IMPLICATIONS FOR THE BLAZAR SEQUENCE AND INVERSE COMPTON MODELS FROM FERMI BRIGHT BLAZARS

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ABSTRACT

In this paper, we use the quasi-simultaneous spectra of Fermi bright blazars and Fermi-detected narrow-line Seyfert 1 (NLS1) to study the blazar sequence and inverse Compton models. (1) The synchrotron peak luminosities ($L_s$) significantly correlate inversely with the synchrotron peak frequencies ($\nu_s$), $L_s \propto \nu_s^{-0.44\pm0.11}$, which is consistent with the blazar sequence. In addition to the correlation, there are some blazars showing low $\nu_s$ and low $L_s$. To study the relation between these low-$\nu_s$–low-$L_s$ blazars and the blazar sequence, we present correlations of the parameter $L_s \nu_s^{1/4}$ with the ratio of Compton to synchrotron peak frequencies ($r_{Cs} \equiv \nu_C/\nu_s$) and with the ratio of Compton to synchrotron luminosities ($CD \equiv L_C/L_s$). The results indicate that both correlations are significant with a Pearson’s probability for a null correlation of $p = 0.0218$ and $p = 0.0286$, respectively. This does not support the idea that the low-$\nu_s$–low-$L_s$ blazars are sources with less beaming. Another possibility, as suggested by Ghisellini & Tavecchio, is that these blazars have relatively lower black hole masses. To test this, we collect the black hole masses of 30 blazars from archives and find that the black hole mass correlates with the parameter $L_s \nu_s^{0.34}$ ($p = 0.0344$). Therefore, the black hole masses of low-$\nu_s$–low-$L_s$ blazars are statistically small. The NLS1s are thought to have lower black hole masses. We find that the four NLS1s detected by Fermi have low $\nu_s$ and low $L_s$. This supports the above result. (2) The ratio $r_{Cs}$ correlates with CD significantly ($p = 0.00375$). The external Compton model can naturally explain this correlation, while the synchrotron self-Compton model cannot. This agrees with the findings of many authors that the EC process dominates the gamma-ray emission of flat spectrum radio quasars.

\textit{Key words:} BL Lacertae objects: general – galaxies: jets – quasars: general – radiation mechanisms: non-thermal

1. INTRODUCTION

Blazars are the most extreme active galactic nuclei (AGNs). Their broadband emissions, from radio through $\gamma$-ray, are dominated by nonthermal emissions produced by a relativistic plasma jet aligned with the line of sight (Blandford & Rees 1978). Their spectral energy distribution (SED) shows two broad components in the $\log \nu$–$\log \nu L_{\nu}$ diagram. The lower component peaks at infrared (IR) to X-ray bands and is believed to be the synchrotron emissions of relativistic electrons within the jet. The higher component peaks at the $\gamma$-ray band and is thought to be the inverse Compton (IC) emissions of the same electron population. Models are classified according to different origins of the IC seed photons, synchrotron self-Compton (SSC, seed photons from the synchrotron radiation; see Konigl 1981; Marscher & Gear 1985; Ghisellini & Maraschi 1989; Maraschi et al. 1992; Band & Grindlay 1985), and external Compton (EC, seed photons from the external region; see Dermer et al. 1992; Dermer & Schlickeiser 1993; Blandford & Levinson 1995; Sikora et al. 1994, 2002; Blažejowski et al. 2000). Blazars are often divided into two subclasses of BL Lacertae (BL Lac) objects and flat spectrum radio quasars (FSRQs). FSRQs have strong emission lines, while BL Lac objects have only very weak or non-existent emission lines (equivalent width $< 5$ Å; e.g., Scarpa & Falomo 1997).

