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Polarization microvariability of BL Lacertae objects[⋆]

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ABSTRACT

We present the results of a systematic observational campaign designed to search for microvariability in the optical polarization of BL Lac objects. We observed a sample formed by 8 X-ray-selected and 10 radio-selected sources, looking for rapid changes in both the degree of linear polarization and the corresponding polarization angle. The whole campaign was carried out during the last three years, and most of the objects were observed on at least two consecutive nights. The statistical properties of both classes of BL Lac objects are compared, and some general conclusions on the nature of the phenomenon are drawn. In general, radio selected sources seem to display higher duty cycles for polarimetric microvariability and, on average, they have a stronger polarization.

Key words. galaxies: active – galaxies: BL Lacertae objects: general – polarization

1. Introduction

The existence of rapid changes (time scales from minutes to hours) in the optical brightness of blazars is a well established fact (Racine 1970; Miller et al. 1989; Romero et al. 1999; Stalin et al. 2004, 2005). These variations are usually called *microvariability* or *intranight* variability. The incidence of the phenomenon on different classes of active galactic nuclei (AGNs) also seems to be different (Jang & Miller 1997; Romero et al. 1999, 2002; Stalin et al. 2005). BL Lacertae objects, along with flat radio-spectrum quasars, seem to be among the most variable sources on short time scales. BL Lacs, in turn, can be divided into two groups: X-ray selected BL Lacs (XBLs) and radio-selected BL Lacs (RBLs) according to their spectral energy distributions (SEDs). In general, both types of objects have SEDs with two peaks, one thought to be due to synchrotron emission and the other produced by inverse Compton upscattering of lower energy photons. In the case of XBLs, the synchrotron peak falls in the X-ray band. In RBLs this peak is shifted towards lower energies, being between the radio and infrared bands. The optical microvariability behaviour of both sub-types of BL Lacs seems to be quite different (Heidt & Wagner 1996, 1998; Romero et al. 2002). The XBLs are usually less variable with smaller duty cycles and variability amplitudes than the RBLs.

Although the optical microvariability phenomenon has been extensively studied for different AGNs, little is known about the polarimetric behaviour of these objects on time scales of hours. High-temporal resolution polarimetry has been performed for a few particular sources (e.g. 3C 279, Andruchow et al. 2003) confirming the existence of microvariability in the optical polarization of some objects, but there is still no statistically significant information.

In this paper we present, for first time, results of a systematic search for microvariability in the polarization of a sample of BL Lac objects. We looked for rapid changes in the degree of linear polarization and in the position angle of both XBLs and RBLs. Our total sample has 18 objects, so we are able to extract some statistical conclusions on the duty cycles for these sub-types of sources. For most of the objects, this is the first time that high time resolution polarimetric observations have been performed.

The structure of the paper is as follows. In Sect. 2 we present a detail of the observed sample. In Sect. 3 we describe the polarimetric observations. In Sect. 4.1 we describe the statistical data analysis. Section 4.2 presents individual notes on the behaviour of each source. In Sect. 4.3 we briefly comment on the normalized Stokes parameters. In Sect. 5 we discuss the statistics and the origin of the observed variability. Finally, we close with our conclusions in Sect. 6.

2. Sample

The sample adopted for this work consists of 18 sources –10 radio-selected blazars (RBL) and 8 X-ray-selected blazars (XBL) – and is taken from the AGN catalogs by

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Table 1. Observed sample: general information.

Object	$\alpha(2000)$ [h m s]	$\delta(2000)$ [° ′ ″]	Type	$E(B-V)$	z	$\langle m_v \rangle$ [mag]	$P_{\max} \pm \sigma$ [%]	Ref.[a]
0118−272	01:20:31.6	−27:01:25	RBL	0.014	0.559	16.5	18.7 ± 1.0	SF
0422+004	04:24:46.8	+00:36:06	RBL	0.101	0.310	17.0	23.3 ± 1.1	SF
0521−365	05:22:58.0	−36:27:31	RBL	0.039	0.055	14.5	6.0 ± 1.5	SF
0537−441	05:38:50.3	−44:05:09	RBL	0.038	0.894	15.5	18.7 ± 0.5	SF
0548−322	05:50:39.7	−32:16:18	XBL	0.035	0.069	18.3	1.4 ± 0.8	SF
0558−385	06:00:22.1	−38:53:55	XBL	0.054	0.044	–	–	F
0829+046	08:31:48.9	+04:29:39	RBL	0.033	0.180	16.5	12.0 ± 3.0	SF
1026−174	10:26:58.5	−17:48:58	XBL	0.058	0.114	16.6	–	
1101−232	11:03:37.6	−23:29:30	XBL	0.059	0.186	16.6	7.4 ± 1.5	SF
1144−379	11:47:01.4	−38:12:11	RBL	0.096	1.048	16.2	8.5 ± 1.7	IT
1312−422	13:15:03.4	−42:36:50	XBL	0.105	0.108	16.6	–	
1440+122	14:42:48.2	+12:00:40	XBL	0.028	0.162	17.1	–	
1510−089	15:12:50.5	−09:06:00	RBL	0.097	0.360	16.5	1.9 ± 0.4	SF
1514−241	15:17:41.8	−24:22:19	RBL	0.138	0.049	15.1	6.9 ± 1.3	SF
1553+113	15:55:43.0	+11:11:24	XBL	0.052	0.360	15.0	–	
1749+093	17:51:32.8	+09:39:01	RBL	0.180	0.322	16.8	31.3 ± 0.6	SF
2005−489	20:09:25.4	−48:49:54	RBL	0.056	0.071	15.3	2.0 ± 0.2	SF
2155−304	21:58:52.0	−30:13:32	XBL	0.022	0.116	14.0	10.3 ± 0.3	SF

[a] IT: Impey & Tapia (1990), SF: Scarpa & Falomo (1997), F: J.H. Fan, private communication.

Véron-Cetty & Véron (1998) and Padovani & Giommi (1995). We selected blazars with declinations lower than +20° and brighter (at the time of our observations) than magnitude $V = 18.5$. The redshifts spanned the range from $z = 0.044$ to $z = 1.048$. Basic general information on these objects is given in Table 1. In this table, Col. 1 gives the name of the sources, Cols. 2 and 3 give their equatorial coordinates, Col. 4 their classification; Cols. 5–7 provide the colour excesses, the redshifts, and the visual magnitudes taken from the NASA Extragalactic Database (NED); Col. 8 gives the published maximum degree of optical linear polarization (for those cases in which this value was know from the literature), and Col. 9 gives the corresponding references for Col. 8.

