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SEDs and Beaming Effect for Fermi Blazars

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In this work, based on our previous calculations of spectral energy distributions for a sample of Fermi blazars (Fan et al. 2015a), we calculated the radio loudness and performed correlation analyses. Our analysis results show that radio loudness is closely anti-correlated with synchrotron peak frequency and positively correlated with gamma-ray luminosity, suggesting that the gamma-ray emissions are strongly beamed.

Keywords: galaxies, active-galaxies, BL Lacs-galaxies, jets

1. INTRODUCTION

As a special subclass of active galactic nuclei (AGNs), blazars are the major population in Fermi missions (Abdo et al. 2009, 2010a; Ackermann et al. 2011; Acero et al. 2015). They show some extreme observational properties: rapid and high amplitude variability, high and variable polarization, strong and variable γ-ray emissions, superluminal motions, etc. (see Fan et al. 2011; Yang et al. 2012; Fan et al. 2013, 2014; Yang et al. 2014). Blazars have two subclasses, namely BL Lacertae objects (BL Lacs) and flat spectrum radio quasars (FSRQs). They both show common continuum but different emission lines. FSRQs have very strong emission lines while BL Lacs have weak emission lines or no emission line at all. BL Lacs can be classified as radio selected (RBLs) and X-ray selected (XBLs) BL Lacs from surveys, and they have different synchrotron peak frequencies with most XBLs showing synchrotron peak frequencies $\log\nu_p > 15$ Hz (highly peaked BL Lacs-HBLs) and RBLs showing $\log\nu_p < 15$ Hz (lowly peaked BL Lacs-LBLs) (Padovani & Giommi 1996). According to the peak frequency, BL Lacs can be divided into LBL, IBL, and HBL: LBL if $\log\nu_p < 14.5$ Hz, IBL (intermediately peaked BL Lacs) if 14.5 Hz $< \log\nu_p <$ 16.5 Hz, and HBL if $\log\nu_p > 16.5$ Hz (Nieppola et al. 2006); LBLs if $\log\nu_p < 14$ Hz, IBL if 14 Hz $< \log\nu_p <$ 15 Hz, and HBL if $\log\nu_p > 15$ Hz (Abdo et al. 2010b); or LBL, $\log\nu_p < 13.98$ Hz, IBL 13.98 Hz $< \log\nu_p <$ 15.30 Hz, and HBL if $\log\nu_p > 15.30$ Hz (Fan et al. 2015a). We can see that our previous classifications are similar to those of Abdo et al. (2010b).

The observations of strong γ-ray emissions in blazars suggest the existence of a relativistic beaming effect, which has been discussed in some papers (see Savolainen et al. 2010; Giroletti et al. 2012; Fan et al. 2013, 2014; Lin & Fan 2016). Very recently, following the work by Mattox et al. (1993), the Doppler factors were evaluated for a sample of Fermi blazars by assuming time scales of 6 hr and 24 hr (Fan et al. 2013, 2014; Liodakis & Pavlidou 2015). In our previous papers, we also found that the Fermi detected blazars have larger core-dominance parameters (Pei et al. 2016) and the de-beamed gamma-ray flux densities show a close correlation with redshift (Xiao et al. 2015).

The present work follows our previous paper of Fan et al. (2015a), which reported the classifications of blazars and investigated the correlation between radio loudness and synchrotron peak frequency or gamma-ray luminosity. In section 2, we present the results and in Section 3 the discussions and conclusions. In our analysis, we adopt the Hubble constant $H_0 = 73\ \mathrm{km \cdot s^{-1} \cdot Mpc^{-1}}$, and the spectral index

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α is defined as $f_\nu \propto \nu^\alpha$ through this paper.

2. LUMINOSITY AND RADIO LOUDNESS

The γ-ray photon number per unit energy can be expressed as

$$\frac{dN}{dE} = N_0 E^{-\Gamma} \tag{1}$$

where Γ is the γ-ray photon spectral index. N_0 is a constant, and can be obtained by integrating Eq. (1):

$$N_0 = N \cdot \frac{1-\Gamma}{E_U^{1-\Gamma} - E_L^{1-\Gamma}}, \text{ if } \Gamma = 2, \text{ then } N_0 = N \cdot \frac{E_L E_U}{E_U - E_L}$$

for the rest case. (2)

N is the γ-ray integral photon flux in units of photons·cm^{-2}·s^{-1} in the energy range of EL~EU, where EL and EU are the lower and upper energy limits, respectively, and EL = 1 GeV and EU = 100 GeV in this paper.

