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Multi-Wave Luminosity of High-Synchrotron-Peaked TeV BL Lacs Detected by Fermi LAT

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Abstract. We have studied the correlations between luminosities ($L_{\rm R}$, $L_{\rm IR}$, L_γ) in the radio, near-infrared and γ-ray wave bands for HSP TeV BL Lacs. The results show that there are significant intrinsic correlations between $L_{\rm R}$ and L_γ and between $L_{\rm IR}$ and L_γ in all states (high/average/low), and suggest that for HSP TeV BL Lacs, the Synchrotron Self-Compton radiation (SSC) is the main mechanism of high energy γ-ray emission, and the inverse Compton scattering of circumnuclear dust is likely to be an important complementary mechanism.

Key words. BL Lacertae objects: general—gamma rays: observations—radiation mechanisms: nonthermal.

1. Introduction

Blazars are the most extreme type of Active Galactic Nuclei (AGNs), including BL Lacertae objects (BL Lacs) and Flat-Spectrum Radio Quasars (FSRQs). The origin of the gamma-ray of blazar is intriguing. One possible scenario is Synchrotron Self-Compton (SSC) radiation (e.g. Maraschi *et al.* 1992). The other is external inverse Compton (EC) radiation, for which the seed photons come from a source external to the jet (e.g. Zhang & Cheng 1997; Sikora *et al.* 1994; Ghisellini & Madau 1996; Xie *et al.* 1997). However, there is no consensus on the dominant emission process. The various correlations in different wavelengths can be used to distinguish among them.

From the most recent version of TeV Cat catalog[1], 50 AGNs have been detected in the TeV or Very High Energy regime (VHE; $E > 100$ GeV). These TeV AGNs include 42 BL Lacs (1ES $0033+595$, 1ES $0647+250$, 1ES $1727+502$ and 1ES $1741+196$ are newly announced), 3 FSRQs, 4 radio galaxies and 1 AGN of unknown type. According to the Spectral Energy Distribution (SED) proposed by Abdo *et al.* (2010b) and Ackermann *et al.* (2011b), most of the TeV BL Lacs are High-Synchrotron Peaked blazars (HSPs, for the synchrotron peak frequency $v^s_{\rm peak} > 10^{15}$ Hz). Recently these sources have also been detected at MeV–GeV energies by Fermi satellite (Abdo *et al.* 2010a, 2012; Ackermann *et al.* 2011a), except for

[1] http://tevcat.uchicago.edu

Table 1. The results of partial correlation analysis.

X	Y	N	r	P
$\log L_{\mathrm{R(H)}}$	$\log L_\gamma$	25	0.77	$<10^{-4}$
$\log L_{\mathrm{R(L)}}$	$\log L_\gamma$	25	0.72	$<10^{-4}$
$\log L_{\mathrm{R(A)}}$	$\log L_\gamma$	29	0.76	$<10^{-4}$
$\log L_{\mathrm{IR(H)}}$	$\log L_\gamma$	19	0.72	1×10^{-3}
$\log L_{\mathrm{IR(L)}}$	$\log L_\gamma$	19	0.56	1.6×10^{-2}
$\log L_{\mathrm{IR(A)}}$	$\log L_\gamma$	29	0.71	$<10^{-4}$

six TeV AGNs (SHBL J0013555.9-185406, 1ES 0229 + 200, 1ES 0347-121, PKS 0548-322, 1ES 1312-423 and HESS J1943 + 213).

In this paper, we collect 29 HSP TeV BL Lacs detected by Fermi satellite and study the correlations between L_{R} and L_γ and between L_{IR} and L_γ in order to explore the origin of high energy γ-ray of HSP TeV BL Lacs. It should be pointed out that in view of the large variation in the flux of all the bands for blazars, simultaneous observation are required (e.g., Cheng *et al.* 2000). Unfortunately, only a small number of Fermi sources have multi-wave band fluxes, and most of them are not simultaneous. Because of lack of simultaneous multi-wave band data for the sources, we seek to find the same kind of flux state (high/average/low) (Xiong *et al.* 2012). The paper is structured as follows: in section 2, we briefly describe the data and associated procedures; the correlation analysis and discussion are in sections 3 and 4 respectively. The cosmological parameters $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_{\mathrm{m}} = 0.27$, and $\Omega_\Lambda = 0.73$ have been adopted in this work.

2. Data description

We collected radio (8.4 GHz), near-infrared (K band) and gamma-ray (0.1–100 GeV) K-corrected flux densities of 25 HSP TeV BL Lacs from Xiong *et al.* (2012). The description and associated procedures of these data can be seen in Xiong *et al.* (2012). In addition, we also collected the radio, near-infrared and gamma flux densities of four objects newly announced. Finally, the luminosities of three bands were calculated from the relation $L_\nu = 4\pi {d_{\mathrm{L}}}^2 S_\nu$, where d_{L} is the luminosity distance.

