Do BL Lacs lack the circular polarization?

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We present the first preliminary evidence of difference in the circular polarized emission between quasars and BL Lacs. BL Lac objects seem to lack the sources with high circular polarization degrees. It cannot be due to selection effects, so some intrinsic effects are involved. These possible differences can be attributed to jet composition, energy of particles or magnetic field properties. The first one can be the intriguing possibility of different central engine mechanisms of these objects. However, the small detection rate for BL Lac objects and therefore a small sample size still prevents us from making the firm conclusion, so further observations of BL Lacs are highly desired.

Introduction

Blazars are radio-loud AGNs being dominated by the Doppler-boosted emission from relativistic radio jets shooting almost toward the observer. The family consists of flat-spectrum radio quasars (later referenced as quasars) and BL Lacertae objects. Historically the key observational difference was the absence of broad permitted emission lines in optical spectra of BL Lacs. There was an attempt to explain this difference geometrically: the jets of BL Lacs were considered to have smaller angles to the LOS, however much more differences were discovered, including the absence of thermal emission in BL Lacs, which states that accretion is radiatively inefficient [3], different broadband spectral energy distribution of blazing jet [2], different Fanaroff-Riley type of their extended radio emission [5], different environment and cosmological evolution, different linear polarization properties of radio jets on VLBI (parsec) scales [1] etc. All these leads to the conclusion that the properties of central engine of these two classes of objects are actually different. Current work is dedicated to yet another dichotomy between BL Lacs and quasars that opens the new possibility to shed the light on the subject.

Circular polarization

Circular polarization in AGN is very hard to detect due to its low degrees ($<1\%$) and VLBI-scale circular polarization (CP) measurements became available only recently. Despite its low degrees, CP can become the new key for estimating various vital AGN parameters, which cannot be obtained otherwise. There are two mechanisms of CP generation which are likely dominating in AGN jets [9]:
a) direct synchrotron emission (only for normal e-p plasma) and
b) conversion from linear polarization (LP) which can have 2 modes:
  b.1) conversion in changing perpendicular B-field and
  b.2) conversion driven by internal Faraday rotation (again, only for normal e-p plasma).

Due to extremely low radiative transfer coefficients in interstellar medium, CP is immune to propagation effects, which, on the contrary, can totally distort linear polarization on the way from the source to the observer. Jet plasma composition is one of the main parameters defining the generation of CP, so it can be derived from CP observations. Strong dependence of CP radiative transfer coefficients (emission, absorption and conversion) inside the source itself on particle energy distribution makes CP a good probe for invisible low-energy jet particles. CP is also sensitive to the B-field. For instance, in the case of Faraday conversion mechanism of generation, CP signal strongly depends on perpendicular B-field component (while Faraday rotation derived from LP observations traces the longitudinal component).

Observations

We used VLBA data at 15 GHz from the samples [7], [8] and [4] that contain 144 objects (97 quasars and 47 BL Lacs, see Table 1). 2σ level was used as a criterion for detection of the CP signal due to typically low signal-to-noise ratios. CP degrees (m_c) were sampled at the total intensity peak (Stokes parameter I). Note the absence of systematic shifts between the two samples used to make the combined sample and the overall agreement between the obtained CP values, including agreement in their sign, as shown in Figures 1 and 2 which means no substantial variability on the time scales separating the different observing epochs. Detection frequencies for the signals at the level $>2\sigma$ coincide for samples [7], [8] and [4] within the errors (Table 1). The relatively large number of objects on the axes in Figure 1 is due to the insufficient measurement sensitivity.

Results and conclusions

Figure 3 represents the distributions of the CP degree (m_c) for quasars and BL Lac objects for the combined sample. No objects with low m_c are detected which is easily explained by the selection effect of 2σ-criteria used. On the contrary, one can clearly see the absence of BL Lac objects with high m_c ($>0.4\%$). If such objects existed, they would be the first (most likely) ones to be detected. Mean CP degrees for BL Lacs $m_c^{BL} = 0.26\pm0.02$ and quasars $m_c^{QSO} = 0.35\pm0.03$ differ at 2σ level. Kolmogorov-Smirnov test for the total sample taking into account all observing epochs for [7], [8] (15 values of m_c^{BL} and 40 values of m_c^{QSO}) shows that the distributions are different at the $\alpha = 0.05$ significance level, which is good enough to make preliminary conclusion about the observed difference in CP for these two classes of objects. This is the first evidence of any differences in the properties of the observed CP signals for AGNs of different optical classes detected so far. It is also interesting, that all sources with resolved CP signal are quasars. This may represent another dichotomy between quasars and BL Lac objects as representatives of the Fanaroff-Riley II and I radio sources, reflecting differences in the physical properties of their jets. Nevertheless, further investigation is needed on bigger samples of objects.