Fossati et al. (1998) presented a unifying view of the SEDs of blazars, in which both the synchrotron peak luminosity (hereafter $L_s \equiv \langle \nu L_{\nu} \rangle_0^c$) and the Compton dominance (the ratio between Compton and synchrotron luminosities, $CD \equiv L_C/L_s$) decrease with increasing synchrotron peak frequency (hereafter $\nu_s$). Ghisellini et al. (1998) modeled the broadband SEDs of 51 $\gamma$-ray loud blazars and showed that in powerful blazars the radiative energy density is large. The effective IC cooling yields lower electron energy and larger CD. The lower electron energy is emitted at lower frequency. An inverse correlation between $\gamma_p$ and $U_{\text{tot}}$ is further derived, where $\gamma_p$ is the electron energy emitting at the synchrotron peak and $U_{\text{tot}}$ is the summation of the magnetic and radiative energy densities within the Thomson regime. In several works (e.g., Ghisellini et al. 2002, 2009b, 2010; Celotti & Ghisellini 2008), the $\gamma_p - U_{\text{tot}}$ inverse correlation is confirmed. Researchers often call $\nu_s - L_s$ and/or $\gamma_p - U_{\text{tot}}$ the blazar sequence. A large number of blazars are detected by Fermi/LAT, which are compiled as the LAT Bright AGN Sample (LBAS; Abdo et al. 2009a) and the First LAT AGN Catalog (1LAC; Abdo et al. 2010a). Both LBAS and 1LAC show correlations between the $\gamma$-ray luminosity ($L_\gamma$) and photon indices ($\Gamma_\gamma$). The photon indices correlate with peak frequencies and the $\gamma$-ray luminosity can represent the peak luminosity roughly (see Abdo et al. 2010a, 2010b). Therefore, it seems to support the blazar sequence.

Many contrary arguments are also reported (Georganopoulos et al. 2001; Caccianiga & Marchář 2004; Antón & Browne 2005; Nieppola et al. 2006; Padovani 2007). They mainly focus on three points. First, many low-peak-frequency low-power blazars are found. This causes no significant correlation between $\log \nu_s$ and $\log L_s$. Second, several high-peak-frequency FSRQs are reported, in contrast with the correlation mentioned above. The SED properties of these sources are mainly determined...
from composite spectral indices\textsuperscript{5} rather than from broadband SEDs. This causes uncertainties in the result (see Padovani 2007). Maraschi et al. (2008) re-studied these FSRQs and found that they do follow the log $v_s$–log $L_s$ sequence. Third, the blazar sequence predicts that blazars with higher peak frequency (mainly BL Lac objects) should be more numerous than blazars with lower peak frequency. However, this prediction has not been proved. As indicated by Ghisellini & Tavecchio (2008), the reason may be that the samples considered are flux limited, introducing a bias against low-luminosity/high-peak-frequency blazars. The Fermi/LAT sensitivity is better than that of EGRET, especially for harder spectra (Abdo et al. 2009a, 2010a). Very recently, an interesting finding is that the fraction of BL Lac objects in $\gamma$-ray blazars increases from EGRET to Fermi/LAT (see Hartman et al. 1999; Abdo et al. 2009a, 2010a). In 1LAC (Abdo et al. 2010a), the number of BL Lac objects is even larger than the number of FSRQs.

The first objection mentioned above is the strongest evidence against the blazar sequence. Ghisellini & Tavecchio (2008) showed that there are two possibilities to account for it. The first explanation is that those low-$v_s$–low-$L_s$ sources may be misaligned. The weak beaming effect would shift blazars to low peak frequency and low observed luminosity. The second explanation is that sources with low luminosity and low $v_s$ may be associated with black holes of smaller mass. The jets of these sources will dissipate energy within the broad-line region (BLR). The electrons then cool efficiently and emit at low frequency (Ghisellini & Tavecchio 2008).

The blazar sequence constrains our understanding on jet physics. It relates to jet energy dissipation, particle acceleration, the emission region properties and environments, etc. In this paper, we collect the black hole masses and use the quasi-simultaneous broadband SEDs of Fermi bright blazars (Abdo et al. 2009a, 2010b) and the SEDs of four Fermi-detected narrow-line Seyfert 1 (NLS1; Abdo et al. 2009d) to study the blazar sequence. In addition, we study the EC/SSC models.

In Section 2, we discuss the sample. Section 3 discusses the relations between our result and the blazar sequence. Section 4 discusses the IC models. We summarize and discuss our findings in Section 5. The cosmology with $H_0 = 70$ km s\textsuperscript{-1} Mpc\textsuperscript{-1}, $\Omega_m = 0.3$, and $\Omega_L = 0.7$ is adopted throughout the paper.

