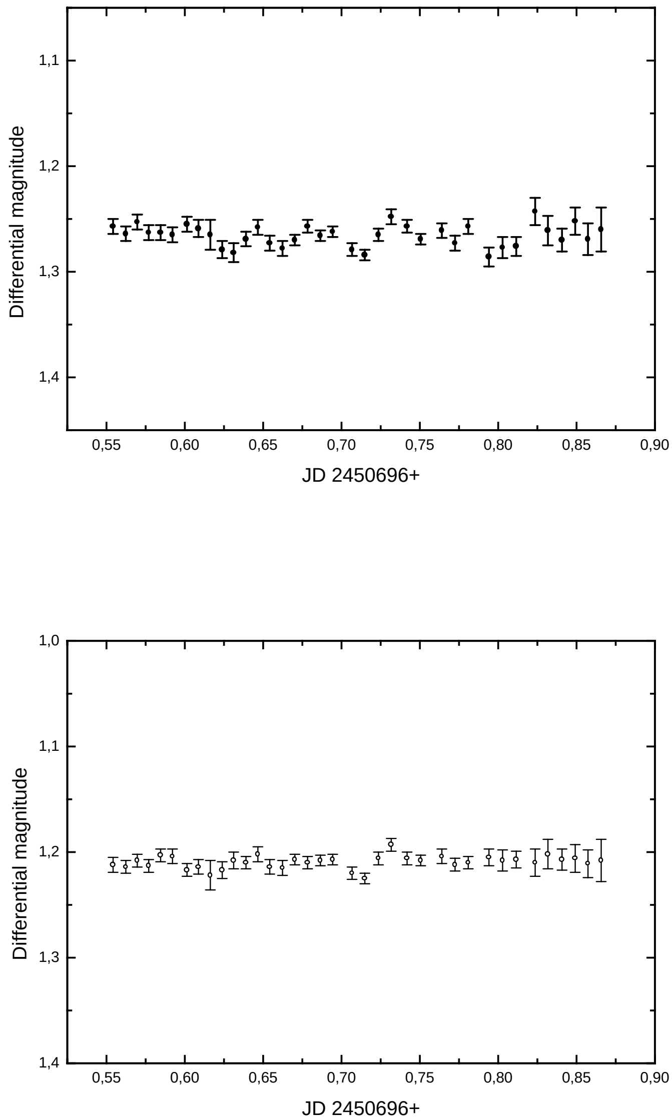

Fig. 7. Lightcurves for the RQQSO 2340 − 469 (filled symbols) and comparison (open symbols) obtained April 9th, 1997

microfluctuations. Besides, since most sources have not been monitored during equals spans it is better to weight the contribution to the duty cycle by the hours each source was observed in each observing session. Consequently, we define the following estimator for the duty cycle (DC) of objects of a given class:

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

where $\Delta t_i = \Delta t_{i,\mathrm{obs}}(1+z)^{-1}$ is the duration (corrected by redshift) of a monitoring session of a source of the selected class, and N_i equals 0 or 1 if the object was NV or V during Δt_i, respectively.

Using this approach the duty cycles for RL, RQ, and XBL objects result of 68%, 6.9%, and 27.9%, respectively (see Fig. 11). The duty cycle of RQAGNs is, then, about one order of magnitude lower than the duty cycle of radio-selected AGNs. XBLs seem to present an intermediate

