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Radio Polarization Properties for Blazars

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Abstract

We used data from the University of Michigan Radio Astronomy Observatory (UMRAO) at three different bands (4.8 GHz, 8 GHz, and 14.5 GHz) to calculate the radio spectral index and the averaged polarization in a sample of 92 flat spectrum radio quasars (FSRQs). We analyzed the relationship between the polarization and other physical parameters for these objects. The results show that: 1) the polarization and its variability at high radio frequencies are higher than those at lower frequencies, 2) the degree of linear polarization is correlated with the radio spectral index, suggesting that the synchrotron mechanism is responsible for the radio emission, 3) the polarization is correlated with the core-dominance parameter for those objects for which this parameter is known, which suggests that relativistic beaming could explain some polarization characteristics of FSRQs, and 4) the polarization and flux density variabilities are correlated. These results are similar to those found for RBLs in our previous work (Fan et al. 2006). However, the distributions in the averaged polarization and the spectral index in FSRQs are different from those in RBLs.

Key words: galaxies: active — galaxies: jet — galaxies: quasars: geueral

1. Introduction

Blazars form an extreme subclass of Active Galactic Nuclei (AGNs), showing high and variable luminosity, superluminal motions in their radio components, high γ-ray emission, high polarization, etc. (e.g., Aller et al. 1992, 1999, 2003; Andruchow et al. 2005; Angel & Stockman 1980; Cellone et al. 2007; Ciprini et al. 2007; Efimov et al. 2002; Fan et al. 1996, 2004a; Fan 2005a, b; Gabuzda 2003; Gupta et al. 2004; Romero et al. 1999, 2002; Sambruna et al. 2000; Wills et al. 1992). The blazar group consists of two subclasses: BL Lacertae objects (BLs) and flat spectrum radio quasars (FSRQs). BLs display violent variability on different time scales ranging from hours to years at frequencies from the radio to γ-rays (see Fan 2005b). The emission of BLs is believed to originate in a relativistic jet oriented very close to the line of sight. These objects are dominated by a broad, featureless continuum (Urry & Padovani 1995). The relativistic jet is thought to be responsible for the extreme observational properties (e.g., Jannuzi et al. 1994). BLs can be further divided into X-ray selected BLs (XBLs) and radio-selected BLs (RBLs) or low-energy-cutoff BL Lacertae objects (LBLs), high-energy-cutoff BL Lacertae objects (HBLs) according to the location of the synchrotron peak in their spectral energy distributions (SEDs). FSRQs include highly polarized quasars (HPQs), optically violent variable quasars (OVVs), and core-dominated quasars (CDQs). The observational properties of the BLs are quite similar to those of the FSRQs, except for their emission line properties. The FSRQs show strong emission lines, whereas BLs show weak emission lines, or even no emission line at all. The observational properties of these two types of sources and their possible relationship has drawn much attention in recent years. There are some proposals, including gravitational enhancement, core-boosted emissions, environmental and evolutionary effects, etc, aimed at explaining their relationship. However, as mentioned in some previous studies (Fan 2002, 2003), any proposal in this sense should explain the similarity in the continuum and the difference in the emission lines between BLs and FSRQs.

In the radio bands, monitoring programs provide good ground for investigating the radio properties. These properties could shed some light on the emission mechanism, and even on the relationship between BLs and FSRQs. Based on the the UMRAO data base, Aller et al. (1992, 2003) investigated the statistical behavior of the flux and the linear polarization of AGNs, as well as the relation between different radio bands for the Pearson–Readhead sample. The present paper is the second article in a series. In the first paper (Fan et al. 2006), we considered the radio-polarization properties of BLs. In this paper, we mainly look at the properties of the radio polarization of FSRQs based on UMRAO data base, and compare the results with the sample of RBLs that we published in our previous article.

The structure of the paper is as follows: in section 2 we calculate the average polarization and the variability of the linear polarization for the FSRQs sample. In section 3, we provide some discussions, and then close with a brief conclusion in section 4.

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Table 1. Sample of 92 FSRQs.