Hence, the total γ-ray flux density in the range of EL~EU is

$$F = \int_{E_L}^{E_U} E dN = 1.602 \times 10^{-3} \cdot N \cdot \frac{E_L E_U}{E_U - E_L} \ln \frac{E_U}{E_L} \text{ if } \Gamma = 2,$$

$$F = \int_{E_L}^{E_U} E dN = 1.602 \times 10^{-3} \frac{1-\Gamma}{2-\Gamma} \cdot \frac{E_U^{2-\Gamma} - E_L^{2-\Gamma}}{E_U^{1-\Gamma} - E_L^{1-\Gamma}}$$

otherwise (3)

The integral γ-ray luminosity is calculated by the formula $L = 4\pi d_L^2 F$, where d_L is the luminosity distance (Fan et al. 2015b).

Radio loudness can be calculated as the ratio of the radio emissions to the optical emissions: $R_L = {}^{L_R}\!/\!_{L_o}$, where L_R and L_O are radio and optical luminosities, respectively.

3. RESULTS

In our previous paper, we compiled multiwavelength data for a sample of 1,425 sources and successfully calculated spectral density distributions (SEDs) for 1,392 sources; among them 999 sources have shown redshift. Based on the calculated synchrotron peak frequency (ν_p), we classified the subclasses of blazars as LBL if $\log\nu_p < 13.98$ Hz, IBL if 13.98 Hz $< \log\nu_p <$ 15.3 Hz, and HBL if $\log\nu_p > 15.3$ Hz (Fan et al. 2015a). From Table 1 of Fan et al. (2015a), we can obtain a sub-sample of 983 sources with available redshift, radio-, optical-, and γ-ray luminosities.

Averaged values: For the 983 FSRQs, there are 447 FSRQs, 536 BL Lacs (148 HBLs, 339 IBLs, and 49 LBLs). The radio loudness $<R_L>$ = 3.23 0.54 for FSRQs, $<R_L>$ = 2.69 ± 0.93 for LBLs, $<R_L>$ = 2.11 ± 0.80 for IBLs, and $<R_L>$ = 1.66 ± 0.0.56 for HBLs.

Correlations: From the relevant data of Fan et al. (2015a), we can obtain the following correlations. For RL and ν_p,

$\log R_L = -(0.46 \pm 0.02) \log\nu_p + 9.24 \pm 0.33$ with a correlation coefficient $r = -0.54$ and a chance probability $p = 10^{-4}$ for the whole sample, as shown in Fig. 1. For the subclasses, FSRQs, LBLS, and HBLs, we have $\log R_L = -(0.22 \pm 0.04) \log\nu_p + 6.29 \pm 0.54$ with $r = -0.54$ and $p < 10^{-4}$ for 447 FSRQs, $\log R_L = (0.79 \pm 0.49) \log\nu_p - (7.84 \pm 6.52)$ with $r = 0.23$ and $p = 11.3\%$ for 49 LBLs and $\log R_L = (0.05 \pm 0.05) \log\nu_p + 0.83 \pm 0.87$ with $r = 0.08$ and $p = 33.4\%$ for 148 HBLs, as shown in Fig. 2.

For the radio loudness and the gamma-ray luminosity, we have

$\log L_\gamma = (0.72 \pm 0.06)\log R_L + (43.62 \pm 0.18)$ with $r = 0.51$ and $p < 10^{-4}$ for 447 FSRQs,

$\log L_\gamma = (0.64 \pm 0.12)\log R_L + (43.31 \pm 0.23)$ with $r = 0.39$ and $p < 10^{-4}$ for 148 HBLs, and

$\log L_\gamma = (0.42 \pm 0.36)\log R_L + (44.76 \pm 1.18)$ with $r = 0.17$ and $p < 24.7\%$ for 49 LBLs, as shown in Fig. 3. The corresponding correlation results are listed in Tables 1 and 2.