2. THE SAMPLE

The first three months of operation of Fermi/LAT have revealed more than 100 blazars (>10$^9$L$, which are named as the Fermi/LAT Bright AGN Sample (LBAS; Abdo et al. 2009a). Abdo et al. (2010b) presented quasi-simultaneous SEDs for 48 LBAS blazars, whose data were collected from radio through $\gamma$-ray within those three months. The IC and the synchrotron peak frequencies/fluxes are estimated by fitting the two components with a third-degree polynomial, $v_F = a + b \cdot v^2 + c \cdot v + d$. There are 43 of these 48 sources having measured redshifts. The peak luminosities and frequencies (in the AGN frame) of these blazars can be calculated through $L_{\gamma,C} = 4\pi d_L^2 \nu^2 F_{\nu,C}$, and $\nu_{s,C} = (1 + z) \nu_{s,C}^{\text{obs}}$, where $d_L$ is the luminosity distance. The results are listed in Table 1. Column 1 provides the LAT name of the source. Columns 2 and 3 indicate the synchrotron peak frequency and luminosity. Columns 4 and 5 denote the IC peak frequency and luminosity. The redshift, $\gamma$-ray photon indices $\Gamma_{\gamma}$, $\gamma$-ray luminosity $L_{\gamma}$, and the optical classification are listed in Columns 6, 7, 8, and 9, respectively. Columns 10 and 11 are the black hole masses and the references. For Columns 7, 8, 10, and 11, see below.

3. IMPLICATIONS FOR THE BLAZAR SEQUENCE

As discussed above, both LBAS and 1LAC show the correlations between $\gamma$-ray photon indices $\Gamma_{\gamma}$ and $\gamma$-ray luminosity $L_{\gamma}$. Because the spectral index correlates with the synchrotron peak frequency (see, e.g., Abdo et al. 2010a), the correlation between $\Gamma_{\gamma}$ and $L_{\gamma}$ can be thought of as evidence to support the blazar sequence (but see the discussion below). Here we use the peak frequency directly to test the sequence.

Figure 1 shows the correlation between the peak frequency ($\nu_s$) and luminosity ($L_s$), in which squares are for those 43 sources (the opened circles are NLS1s, see below). It can be seen that the luminosity statistically decreases with increasing peak frequency. The solid line presents the best fitting (excluding the NLS1s), which gives $L_s \propto \nu_s^{-0.44 \pm 0.11}$ and Pearson’s p-value (the significance level at which the null hypothesis of zero correlation is disproved) $p = 2.06 \times 10^{-4}$. This is consistent with those studies using $\Gamma_{\gamma}$ and $L_{\gamma}$ (e.g., Ghisellini et al. 2009a; Abdo et al. 2009a, 2010a) and supports the blazar sequence. But it can also be seen (see Figure 1), in addition to the statistical inverse correlation, that there are some sources with low $\nu_s$ and low $L_s$. This makes the log $\nu_s$–log $L_s$ plane more like a wedge shape. This result has been presented in previous studies, which yield less significant correlation between log $\nu_s$ and log $L_s$ and may be taken as evidence opposing the blazar sequence (e.g., Georganopoulos et al. 2001; Caccianiga & Marchi 2004; Antón & Browne 2005; Niepola et al. 2006; Padovani 2007).

Additionally, we present the correlation between the CD and luminosity ($L_s$), which gives $p = 0.00307$ (see Figure 2). This result is consistent with another statement of the blazar sequence, which claims an inverse correlation between the luminosity and the Compton dominance. This is the first time quasi-simultaneous broadband data have been used to confirm the statement. From Figures 1 and 2, it is expected that low-$\nu_s$–low-$L_s$ sources would have lower CD. We have plotted the $\nu_s$ versus CD plane (figure not supplied here), which is also wedge

\textsuperscript{5} The composite spectral index, $\alpha_{12}$, is usually used to measure the overall trend of the broadband spectra when more detailed spectral information is lacking. It is defined as $f_\nu(f_\nu) = (\nu_1/\nu_2)^{-\alpha_{12}}$, where $f_\nu$ and $f_\nu$ are the flux densities at frequencies $\nu_1, \nu_2$ (Ledden & Odell 1985).
shape. Ghisellini & Tavecchio (2008) suggested that those low-$\nu_i$-low-$L_s$ blazars may be misaligned or have smaller black holes.