IAU name*	$P_{8\mathrm{GHz}}^{\mathrm{max}}$ †	$P_{8\mathrm{GHz}}^{\mathrm{aver}}$ ‡	α§	Span‖	σ_p#	NVA**	log R††	Reference‡‡	Data span
0016+731	66.45	3.013	−0.125	7	8.195	0.325	0.5	G93	1983–1999
0059+581	5.06	1.978	−0.285	30	1.123	0.103			1994–1999
0106+013	9.9	2.573	0.228	7	1.182	0.298	0.9	G93	1974–1999
0108+388	19.94	2.778	0.846	30	3.573	0.121	2.2	G93	1983–1999
0127+233	19.35	4.212	0.756	30	3.647	0.151			1982–1999
0133+476	12.83	2.002	−0.286	7	1.49	0.238	0.7	G93	1971–1999
0134+329	10.15	5.267	0.921	30	1.03	0.042	−1.14	W92	1972–1999
0153+744	61.01	12.697	0.885	30	12.936	0.288			1984–1999
0202+149	5.2	0.824	0.162	7	0.922	0.120	0.41	F03	1979–1999
0212+735	8.89	2.685	0.058	7	1.386	0.127	0.39	F03	1981–1999
0218+357	23.94	3.103	0.242	30	4.794	0.110			1992–1999
0234+285	9.24	1.911	0.004	7	1.237	0.360	2	G93	1981–1998
0306+102	50.7	4.791	−0.312	7	3.932	0.254			1978–1999
0316+413	0.86	0.145	0.127	7	0.128	0.298	1	G93	1967–1999
0333+321	13.86	5.727	0.211	7	1.995	0.197	−0.54	F03	1978–1999
0336−019	12.64	2.294	0.017	7	1.739	0.154	1.5	G93	1974–1999
0420−014	5.83	1.75	−0.183	7	1.057	0.229	0.13	F03	1977–1999
0430+052	10.14	3.246	0.088	7	1.573	0.529	1.4	G93	1970–1999
0440−003	6.18	2.407	0.127	30	1.323	0.232	1.3	W92	1978–1996
0454−234	10.97	2.496	−0.138	60	2.712	0.169			1980–1995
0518+165	9.86	3.085	−0.091	7	1.343	0.247	−0.82	F03	1982–1999
0521−365	4.2	2.278	0.508	7	0.514	0.077	−0.49	F03	1979–1999
0528+134	6.35	2.129	−0.256	7	1.374	0.398	0.01	F03	1976–1999
0528−250	21.45	15.061	0.62	30	11.503	0.100			1978–1999
0538+498	4.13	0.941	0.981	7	0.8	0.040	−0.59	F03	1971–1999
0552+398	4.55	0.847	−0.109	7	0.594	0.186	0.4	G93	1970–1999
0605−085	9.53	2.25	−0.019	7	1.279	0.169	0.23	F03	1974–1999
0607−157	16.48	2.228	−0.383	7	2.145	0.572			1974–1999
0710+439	16.22	2.229	0.639	30	2.994	0.096			1977–1999
0711+356	17.51	3.672	0.568	7	3.209	0.170	−1.29	F03	1983–1999
0723+679	30.6	8.701	0.802	7	5.395	0.236	−0.14	F03	1981–1999
0804+499	32.18	4.605	−0.242	7	4.138	0.380	0.6	G93	1980–1999
0809+483	6.51	2.08	1.157	30	1.183	0.039			1967–1999
0836+710	25.56	7.327	0.004	7	3.557	0.203	−0.22	F03	1982–1999
0838+133	14.17	2.89	−0.071	7	2.342	0.104	−0.15	F03	1977–1998
0850+581	9.79	4.725	0.334	30	2.228	0.146	−0.4	G93	1984–1999
0859+470	12.43	2.975	0.286	30	2.46	0.118			1982–1999
0906+430	12.04	1.864	0.348	7	1.95	0.151	−0.1	G93	1979–1999
0917+458	8.66	3.463	1.128	30	1.741	0.078			1983–1999
0917+624	14.23	2.89			2.946	0.323	1.2	W92	1967–1999
0954+556	16.06	3.943	0.345	30	2.477	0.063	0.32	W92	1974–1999
1003+351	9.11	2.332	0.593	30	2.204	0.105			1983–1999
1034−293	15.97	4.477	−0.42	7	2.902	0.197	0.8	G93	1978–1999
1038+528	17.99	4.447	0.026	7	3.911	0.282	1.47	F03	1988–1999
1040+123	17.04	7.176	0.384	7	2.08	0.093	−0.4	G93	1984–1999
1055+018	12.77	2.22	−0.314	7	1.73	0.134	0.78	W92	1967–1999
1127−145	9.25	4.122	0.404	7	1.527	0.141	1.7	W92	1967–1998
1137+660	65.83	6.159	0.644	7	8.829	0.250	−1.36	F03	1980–1999
1148−001	10	4.574	0.436	30	2.075	0.052	1.23	W92	1978–1993
1156+295	13.11	2.156	−0.247	7	1.813	0.229	1.09	F03	1977–1999
1217+023	13.68	5.723	0.088	30	4.288	0.152	0.11	W92	1993–1994
1222+216	5.67	3.014	−0.241	7	1.328	0.114	0.29	F03	1993–1997
1225+206	69.37	8.828	1.448	7	10.759	0.228			1979–1999
1226+023	6.67	2.801	0.073	7	1.192	0.142	0.73	F03	1965–1999
1253−055	5.66	2.391	−0.144	7	1.161	0.270	−1.54	F03	1965–1999