4. DISCUSSION AND CONCLUSION

Blazars consist of FSRQs and BL Lacs, and BLs are composed

Table 1. Correlation for $\log R_L$ and $\log\nu_p$

Sample	a	Δa	b	Δb	r	n	p
Total	9.24	0.33	-0.46	0.02	-0.54	983	<0.0001
FSRQ	6.29	0.54	-0.22	0.04	-0.26	447	<0.0001
HBL	0.83	0.87	0.05	0.05	0.08	148	0.3396
LBL	-7.84	6.52	0.79	0.49	0.23	49	0.1129

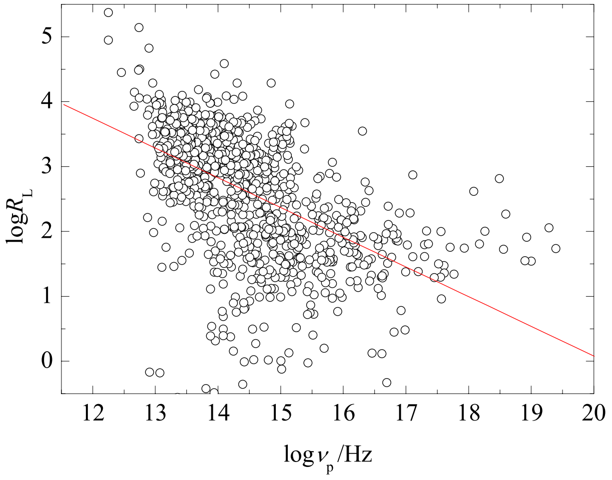

Fig. 1. Plot of radio loudness ($\log R_L$) against peak frequency ($\log\nu_p$) for the whole sample (983 sources).

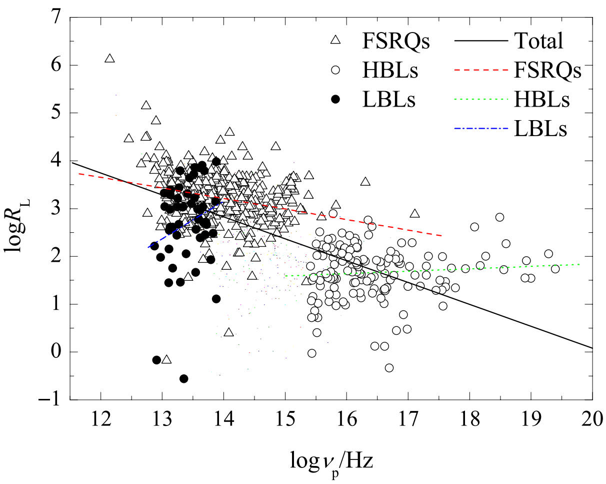

Fig. 2. Plot of radio loudness ($\log R_L$) against peak frequency ($\log \nu_p$) for FSRQs (triangles), LBLs (filled points), and HBLs (open circles).

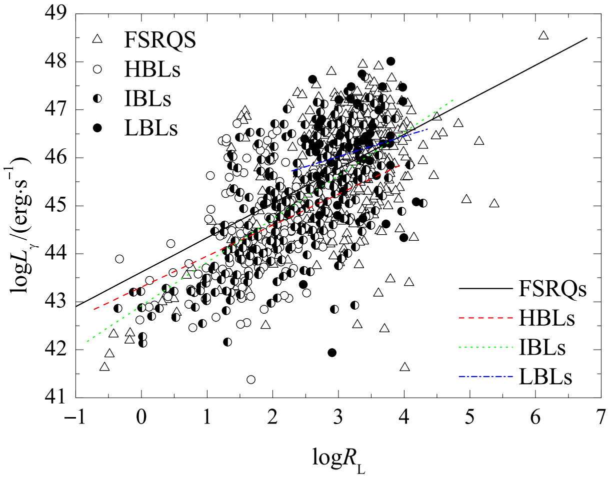

Fig. 3. Correlations between gamma-ray luminosity and radio loudness for the whole sample and the subclasses, FSRQs (triangles), LBLs (filled points), IBLs (half-filled circles), and HBLs (open circles).

Table 2. Correlation for $\log L_\gamma$ and $\log R_L$

Sample	*a*	Δ*a*	*b*	Δ*b*	*r*	*sd*	*n*	*p*
FSRQs	43.62	0.18	0.72	0.06	0.51	0.99	447	<0.0001
HBLs	43.31	0.23	0.64	0.13	0.39	0.95	148	<0.0001
IBLs	42.92	0.16	0.90	0.07	0.65	0.94	265	<0.0001
LBLs	44.76	1.18	0.42	0.36	0.17	1.13	49	0.24657