3. Polarimetric observations and data reduction

The observations were done with the 2.15-m Jorge Sahade telescope at CASLEO, San Juan, Argentina, during 22 nights in April and November 2002, May 2003, and April 2004. On all occasions, we used the CASPROF photopolarimeter. This is an instrument developed at CASLEO and based on other similar two-channel photopolarimeters, such as MINIPOL and VATPOL (Magalhães et al. 1984; Martínez et al. 1990). The observations were carried out always using the same configuration: a Johnson V filter and an 11.3 arcsec aperture diaphragm. Integration times varied between 300 and 900 s, depending on the object brightness and the quality of the night. In all cases, we observed the target followed by a sky integration. Standard stars chosen from the catalog by Turnshek et al. (1990) were observed to determine the zero point for the position angle and the instrumental polarization; the latter was found to be practically zero. Weather conditions varied during the whole campaign from photometric to partially cloudy (thin cirrus).

The data were processed using a systematic method, after discarding some data points affected by moonlight contamination or passing clouds. We averaged each two consecutive target observations (on the $Q-U$ plane) in order to improve the signal-to-noise ratio. A factor that affects both the object and the sky is the presence of the Moon above the horizon. However, any systematic error leading to spurious variations in the sky polarization should be removed when the data are reduced, because each sky observation is made near in time and position to the corresponding source measurement. To prevent errors due to rapid sky variations, we interpolated the sky flux and polarization (on the $Q-U$ plane) to the time corresponding to each object observation, thus giving a more accurate sky subtraction.

For each observing session we searched for any residual systematic errors by plotting the sky magnitude, as well as its polarization percentage and position angle, against time and then comparing these graphs with the corresponding time-curves for the sources. No spurious variations due to rapid sky changes were evident. Two examples of typical microvariability curves are shown in Figs. 1 and 2; Fig. 1 presents the behaviour of the RBL object PKS 0422+004 during two consecutive nights in November 2002, whereas Fig. 2 shows the behaviour of the XBL source PKS 2155−304 for three nights in November 2002. Sky values are given as open symbols in both figures; note that a different scale was used for the sky plots. Both objects were always ~0.5–3 mag brighter than the sky, thus confirming that any effect due to sky variations should not be important.

We also checked for the incidence of the foreground polarization, the polarization generated by interstellar dust particles oriented by the magnetic field of the Galaxy. Following Hough (1996), we used the known relation $P_{\max}\,(\%) \leq 9\,E_{(B-V)}$ to set

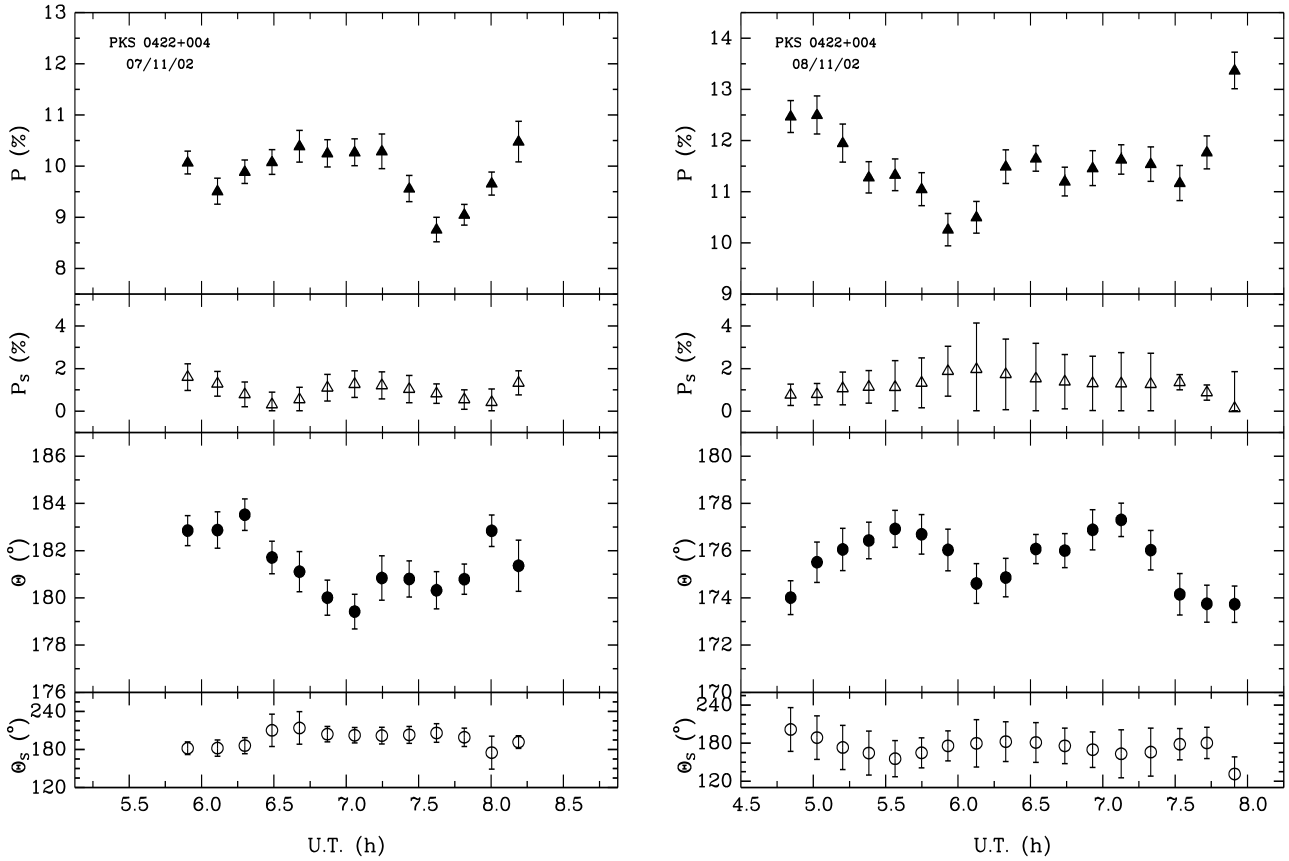

Fig. 1. Polarization and position angle for the RBL PKS 0422+004 (solid symbols) and for the corresponding sky measurements (open symbols) as a function of time for two consecutive nights in November 2002.

an upper limit to the foreground polarization in each of our fields. In Col. 5 of Table 1 we give the $E_{(B-V)}$ values taken from the NED; the result is that, since we observed at relatively high Galactic latitudes, the values of $P_{\max}$ are between 0.13% and 1.62%. With the same purpose, we observed faint stars in most of the target fields in order to check their polarization values. In all the cases, values were $\ll 1\%$. Thus, we are able to confirm that the foreground polarization does not affect our results.

We used the Stokes parameters to check whether the pattern of the observations was random in the $Q-U$ plane or not. We consider, as usual, normalized dimensionless parameters U/I and Q/I. $Q-U$ plots for all objects of our sample are available at `http://www.iar.unlp.edu.ar/garra/garra-sdata.html`.

