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Spectral Index Changes with Brightness for γ-Ray Loud Blazars

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Abstract. Based on Fermi 1FGL and 2FGL data, a sample of 572 γ-ray loud blazars are selected, in which each source has both γ-ray flux and spectral index in 1FGL and 2FGL, respectively. Theoretic relation of spectral index changes depending on γ-ray brightness is obtained. The correlations between the ratio of γ-ray flux densities and the differences of the γ-ray spectral indices are discussed for the three subclasses of HBL, LBL and FSRQs. Results show that the ratio is related with the differences for the three subclasses. It is consistent with the theoretical result and it indicates that the spectrum becomes flat as the source brightens in the γ-ray band.

Key words. Active galactic nuclei (AGN): blazars: γ-ray emission: spectral index.

1. Introduction

Generally, the spectrum of one source changes with its brightness (Yang *et al*. 2012; Fan *et al*. 1998; Fan & Lin 1999; Yang & Fan 2005; Fan *et al*. 2012). However, it is hard to do statistical investigations of the spectrum changes with the brightness, since there are not enough sets of data of brightness and the corresponding spectral index for a single source.

The Fermi γ-ray space telescope has provided us with new data about γ-ray activities of AGNs. The first Fermi LAT catalogue (1FGL) (Abdo *et al.* 2010) was based on 11 months of flight data, 2FGL catalogue (Nolan *et al.* 2012) was based on data from 24 months of observations. In both 1FGL and 2FGL, there are many blazars which have both γ-ray flux and spectral index. Therefore, the two catalogues are invaluable resources to research the relation of spectrum changes with brightness.

2. Sample and results

2.1 *Sample*

A sample of 572 blazars (278 BL Lacs and 294 FSRQs) is selected from Fermi 1FGL and 2FGL catalogues. Each source in the sample has available γ-ray photon flux and spectral index in both 1FGL and 2FGL.

2.2 *Theoretic relation of spectral index changes*

A power law is adopted for γ-ray photon fluxes, viz. $dN/dE = N_0 E^{-\alpha_{ph}}$, here, N is the γ-ray integral photon flux in units of photons $\cdot$ cm^{-2} $\cdot$ s^{-1}, α_{ph} is the γ-ray photon spectral index, N_0 can be expressed as $N_0 = N \cdot \frac{1-\alpha_{ph}}{E_U^{1-\alpha_{ph}} - E_L^{1-\alpha_{ph}}}$ (Fan *et al.* 2012). Therefore, the γ-ray flux density at E GeV in units of Jy can be obtained by the equation

$$f_{E\,\mathrm{GeV}} = 6.63 \times 10^{-4} N \cdot \frac{1-\alpha_{ph}}{E_U^{1-\alpha_{ph}} - E_L^{1-\alpha_{ph}}} \cdot E^{1-\alpha_{ph}}\ (\mathrm{Jy}), \tag{1}$$

with E_L and E_U being the lower and upper energy limits respectively, and $E_L = 1$ GeV, $E_U = 100$ GeV in this paper.

If the γ-ray spectral index α_γ is defined as $f_\nu \propto \nu^{-\alpha_\gamma}$, and $\alpha_\gamma = \alpha_{ph} - 1$, $f_\nu = f_0 \nu^{-\alpha_\gamma}$, here, f_ν is the flux density at frequency ν, f_0 is a constant. For 1FGL and 2FGL, we have $f_\nu^{1F} = f_0^{1F} \nu^{-\alpha_\gamma^{1F}}$, $f_\nu^{2F} = f_0^{2F} \nu^{-\alpha_\gamma^{2F}}$, where superscripts 1F and 2F represent 1FGL and 2FGL data, respectively. If we define a parameter

$$F_\nu = f_\nu^{2F} / f_\nu^{1F}, \tag{2}$$

then $\log F_\nu = \log(f_0^{2F}/f_0^{1F}) - (\alpha_\gamma^{2F} - \alpha_\gamma^{1F}) \log \nu$.

Let

$$K = f_0^{2F}/f_0^{1F} \quad \text{and} \quad A_\nu = \alpha_\gamma^{2F} - \alpha_\gamma^{1F} = \alpha_{ph}^{2F} - \alpha_{ph}^{1F}. \tag{3}$$

So, we can get a relation of spectral index changes depending on brightness as follows:

$$\log F_\nu = -\log \nu \cdot A_\nu + \log K. \tag{4}$$

2.3 *Data processing method*

Because the integrated γ-ray photon fluxes data in our sample are from the range of 1$\sim$100 GeV energy bands, the γ-ray flux density of each source is calculated at the middle energy 50 GeV by equation (1). The flux densities calculated are K-corrected by a formula, $f_{\text{K-corr}} = f^{ob}(1+z)^{\alpha_\gamma - 1}$. The parameters F_ν and A_ν can be obtained by equations (2) and (3). Finally, the correlations between $\log F_\nu$ and A_ν are investigated for subclasses of FSRQ, HBL and LBL.

