

Article

The Classifications and Some Correlations for Fermi Blazars

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Abstract: In a recent paper, we calculate spectral energy distributions (SEDs) for 1425 Fermi blazars, classifications of low synchrotron peak sources (LSPs) if $\log \nu_p(\text{Hz}) \leq 14.0$, intermediate synchrotron peak sources (ISPs) if $14.0 < \log \nu_p(\text{Hz}) \leq 15.3$, and high synchrotron peak sources (HSPs) if $\log \nu_p(\text{Hz}) > 15.3$ are made based on 999 logarithms of synchrotron peak frequencies with known redshift, and we obtain an empirical relation to estimate the synchrotron peak frequency, ν_p^{Eq} from effective spectral indexes α_{ox} and α_{ro} as $\log \nu_p^{\text{Eq}} = 16 + 4.238X$ if $X < 0$, and $\log \nu_p^{\text{Eq}} = 16 + 4.005Y$ if $X > 0$, where $X = 1.0 - 1.262\alpha_{ro} - 0.623\alpha_{ox}$, and $Y = 1.0 + 0.034\alpha_{ro} - 0.978\alpha_{ox}$ [1]. In the present work, we investigate the correlation between the peak frequency and the radio to X-ray spectral index, that between peak luminosity (integrated luminosity) and γ -ray/optical luminosity, and that between peak luminosity and integrated luminosity. Some discussions are presented.

Keywords: galaxies: active; galaxies: jets; galaxies: nuclei

1. Introduction

As the most special subclass of active galactic nuclei (AGNs), blazars show rapid variability and luminous brightness, high and variable polarization, superluminal motions, core-dominated non-thermal continuum, and strong γ -ray emissions, etc. [2–25]. Blazars consist of two subclasses, namely BL Lacertae objects (BL Lacs) and flat spectrum radio quasars (FSRQs), both subclasses have the common continuum properties while their emission line features are quite different, namely FSRQs have strong emission lines while BL Lacs have no emission lines or very weak emission lines. The spectral energy distributions of blazars consist of two bumps, the first one, for which synchrotron radiation is responsible, locates at infrared/optical region or UV/X-ray or even higher energetic bands; the second one locates at GeV or TeV bands, it is often attributed to the inverse Compton process.

In 2010, [26] calculated the SEDs for 48 Fermi blazars and proposed the subclasses of blazars using the acronyms LSP, ISP and HSPs as: LSPs if $\log \nu_p(\text{Hz}) \leq 14$, ISPs if $14.0 < \log \nu_p(\text{Hz}) \leq 15$, and HSPs if $\log \nu_p(\text{Hz}) > 15$. An empirical function is suggested for the estimation of peak frequency using the effective spectral indexes. Quite recently, we calculated the SEDs for 1425 Fermi blazars and successfully obtained SEDs for 1392 sources [1]. Based on the paper, we will investigate some correlations statistically.

The spectral index α is defined as $F_\nu \propto \nu^{-\alpha}$, and all luminosities νL_ν are denoted simply by L_ν .

2. Sample and Classifications

In our previous paper, SEDs were calculated for a sample of 1425 Fermi detected blazars selected from the 3FGL [2] by fitting following relation with a least square fitting method,

$$\log(\nu F_\nu) = P_1(\log \nu - P_2)^2 + P_3,$$

where P_1 , P_2 and P_3 are constants with P_1 being the spectral curvature, P_2 the peak frequency ($\log \nu_p$) and P_3 peak flux ($\log(\nu_p F_{\nu_p})$). But only 1392 sources were obtained SEDs, amongst them 999 have known redshift. When Bayesian Information Criterion (BIC) is adopted to the 999 sources, following criteria was proposed for the classifications.

$$\begin{aligned} \log \nu_p(\text{Hz}) &\leq 14.0 \text{ for LSPs,} \\ 14.0 < \log \nu_p(\text{Hz}) &\leq 15.3 \text{ for ISPs, and} \\ \log \nu_p(\text{Hz}) &> 15.3 \text{ for HSPs.} \end{aligned}$$

When the averaged redshifts are adopted to the redshift unknown sources, and based on the criteria, we have 34.77% of the whole sample are LSPs, 40.09% are ISPs, and 25.14% are HSPs for 1392 blazars.