of radio selected BL Lacs and X-ray selected BL Lacs from surveys or high synchrotron peak BL Lacs (HBLs), intermediate synchrotron peak BL Lacs (IBLs), and low synchrotron peak BL Lacs (LBLs) from their peak frequency in their spectral energy distributions. Generally, FSRQs are low synchrotron peak sources; therefore, in the paper of Abdo et al. (2010b), the authors classified blazars as low synchrotron peak sources (LSPs), intermediate synchrotron peak sources (ISPs) and high synchrotron peak sources (HBLs). Blazars are the main population detected in the Fermi missions (See Acero et al. 2015 and references therein). To date, some blazars are TeV emitters and most are HSPs with smaller radio to optical spectral indexes and hard GeV spectral indexes (Lin & Fan 2016). Observations show that the gamma-ray emissions in Fermi blazars are strongly beamed. The gamma-ray beaming factor can be estimated by (Fan et al. 2013, 2014).

$$\delta \geq [1.54 \times 10^{-3}(1+z)^{4+2\alpha}(\frac{d_L}{Mpc})^2(\frac{\Delta T}{hr})^{-1}(\frac{F_{keV}}{\mu Jy})(\frac{E_\gamma}{GeV})^\alpha]^{\frac{1}{4+2\alpha}} \quad (4)$$

Here, z is the redshift, d_L is the luminosity distance, ΔT is the variability time scale, F_{keV} is the X-ray flux density, and E_γ is the gamma-ray energy. The Doppler factor (boosting factor) can be estimated using available observations.

It is known that the radio emissions in blazars are strongly beamed and the beaming factors were estimated in our previous work (Fan et al. 2009), and the de-beamed gamma-ray flux density is closely correlated with the redshift (Xiao et al. 2015) and the Fermi blazars show higher core-dominance parameters than those of non-Fermi detected blazars (Wu et al. 2014; Pei et al. 2016). For the correlation between radio loudness and peak frequency (Table 1 and Figs. 1 and 2), we find that the anti-correlation is strong for FSRQs but almost non-existent for both LBLs ($r = 0.23$) and HBLs ($r = 0.08$). If the radio emissions are strongly beamed, then the radio loudness is an indicator of beaming effect since $R_L = {}^{F_R}\!/_{F_O} \sim {}^{L_R}\!/_{L_O}$. The results of the correlation are then consistent with the result that FSRQs show a higher Doppler factor than BL Lacs. The anti-correlation between the radio loudness and peak frequency is similar to the anti-correlation between the Doppler factor and the peak frequency (Nieppola et al. 2006). In this sense, we expect that the de-beamed radio loudness will be positively beamed with the peak frequency. Fortunately, the correlation for HBLs showing a positive tendency appears to support our expectation.

From Fig. 3 and Table 2, we can see that the gamma-ray luminosity increases with radio loudness, and the slope in FSRQs is steeper than that in HBLs and LBLs, which suggests that the Fermi blazars are radio loud and the gamma-ray emissions in FSRQs are more beamed. From our analyses, we can conclude that the gamma-ray sources are radio loud and beamed.

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REFERENCES

Abdo AA, Ackermann M, Ajello M, Atwood WB, Axelsson M, et al., Bright active galactic nuclei source list from the first three months of the Fermi large area telescope all-sky survey, Astrophys. J. 700, 597-622 (2009). http://dx.doi.org/10.1088/0004-637X/700/1/597

Abdo AA, Ackermann M, Ajello M, Allafort A, Antolini E, et al., Fermi large area telescope first source catalog, Astrophys. J. Suppl. Ser. 188, 405-436 (2010a). http://dx.doi.org/10.1088/0067-0049/188/2/405

Abdo AA, Ackermann M, Agudo I, Ajello M, Aller HD, et al., The spectral energy distribution of Fermi bright blazars, Astrophys. J. 716, 30-70 (2010b). http://dx.doi.org/10.1088/0004-637X/716/1/30

Acero F, Ackermann M, Ajello M, Albert A, Atwood WB, et al., Fermi large area telescope third source catalog, Astrophys. J. Suppl. Ser. 218, 23-63 (2015). http://dx.doi.org/10.1088/0067-0049/218/2/23

Ackermann M, Ajello M, Allafort A, Antolini E, Atwood WB, et al., The second catalog of active galactic nuclei detected by the Fermi large area telescope, Astrophys. J. 743, 171-207 (2011). http://dx.doi.org/10.1088/0004-637X/743/2/171