If those sources have relatively larger viewing angles, appear to have lower luminosity and lower peak frequency. As we know, the Compton and synchrotron peak frequencies are dependent on the beaming effect in the same way. Therefore, the ratio of Compton to synchrotron peak frequencies $r_{Cs} \equiv \nu_C/\nu_s$ should be independent of the viewing angle, and similarly for the Compton dominance $C \equiv L_C/L_s$. Luminosity is proportional to $\delta^4$ and frequency is proportional to $\delta$, where $\delta \equiv 1/|\Gamma(1 - \beta \cos \theta)|$ is the beaming factor, $\Gamma \equiv (1 - \beta^2)^{-1/2}$ is the Lorentz factor, $\beta \equiv v/c$ is the velocity in units of light speed, and $\theta$ is the viewing angle. Therefore, it is expected that $r_{Cs}$ and $CD$ will be independent of the parameter $L_s \nu_s^{1/4}$ if the difference really relies on the beaming effect. Hence, we present the correlation between the parameter $L_s \nu_s^{1/4}$ and $r_{Cs}$ in Figure 3. Figure 4 is the correlation between $L_s \nu_s^{1/4}$ and CD. From Figure 3, we can see that there is a blazar, 0FGL J1719.3+1746, having an extreme ratio $r_{Cs}$ (the triangle at the top left corner). From the SED of 0FGL J1719.3+1746 (see Abdo et al. 2010b), we can see that the IC peak frequency is

| Name(OFGL) | $\log \nu_i$ | $\log L_s$ | $\log \nu_C$ | $\log L_C$ | $\log Cs$ | $\log L_{r_s}$ | Type* | $\log M_{BH}$ | Ref. |
|------------|-------------|-------------|-------------|-------------|-----------|----------------|-------|--------------|------|
| J0033.6−1921 | 16.3 | 46.1 | 24.5 | 46.1 | 0.610 | 1.70 | 46.4 | BL | |
| J0137.1+4751 | 13.9 | 47.1 | 22.9 | 47.0 | 0.859 | 2.20 | 47.4 | FSRQ | 9.309 | C02 |
| J0210.8+5100 | 12.8 | 47.0 | 22.7 | 47.5 | 1.003 | 2.28 | 47.9 | FSRQ | 9.208 | F04 |
| J0222.6+4302 | 15.3 | 46.7 | 24.4 | 46.7 | 0.444 | 1.97 | 47.2 | BL | 8.600 | L03 |
| J0229.5−3640 | 14.0 | 47.2 | 23.5 | 47.8 | 2.115 | 2.57 | 48.6 | FSRQ | |
| J0238.4+2855 | 13.1 | 47.2 | 22.4 | 47.1 | 1.213 | 2.49 | 47.7 | FSRQ | |
| J0238.6+1636 | 13.8 | 47.2 | 23.5 | 47.8 | 0.940 | 2.05 | 48.4 | BL | 9.300 | L03 |
| J0349.8−2102 | 13.5 | 47.6 | 22.4 | 48.7 | 2.944 | 2.55 | 49.1 | FSRQ | |
| J0423.1−0112 | 13.7 | 46.7 | 22.0 | 47.3 | 0.915 | 2.38 | 47.3 | FSRQ | 9.760 | C02 |
| J0428.7−3755 | 13.6 | 46.8 | 23.1 | 47.6 | 1.112 | 2.14 | 48.1 | BL | 8.900 | D10 |
| J0449.7−4304 | 15.7 | 45.9 | 24.0 | 45.6 | 0.205 | 2.01 | 46.0 | BL | |
| J0547.1−2352 | 13.4 | 46.7 | 23.1 | 47.8 | 1.003 | 2.23 | 48.2 | FSRQ | 9.173 | F04 |
| J0507.9+6739 | 16.8 | 46.1 | 24.5 | 46.3 | 0.416 | 1.67 | 46.0 | BL | 8.800 | F03 |
| J0531.0+1331 | 13.3 | 47.6 | 21.8 | 48.7 | 2.070 | 2.54 | 48.8 | FSRQ | 10.200 | L03 |
| J0538.8−4403 | 13.7 | 47.0 | 23.0 | 47.5 | 0.892 | 2.19 | 48.0 | BL | 8.709 | F04 |
| J0722.0+7120 | 14.7 | 46.6 | 24.0 | 46.1 | 0.310 | 2.08 | 46.5 | BL | 8.100 | L03 |
| J0730.4−1142 | 13.5 | 47.1 | 23.0 | 48.2 | 1.589 | 2.29 | 48.7 | FSRQ | |
| J0855.4+2009 | 13.6 | 47.5 | 21.5 | 46.0 | 0.306 | 2.31 | 46.2 | BL | 9.919 | F04 |
| J0921.2+4437 | 13.9 | 47.4 | 22.5 | 48.0 | 2.190 | 2.35 | 48.4 | FSRQ | 9.880 | C09 |
| J1105.2+4927 | 16.4 | 45.5 | 24.6 | 45.2 | 0.212 | 1.73 | 45.8 | BL | 8.280 | W08 |
| J1108.9+5629 | 14.7 | 44.8 | 22.4 | 44.7 | 0.143 | 2.11 | 45.1 | BL | |
| J1108.9+5629 | 14.7 | 44.8 | 22.4 | 44.7 | 0.143 | 2.11 | 45.1 | BL | |
| J1108.9+5629 | 14.7 | 44.8 | 22.4 | 44.7 | 0.143 | 2.11 | 45.1 | BL | |
| J1108.9+5629 | 14.7 | 44.8 | 22.4 | 44.7 | 0.143 | 2.11 | 45.1 | BL | |