4. Data analysis and results

4.1. Statistical analysis

We quantitatively analyzed our data by computing a formal variability indicator, following the criterion of Kesteven et al. (1976), which was used by several other authors in variability studies (Altschuler 1982; Romero et al. 1994; Andruchow et al. 2003). According to this criterion, a source is classified as variable in an observing session for the observable S, if the probability of exceeding the value

$$X^2 = \sum_{i=1}^{n} \epsilon_i^{-2} (S_i - \langle S \rangle)^2 \qquad (1)$$

by chance is <0.1%, and it is classified as non-variable if the probability is >0.5%. In this equation, ϵ_i is the error corresponding to each measured value S_i, and $\langle S \rangle$ is the mean value of S, given by:

$$\langle S \rangle = \frac{\sum_{i=1}^{n} \epsilon_i^{-2} S_i}{\sum_{i=1}^{n} \epsilon_i^{-2}}. \qquad (2)$$

If the errors are random, X^2 should be distributed as χ^2 with $n-1$ degrees of freedom, where n is the number of points in the distribution.

The other parameters that quantify the variability, in amplitude as well as in timescale, are: the fluctuations index μ,

$$\mu = 100 \frac{\sigma_s}{\langle S \rangle}\ \%, \qquad (3)$$

where σ_s is the standard deviation of one data set; the fractional variability index of the source FV,

$$FV = \frac{S_{\max} - S_{\min}}{S_{\max} + S_{\min}}, \qquad (4)$$

where $S_{\max}$ and $S_{\min}$ are the maximum and minimum values, respectively, for the polarization or the position angle. Finally, the time interval Δt between the extrema in the polarization curve is defined as:

$$\Delta t = |t_{\max} - t_{\min}|, \qquad (5)$$

where $t_{\max}$ and $t_{\min}$ are the times when the extreme points occur.

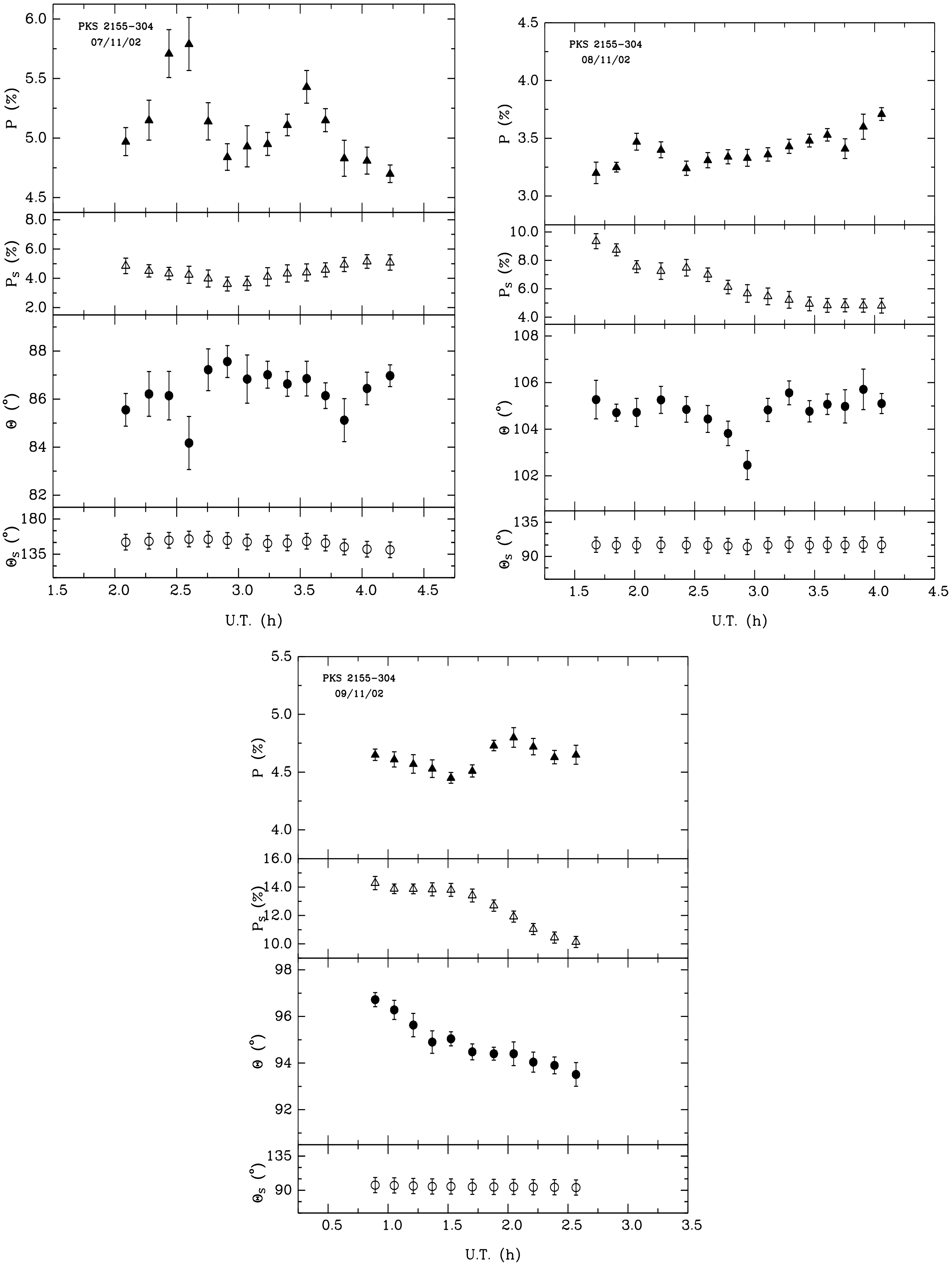

Fig. 2. Polarization and position angle for the XBL PKS 2155−304 (solid symbols) and for the corresponding sky measurements (open symbols) as a function of time for three consecutive nights in November 2002.

Table 2. Variability results for the class of RBL.