Table 1. (Continued)

IAU name*	$P^{\max}_{8\mathrm{GHz}}$ †	$P^{\mathrm{aver}}_{8\mathrm{GHz}}$ ‡	α§	Span‖	σ_p#	NVA**	log R††	Reference‡‡	Data span
1328+307	13.88	11.468	0.665	7	0.614	0.009	0.55	F03	1972–1999
1335−127	8.05	2.792	−0.344	7	1.387	0.256	1.1	G93	1974–1999
1354−152	12.12	2.769	−0.173	30	3.44	0.319			1978–1994
1458+718	7.46	2.562	0.426	30	1.691	0.158	−1	W92	1972–1999
1504−166	10.24	1.755	0.133	7	1.887	0.110			1977–1999
1510−089	8.62	2.604	−0.075	7	1.465	0.305	2.19	F03	1974–1999
1606+106	15.46	2.449	0.016	7	2.338	0.259			1977–1999
1611+343	11.63	3.093	−0.011	7	1.834	0.315	1.14	F03	1979–1999
1624+416	12.02	2.308	0.355	30	2.309	0.146			1984–1999
1633+382	7.09	1.669	0.091	7	1.293	0.241	0.84	F03	1974–1999
1634+628	15.29	3.219	1.172	30	4.026	0.189			1984–1999
1637+574	15.04	2.982	0.09	7	3.097	0.234	0.56	W92	1984–1999
1641+399	7.4	2.488	−0.16	7	1.121	0.260	−1.16	F03	1965–1999
1642+690	32.43	6.385	0.047	7	4.539	0.250	−0.66	F03	1978–1999
1721+343	37.09	12.312	0.886	30	9.51	0.220	0.06	W92	1988–1999
1730−130	8.19	2.679	−0.069	7	1.477	0.310	1.8	G93	1967–1999
1741−038	6.24	1.277	−0.433	7	0.992	0.286	0.6	G93	1974–1999
1828+487	3.15	1.06	0.5	30	0.72	0.083	−0.35	W92	1968–1999
1901+319	9.57	3.705	0.26	7	1.922	0.125	0.44	F03	1974–1999
1921−293	5.73	2.15	−0.201	7	1.257	0.302	0.8	G93	1974–1999
1928+738	6.16	2.289	−0.015	7	1.109	0.132	1.19	F03	1981–1999
1951+498	44.72	25.031	0.062	30	13.537	0.485			1988–1999
1954+513	11.51	1.797	−0.014	30	2.388	0.206			1980–1999
2005+403	7.93	2.603	0.108	7	1.106	0.213			1975–1999
2121+053	14.38	2.45	0.006	7	1.576	0.479			1976–1999
2134+004	7.3	1.268	0.301	7	0.931	0.102	−0.54	F03	1967–1999
2136+141	3.59	1.177	−0.333	7	0.734	0.272			1978–1999
2145+067	4.42	0.591	−0.619	7	0.607	0.379	0.46	F03	1967–1999
2155−152	15.3	4.806	0.26	7	3.415	0.260			1979–1999
2202+315	6.07	1.441	−0.154	7	1.008	0.321	1.31	F03	1978–1999
2223−052	7.69	3.077	−0.201	7	1.18	0.262	−1.23	F03	1967–1999
2230+114	10.45	3.083	0.267	7	1.115	0.136	0.44	F03	1974–1999
2251+158	5.78	3.173	0.129	7	1.114	0.308	1.31	F03	1966–1999
2345−167	8.91	2.814	0.137	30	1.511	0.214	1.39	W92	1978–1999
2351+456	24.64	3.765	0.119	30	3.768	0.140	0.5	G93	1979–1999
2352+495	12.94	3.192	0.728	30	2.664	0.114			1984–1999
2356+196	10.99	3.996	0.479	30	3.147	0.127			1978–1995

* Name of the source. † Highest polarization at 8 GHz. ‡ Average polarization at 8 GHz. § Spectral index. ‖ Time bin for calculating spectral index for each set data. # Standard deviation of the polarization. ** Data span. †† Logarithm of the core dominance parameter–log R. ‡‡ References for R, here F03 is Fan and Zhang (2003), G93 is Ghisellini et al. (1993), and W92 is Wills et al. (1992).

2. Data and Results

Based on the UMRAO data base, we obtained a sample of 92 FSRQs. For this sample we extracted the following information.

