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Optical Spectra Evolution of BL Lac Objects

X. W. Bi[1,*], B. Z. Wang[2], Z. Q. Ni[3], Q. Cai[1] & J. J. Tian[1]
[1]*Department of Physics, Honghe University, Mengzi 661100, Yunnan, China.*
[2]*Department of Physics and Electronic Engineering, Jiaozuo Teachers College, Jiaozuo 454000, Henan, China.*
[3]*Nationality Middle School of Shilin, Shilin 651000, Yunnan, China.*
**e-mail: bxw7910@sohu.com*

Abstract. Many quasi-simultaneous optical observations of nine BL Lac objects are obtained from literature. We study the relationship between the optical spectral index and the luminosity of BL Lac objects, and are tempted to exploit spectral evolution in the optical frequency ranges. Our results show that: (i) The optical spectra index of the low-frequency peaked BL Lac objects (LBLs) is steeper than the high-frequency peaked BL Lac objects (HBLs); (ii) The spectra tend to be softer when the source becomes brighter for LBLs and the intermediate BL Lac objects (IBLs) (i.e., bluer-when-brighter), and the spectra of HBLs does not vary when the brightness of HBLs changes. Possible explanations are briefly discussed for this phenomenon.

Key words. Galaxies: active—galaxies: evolution—BL Lac objects: general.

1. Introduction

Study of the spectral energy distribution (SED) properties is important for theoretical model. We can obtain significant information related to the physical properties of the emitting region. Quantifying spectral evolution will help in understanding the physical properties of the emitting region. In recent years, more and more observational proof has been gathered, arguing against traditional survey classification of the BL Lac objects. In particular, two obvious bumps of SED have prompted a new subdivision of BL Lac objects. Many investigators have pursued the issue and have found significant variation in the spectral index (e.g., D'Amicis *et al.* 2002; Foschini *et al.* 2006; Zheng *et al.* 2007, 2008). In this paper, we study the relationship between the spectral index and the luminosity of nine BL Lac objects, and are tempted to exploit spectral evolution in the optical ranges.

2. Data reduction

We have compiled all available U, B, V, R and I band optical data of nine BL Lac objects from literature (Smith *et al.* 1987; Takalo 1991; Takalo *et al.* 1992; Massaro *et al.* 1996; Belokon *et al.* 2000; Fan *et al.* 2001; Qian & Tao 2002, 2004; Zheng *et al.* 2008). In order to counteract the heavy weight of the observational data and to reduce small-amplitude intra-hour fluctuations, we calculate the daily-averaged magnitude values of the literature data. All of the daily-averaged magnitude values are corrected for foreground galactic inter-stellar reddening using colour excess $E_{(B-V)}$, which is deduced from maps of dust infrared emission (Schlegel *et al.* 1998). From the value of $E_{(B-V)}$, we evaluate the U, B, V, R and I extinction coefficients with a formula from Cardelli *et al.* (1989), assuming $R_V = 3.1$ (Rieke & Lebofsky 1985), and convert from apparent to optical flux density using the zero-magnitude equivalent flux density reported by Mead *et al.* (1990).

It is generally the case that optical radiation can be described by a typical power law

$$f_\nu \propto \nu^{-\alpha}, \tag{1}$$

where α is the spectral index and f_ν is the flux density. According to the above relation, we have

$$\log f_\nu = k - \alpha \log \nu. \tag{2}$$

So, we can obtain the optical spectral index from a linear least-square fit with a straight line in the $\log f_\nu$ *versus* $\log \nu$ frame. We only selected intra-day observational data that produce three or more bands using literature data. To ensure the accuracy of the spectral index, we only accept a square of Pearson's linear correlation coefficient of more than 0.9 and a standard deviation of the slope of less than 0.1.

According to the above criteria, we can calculate the daily optical spectral index of nine BL Lac objects, using literature data. In order to eliminate the effect of red-shift, the fluxes are multiplied by $4\pi d_{\rm L}^2$, i.e.,

$$L_\nu = 4\pi d_{\rm L}^2 f_\nu, \tag{3}$$

where L_ν is the luminosity of source and $d_{\rm L}$ is the luminosity distance.