				Degree of polarization						Position Angle					
Object	Date [d/m/y]	n	Δt_{obs} [h]	$\langle P \rangle$ [%]	σ_P	*F.V.*	Δt [h]	χ^2	*V/NV*	$\langle \theta \rangle$ [°]	σ_θ	*F.V.*	Δt [h]	χ^2	*V/NV*
0118-272	02/11/02	9	1.75	8.17	1.091	0.24	0.9000	42.106	*V*	139.43	1.539	0.026	0.7500	13.769	*V*
	03/11/02	14	2.22	7.97	0.265	0.051	0.2482	7.632	*NV*	140.38	2.108	0.029	2.0145	39.788	*V*
0422+004	07/11/02	13	2.44	9.75	0.544	0.089	0.5667	53.461	*V*	1.44	2.117	0.023	2.045	52.255	*V*
	08/11/02	17	3.44	11.52	0.739	0.132	1.9803	77.395	*V*	175.61	1.177	0.017	0.784	36.725	*V*
0521-365	05/11/02	6	4.22	3.05	0.769	0.331	2.1387	61.38	*V*	140.63	4.924	0.044	1.2391	48.146	*V*
	06/11/02	8	3.93	2.88	0.105	0.054	2.1621	3.583	*NV*	144.43	5.874	0.061	2.3018	82.220	*V*
0537-441	05/11/02	5	3.05	9.92	0.744	0.095	0.9363	5.539	*Dubious*	6.93	2.120	0.377	0.936	6.594	*V*
	06/11/02	8	3.90	7.93	0.717	0.148	2.7658	16.412	*V*	0.74	1.869	0.015	0.5347	9.716	*Dubious*
0829+049	08/05/03	4	0.77	17.93	0.759	0.042	0.5137	9.108	*V*	215.03	3.770	0.021	0.7740	97.224	*V*
1144-379	09/04/02	8	5.61	3.36	2.405	0.804	4.1942	15.849	*V*	117.48	24.269	0.258	1.138	37.343	*V*
	10/04/02	8	5.76	3.91	5.729	0.735	4.3768	85.500	*V*	136.64	7.426	0.088	4.0491	12.018	*V*
1510-089	11/04/02	9	5.20	3.33	4.177	0.910	2.5129	63.811	*V*	79.25	44.994	0.734	0.5221	116.431	*V*
	15/04/04	12	3.85	3.41	1.990	0.769	0.9415	16.299	*V*	108.56	36.589	0.473	2.8886	47083.1	*V*
	16/04/04	8	3.23	3.35	1.738	0.727	0.7196	4.552	*NV*	51.16	37.264	0.973	1.7916	46.579	*V*
1514+939	09/04/02	12	5.46	1.81	0.278	0.256	1.0489	46.857	*V*	155.52	10.666	0.086	2.9042	231.435	*V*
	10/05/03	11	3.08	2.91	0.442	0.258	1.5780	18.14	*V*	157.62	4.060	0.039	2.7840	19.759	*V*
	18/04/04	6	1.49	3.33	0.329	0.113	0.626	12.254	*V*	174.09	10.150	0.027	0.8911	13.444	*V*
1749+094	06/05/03	15	4.55	2.41	1.447	0.876	2.628	17.718	*Dubious*	81.771	62.561	0.644	1.9750	256.071	*V*
	07/05/03	14	4.66	4.66	2.489	0.739	0.579	30.725	*V*	91.492	58.908	0.618	1.8922	530.175	*V*
2005-489	10/11/02	9	1.35	11.93	0.136	0.016	0.344	12.376	*V*	93.560	0.262	0.003	1.0270	7.701	*Dubious*

In Tables 2 and 3 we show the values of the variability parameters for the linear polarization percentage and the position angle for the RBLs and XBLs, respectively. Column 1 gives the name of the object, Col. 2 lists the observation dates, Col. 3 shows the number of points for each night, Col. 4 gives the total duration of the observation, Col. 5 gives the mean polarization for the observing night using Eq. (2), Col. 6 shows the rms σ_{P}, Col. 7 gives the value for FV, Col. 8 is Δt, Col. 9 shows the value of χ^2, and Col. 10 shows the variability class (V: if the source is variable, NV: if it is not variable, and *dubious* in the cases where no definite decision could be reached using the above given criteria). Columns 11 to 16 give the same information for the position angle.

4.2. Notes on individual sources

We now comment briefly on the observed behaviour of each object in our sample.

RBLs:

0118−272: the linear optical polarization of this object was measured by Impey & Tapia (1988) with a significantly high value ($P_V \sim 17\%$). This was one of the reasons for its classification as a blazar; a similar result was obtained by Mead et al. (1990). We observed this blazar on two consecutive nights, presenting variability on the first one, with the degree of polarization rising from $P = 5.77\%$ to $P = 9.41\%$ in about one hour. On the second night, the degree of polarization appears as not variable but with a value of about 8%. Meanwhile, the position angle was variable with similar averages on both nights.

0422+004: this blazar was reported to have quite high values of linear optical polarization, between 7–22% (Angel & Stockman 1980), presenting high variability over long periods of time (months). Mead et al. (1990) observed the source on two consecutive nights, detecting a decreasing degree of polarization from the first night to the second one (21.4%–12.4%, respectively). In Fig. 1 we show the temporal evolution of the linear polarization degree and position angle for this object, as an example of the RBL class. This is the best sampled RBL in our campaign. It turned out to be variable, both in P and θ, on the two nights. The degree of polarization was quite high, mostly during the second night, reaching values up to ~13%. The general trend was a smooth variation each night, with a higher mean value for the second night. These values are in agreement with the published ones. The position angle was variable; however, its mean value did not change significantly between both nights.

0521−365: this southern blazar has been reported to have rapid variability at radio frequencies (see Romero et al. 1995b), as well as optical flux microvariability (Romero et al. 2002). Its host was detected and classified as a luminous giant elliptical by Falomo (1994). During the present campaign, the object experienced polarization variability on the first night, but the variability is not significant on the second one. We think that the cause of this could be the relatively large error bars for

Table 3. Variability results for the class of XBL.