In 2010, [26] presented an empirical relation to estimate the synchrotron peak frequency, ν_p from effective spectral indexes α_{ox} and α_{ro} . Following their work, we obtain an empirical relation to estimate the synchrotron peak frequency, $\nu_p^{\text{Eq.}}$ from effective spectral indexes α_{ox} and α_{ro} as

$$\log \nu_p^{\text{Eq.}} = \begin{cases} 16 + 4.238X & X < 0 \\ 16 + 4.005Y & X > 0 \end{cases} \quad (1)$$

where $X = 1.0 - 1.262\alpha_{ro} - 0.623\alpha_{ox}$, and $Y = 1.0 + 0.034\alpha_{ro} - 0.978\alpha_{ox}$. The estimated peak frequency and the fitted peak frequency follow a linear correlation, $\log \nu_p' = (0.675 \pm 0.017) \log \nu_p + (4.822 \pm 0.252)$ with a correlation coefficient $r = 0.804$ and a chance probability $p < 10^{-4}$, and is shown in Fig. 1.

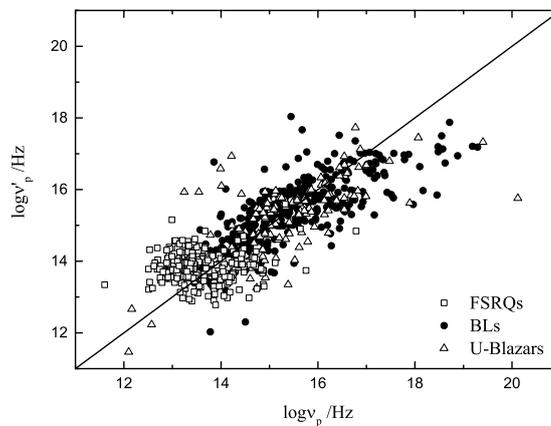


Figure 1. The correlations between estimated peak frequency using the empirical function and the fitted peak frequency. The solid line stands for a best fitting result.

3. Correlations

In our previous work, spectral indexes (α_{ro} and α_{ox}), peak frequency ($\log \nu_p$), integrate luminosity ($\log L_{\text{bol}}$), peak luminosity ($\log L_{\nu_p}$), and monochromatic luminosity at radio, optical, X-ray and γ -ray luminosity are listed in [1]. From the data, we obtain that $\log L_{\text{bol}} = (0.597 \pm 0.011) \log L_{\gamma} + (18.717 \pm 0.497)$ with a correlation coefficient $r = 0.825$ and a chance probability $p < 10^{-4}$, $\log L_p = (0.595 \pm 0.012) \log L_{\gamma} + (18.384 \pm 0.525)$ with $r = 0.810$ and $p < 10^{-4}$, $\log L_p = (0.866 \pm 0.016) \log L_o + (6.145 \pm 0.747)$ with $r = 0.818$ and $p < 10^{-4}$, $\log L_{\text{bol}} = (0.973 \pm 0.004) \log L_p + (1.601 \pm 0.169)$ with $r = 0.990$ and $p < 10^{-4}$, $\log L_{\text{bol}} = (0.851 \pm 0.016) \log L_o + (7.212 \pm 0.735)$ with $r = 0.818$ and $p < 10^{-4}$, and $\alpha_{rx} = -(0.078 \pm 0.002) \log \nu_p + (1.822 \pm 0.026)$ with $r = 0.837$ and $p < 10^{-4}$ for the whole sample. The linear analysis results for the whole and the subclasses are listed in Table 1 and the corresponding Figures are shown in Fig. 2 to 5.