Notes. Column 1 provides the LAT name of the source. Columns 2 and 3 indicate the synchrotron peak frequency and luminosity. Columns 4 and 5 denote the IC peak frequency and luminosity. The redshift, $\gamma$-ray photon indices $\Gamma_\gamma$, $\gamma$-ray luminosity $L_{r_\gamma}$, and the optical classification are listed in Columns 6, 7, 8, and 9, respectively. Columns 10 and 11 are the black hole masses and the references. Data from Abdo et al. (2009a, 2010b).

* BL is the abbreviation of BL Lac; BZU denotes a blazar of unknown type (see Abdo et al. 2010b).

References. (C02) Caio & Jiang 2002; (C09) Chen et al. 2009; (D10) Decarl et al. 2011; (F03) Falomo et al. 2003a; (F04) Fan & Cao 2004; (L03) Liang & Liu 2003; (W08) Wagner 2008.
overestimated. Excluding 0FGL J1719.3+1746, the parameter $L_s \nu_s^{1/4}$ is correlated with the ratio $r_{Cs}$ although there is large scatter ($p = 0.0218$). A similar result is derived for $L_s \nu_s^{1/4}$ versus CD ($p = 0.0286$, see Figure 4). This does not support the idea that low-$\nu_s$–low-$L_s$ sources are misaligned.

As suggested by Ghisellini & Tavecchio (2008), those low-$\nu_s$–low-$L_s$ blazars may have smaller black holes (Ghisellini & Tavecchio 2008), and the jet will dissipate energy within the BLR. This will cause efficient cooling of the electrons, and yields low frequency and low power (see Ghisellini & Tavecchio 2008). The low black hole mass also produces lower CD (see Ghisellini & Tavecchio 2008). To check if the black hole masses account for those low-$\nu_s$–low-$L_s$ blazars, we collect black hole masses from previous works.

Many authors have derived the black hole masses of blazars in different ways (e.g., Ghisellini et al. 2010; Cao & Jiang 2002; Chen et al. 2009; Decarli et al. 2011; Falomo et al. 2003a, 2003b; Fan & Cao 2004; Liang & Liu 2003; Wagner 2008; Barth et al. 2003; Gu et al. 2001; Liu et al. 2006; Pian et al. 2005; Wang et al. 2004; Woo et al. 2005; Wu et al. 2002; Xie et al. 2004, 2005). From all the papers we know, we have collected 30 black hole masses for these 43 blazars. Some blazars were studied by many authors and different hole masses derived. To reduce the uncertainty, we try to select the hole masses from a single paper and a uniform method of deriving the hole mass. The result is presented in Table 1. Columns 10 and 11 are for black hole masses and references.

