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Doppler boosting as the generator of the blazar sequence

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The most prominent result of the blazar sequence scenario is the anticorrelation between the synchrotron peak frequency and synchrotron peak luminosity of blazar spectral energy distributions. However, the effect of Doppler boosting on this correlation has been largely ignored in the past. We have studied the intirinsic, Doppler-corrected blazar sequence using a sample of 135 radio-bright active galactic nuclei. We find that the negative correlation between frequency and luminosity turns positive, when properly Doppler-corrected values are used. For BL Lacertae objects, this positive luminosity sequence spans across the whole range of peak frequencies.

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1. Introduction

The blazar sequence is a scenario in which the bolometric luminosity of the blazar governs the appearance of its spectral energy distribution (SED) [1, 2]. One of its predicted results is the anticorrelation of the peak luminosity, $\nu_p L_p$, and the peak frequency, ν_p, of the synchrotron components of the blazar SEDs. Lately, the existence of this luminosity sequence has been a matter of controversy, with both supporting [3, 4] and conflicting [5, 6, 7] results. However, most studies have either neglected entirely the effect of Doppler boosting, affecting both $\nu_p L_p$ and ν_p, or assumed it to be roughly constant in all sources. This prompted us to study the blazar sequence using Doppler-corrected quantities [8].

2. Sample & methods

Our sample consists of 135 radio-bright active galactic nuclei (AGN) selected from the Metsähovi Radio observatory monitoring source list. 113 of them comprise a complete flux-limited 1.2 Jy northern AGN sample. The sample includes 34 high polarized quasars (HPQ), 33 low polarized quasars (LPQ), 31 BL Lacertae objects (BLO), 26 quasars with no polarization data (QSO), 9 radio galaxies with diverse properties (GAL) and 2 unclassified objects. The boundary between high and low polarization was $P = 3\%$.

We determined the SEDs for the sample sources using archival data from CATS[1] and NED[2] databases and from literature. Typically, for these bright sources, sufficient data could be found for the accurate determination of the synchrotron component of the SED. We fitted the synchrotron component with a simple parabolic funtion

$$\log(\nu F_\nu) = A(\log\nu)^2 + B(\log\nu) + C, \tag{2.1}$$

where A, B and C are constants. From the fit we obtain the peak frequency ν_p and the peak luminosity $\nu_p L_p$. The peak frequencies in the sample range as 11.99-17.19.

The Doppler factors D_{var} were determined in a separate publication [9] from total flux density variability data at 22 and 37 GHz. An exponential fit to the flare components visible in the flux curve gives the necessary parameters for the calculation of the variability brightness temperature [10]. Comparison with the equipartition brightness temperature gives the amount of boosting. D_{var} could be determined for 89 sources in our sample.

3. Results

The salient question in our study is whether D_{var} depends on ν_p. A strong dependency between these quantities would certainly affect the appearance of the blazar sequence. The result can be seen clearly in Fig. 1, where we have plotted D_{var} against the redshift- and Doppler-corrected ν_p. There is a strong statistically significant anticorrelation between the quantities ($\rho = -0.698$ and $P < 0.001$, according to the Spearman rank correlation test). We tested this result also using other,

[1]http://cats.sao.ru
[2]http://nedwww.ipac.caltech.edu/

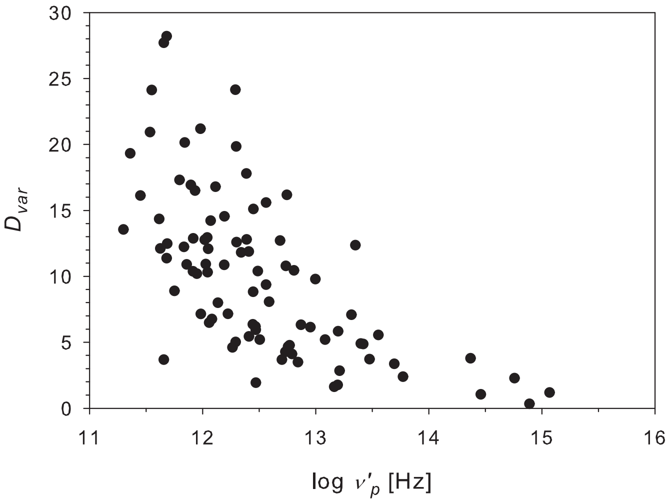

Figure 1: The variability Doppler factors D_{var} plotted against the Doppler-corrected synchrotron peak frequencies ν'_p.