Fan JH, Huang Y, He TM, Yang JH, Hua TX, et al., Radio variability and relativistic beaming effect for blazars, Publ. Astron. Soc. Jpn. 61, 639-643 (2009). http://dx.doi.org/10.1093/pasj/61.4.639

Fan JH, Liu Y, Li Y, Zhang QF, Tao J, et al., Variability of blazars, J. Astrophys. Astron. 32, 67-71 (2011). http://dx.doi.org/10.1007/s12036-011-9037-0

Fan JH, Yang JH, Liu Y, Zhang JY, The gamma-ray Doppler factor determinations for a Fermi blazar sample, Res. Astron. Astrophys. 13, 259-269 (2013). http://dx.doi.org/10.1088/1674-4527/13/3/002

Fan JH, Bastieri D, Yang JH, Liu Y, Hua TX, et al., The lower limit of the Doppler factor for a Fermi blazar sample, Res. Astron. Astrophys. 14, 1135-1145 (2014). http://dx.doi.org/10.1088/1674-4527/14/9/004

Fan JH, Yang JH, Liu Y, et al., Spectral energy distribution of *Fermi* Blazars, Astrophys. J. Suppl. Ser., submitted (2015a).

Fan JH, Yang JH, Liu Y, Cai W, Lin C, Spectral energy distributions and some correlations for Fermi blazars, Int. Mod. Phys. Lett. A 30, 1545020 (2015b). http://dx.doi.org/10.1142/S0217751X15450207

Giroletti M, Pavlidou V, Reimer A, Taylor GB, Tosti G, et al., Radio-faint BL Lacobjects and their impact on the radio/gamma-ray connection, Adv. Space Res. 49, 1320-1326 (2012). http://dx.doi.org/10.1016/j.asr.2012.02.005

Lin C, Fan JH, Comparison between TeV and non-TeV BL Lac Objects, Res. Astron. Astrophys., submitted (2016).

Liodakis I, Pavlidou V, Population statistics of beamed sources - II. Evaluation of Doppler factor estimates, Mon. Not. Roy. Astron. Soc. 454, 1767-1777 (2015). http://dx.doi.org/10.1093/mnras/stv2028

Mattox JR, Bertsch DL, Chiang J, Dingus BL, Fichtel CE, et al., The EGRET detection of quasar 1633 + 382, Astrophys. J. 410, 609-614 (1993).

Nieppola E, Tornikoski M, Valtaoja E, Spectral energy distributions of a large sample of BL Lacertae objects, Astron. Astrophys. 445, 441-450 (2006). http://dx.doi.org/10.1051/0004-6361:20053316

Padovani P, Giommi P, The connection between x-ray- and radio-selected BL Lacertae objects, Astrophys. J. 444, 567-581 (1995).

Padovani P, Giommi P, The ROSAT X-ray spectra of BL Lacertae objects, Mon. Not. Roy. Astron. Soc. 279, 526-534 (1996). http://dx.doi.org/10.1093/mnras/279.2.526

Pei ZY, Fan JH, Yang JH, et al., Radio core-dominance of Fermi blazars, Astrophys. Space Sci., accepted (2016)

Savolainen T, Homan DC, Hovatta T, Kadler M, Kovalev YY, et al., Relativistic beaming and gamma-ray brightness of blazars, Astron. Astrophys. 512, A24 (2010). http://dx.doi.org/10.1051/0004-6361/200913740

Wu DX, Fan JH, Liu Y, Yang JH, Hao JM, et al., Correlation between γ-ray and radio emissions in Fermi blazars, Publ. Astron. Soc. Jpn. 66, 11711 (2014). http://dx.doi.org/10.1093/pasj/psu111

Xiao HB, Pei ZY, Xie HJ, Hao JM, Yang JH, et al., Correlation between γ-Ray flux density and redshift for Fermi blazars, Astrophys. Space Sci. 359, 39 (2015). http://dx.doi.org/10.1007/s10509-015-2433-1

Yang JH, Fan JH, Nie JJ, Yang RS, The gamma-ray spectral index changes for blazers, Sci. China Phys. Mech. Astron. 55, 2179-2185 (2012). http://dx.doi.org/10.1007/s11433-012-4901-8

Yang JH, Fan JH, Hua TX, Wu DX, The γ-ray emission mechanism for Fermi blazars, Astrophys. Space Sci. 352, 819-824 (2014). http://dx.doi.org/10.1007/s10509-014-1983-y