The best fitting of Figure 1 shows $L_s \propto \nu_s^{-0.44 \pm 0.11}$. Therefore, the correlation between the parameter $L_s \nu_s^{0.44}$ and hole masses...
Table 2

| Name          | log ν  | log L  |
|---------------|--------|--------|
| (1)           | (2)    | (3)    |
| J1 323+342    | 13.75  | 44.39  |
| PMN J0048+0022| 12.94  | 45.43  |
| PKS 1502+036  | 13.02  | 45.14  |
| PKS 2004−447  | 13.05  | 44.55  |

Notes. Column 1 provides the name of the source. We use a quadratic polynomial to fit the SED of the low component of the four NLS1s and get the synchrotron peak frequency and luminosity, which are listed in Columns 2 and 3 (see Abdo et al. 2009d).

could be used to check if these low-νs−low-Ls blazars have lower hole masses. Figure 5 presents the result, and the best fitting indicates \( p = 0.0344 \). Despite the scatter, our result supports the idea that low-νs−low-Ls blazars have smaller black holes (see Ghisellini & Tavecchio 2008). In order to find more evidence, we use broadband SEDs of four radio-loud NLS1s detected by Fermi/LAT (Abdo et al. 2009d) to check the above result. NLS1s are thought to have smaller black holes (e.g., Yuan et al. 2008, and references therein). These four radio-loud NLS1s are believed to have similar central mechanisms to blazars (see Abdo et al. 2009b, 2009c, 2009d). Therefore, if our above result is correct, these NLS1s should be in the low-νs−low-Ls region. We collect the broadband SEDs of these four NLS1s (from NED6 and Abdo et al. 2009d). For simplicity, we use a two-order polynomial to fit the synchrotron component in the log ν−log νLs diagram. The peak frequency and luminosity are presented in Table 2. We plot these in Figure 1 as open circles. It can be seen that these four sources do have low νs and low Ls values. This supports our result above.

4. IMPLICATIONS FOR INVERSE COMPTON MODELS

From the discussion in the previous section, we know that both the ratio \( r_{\text{CS}} \) and CD correlate with the parameter \( L_s^{-1/4} \nu_s^{1/4} \). This indicates that \( r_{\text{CS}} \) and CD may correlate with each other, although we do not know what the correlation implies. Figure 6 shows the plane of \( r_{\text{CS}} \) versus CD. The best fitting gives \( p = 0.00375 \) (excluding the blazar 0FGL J1719.3+1746). This is a new result. We will discuss its implications for the emission models (i.e., SSC versus EC). Of course, no matter what conclusion is reached, it works statistically. After the following discussion, it will be seen that the EC model can predict this correlation naturally, while the SSC model cannot.

Within the symmetrical sphere model, if an electron population emits the broadband SED of a blazar, the synchrotron peak frequency (\( \nu_s \)) corresponds to a peak electron energy (\( \gamma_p \) in the \( \gamma \nu^2 = N_\gamma \) diagram; Tavecchio et al. 1998),

\[
\nu_s = \frac{4}{3} \frac{\nu_L \gamma_p^2 \delta}{\nu_p},
\]

where \( \nu_L = eB/(2\pi mc) \) is the Larmor frequency. If the external radiation is prominent at frequency \( \nu_{\text{ext}} \), the EC component peaks at (inverse Compton scatter within the Thomson regime; Blumenthal & Gould 1970; Coppi & Blandford 1990; Tavecchio et al. 1998; Ghisellini & Tavecchio 2008)

\[
\nu_{\text{EC}} = \frac{4}{3} \nu_{\text{ext}} \gamma_p^2 \Gamma \delta,
\]

where \( \Gamma \) is the jet Lorentz factor. If the EC is dominant, the EC and synchrotron luminosities follow (Ghisellini & Madau 1996; Ghisellini & Tavecchio 2008)

\[
\frac{L_{\text{EC}}}{L_{\text{sy}}} = \left( \frac{U_{\text{ext}}}{U_B} \right) \sim \frac{17 \Gamma^2 U_{\text{ext}}}{12 U_B},
\]

where \( U_{\text{ext}} \) is the energy density of external photons in the rest frame of the source, \( U_{\text{ext}}' \sim (17/12) \Gamma^2 U_{\text{ext}} \) is that measured in the jet comoving frame, and \( U_B \equiv B^2/(8\pi) \) is the magnetic field energy density.