2.4 *Results*

The results of correlations between $\log F_\nu$ and A_ν are as follows $\log F_\nu = -(1.755 \pm 0.042) A_\nu - (0.050 \pm 0.005)$, with a correlation coefficient $r = -0.651$ for the whole sample, $\log F_\nu = -(2.322 \pm 0.062) A_\nu - (0.072 \pm 0.006)$ with $r = -0.709$ for 294 FSRQs, $\log F_\nu = -(1.298 \pm 0.057) A_\nu - (0.024 \pm 0.007)$ with $r = -0.609$ for 278 BL Lacs, $\log F_\nu = -(0.699 \pm 0.087) A_\nu - (0.011 \pm 0.011)$ with $r = -0.362$ for 138 HBLs, $\log F_\nu = -(2.003 \pm 0.115) A_\nu - (0.090 \pm 0.014)$ with $r = -0.774$ for 67 LBLs and the chance probability $p < 10^{-4}$, for each sample. Also, the results are shown in Fig. 1.

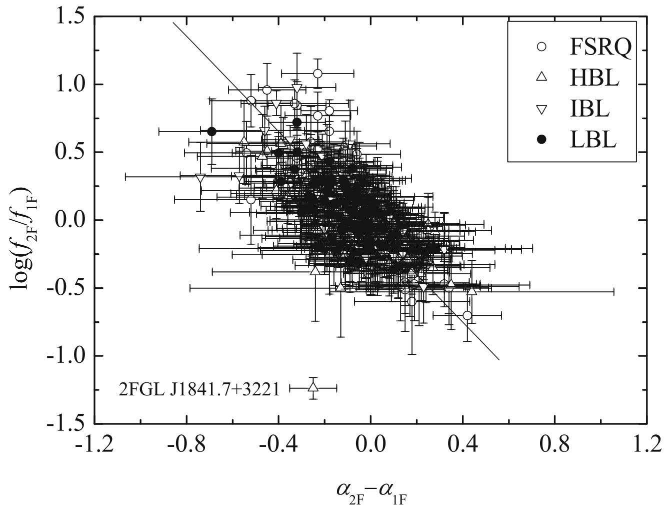

Figure 1. Plot of $\log F_\nu$ vs. A_ν.

3. Discussion and conclusion

In this paper, we have discussed the dependence of the spectrum changes with the brightness using two parameters, which are the ratio of the flux densities of Fermi 1FGL to 2FGL blazars, viz. $F_\nu = f_\nu^{2F}/f_\nu^{1F}$, and the spectral index difference, viz. $A_\nu = \alpha_\gamma^{2F} - \alpha_\gamma^{1F} = \alpha_{ph}^{2F} - \alpha_{ph}^{1F}$. The correlation between $\log F_\nu$ and A_ν is investigated. Our results show that there are good anticorrelations between $\log F_\nu$ and A_ν for subclasses FSRQ, HBL, IBL and LBL (Fig. 1).

Equation (4), $\log F_\nu = -\log\nu \cdot A_\nu + \log K$ shows that there is an anticorrelation between $\log F_\nu$ and A_ν. Our statistical analysis results have confirmed the relation, which suggests that the spectrum becomes flat when the source becomes bright in the γ-ray band. This phenomenon is similar to that in the X-ray band (Yang *et al.* 2006).

From our results, we have straight line slopes of the linear regression $b = -2.32$ for 294 FSRQs, $b = -0.70$ for 138 HBLs, $b = -2.00$ for 67 LBLs, if the source of 2FGL J1841.7 + 3221 is not considered, $b = -1.02$ for 137 HBLs (Fig. 1). Therefore, there is a tendency with $b^{\mathrm{FSRQs}} < b^{\mathrm{LBLs}} < b^{\mathrm{HBLs}}$. The sequence followed by HBLs, LBLs and FSRQs is consistent with those results obtained by many (Fossati *et al*. 1997, 1998; Yang *et al*. 2006), and it supports the argument that LBLs are intermediate between HBLs and FSRQs.

We can get the following conclusions. There are good anticorrelations between the ratio of two γ-ray flux densities and the spectral index difference for the total sample and the subclasses of FSRQ, HBL, IBL and LBL samples. The result is consistent with the theoretical result and it indicates that the spectrum becomes flat when the source becomes bright in the γ-ray band. The correlation slopes follow a continuous sequence from FSRQs to LBLs to HBLs, which is consistent with the 'blazar sequence'.

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