2.1. Radio Spectral Index

Blazars generally show a flat and inverted radio spectrum. However, it is not easy to obtain a typical spectral index for a given source, since the flux is variable. Here, we calculated the spectral index, α ($F_\nu \propto \nu^{-\alpha}$). We used the averaged flux densities at the three available frequencies (4.8 GHz, 8 GHz, and 14.5 GHz). The detailed process was as follows: for sources with densely sampled data, we averaged the data every week, whereas for those with sparsely distributed data, we averaged the flux densities every month. Therefore, we could obtain N sets of data for each source using the time bins (a time bin is one week for the densely sampled data sources and one month for the sparsely sampled data sources). Each set had three pairs of flux densities for the corresponding frequencies; then, for the i-th set we fit the three pairs of data using a linear regression to obtain the spectral index, α_i. Afterward, we used the averaged value, $\Sigma\alpha_i/N$, as an estimator of the spectral index, α, for a particular source. The results are listed in table 1.

From table 1, we obtained $-0.62 \le \alpha \le 1.45$ with an

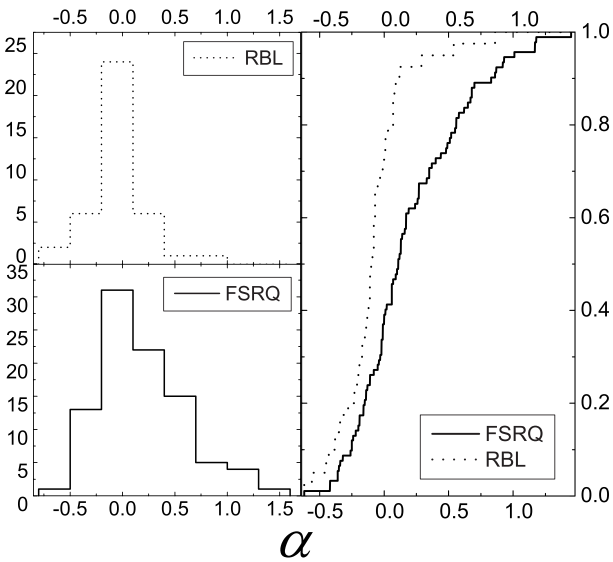

Fig. 1. Distribution of spectral index for RBLs and FSRQs.

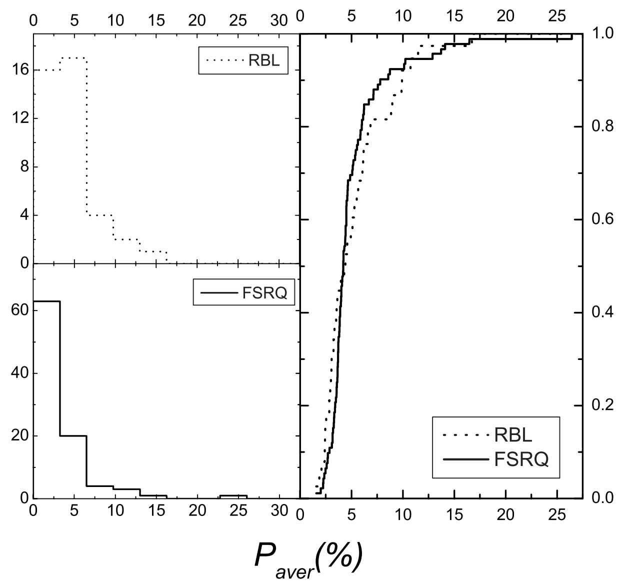

Fig. 2. Distribution of the averaged polarization for RBLs and FSRQs.

averaged value of $\langle \alpha \rangle = 0.20 \pm 0.42$. We performed a Kolmogolov–Smirnov (K–S) test on the FSRQ-sample of the present paper and on the RBL-sample of our recent paper (Fan et al. 2006). The K–S test indicates that the confidence level for the spectral index distributions of both RBLs and FSRQs to be from the same parent population, and is 2.4×10^{-3} (see figure 1).

2.2. *Radio Polarization*

High and variable polarization is one of the observational properties of blazars. To revisit the polarization characteristic of FSRQs, we obtained the maximum polarization of each source and calculated the averaged polarization based on the observational data sample. The procedure was as follows. At each frequency for each source, we chose the observed maximum polarization value as the maximum polarization at the corresponding frequency, and calculated the averaged value of the whole polarization series as the averaged polarization. The averaged polarization at frequency ν (ν = 4.8, 8.0, and 14.5 GHz) was weighted with errors as

$$\langle p_\nu^{\rm aver} \rangle = \frac{\sum_{i=1}^{n} \epsilon_i^{-2} p_{i,\nu}}{\sum_{i=1}^{n} \epsilon_i^{-2}}, \tag{1}$$

where $p_{i,\nu}$ is the observed polarization for the i-th observation, and ϵ_i are the individual errors for the corresponding source. The average error is

$$\langle \epsilon \rangle = \sqrt{\frac{\sum_{i=1}^{n} (\langle p \rangle - p_i)^2 \epsilon_i^{-2}}{\sum_{i=1}^{n} \epsilon_i^{-2}}}. \tag{2}$$