3. Correlation analysis

As pointed out by Padovani (1992), for flux-limited sample, the luminosity is strongly correlated with redshift, and would result in a spurious correlation. So Pearson's partial correlation analysis is applied to the relevant data to analyse the correlations between L_{R} and L_γ and between L_{IR} and L_γ (Machalski & Jamrozy 2006). The results of the analysis are given in Table 1. The main results are as follows:

(1) There are intrinsic significant correlations between L_{R} and L_γ, and between L_{IR} and L_γ in all states (the chance probability $P < 0.05$ confident level from Fig. 1 and Table 1).
(2) The coefficients of correlations between L_{R} and L_γ, and between L_{IR} and L_γ in the high and average states are much better than that in the low states (see Fig. 1, Table 1).

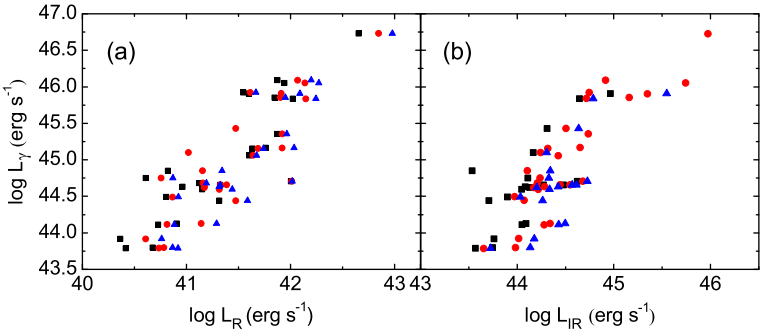

Figure 1. Correlations between $L_{\rm R}$ and L_γ (**a**), and between $L_{\rm IR}$ and L_γ (**b**) in all states (the blue triangles represent high state; the red circles represent average state; the black squares represent the low state).

4. Discussion

The most important results of this study are that there are intrinsic correlations between $L_{\rm R}$ and L_γ and between $L_{\rm IR}$ and L_γ which places a strong constraint on γ-ray radiation mechanism and can be applied to test radiation models for HSP TeV BL Lacs. Since the launch of the Fermi satellite, we have entered a new era of blazars research. The correlation between radio and γ-ray fluxes/luminosities has been found by many authors for different Fermi samples (e.g., Nieppola *et al.* 2011; Ackermann *et al.* 2011b; Ghirlanda *et al.* 2011; Linford *et al.* 2012; Leon-Tavares *et al.* 2012). From our study, we also find intrinsic correlations between $L_{\rm R}$ and L_γ in all states for HSP TeV BL Lacs that suggests that for HSP TeV BL Lacs, γ-ray and radio emission regions are co-spatial, i.e., in the jet, and the Synchrotron Self-Compton (SSC) radiation is the main mechanism of high-energy γ-ray emission.

On the other hand, the intrinsic correlations between $L_{\rm IR}$ and L_γ in all states for HSP TeV BL Lacs indicate that γ-ray emission is related to the near-IR radiation. Xie *et al.* (1998) found that the variability behavior of the γ-ray and the near-IR flux seems to be the same. There are two models to explain the origin of IR photons for IC process, including hot circum-nuclear dust model and synchrotron radiation model (Xie *et al.* 1997). According to the hot circum-nuclear dust model, the dust grains from radiation field provide seed photons for IC processes. In addition, the observed correlation between $L_{\rm IR}$ and L_γ is also compatible with standard Synchrotron Self-Compton (SSC) mechanism. Xie *et al.* (1998) found that the electrons emitting IR and optical photons via synchrotron are responsible for upscattering them to γ-rays, and variability in IR regime should be accompanied by changes in the γ-rays. Ghisellini & Maraschi (1986) also found that the synchrotron and IC flux vary together. Therefore, based on the above discussions, we conclude that for HSP TeV BL Lacs, IR photons are mainly produced by synchrotron radiations and the γ-rays are by IC scattering of these IR photons by a relativistic electron beamed source; circum-nuclear dust is also an important complementary source of the soft photon field for IC process.

We also found that the correlations between $L_{\rm R}$ and L_γ, and between $L_{\rm IR}$ and L_γ in the high and average states are much better than that in the low state. The possible

interpretation is that for large γ-ray flares in blazars, they occur when the sources are in the high state (Fan *et al.* 1998). Finally, we stress that our results should be tested by simultaneous multiwavelength observations.

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