Combining Equations (1)–(3) yields

\[
\frac{L_{\text{EC}}}{L_{\text{sy}}} \sim \frac{17e^2}{6\pi m_e^2 c^2} \frac{U_{\text{ext}}}{v_{\text{ext}}^3} \left( \frac{\nu_{\text{EC}}}{\nu_s} \right)^2.
\]

Thus, we expect \( L_{\text{EC}}/L_{\text{sy}} \propto (\nu_{\text{EC}}/\nu_s)^2 \) if the external radiation is constant.
most blazars are EC dominant (see also Sikora et al. 2009). Our divide by any criterion (e.g., the Eddington ratio are combined as a uniform class in our study. Although they result is consistent with that.

For SSC, the IC emissions rely on the synchrotron emissions. Therefore, the simple relation between CD and $r_{\text{CS}}$ cannot be derived.

As suggested by Ghisellini et al. (1998) (see also Huang et al. 1999; Fan et al. 2006; Ghisellini et al. 2002; Celotti & Ghisellini 2008), the external photons of most blazars are contributed by BLR. And the BLR emissions can be almost uniformly taken as $U_{\text{BLR}} \simeq 2.65 \times 10^{-2} \, \text{erg cm}^{-3}$ and $v_{\text{BLR}} \simeq 2 \times 10^{15} \, \text{Hz}$ (see Ghisellini & Tavecchio 2008). In this case, $CD = L_C/L_s \simeq L_{\text{EC}}/L_s$ correlates with $r_{\text{CS}}$. The statistical correlation shown in Figure 6 between CD and $r_{\text{CS}}$ suggests that most blazars are EC dominant. However, this is only a qualitative result, because the slope of the best fitting ($s \approx 0.4$) is not equal to the predicted slope $s = 2$. On the other hand, it is interesting to note that if we use the relation $L_C/L_s \propto (v_C/v_s)^2$ to fit the data, the best fitting $(U_{\text{ext}}/v_s^2)_{\text{fit}}$ does not significantly depart from the BLR value: $(U_{\text{ext}}/v_s^2)_{\text{fit}} \approx 3.2 (U_{\text{BLR}}/v_{BLR}^2)$ (corresponding to the dashed line in Figure 6). Ghisellini et al. (2009b, 2010) modeled the SEDs of the Fermi bright blazars in detail and suggested that most blazars are EC dominant (see also Sikora et al. 2009). Our result is consistent with that.

5. DISCUSSION

Because the sample is small, FSRQs and BL Lac objects are combined as a uniform class in our study. Although they divide by any criterion (e.g., the Eddington ratio $\dot{m} \sim 0.01$, see Ghisellini et al. 2009a; Xu et al. 2009, and references therein), their properties vary continuously. In discussing Fermi-detected blazars, people sometimes use the terms Low Synchrotron Peaked (LSP) blazars, Intermediate Synchrotron Peaked (ISP) blazars, and High Synchrotron Peaked (HSP) blazars instead of FSRQs and BL Lac objects (e.g., Abdo et al. 2010a, 2010b). Throughout this paper, we consider them as a single class. If the sample is enlarged, different subclasses can be separately studied in detail.

Our result of the log $\nu_s$ versus log $L_s$ plane is similar to the result of, e.g., Padovani (2007). Although the latter study is based on large radio- or X-ray-selected samples, while ours is based on a gamma-ray-selected sample, in both of them blazars with low $\nu_s$ and low $L_s$ are presented. In the former study, the absence of gamma-ray data does not allow the IC component to be determined, therefore the properties of CD cannot be studied.