Therefore, we have three maximum polarizations and three averaged polarizations (at 4.8, 8.0, and 14.5 GHz) for each source. Then, for the FSRQ-sample of the present paper, and the RBL-sample of Fan et al. (2006), we calculated the averaged maximum polarization at frequency ν (ν = 4.8, 8.0, and 14.5 GHz), $P_\nu^{\rm max} = \Sigma p_{i,\nu}^{\rm max}/N$. Here, $p_{i,\nu}^{\rm max}$ is the maximum observed polarization at frequency ν for the i-th source in the FSRQs and RBLs samples, and N is the number of sources in the FSRQs and RBLs samples. We had N = 92 and 38 in our FSRQ and RBL lists, respectively. The averaged-averaged polarization was also calculated as $P_\nu^{\rm aver} = \Sigma p_{i,\nu}^{\rm aver}/N$, where $p_{i,\nu}^{\rm aver}$ is the averaged polarization weighted with the error for the i-th source in the list. Therefore, we obtained the following results:

$$\begin{aligned} \langle P_{\rm 4.80GHz}^{\rm max}(\%) \rangle &= 9 \pm 10, \\ \langle P_{\rm 8.00GHz}^{\rm max}(\%) \rangle &= 15 \pm 14, \\ \langle P_{\rm 14.5GHz}^{\rm max}(\%) \rangle &= 15 \pm 13, \end{aligned} \tag{3}$$

and

$$\begin{aligned} \langle P_{\rm 4.80GHz}^{\rm aver}(\%) \rangle &= 4 \pm 4, \\ \langle P_{\rm 8.00GHz}^{\rm aver}(\%) \rangle &= 4 \pm 3, \\ \langle P_{\rm 14.5GHz}^{\rm aver}(\%) \rangle &= 3 \pm 2 \end{aligned} \tag{4}$$

for the 92 FSRQs;

$$\begin{aligned} \langle P_{\rm 4.80GHz}^{\rm max}(\%) \rangle &= 17 \pm 13, \\ \langle P_{\rm 8.00GHz}^{\rm max}(\%) \rangle &= 26 \pm 21, \\ \langle P_{\rm 14.5GHz}^{\rm max}(\%) \rangle &= 29 \pm 21, \end{aligned} \tag{5}$$

and

$$\begin{aligned} \langle P_{\rm 4.80GHz}^{\rm aver}(\%) \rangle &= 4 \pm 2, \\ \langle P_{\rm 8.00GHz}^{\rm aver}(\%) \rangle &= 5 \pm 3, \\ \langle P_{\rm 14.5GHz}^{\rm aver}(\%) \rangle &= 7 \pm 5 \end{aligned} \tag{6}$$

for the 38 RBLs.

For the averaged polarization at 8 GHz, a K–S test showed that the distribution of FSRQs and RBLs is from a common parent population at confidence level of 99.7% (see figure 2).

For the averaged polarization and spectral index relation, we obtained the following results, $P_{\rm aver}(\%) = (1.48 \pm 0.75)\alpha + (3.98 \pm 0.31)$, $p = 0.05$, for the whole sample (see figure 3). When we considered the FSRQs and

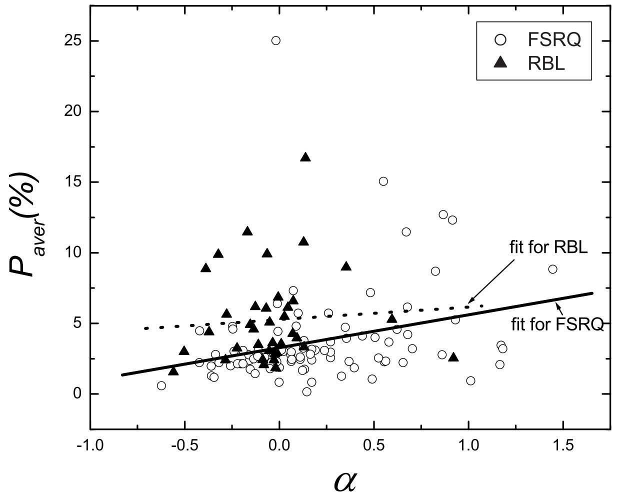

Fig. 3. Relation between the averaged polarization at 8 GHz and the radio spectral index for the whole blazar sample. The filled triangles stand for RBLs; the best fitting result is $P_{\text{aver}}(\%) = (0.89 \pm 2.02)\alpha + (5.28 \pm 0.54)$, while the open circles for FSRQs with a best fitting result of $P_{\text{aver}}(\%) = (2.33 \pm 0.83)\alpha + (3.28 \pm 0.38)$.