Table 1. Some correlation results for Fermi blazars.

y vs x	Sample	$a \pm \Delta a$	$b \pm \Delta b$	r	N	p
α_{RX} vs $\log \nu_p$	All Blazars	-0.078 ± 0.002	1.822 ± 0.026	0.837	853	$< 10^{-4}$
	FSRQs	-0.017 ± 0.006	1.025 ± 0.077	0.174	283	0.33%
	BL Lacs	-0.079 ± 0.003	1.836 ± 0.046	0.787	428	$< 10^{-4}$
	HBLs	-0.039 ± 0.006	1.178 ± 0.090	0.473	176	$< 10^{-4}$
	IBLs	-0.071 ± 0.005	1.740 ± 0.076	0.663	244	$< 10^{-4}$
	LBLs	0.018 ± 0.038	0.567 ± 0.497	0.195	8	64.31%
$\log L_p$ vs $\log L_O$	All Blazars	0.866 ± 0.016	6.145 ± 0.747	0.818	1360	$< 10^{-4}$
	FSRQs	0.765 ± 0.028	10.921 ± 1.275	0.792	447	$< 10^{-4}$
	BL Lacs	0.886 ± 0.025	5.086 ± 1.110	0.824	614	$< 10^{-4}$
	HBLs	0.818 ± 0.042	8.140 ± 1.875	0.811	202	$< 10^{-4}$
	IBLs	0.933 ± 0.032	2.921 ± 1.458	0.841	347	$< 10^{-4}$
	LBLs	0.871 ± 0.068	6.141 ± 3.076	0.849	65	$< 10^{-4}$
$\log L_{blo}$ vs $\log L_O$	All Blazars	0.851 ± 0.016	7.212 ± 0.735	0.818	1360	$< 10^{-4}$
	FSRQs	0.775 ± 0.026	10.870 ± 1.163	0.821	447	$< 10^{-4}$
	BL Lacs	0.859 ± 0.025	6.696 ± 1.112	0.816	614	$< 10^{-4}$
	HBLs	0.791 ± 0.042	9.837 ± 1.907	0.797	202	$< 10^{-4}$
	IBLs	0.913 ± 0.033	4.183 ± 1.483	0.832	347	$< 10^{-4}$
	LBLs	0.851 ± 0.069	7.287 ± 3.123	0.840	65	$< 10^{-4}$
$\log L_{blo}$ vs $\log L_p$	All Blazars	0.973 ± 0.004	1.601 ± 0.169	0.990	1392	$< 10^{-4}$
	FSRQs	0.962 ± 0.008	2.136 ± 0.354	0.986	461	$< 10^{-4}$
	BL Lacs	0.970 ± 0.005	1.728 ± 0.237	0.991	620	$< 10^{-4}$
	HBLs	0.978 ± 0.007	1.459 ± 0.299	0.995	207	$< 10^{-4}$
	IBLs	0.984 ± 0.006	1.072 ± 0.248	0.995	348	$< 10^{-4}$
	LBLs	0.975 ± 0.020	1.376 ± 0.904	0.987	65	$< 10^{-4}$
$\log L_p$ vs $\log L_\gamma$	All Blazars	0.595 ± 0.012	18.384 ± 0.525	0.810	1392	$< 10^{-4}$
	FSRQs	0.584 ± 0.023	18.806 ± 1.060	0.765	461	$< 10^{-4}$
	BL Lacs	0.675 ± 0.016	14.835 ± 0.723	0.860	620	$< 10^{-4}$
	HBLs	0.701 ± 0.037	13.754 ± 1.644	0.798	207	$< 10^{-4}$
	IBLs	0.705 ± 0.018	13.419 ± 0.807	0.904	348	$< 10^{-4}$
	LBLs	0.572 ± 0.059	19.498 ± 2.663	0.775	65	$< 10^{-4}$
$\log L_{blo}$ vs $\log L_\gamma$	All Blazars	0.597 ± 0.011	18.717 ± 0.497	0.825	1392	$< 10^{-4}$
	FSRQs	0.583 ± 0.022	19.277 ± 1.002	0.782	461	$< 10^{-4}$
	BL Lacs	0.670 ± 0.015	15.449 ± 0.679	0.872	620	$< 10^{-4}$
	HBLs	0.699 ± 0.035	14.311 ± 1.572	0.810	207	$< 10^{-4}$
	IBLs	0.712 ± 0.016	13.478 ± 0.722	0.922	348	$< 10^{-4}$
	LBLs	0.619 ± 0.049	17.631 ± 2.203	0.848	65	$< 10^{-4}$

4. Discussions and Conclusions

Blazars are extreme subclass of AGNs, they are the main discovery of Fermi missions [2,3]. SEDs were calculated for a sample of 1425 Fermi blazars in our previous paper [1].