				Degree of polarization						Position Angle					
Object	Date [d/m/y]	n	$\Delta t_{\rm obs}$ [h]	$\langle P\rangle$ [%]	σ_P	*F.V.*	Δt [h]	χ^2	*V*/*NV*	$\langle\theta\rangle$ [°]	σ_θ	*F.V.*	Δt [h]	χ^2	*V*/*NV*
0548-322	09/11/02	21	5.06	1.48	0.446	0.640	0.7730	44.687	*V*	38.24	16.447	0.646	3.4790	116.351	*V*
	10/11/02	15	1.35	1.31	0.383	0.469	1.3610	22.713	*V*	37.63	12.257	0.666	1.9260	41.939	*V*
0558-385	02/11/02	9	2.43	0.81	0.829	0.940	1.2323	40.135	*V*	110.97	50.081	0.786	0.3138	149.150	*V*
	03/11/02	11	2.68	0.73	0.966	0.881	0.8140	22.137	*V*	89.17	40.305	0.648	0.8329	101.247	*V*
1026-174	06/05/03	9	2.64	6.31	1.117	0.229	0.3229	6.436	*Dubious*	181.14	9.160	0.077	1.3460	15.106	*V*
	07/05/03	5	1.17	5.44	1.173	0.278	0.8190	5.615	*Dubious*	184.63	6.203	0.043	0.5590	4.792	*Dubious*
1101-232	08/04/02	3	0.89	1.77	1.301	0.731	0.8853	6.729	*V*	56.96	18.632	0.344	0.4461	0.955	*Dubious*
	11/04/02	4	1.40	2.68	0.855	0.317	0.4100	3.761	*Dubious*	73.02	9.081	0.132	0.3740	2.966	*NV*
	12/04/02	3	0.76	1.72	0.807	0.476	0.7585	1.805	*Dubious*	70.34	8.846	0.104	0.3796	0.9800	*NV*
	09/05/03	3	2.04	8.38	4.713	0.376	0.3350	28.232	*V*	8.84	11.634	0.948	0.3350	33.480	*V*
	15/04/04	8	2.76	1.68	0.981	0.622	0.3710	4.765	*NV*	47.80	32.350	0.229	1.1411	23.578	*V*
1312-422	07/04/02	3	0.73	2.23	0.796	0.347	0.7760	0.699	*NV*	47.53	23.597	0.570	0.7760	2.258	*V*
	16/04/04	6	1.96	1.62	1.202	0.937	0.7929	6.476	*Dubious*	81.88	28.538	0.503	0.3613	6.897	*Dubious*
1440+122	07/04/02	11	1.62	3.36	3.014	0.883	0.9375	39.004	*V*	90.65	30.748	0.655	0.5041	52.332	*V*
	08/04/02	11	4.92	2.40	2.223	0.769	2.2501	22.142	*V*	95.62	27.990	0.459	3.1650	32.290	*V*
1553+113	08/05/03	12	3.69	3.22	0.275	0.130	0.6070	58.190	*V*	145.72	3.899	0.042	1.7940	169.885	*V*
	09/05/03	16	3.96	3.52	0.233	0.109	0.9913	43.744	*V*	150.40	2.807	0.032	1.7616	122.118	*V*
2155-304	07/11/02	14	2.14	4.99	0.349	0.104	1.6264	63.442	*V*	86.53	0.925	0.020	0.3102	14.979	*Dubious*
	08/11/02	15	2.38	3.40	0.135	0.074	2.3804	72.483	*V*	104.77	0.748	0.016	0.9676	23.177	*V*
	09/11/02	11	1.67	4.70	0.018	0.038	0.5227	56.893	*V*	94.93	1.008	0.017	1.6744	74.863	*V*

the degree of polarization during that night, which could mask any variation. The typical error was about 6% of the measurement because of the weather conditions. The mean value of the degree of linear polarization was almost the same in the two nights, about 3%. The position angle was clearly variable during the two nights, with a small but clear rotation on the second night: during the first hours, of 5°/h in a clockwise direction, and during the last hours, of 7.6°/h in an anticlockwise direction. Large rotations of the polarization angle have been previously found at radio wavelengths by Luna et al. (1993) for this source.

0537−441: this is another well-studied BL Lac object, which has shown very high optical polarization during observations carried out by Impey and Tapia in the 1980s (Impey & Tapia 1988). This object was extensively monitored by Romero et al. (2000, 2002), presenting both behaviours as *variable* and as *non-variable* in its optical flux at different epochs. We report here that during two consecutive nights in November 2002, 0537−441 presented a high degree of polarization. On the first night the object's variability appeared as *dubious*; meanwhile on the second night it was clearly *variable*, undergoing rapid fluctuations with typical time scales of ~1 h and amplitudes of ~1.4%. On the contrary, θ was *variable* on the first night and *dubious* on the second one, with a mean $\langle\theta\rangle \sim 0°$.

0829+046: its first polarization observations at optical wavelengths were presented by Wills et al. (1980), who reported variability over a few days time interval. Unfortunately, we could only follow this object for one night. During this period, the object presented a very high degree of polarization (up to 17%), increasing with time, and it was variable in both the degree of polarization and position angle. It is also interesting to mention that this object was observed by Giroletti et al. (2004) at different radio wavelengths in order to resolve the jet structure, and they found that it is one of the BL Lacs that presents evidence of emission on both sides of the core: two symmetric jets were detected emerging from the core and both are bended.

1144−379: this object was classified as a blazar by Impey & Tapia (1988), who reported values for the degree of polarization between 0.0% and 9.4%. We observed the source in April 2002 when it was variable in both P and θ. During the last night, the degree of polarization showed a peculiar behaviour as it rose about 14% in 4 hours, starting at $P = 2.5\%$ and ending at $P = 16.5\%$. After ruling out all possible error sources (see Sect. 3), we conclude that the cause of this peculiar behaviour is intrinsic to the source.

1510−089: this object was confirmed as a blazar by Moore & Stockman (1981). Previous measurements of its optical polarization degree, made in 1980, were all under 7.8%; however, Mead et al. (1990) reported a high value of $P = 9.1\%$, in the I band. We observed 1510−089 during three nights, one in April 2002 and two in April 2004. The position angle was always variable. The degree of polarization was variable in 2002 and on the first night in 2004, but not on the second one. Its average value was about 3% throughout all three nights, but reached values as high as 13.8% during 2002. This BL Lac presented no microvariability during 1998 and 1999 in its optical flux (Romero et al. 2002).

1514−241 (AP Lib): this is one of the objects which defined the blazar class; it has presented values of optical polarization between 2 – 7% (Angel & Stockman 1980). Mead et al. (1990) reported similar values. We followed AP Lib on different occasions, always with variable results; however, the average degree of polarization was quite low. During the last night in April 2004 the position angle rotated in an anti-clockwise direction from 180.3° to 170.9° with a speed of 10.5°/h[1].

1749+093: this object has displayed dramatic polarization variability at optical and infrared wavelengths (Brindle et al. 1986), whereas no significant variations were detected later (Mead et al. 1990). Typical values for the degree of the optical polarization are between 3–9% (Kühr & Schmidt 1990). Our variability data classify the source as *dubious* during the first night and variable on the second one, with a low mean value of the degree of polarization, but reaching a maximum value of $P_V = 9.8\%$. The position angle was variable on both nights, but this variability was probably not real, because when the modulus of the polarization vector is small, the angle is ill defined, thus preventing any real variability to be detected.

2005−489: as far as we know, we are presenting here the first optical polarization data for this BL Lac object. The source was variable with a relatively high degree of polarization during the only night when we could observe it. The position angle variability was classified as *dubious*, but in fact it remained almost constant around 93.7° with a sigma of 0.2°.

XBLs:

0548−322: Angel & Stockman (1980) reported low levels in the degree of polarization (1.5–2%). Similar results were obtained during the campaign undertaken by Jannuzi et al. (1993), when P did not rise above 4%, with position angle variable and showing a 0.5 mag change in its optical flux. We followed this typical BL Lac for two consecutive nights in November 2002 with a good time resolution. During both nights, the degree of optical polarization appeared to be variable but low, and the position angle was variable, too.

0558−385: we present the first polarization results for this object. The average polarization is very low, $\langle P\rangle \sim 0.8$–$0.9$ %. The object formally classifies as *variable* but, since its polarization is so low, the large fluctuations detected in the position angle might be spurious.