As CP generation depends on various jet parameters, the observed difference in CP signals for quasars and BL Lacs can be due to lots of reasons. Source modeling and solving radiative transfer problem for various models is required to determine the particular reason(s) of such difference. We are working on implementation of such modeling; the results will be published elsewhere. However, it is possible to list the possible qualitative differences between the objects of these two optical classes that can lead to the observed dichotomy:

1. Different jet plasma composition. CP in e^-–e^+ plasma can be generated only via Faraday conversion in changing transverse B-field, while all mechanisms, including direct synchrotron emission and Faraday conversion driven by Faraday rotation are possible in e^-–p plasma, which just gives more possibilities to create higher CP signal. If normal e^-–p plasma dominated in quasars/FRII-radio galaxies jets and BL Lacs/FRI-radio galaxies jets consisted mostly of e^-–e^+ plasma, this could explain the observed CP difference. It should be noted that authors of [6] attributed Fanaroff-Riley dichotomy to different plasma composition of parsec scale jet.

2. Difference in plasma composition listed above can be related to the mechanism of jet generation. Pair jet plasma (presumably dominating in BL Lacs) can be related to the action of the Blandford–Znajek mechanism of jet generation, where rotational energy of the black hole is being released and high accretion rates are not required, which is consistent with the absence of any sign of thermal radiation in the optical spectra of many BL Lac objects. Mechanisms associated with the presence of a magnetized disk (e.g. Blandford–Payne mechanism) lead to the formation of jets made of normal (e^-–p) plasma, which can be the case of quasars.

3. Differences in the energy spectra for the particles in the jets can also lead to the effect observed. Since electrons with lower energies make a larger contribution to all CP generation mechanisms, the observed difference in the degrees of CP can be explained as presence of more less-energetic particles in quasar jets than in BL Lacs jets. Also, dense thermal radiation field in the vicinity of quasars could cool relativistic particles through Inverse Compton radiation. High density cosmic microwave background near high-z quasars does the same.

4. Magnetic field properties (value and geometry) in quasars and BL Lac jets could be different. This is supported by the VLBI observations of linear polarization. As magnetic field plays very important role in CP generation this can be the main reason of the difference of CP signal observed.

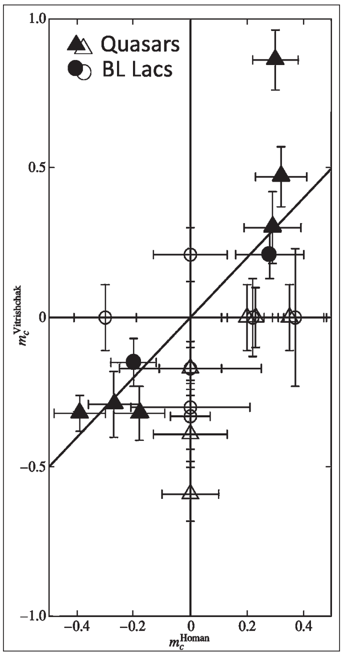

Figure 1: Observed CP degrees from [7]–[8] vs. CP degrees from [4] for the same sources

Table 1: Samples used in analysis

sample	size	no. QSOs	no. BL Lacs	no. detected QSOs (>2σ)	no. detected BL Lacs (>2σ)	QSO detection frequency	BL Lac detection frequency
[4]	114	92	22	28	5	0.03±0.06	0.23±0.10
[7]–[8]	71	25	46	9	7	0.36±0.12	0.15±0.06
[4] and [7]–[8]	144	97	47	31	10	0.32±0.06	0.21±0.07

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References

[1] Cawthorne T. V., Wardle J. F. C., Roberts D. H., Gabuzda D. C. Astroph. J., V. 416, p. 519 (1993)

[2] Fossati G., Maraschi L., Celotti A., Comastri A., Ghisellini G. Mon. Notic. Roy. Astron. Soc., V. 299, pp. 433-448 (1998)

[3] Hardcastle M. J., Evans D. A., Croston J. H. Mon. Notic. Roy. Aston. Soc., V. 376, pp. 1849-1856 (2007)

[4] Homan D. C., Lister M. L. Astron. J., V. 131, pp. 1262-1279 (2006)

[5] Padovani P. Mon. Notic. Roy. Astron. Soc., V. 257, pp. 404-414 (1992)

[6] Reynolds C. S., Fabian A. C., Celotti A., Rees M. J. Mon. Notic. Roy. Astron. Soc., V. 283, pp. 873-880 (1996)

[7] Vitrishchak V. M., Gabuzda D. C. Astron. Rep., V. 51, pp. 695-708 (2007)