3. Results and discussion

The distributions of optical luminosity (5500 Å) and optical spectral indices for BL Lac objects are summarized in Fig. 1. We find that there are two clear trends: (i) The average value of the spectral index for LBLs, IBLs and HBLs is $\alpha = 1.172 \pm 0.054$, 0.937 ± 0.052 and 0.802 ± 0.051, respectively. That is, the optical spectra index of the low-frequency peaked BL Lac objects (LBLs) is steeper than the high-frequency peaked BL Lac objects (HBLs); (ii) The spectra tend to be softer when the source becomes brighter for LBLs and the intermediate BL Lac objects (IBLs) (i.e., bluer-when-brighter), and the spectra of HBLs does not vary when the brightness of HBLs changes.

The sources show that the spectral slope of the LBLs and IBLs is flatter when the source becomes brighter. We argue that, if the optical emission comes from the synchrotron radiation, these can be expected. Otherwise, we can not exclude the statistic fluctuation near the peak frequency, because, for HBLs, the optical frequency is far from the synchrotron peak frequency, and the distribution of optical luminosities and optical spectral indices do not show significant variability.

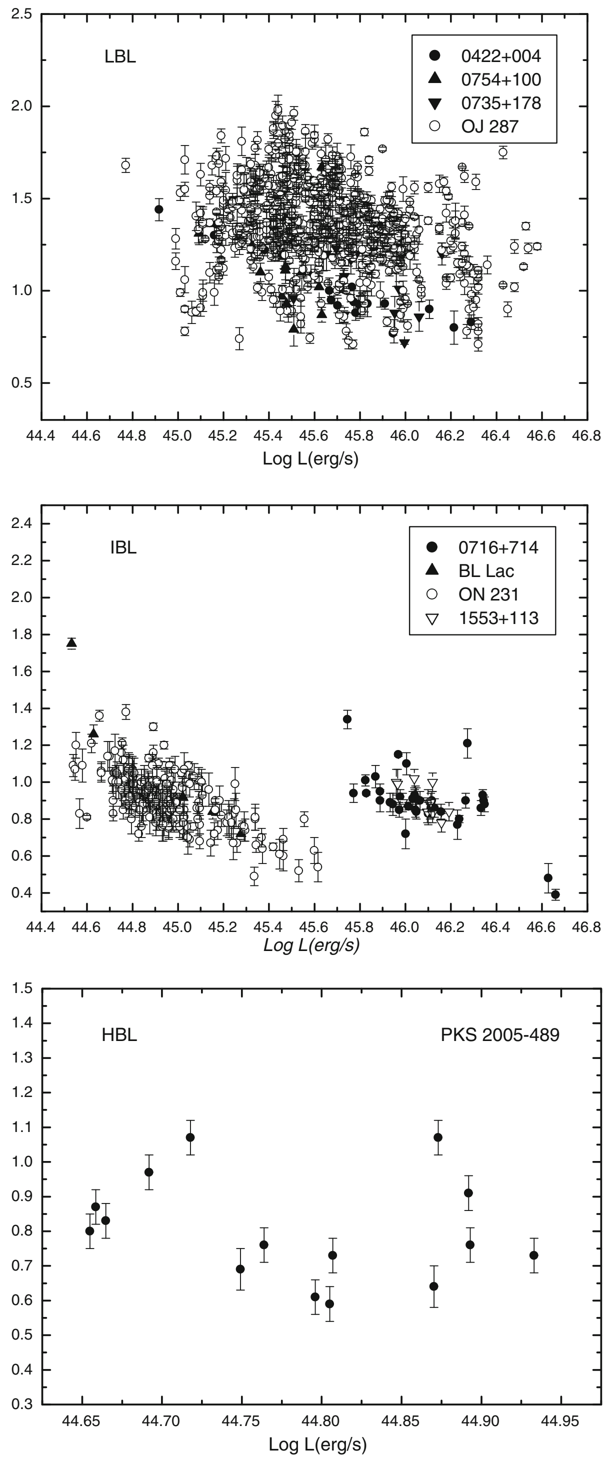

Figure 1. Distribution of the optical spectral indices and the optical luminosity (5500 Å) for BL Lac objects. Upper panel: LBLs, middle panel: IBLs, and lower panel: HBLs.

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