When Bayesian Information Criterion (BIC) was adopted to the comoving peak frequencies, we found that 3 components are enough to fit the peak frequency distribution and proposed the boundaries for subclasses as $\log \nu_p(\text{Hz}) \leq 14.0$ for LSPs, $14.0 < \log \nu_p(\text{Hz}) \leq 15.3$ for ISPs, and $\log \nu_p(\text{Hz}) > 15.3$ for HSPs. This classification is quite similar to that of [26]. There is no extreme high peak frequency component. We also proposed a function to estimate the peak frequency by using effective spectral indexes. From the comparison shown in Fig. 1, we can see that the empirical function can estimate the peak frequency well when peak frequency is lower than $\log \nu_p < 17$, but the estimated peak frequency is under-estimated when $\log \nu_p > 17$.

Fig. 2 show that there is an anti-correlation between the effective spectral index, α_{rx} , and the peak frequency, $\log \nu_p$ for the whole sample. However, we can see that there is a tendency for α_{rx} to increase with $\log \nu_p$ for lower peak frequency sources. When the peak frequency move to the lower side, then the X-ray emissions will increase for they are the sum of the synchrotron emission tail and the inverse Compton emission, therefore α_{rx} will decrease resulting in the positive tendency.

We also investigate the correlation between the peak luminosity/integrate luminosity and γ -ray luminosity. We really found that there is good correlation. Similar results are also found between the

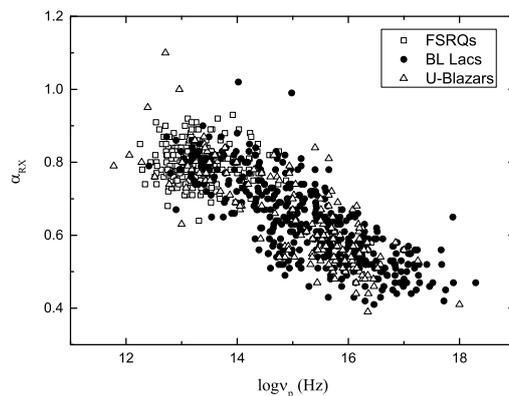


Figure 2. The correlations between spectral index α_{rX} and peak frequency ($\log \nu_p$).

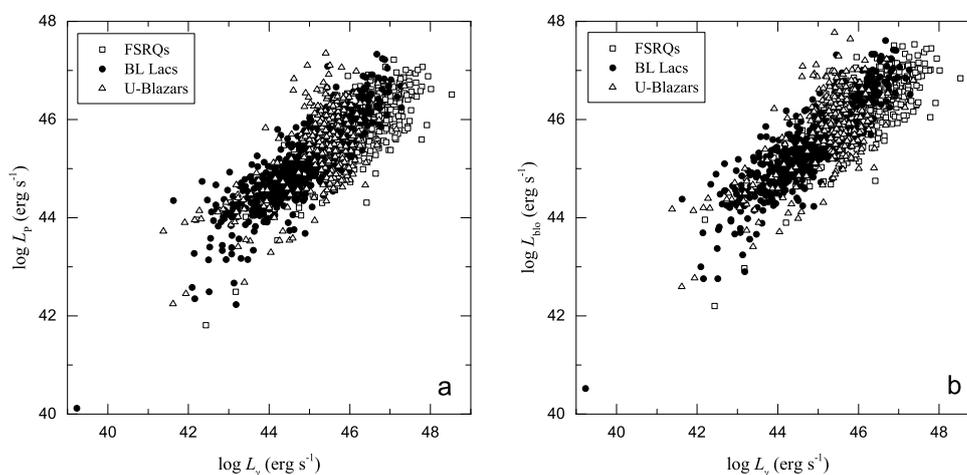


Figure 3. The correlations between γ -ray luminosity ($\log L_\gamma$ at 1 GeV) and peak luminosity ($\log L_p$)(a), and integrated luminosity ($\log L_{\text{boi}}$)(b).

peak luminosity/integrate luminosity and optical luminosity. This means that we can use γ -ray (or optical) luminosity to estimate the peak luminosity/integrate luminosity and γ -ray luminosity.