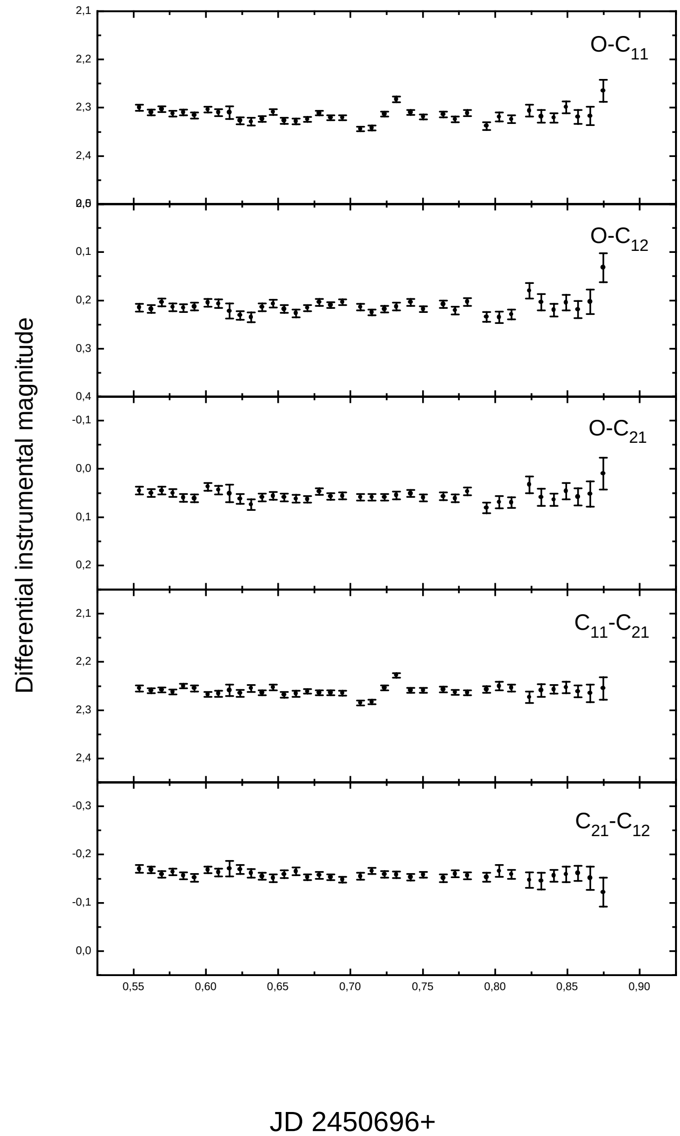

Fig. 8. Differential lightcurves for 2340−469 with respect to different stars in the CCD frame, and comparison curves formed from diffrences among the stars

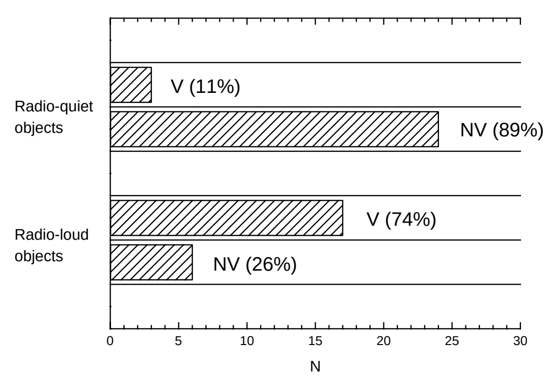

Fig. 9. Histogram with variable (V) and nonvariable (NV) sources of each class (data from northern (Jang & Miller 1995, 1997) and southern (this paper) observations)

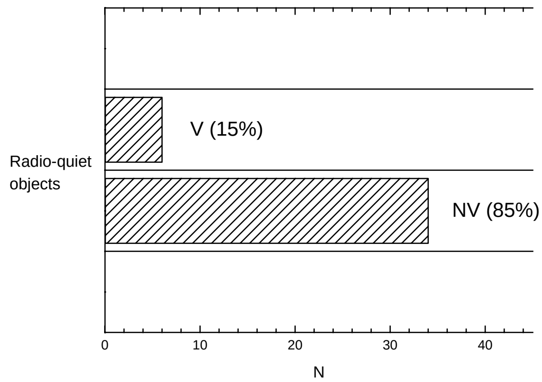

Fig. 10. Histogram for radio-quiet quasars taking into account different available data (see main text)

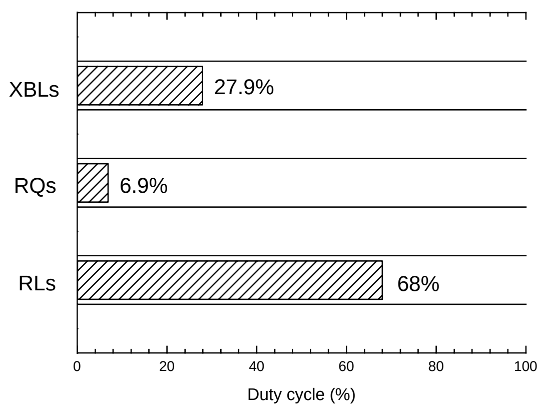

Fig. 11. Microvariability duty cycles for X-ray selected BL Lac objetcs (XBLs), radio-quiet quasars (RQs) and radio-selected objects (RLs). The duty cycle is estimated according to Eq. (2)

level of activity, as previously noted by Heidt & Wagner (1998) from their intraday observations. We notice, however, that microvariability is not as frequent as optical intraday variability. The variability amplitudes for RBLs are also considerably smaller at timescales of a few hours: Heidt & Wagner (1996) estimate a mean IDV amplitude of $\sim$28% while for microvariations we obtain $< Y > \ \sim 5\%$.