1026−174: there are no previous optical polarization data for this blazar. We observed it in May 2003, when it displayed a *dubious* behaviour in its polarization degree. However, during the second night, some variation is present, unfortunately masked by the large error bars due to the weakness of the source. The highest and lowest values of the optical polarization were 7.6% and 3.9%, respectively. The position angle was variable, showing no clear rotation trend with values around 185°.

1101−232: this blazar has been reported as having quite low values of optical polarization (the maximum detected was 2.7%), with evidence of intrinsic variability (Jannuzi et al. 1993). We observed this source in 2002, 2003, and 2004. The behaviour displayed by the source went through different stages (from V to NV) during the different opportunities we had to observe it. During the only night that we observed it in May 2003, P_V rose to 14.7%, a very high value for this object (previously presented lower polarization values).

1312−422: this is another BL Lac with no previous data on its optical polarization. We just followed it on one night in April 2002 and another night in April 2004. The degree of polarization was quite low ($P_V \lesssim 3.4\%$) and not variable on both occasions.

1440+122: published information about this object is scarce. Recent radio observations (Giroletti et al. 2004) revealed more details about its structure, but no previous optical polarization data are available. This blazar was variable in both P_V and θ during April 2002. P_V reached as high a value as ≈8.3%, with a peculiar behaviour during the first night we followed it. After discarding any possible error sources (see Sect. 3), the trend in the polarization degree is an interesting one, rising from $P_V = 1.3\%$ to $P_V = 8.3\%$ during the first 1.8 h, then going down to $P_V = 0.5\%$ in about 1 h, and finally rising again up to $P_V = 7.5\%$. Meanwhile, the mean polarization was not too high ($\langle P_V\rangle = 3.4\%$). On the second night, P_V was variable but with no peculiar trend. The position angle did not follow the variations in P_V; however, it was always variable with values around $\theta \simeq 95°$.

1553+133: the degree of polarization of this BL Lac object was variable during our observations with a flickering behaviour on the first night. A qualitatively similar flickering has been detected before at radio wavelengths in extragalactic radio sources (Heeschen 1984; Romero et al. 1995a). In the optical polarization, the origin of the rapid flickering must be intrinsic to the source, probably related to turbulence in the magnetic field of the inner jet. The upper limit of the polarization was 4.2% for this object.

2155-304: this is a very well-studied BL Lac object, known for its short variability time scales at optical to X-ray wavelengths (Jannuzi et al. 1993). Angel & Stockman (1980) reported values for the degree of optical polarization between 3–7%. In the mid 1980s, Brindle et al. (1986) detected polarization percentage variations and a clockwise rotation of the position angle, although on a ~48 h time scale. Four years later, Mead et al. (1990) measured a higher than usual polarization ($P_V \approx 10\%$). The extensive monitoring by Smith et al. (1992) in optical polarization and photometry revealed clear variations

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[1] Joining this information with additional data obtained without filters, the general trend in the position angle was a constant rotation with sporadic direction reversals.

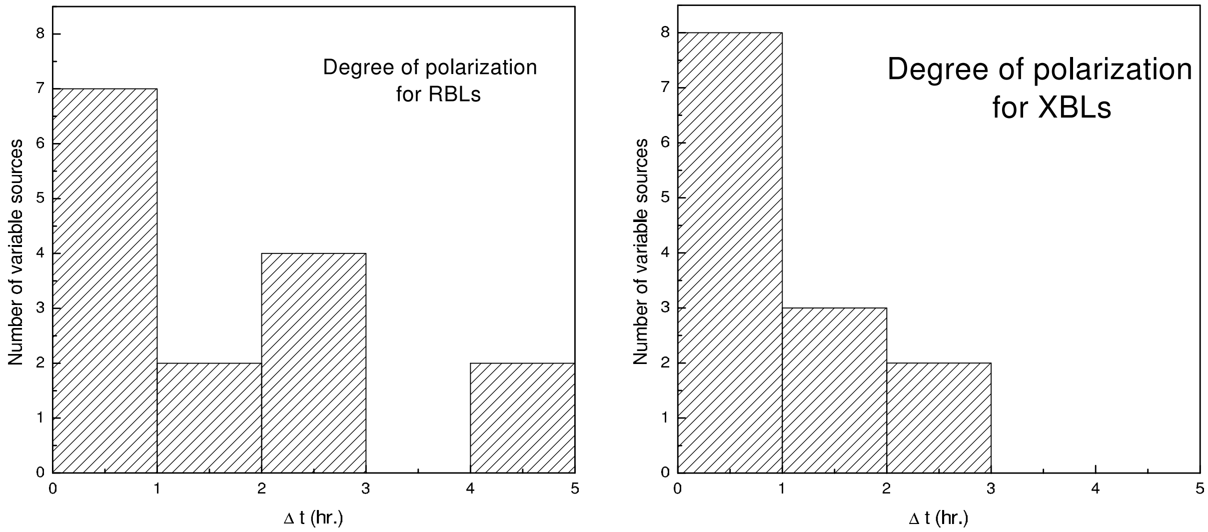

Fig. 3. Histogram with the distribution of variable RBLs and XBLs against the variability timescales (degree of polarization).

over long time scales; the authors also reported a 2%–3% variation in P_V and as much as 25° in θ, in 24 h. They also found a mild wavelength dependent polarization and a more rapid variation in the optical polarization than in the total optical flux. In a more recent work, Tommasi et al. (2001) reported a multiband monitoring of the optical polarization searching for intranight and also long-term variability. This campaign was made using the 2.15 m telescope at CASLEO equipped with the Photopolarimeter of the Turin Observatory, and the total observing time was ~47 h along four different periods in 1998 and 1999. The authors reported a P_V lower than 7% with small amplitude intranight variations, ~1.3% in P and ~7° in θ, but no statistical analysis of this behaviour was reported. They also found a low wavelength dependence in both the linear polarization and the position angle.

Being a relatively bright object, we were able to use short exposure times, thus getting well-sampled time curves. These are shown as an example for the XBL class in Fig. 2. Significant variations both in P_V and θ are clearly seen on each of the three consecutive nights that we followed the source, with a moderately high mean polarization $\langle P_V \rangle \sim 5\%$ and with a position angle varying from $\langle\theta\rangle = 87°$ to $\langle\theta\rangle = 105°$. During the first night, P_V rose as high as 5.7% at the beginning of the night and then went down, ending at 4.7%. Apparently, this decreasing trend continued during the day hours, because at the beginning of the second night, P_V started at 3.2%, going up for the rest of the night and presenting an inverse behaviour during the last night. With respect to the position angle, the variation was clear and presented a fast rotation during the third night. The angle rotated in an anti-clockwise direction from 96.7° to 93.5° with a speed of 1.9°/h.