In this work, we introduce the classification of subclasses of blazars and an empirical function of peak frequency estimation using effective spectral indexes, investigate the correlation between effective radio to X-ray spectral index and peak frequency, the correlations between peak/integrate luminosity and γ -ray/optical luminosity. Following conclusions can be come to: 1. There are only 3 subclasses (LSPs, ISPs, and HSPs) for Fermi blazars, and there is no extreme high peak frequency component for blazars; 2. There is an anti-correlation between effective spectral index (α_{rX}) and peak frequency; 3. Peak frequency can be estimate using effective spectral indexes; 4. The peak/integrate luminosity can be estimated using γ /optical luminosity; 5. There is a very significant correlation between peak and integrate luminosity.

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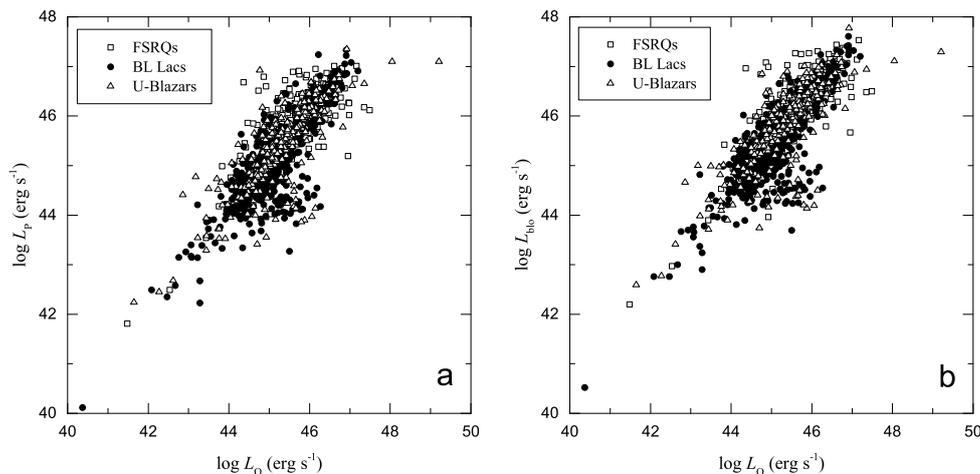


Figure 4. The correlations between optical luminosity ($\log L_o$) and peak luminosity ($\log L_p$)(a), and integrated luminosity ($\log L_{bol}$)(b).

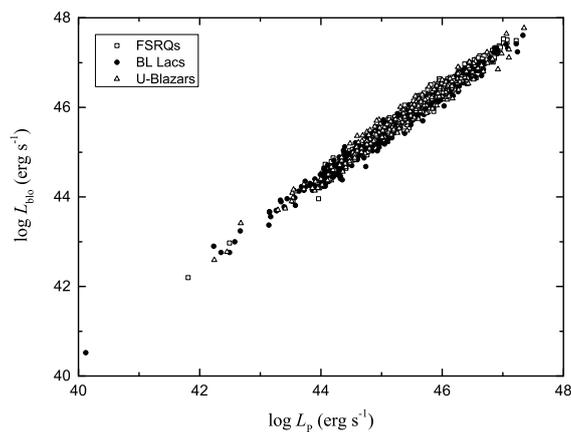


Figure 5. The correlations between integrate luminosity ($\log L_{bol}$) and peak luminosity ($\log L_p$).

Author Contributions: JHFan is responsible for the writing and the motivation of the paper; YLiu is responsible for the classification; JHYang for the SED calculation, CLin for the figures and linear correlation analysis, JMHao for some discussions.

Conflicts of Interest: The author declares no conflict of interest.

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