In Table 5 we present the duty cycles estimated for the different types of objects (RQQSOs, RQS1s, RLQSOs, RLS1s, etc.). It is clear that these numbers must be considered with caution because of the limited size of the sample. Future observations could improve, and may be strongly modify, these estimates.

Table 5. Duty cycles for different types of AGNs from a sample of 53 objetcs

Type	Number of objects	Duty cycle (%)
RQQSOs	15	2.7
RQS1s	12	11.3
RQQSOs+RQS1s	27	6.9
RLQSOs[1]	14	71.5
RLS1s	9	61.9
RLQSOs+RLS1s	23	68.0
XBLs	3	27.9

[1] "RLQSOs" includes both radio-loud quasars and radio-selected BL Lacs.

After the first version of this paper was completed we became aware of the comparative study of microvariability properties in RL and RQQSOs carried out by de Diego et al. (1998). On the basis of their analysis of the results of intranight observations of 17 radio-quiet and 17 radio-loud objects they claim, contrarily to what is suggested by all previous studies, that microvariability is a rather common phenomenon among RQQSOs, with duty cycles perhaps similar to those of RLQSOs. Their results, unfortunately, cannot be directly compared with those presented in this paper. Observational and analysis procedures are radically different between these two studies. de Diego et al. have observed each source between 3 and 9 times per night. Each observation consisted of five 1-min exposures of the target field. The resulting lightcurves have, consequently, lower temporal resolution than the ones discussed here. In addition, the microvariability analysis is made through the ANOVA procedure which determines observational errors directly from the object minus reference star observations within each set of data, and not from the scatter of comparison lightcurves as in our case. The problems of comparing results obtained from such different methods can be clearly appreciated considering the case of US 995, one of the most variable RQQSOs in de Diego et al. sample. After the first hour of observation, the brightness of this object increased about a tenth of magnitude, and dropped again when it was observed 1.5 hr later. The set of five 1-min exposures that contains the variation corresponds, according to de Diego et al., to a change of 0.17 mag in 120 s. Since the dispersion of the corresponding set of five points in a single comparison star is small, they conclude that the atmospheric conditions were good and that the feature in the lightcurve could be real. However, in the remaining 6 sets of observations of that night, the scatter of the comparison is similar to, or even considerably larger than, that displayed by the target. In abscence of other comparison lightcurves, there is no reason to claim that the QSOs was variable in a set of data and the comparison was not in the others. Moreover, an average comparison, as used in our research, would have provided almost certainly a larger scatter for the set of data in question, and the overall scatter of the QSOs lightcurve probably would not have satisfied a 2.6 σ variability criterion. In order to produce a set of data that can be effectively compared with results obtained by other researchers, a larger number of comparison stars are required and the positions of these stars should be made explicit. This would allow to reproduce similar results with different instruments on the same objects, confirming the reality of the events.

5. Discussion

The results found in this research could imply that strong perturbations (like propagating shock waves) are a common phenomenon in the initial section of the jets of RL objects whereas localized disturbances in the accretion disks are more rare occurrencies, at least at very short timescales. Roughly speaking, 1 out of 10 disks would display this latter kind of activity (to the extent it is strong enough to be visible above noise in measurement of the steady flux), according to the microvariability data for RQQSOs. Contrariwise, the relativistic jets of RL sources seem to be very prone to undergo strong perturbations. If the flux microvariations are associated, as proposed by several authors, to the interactions of thin shocks with small features (e.g. eddies or inhomogeneities in the particle density) in the otherwise steady jet flows, then rapid variability studies can be used to explore the fine-scale structure of the inner jets.