5. Discussion

In order to characterize the two different classes of objects under study here, we analyzed the behaviour of the sources from a statistical point of view. First, we calculated the duty cycles (DC) for the sources of a given class. This quantity can be estimated, following Romero et al. (1999, 2002), as

$$DC = 100\frac{\sum_{i=1}^{n} N_i,(1/\Delta t_i)}{\sum_{i=1}^{n}(1/\Delta t_i)}\%, \tag{6}$$

where $\Delta t_i = \Delta t_{i,\mathrm{obs}}(1+z)^{-1}$ is the duration, corrected by the corresponding redshift, of the i-th data set of the quantity and class under study; N_i is the weight (equal to 1 if the source was classified as V, or 0 if the source was NV or *dubious*). Because we weighted *dubious* cases with 0, the DCs calculated are actually lower limits. The corresponding DCs for the degree of polarization (P) and position angle (θ) for both classes of objects (RBLs and XBLs) are: $DC(P,\mathrm{RBL}) = 77.01\%$, $DC(\theta,\mathrm{RBL}) = 87.25\%$, and $DC(P,\mathrm{XBL}) = 51.23\%$, $DC(\theta,\mathrm{XBL}) = 55.15\%$. Hence, the RBLs appear to constitute the most variable class. A similar behaviour has been found when only optical flux variations were considered by Romero et al. (2002), with duty cycles $DC = 71.5\%$ and $DC = 27.9\%$ for the RBLs and XBLs, respectively. The photometric microvariability of XBLs seems to be systematically lower, nonetheless, than their polarization microvariability.

A complementary view can be obtained by plotting the histograms of the distributions of the sources that were variable. Figures 3 and 4 show the number of sources classified as *variable* against the time scales for the variation (Cols. 8 and 14 in Tables 2 and 3), for the degree of polarization and position angle, respectively.

It can be seen that the RBLs have a wider and flatter distribution in the degree of polarization than the XBLs, indicating that, when an XBLs is variable, its variation timescale is shorter than that of the RBLs (typically $\Delta t \lesssim 1$ h). The histograms corresponding to the position angles present no significant differences between the two classes.

Similar histograms were made showing the distributions of variable sources against the fractional variability index (Cols. 7 and 13 in the same tables). This is shown in Figs. 5 and 6 for the same parameters as before. Here, the RBLs appear to have two peaks, one for $P \approx 0.2$–0.3% and the other around

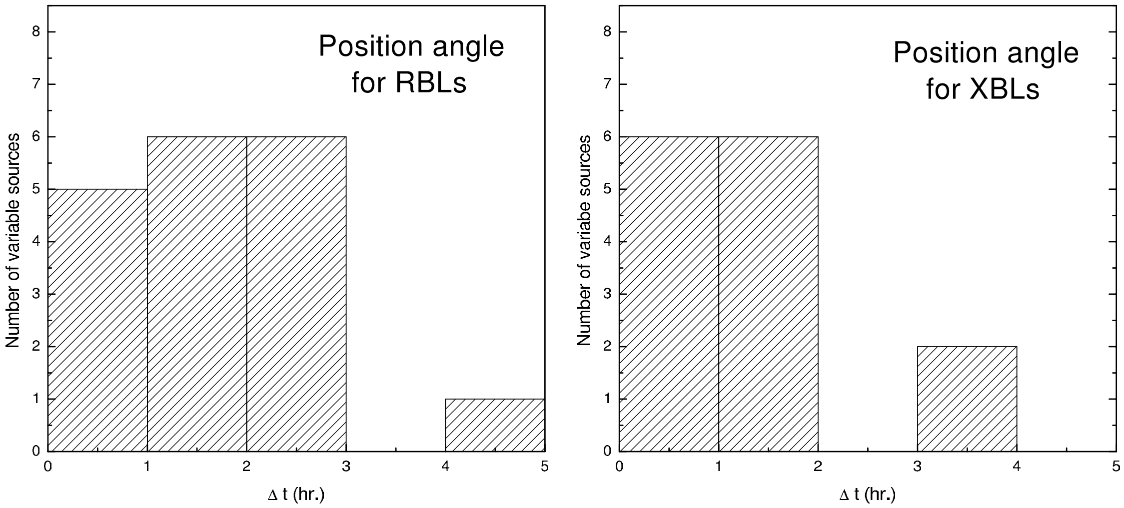

Fig. 4. Idem Fig. 3 (position angle).

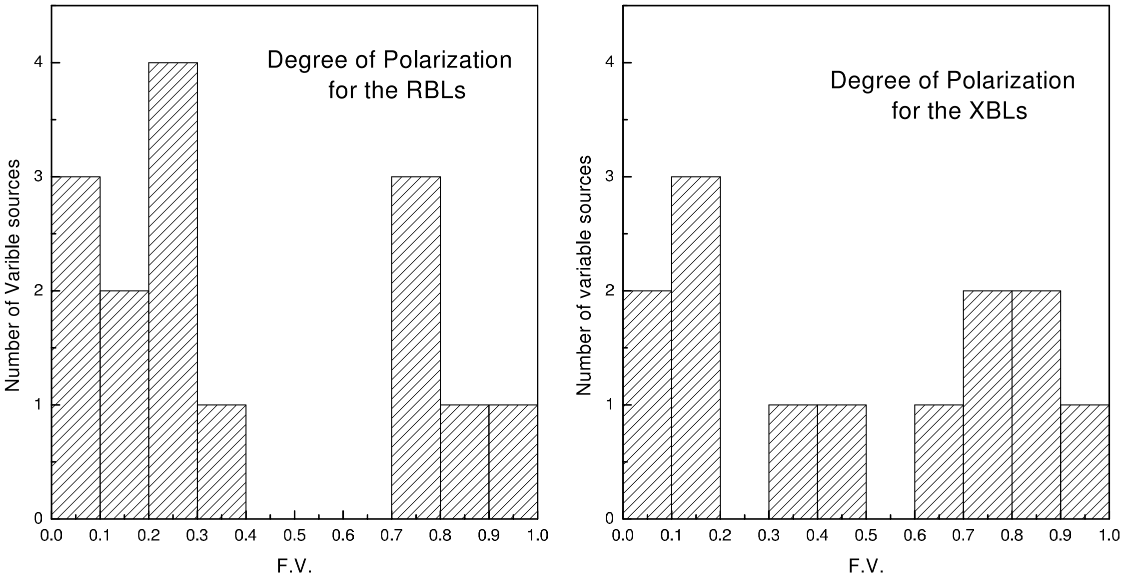

Fig. 5. Histograms with the distribution of variable RBLs and XBLs against the fractional variability index (degree of polarization).