RBLs separately, we obtained $P_{\text{aver}}(\%) = (2.33 \pm 0.83)\alpha + (3.28 \pm 0.38)$, $p = 5.97 \times 10^{-3}$, for FSRQs, and $P_{\text{aver}}(\%) = (0.89 \pm 2.02)\alpha + (5.28 \pm 0.54)$, $p = 0.66$, for RBLs.

These results indicate, for FSRQs, a trend of the polarization to increase with the spectral index.

From the theory of synchrotron emission, we showed that the polarization can be described as

$$P(\%) \propto \frac{\alpha + 1}{\alpha + 5/3} = P_0 \frac{\alpha + 1}{\alpha + 5/3}, \tag{7}$$

where P_0 is a coefficient.

In figure 4, the sample of 92 FSRQs and 38 RBLs are plotted in the top and bottom panels, respectively, and synchrotron-model curves are fitted. From the fitted curves in figure 4 we can see that 1) the polarization is correlated with the spectral index, showing that the polarization increases with the spectral index, and 2) the curves $P \propto (\alpha + 1)/(\alpha + 5/3)$ fit the points well, suggesting that this trend is consistent with a prediction by the synchrotron emission mechanism (see figure 4).

2.3. *Core-Dominance Parameter*

Wills et al. (1992) found that the polarization increases with the core-dominance parameter for blazars; a similar behavior was found for BL Lacertae objects in our previous work (Fan et al. 2006), where we showed that there is a relation between the core-dominance parameter and the polarization:

$$P^{\text{ob}} \sim \frac{R}{1 + R} \frac{\eta}{1 + \eta}. \tag{8}$$

Here, η is the ratio of the polarized emission, S_{j}^{p}, to the unpolarized emission, S_{j}^{up}, in the jets, i.e., $S_{\text{j}}^{\text{p}} = \eta S_{\text{j}}^{\text{up}}$ (see Fan et al. 1997). For a given η, the theoretical relation of the polarization, depending on the core-dominance parameter, can be obtained. In the present work, we adopted $\eta = 0.03$, 0.06, 0.13, and 0.25, respectively, and show the corresponding curves in figure 5.

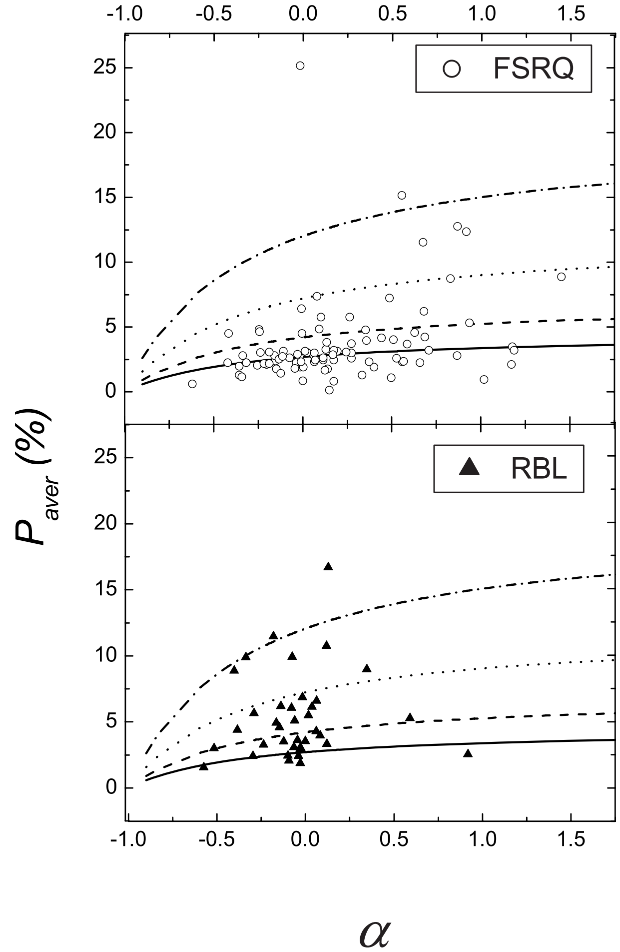

Fig. 4. Relation between the averaged polarization at 8 GHz and the radio spectral index for the whole blazar sample. The curves correspond to $P_0(\%) = 4.5$, 7, 12, and 20 from bottom to top.