[8] Vitrishchak V. M., Gabuzda D. C., Rastorgueva E. A. et al. Mon. Notic. Roy. Astron. Soc., V. 391, pp. 124-135 (2008)

[9] Wardle J. F. C., Homan D. C. Astrophys. Space Sci., V. 288, pp. 143-153 (2003)

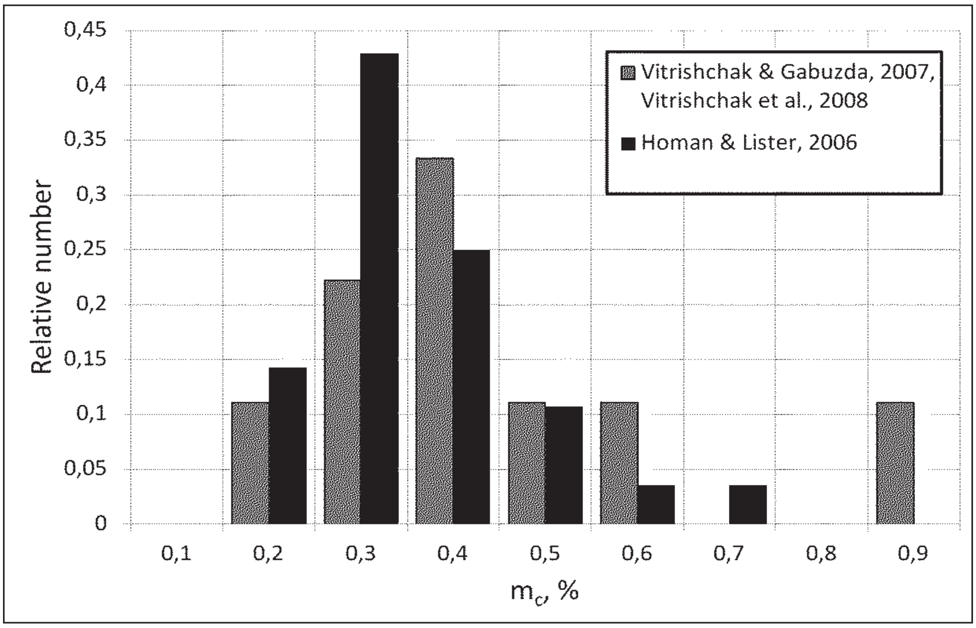

Figure 2: CP degrees of QSOs from [7, 8] (black boxes) and [4] (white boxes)

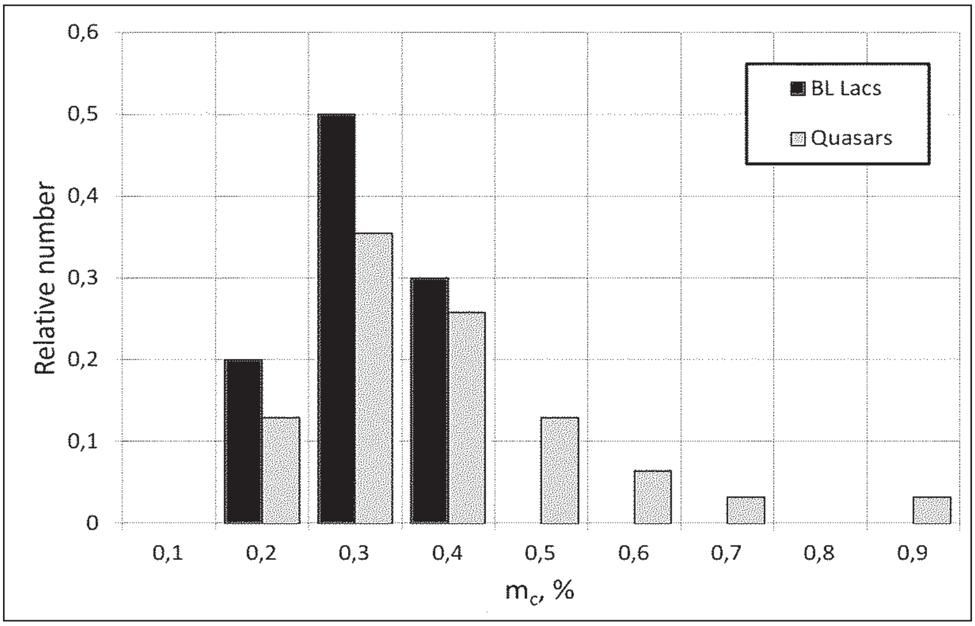

Figure 3: CP degrees of QSOs (white boxes) and BL Lacs (black boxes) in combined ([7, 8] and [4]) sample