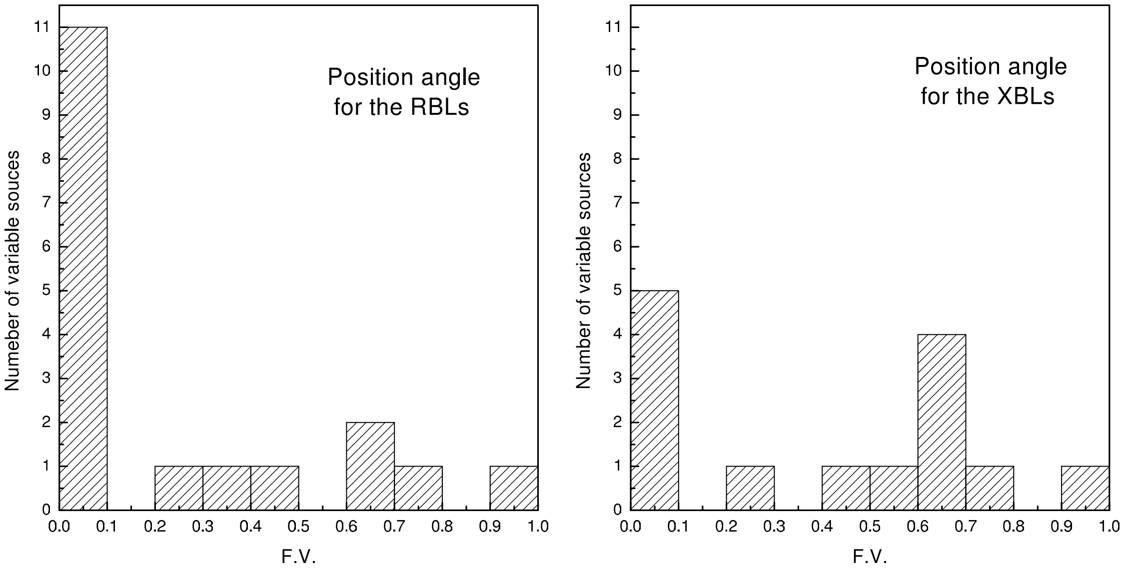

Fig. 6. Same as Fig. 5 (position angle).

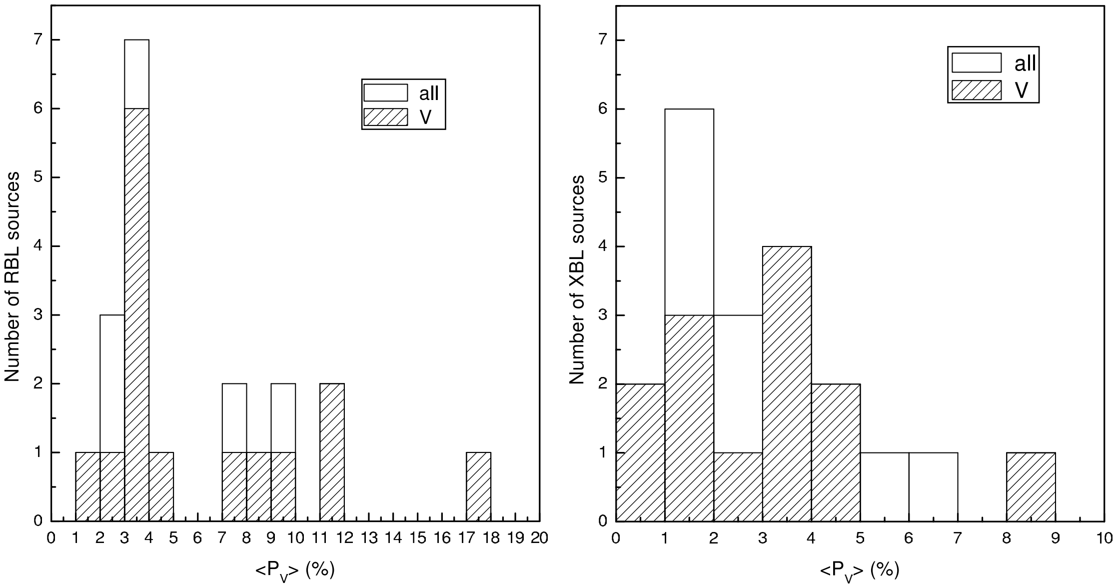

Fig. 7. Histograms with the distributions of all observed sources (*left*: RBLs; *right*: XBLs) against the mean value of the degree of optical polarization.

$P \approx 0.8$–0.9. In contrast, the XBLs have a more uniform distribution. Concerning the position angle, the variation of the RBLs appears to be more frequent for the lowest FV values. Again, the XBLs seem to have a more uniform distribution.

Since we present a significant number of sources here belonging to two different sub-types of BL Lac objects, it is also interesting to compare the average degree of optical polarization between them. Our results confirm the previous ones reported by Fan et al. (1997): the XBLs generally have lower optical polarization than the RBLs. This kind of behaviour can be seen in the histograms drawn in Fig. 7. A Kolmogorov-Smirnov test shows that both data sets are most probably taken from different parent distributions, although the significance level is only moderately high (95%). As an additional piece of information, we also include the distribution of V and NV or *dubious* cases for both classes of BL Lacs studied here.

In general, since XBLs have the synchrotron peak of their spectral energy distribution at X-ray energies, we could expect that these objects have, on average, either higher magnetic fields *or* more energetic particles than RBLs, which peak at radio-IR wavelengths. The fact that they have, on average, less polarization and that this polarization is less variable than what is found for RBLs seems to support the second possibility; i.e., the particles in their jets are systematically more energetic than in RBLs. On the contrary, as noticed by Fan et al. (1997), the RBLs seem to have larger macroscopic relativistic motions, hence displaying higher duty cycles for rapid variability, which is probably associated with relativistic shocks in the jets. Their magnetic fields also seem to be systematically stronger than in XBLs, as indicated by the higher degree of linear polarization. This leads to a simple picture where XBLs have particles with high microscopic Lorentz factors that cool radiating high-energy synchrotron emission, whereas RBLs have less energetic particles but higher macroscopic bulk motions and stronger fields, thus presenting higher variability. Alternatively, XBL could have similar magnetic fields, but less homogeneous ones, hence less degree of linear polarization. The origin of the rapid microvariability seems to be associated with relativistic shocks, in any case (e.g. Romero et al. 1995b, and references therein).

6. Conclusions

We monitored 8 XBLs and 10 RBLs, looking for intranight variability in the optical polarization. We found high duty cycles for both the degree of linear polarization and the polarization angle of RBLs. The average polarization is also stronger than for XBLs. Although displaying a lower level of polarimetric microvariability, XBLs are also significantly variable with duty cycles of ~50 %, higher than what is observed from purely photometric observations. On the basis of our findings we speculate that the stronger synchrotron losses presented by XBLs might be due to systematically higher microscopic Lorentz factors for the particles in the jets, rather than to stronger magnetic fields. However, it should be noted that further observations of objects (with each object monitored on several nights) are needed to establish this conclusion firmly.

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