2.4. *Normalized Variability Amplitude*

Blazars are variable over the whole electromagnetic spectrum. It is useful to use a parameter to characterize the variability amplitude. The normalized variability amplitude (NVA) is a parameter free of instrumental effects, and hence is very convenient for most purposes (Edelson et al. 1996). It can be taken as an indication of the variability, and is defined as

$$NVA = \sqrt{\frac{\sigma_{\text{tot}}^2 - \sigma_{\text{err}}^2}{\langle X \rangle^2}}, \tag{9}$$

where $\langle X \rangle$ is the averaged flux density at 8 GHz, σ_{tot} is the standard deviation for the flux points, and σ_{err} is the mean error level. From the UMRAO data base, we obtained the NVA and the standard deviation of the polarization, σ_p, which is taken as the variability parameter of polarization (Fan et al. 2006). For the 92 FSRQs, we obtained $\langle NVA \rangle = 0.21 \pm 0.12$, and $NVA = (6.36 \times 10^{-3} \pm 4.35 \times 10^{-3})\ \sigma_p + (0.19 \pm 0.017)$, $p = 0.14$. For the 38 RBLs, we obtained $\langle NVA \rangle = 0.28 \pm 0.10$, $NVA = (5.12 \times 10^{-3} \pm 4.96 \times 10^{-3})\ \sigma_p + (0.254 \pm 0.026)$, $p = 0.37$. For all sources, $NVA = (8.1 \times 10^{-3} \pm 3.28 \times 10^{-3})\ \sigma_p + (0.20 \pm 1.39 \times 10^{-2})$, $p = 0.01$. A plot of NVA against the

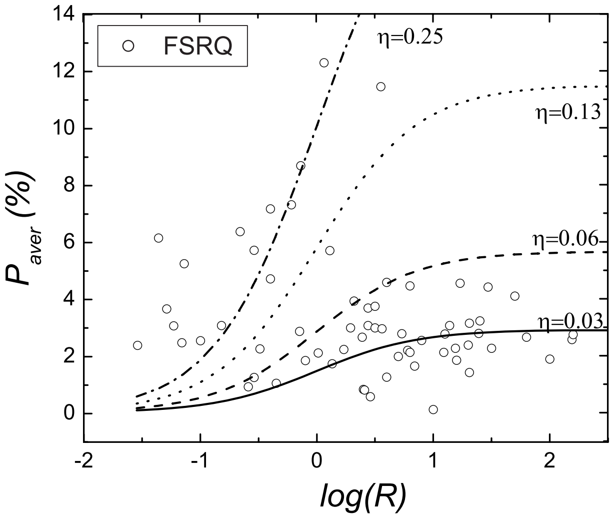

Fig. 5. Relation between the averaged polarization at 8 GHz and the core-dominance parameter for 92 FSRQs.

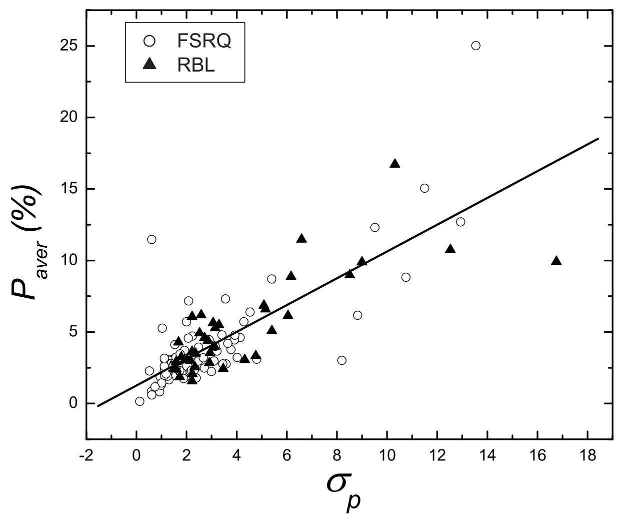

Fig. 7. Relation between the averaged polarization at 8 GHz and the polarization variability for FSRQs and BLs.

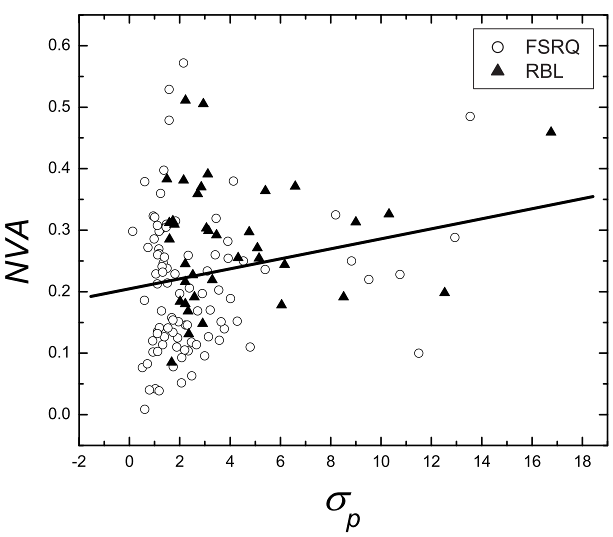

Fig. 6. Relation between NVA and the polarization variability at 8 GHz for BLs and FSRQs.