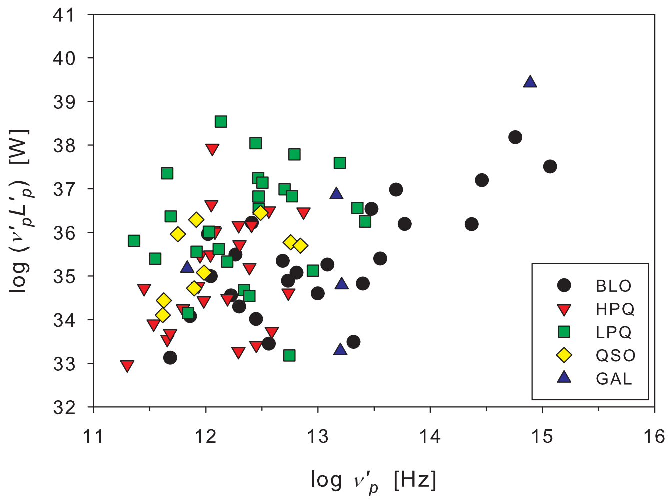

Figure 2: The synchrotron peak luminosity $\nu_p L_p$ plotted against the peak frequency ν_p. Both values are Doppler-corrected.

independent sets of Doppler factors [11, 12], and the anticorrelation is evident regardless of the method of calculating the *D*-factors. This result in itself reveals that any conclusions drawn from incompletely Doppler-corrected data are strongly biased.

Fig. 2 presents the dependence between $\nu_p L_p$ and ν_p, when the Doppler-corrected quantities are used. We have assumed that the intrinsic peak luminosity is proportional to $L_p/D^{3+\alpha}$ (assuming $F \propto \nu^{-\alpha}$), and have taken $\alpha = 1$ according to the definition of the synchrotron peak. According to the blazar sequence scenario, there should be a negative correlation, but it is not present in our results. In fact, there is a significant *positive* correlation between $\nu_p L_p$ and ν_p for the whole

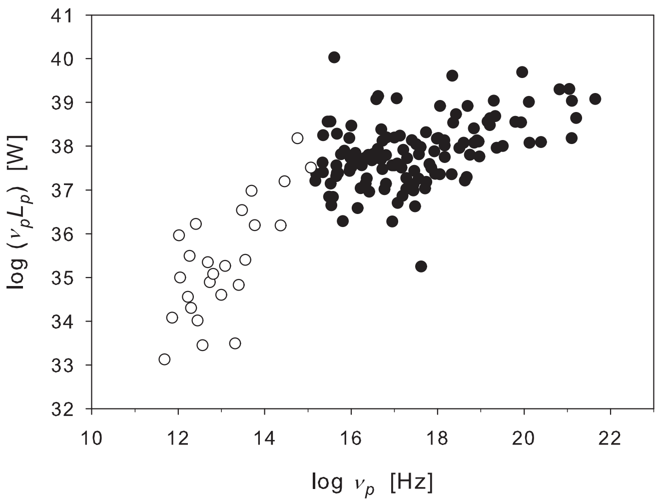

Figure 3: The luminosity sequence of BLOs. The sample is combined from Doppler-corrected data points ([8], open circles) and only z-corrected data points ([7], black circles), for which we assume negligible Doppler boosting.

AGN sample ($\rho = 0.353$ and $P < 0.001$). As for the AGN subgroups, the positive correlation is significant to all except LPQs and QSOs, which feature no correlation at all. Taking into account the fact that our sample includes some sources, which are not traditionally classified as blazars, we checked the correlation using only the 65 bona-fide blazars in the sample. A source was defined as a blazar if it is included in at least one of the following:

- the total blazar sample of [1]
- the extragalactic radio sources list of Wall & Peacock [13] and has $\alpha_{2.7-5GHz} \leq 0.5$ ($F \propto \nu^{-\alpha}$)
- the DXRBS blazar sample [14]

or is included in the BLO sample used in this work. Also for this blazar sample, there is a significant positive correlation between $\nu_p L_p$ and ν_p ($\rho = 0.366$ and $P = 0.003$).

The BLOs in Fig. 2 have a particularly strong positive correlation. Surprised by this result, we combined the BLO sample in this study with the high-ν_p BLOs sample of an earlier paper [7], to extend the correlation further. From Fig. 1 we can deduce that sources with $\log \nu_p \geq 15$ are not very boosted, and thus we felt confident in combining the two samples, low-ν_p sources being D-corrected and high-ν_p sources not (Fig. 3). This approximation indicates that there is a strong positive correlation across the whole peak frequency range between $\nu_p L_p$ and ν_p for the BLOs. This fits results from number counts, which indicate that high-energy BLOs (HBLs) are less numerous than low-energy BLOs (LBLs). As has been pointed out [15], this is difficult to understand if HBLs are intrinsically less luminous than LBLs. This result also agrees with the trend seen in individual sources, in which the peak frequency of the inverse Compton component increases as the luminosity increases during high states.

We tested all our results also using the D^2 -correction, i.e., the exponent $2+\alpha$ in the Doppler correction. The only change was that the positive correlation for HPQs in Fig. 2 turned unsignificant. Otherwise the results are the same using either of the corrections.

4. Conclusions

The following conclusions can be drawn from our work on the Doppler-corrected blazar sequence:

- The amount of Doppler boosting depends on the synchrotron peak frequency of the source, low-energy sources being more boosted.
- The blazar sequence disappears when the *D*-corrected quantities are used. It is an artefact of variable Doppler boosting across the peak frequency range.
- There is a *positive* correlation between $\nu_p L_p$ and ν_p. For BLOs, this correlation spans across the whole peak frequency range and is in accordance with the number counts of LBLs and HBLs.

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