Let us consider, as an example, the microvariations displayed by the BL Lac object 0537−441 during our observations. The variability timescale associated to a flux change ΔF can be estimated as $t_{\rm v} = \Delta F/({\rm d}F/{\rm d}t)$, which in the case of $0537-441$ gives $t_{\rm v} \approx 16.9$ hours. This timescale can be related to the size l of the feature in the jet by (e.g. Romero et al. 1995b):

$$l \sim t_{\rm v} c \gamma^2 (1+z)^{-1}, \tag{3}$$

where $\gamma = (1-\beta^2)^{-1/2}$ is the Lorentz factor of the shock and we have assumed a small viewing angle ($\cos\theta \sim \beta$) as suggested by VLBI observations of $0537-441$ (e.g. Shen et al. 1998). This assumption allows us to replace the Doppler factor $\delta = [\gamma(1-\beta\cos\theta)]^{-1}$ by γ in the calculations. Adopting $\gamma \sim 10$ we get a feature size of $l \sim 0.2$ pc. Notice that the thickness of the shocked region behind the shock front must be considerably smaller than this length if the lightcurve displays a well-defined outburst as it is the case in $0537-441$. We can reasonably assume, consequently, a thickness $\Delta x \sim 0.02$ pc for the post-shock region where the excess of radiation is produced. This means that the shock-feature interaction must be occurring very close to the jet's apex (at, let's say, $0.1-5$ pc) because Δx increases with the distance traveled by the shock along the jet (Blandford & McKee 1976). Features like density inhomogeneities, bends, or even turbulent eddies can be produced at such distances from the nucleus by Kelvin-Helmholtz instabilities in the interface between the jet and the external medium if the magnetic field is not very strong (Romero 1995).

It is an interesting point that XBL objects seem to have higher magnetic fields and/or electron energies than radio-selected blazars (Sambruna et al. 1996). This is consistent, in the shock-in-jet scenario, with the fact that the former objects present lower duty cycles and smaller variability amplitudes. Romero (1995) has shown that axial magnetic fields prevent the development of Kelvin-Helmholtz instabilities in sub-parsec to parsec-scale jets if their values exceed the critical value $B_{\rm c}$ given by:

$$B_{\rm c} = [4\pi n m_{\rm e} c^2 (\gamma^2 - 1)]^{1/2} \gamma^{-1}, \tag{4}$$

where n is the local electron density, $m_{\rm e}$ is the electron rest mass, and γ is the flow's bulk Lorentz factor. In XBLs $B > B_{\rm c}$ fields would inhibit the formation of small-scale structures reducing the incidence of microvariability in the optical lightcurves. Duty cycles for longer variations (timescales from months to years), originated in the shock own evolution (e.g. Marscher 1990), should instead be similar in both kind of objects unless there were differences in the shock-formation mechanism.

As we mentioned in the Introduction, superluminal gravitational microlensing has been also suggested as a possible explanation of microvariability in some objects (e.g. Rabbette et al. 1996). In the case of $0537-441$ this alternative explanation cannot be ruled out. There is a report of a foreground galaxy (Stickel et al. 1988) at a possible redshift of $z = 0.186$. Compact objects (planets, stars) in the galaxy can produce a rapidly variable lightcurve by gravitational magnification of a superluminal component in the background blazar. This scenario for the rapid variability of $0537-441$ has been developed in detail by Romero et al. (1995a), including the constraints introduced in the mass density distribution of the interposed galaxy by the fact that just one macroimage of the blazar is observed (Narayan & Schneider 1990). Using this model, we have estimated that the observed optical microvariations require a superluminal shock with a radius $r_{\rm s} \sim 1.8\ 10^{-3}$ pc, which should be propagating at a distance of ~ 0.018 pc from the jet's apex (we assume, once again, $\gamma \sim 10$ and $\cos\theta \sim \beta$). From the requirement that the angular radius of the source must be smaller than the Einstein angular radius of the lenses in the intervening galaxy we obtain that the masses must be $\gtrsim 0.05\ M_{\odot}$ (i.e. they can be any kind of stars).

Whether microlensing is the main cause of microvariability in 0537−441 or not will be decided by simultaneous multifrequency observations in the near future (Romero et al., in progress). Beyond the final result for this particular object, it is clear that microlensing alone cannot account for the very high duty cycle of RL sources. The main candidate for producing very rapid variability in these AGNs is the interaction of shocks with features in the relativistic jets of these objects. New microvariability studies at different wavelengths of individual sources where shock velocities are well-constrained by frequent VLBI observations can be used to determine the microstructure of the innermost part of the jets.

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