σ_p is shown in figure 6. For a more accurate statistical analysis, we need a larger sample. At this stage, it is difficult to make any distinction with the NVA between FSRQs and RBLs.

3. Discussion

Blazars show extreme observational properties, including variable and strong emission, high and variable polarization and very high-energy radiation, reaching even TeV energies (in the case of some BLs). In the radio bands, the UMRAO provides a very good radio data base, from which we obtained a blazar sample of 92 FSRQs and 38 RBLs for a statistical analysis. It is obvious that the present blazar sample is not complete, but it is a large sample including 130 objects. The results based on this sample should be statistically interesting.

The present work shows that there is a trend for the averaged polarization to increase with the frequency in the radio range from 4.8 GHz to 14.5 GHz for FSRQs; the maximum polarization also shows a similar behavior. This behavior is quite similar to that found in RBLs (Fan et al. 2006). However, RBLs have higher maximum polarization than FSRQs, on average. For the averaged polarization, RBLs also have higher averaged polarization than FSRQs, as shown in figure 2, which shows that the averaged distribution of RBLs is different than that of FSRQs. A similar thing happens to their spectral index distributions, as shown in figure 1, which indicates that the two spectral index distributions are from a common distribution at a confidence of 2.4×10^{-3}. In figure 13 of a paper by Aller et al. (2003), a clear difference in their distribution of the averaged polarization for the FSRQs and BLs can be seen. Our result for the averaged polarization, based on a significantly larger sample, is consistent with results by Aller et al. (2003). As for the spectral index, we found that from Aller et al. (1992, 2003), QSOs appear to have a different distribution from that of BLs. Our present result is consistent with theirs.

Concerning the polarization and the radio spectral index, we find that the averaged polarization is correlated with the spectral index as shown in figure 3. The results shown in figure 4 suggest that the observational points are consistent with curves obtained from the synchrotron emission mechanism. In this sense, the radio emission in blazars should be from the synchrotron mechanism.

In order to analyze the polarization variability, we used the standard deviation, σ_p. The σ_p value can be taken as a good indicator of the variations in the degree of polarization (Fan et al. 2006). In this sense, we found that the averaged polarization at 8 GHz is closely linearly correlated with the variability, σ_p, as shown in figure 7, where the line stands for the best fitting result,

$$P_{\mathrm{aver}}(\%) = (0.93 \pm 0.06)\sigma_p + (1.26 \pm 0.26), \qquad (10)$$

with a $> 99\%$ confidence level. This result suggests that the polarization is closely correlated with the polarization variability. This correlation is from the beaming model, since the polarization is associated with the beaming effect, and the variation is also from this effect (Fan et al. 1997). From a plot of the NVA value vs. the polarization deviation, σ_p, we find that the higher is the NVA value, the higher is σ_p, as shown in figure 6.

From our previous work, we have $P^{\rm ob} \sim [R/(1+R)][\eta/(1+\eta)]$ (Fan et al. 2006). For a given η, a theoretical relation of the polarization, depending on the core-dominance parameter, can be obtained. In figure 5, we show a polarization vs. core-dominance parameter plot. The core-dominance parameter is taken as an indication of a small jet viewing angle, and hence it is an indication of the presence of a beaming effect. For a strongly boosted source, the core-dominance parameter can be simply expressed as $R = f\delta^p$ (Ghisellini et al. 1993). In this sense, one can see clearly that: 1) the polarization is associated with the beaming effect and 2) for most sources, the value of η is less than 0.25, suggesting that the polarization in the jet frame is less than 20%.

From the above discussions, we can say that the distributions of averaged polarization and the radio spectral indices in FSRQs are different from those in RBLs. However, there is no clear difference in their central black-hole masses (Fan 2005a) or in their physically meaningful periods for both types of sources (Fan et al. 2007). The similarities in the central black-hole masses and the period perhaps suggest that both subclasses have a similar central structure. The difference in the polarization perhaps indicates a difference in the beaming effect. In fact, the radio boosting factors found in FSRQs are larger than those in BLs (Ghisellini et al. 1993).

Based on the UMRAO data base, we analyzed the radio polarization of FSRQs, and found that the averaged polarization depends on the frequency, the spectral index and the core-dominance parameter. Those properties are similar to those of RBLs (Fan et al. 2006). The degree of polarization is closely correlated with the polarization variability. For FSRQs and RBLs, we found that the distributions in the polarization and the spectral index are different.

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