Their studies and our results indicate that no blazars with high $\nu_s$ and high $L_s$ have yet been detected. Ghisellini et al. (2009a) (see also Abdo et al. 2009a) studied the Fermi bright blazars and showed the presence of inverse correlations between $L_\gamma$ and $\Gamma_\gamma$. As suggested by them, lowering the $\gamma$-ray flux threshold will detect blazars with steep spectral indices and lower luminosities. Here, we notice an interesting thing, which is that if one plots the log $L_\gamma$ versus $\Gamma_\gamma$ plane, there is a nearly clear inverse correlation (see Ghisellini et al. 2009a; Abdo et al. 2009a). While we plot the log $\nu_s$ versus log $L_s$ plane in this paper (see Figure 1), in addition to the inverse correlation, there are some low-$\nu_s$–low-$L_s$ blazars. Therefore, when one says that the photon index correlates with the peak frequency and the $\gamma$-ray luminosity correlates with the peak luminosity, one should be careful. To check this, we calculate the $\gamma$-ray luminosity of those 43 blazars. The formula we used is similar to that used in Ghisellini et al. (2009a). The values are presented in Table 1 (see Columns 8 and 9). We plot log $L_\gamma$ versus $\Gamma_\gamma$ in Figure 7. The plane is similar to that in Ghisellini et al. (2009a), which shows clear correlation ($p = 2.71 \times 10^{-5}$).

Our results suggest that it is not the beaming effect but the black hole mass that accounts for the properties of the low-$\nu_s$–low-$L_s$ blazars. In drawing this conclusion, there are caveats that should be noted. From Figures 3 and 4, it can be seen that both correlations are not strict, but have large scatter. This means that the beaming effect can also play a certain role although it does not determine the nature of low-$\nu_s$–low-$L_s$ sources. Many radio galaxies are detected by Fermi/LAT. Within a unified model of the radio-loud AGNs, radio galaxies are the parent population of blazars but with large viewing angle. Figure 24 in Abdo et al. (2010a) presents the correlation between the $\gamma$-ray photon spectral index and the $\gamma$-ray luminosity, including radio galaxies. It can be seen that radio galaxies have lower luminosity and, on average, softer spectra than blazars. This is qualitatively consistent with the hypothesis that misaligned sources have lower luminosity and lower peak frequency. Black hole masses of 30 out of 43 blazars have been collected. These blazars show a significant correlation between luminosity $L_s$ and black hole mass ($p = 3.75 \times 10^{-4}$, Figure 8), and also present an inverse correlation between peak frequency $\nu_s$ and black hole mass ($p = 3.44 \times 10^{-3}$, Figure 9). This indicates that the high-peak-frequency blazars have lower black hole masses.

Figure 7. $\gamma$-ray luminosity $(L_\gamma)$ vs. $\gamma$-ray photon indexes $(\Gamma_\gamma)$ with $p = 2.71 \times 10^{-5}$.

Figure 8. Synchrotron peak luminosity $(L_s)$ vs. black hole mass with $p = 3.75 \times 10^{-4}$. 

![Figure 7](image1.png)

![Figure 8](image2.png)
Through the correlation between the black hole mass and \( L_s \nu_s^{6/7} \), we showed that the low-\( \nu_s \)-low-\( L_s \) blazars may have smaller black hole masses. The slope (\( s = 0.44 \)) is derived from the best fitting. As we have shown, the log \( \nu_s - \log L_s \) plane is more like a wedge shape. The upper boundary of the wedge shape seems steeper than \( s = 0.44 \) (see Figure 1). On the other hand, if we linearly fit the log \( \nu_s - \log L_s \) plane excluding the low-\( \nu_s \)-low-\( L_s \) blazars, the fitting slope will be steeper than \( s = 0.44 \). We then choose a steeper slope (\( s = 0.6 \)) and correlate the parameter \( L_s \nu_s^{0.6} \) with the black hole mass. The result presents very poor correlation (\( p = 0.2 \)). Therefore, it seems that a lower black hole mass can account for these low-\( \nu_s \)-low-\( L_s \) blazars, but the nature cannot be definitely determined. To check the results, larger samples are needed. I1AC (Abdo et al. 2010a) supplies a huge amount of data, which can help to determine the properties of IC component. The multi-band SEDs can be derived from ground and space observatories. The black hole masses can be derived using a uniform method. The information about quasi-simultaneous SEDs for the latter sample would probably be less complete than for our sample, but its richness will yield interesting results.

If those blazars really have smaller black holes, this does not support the sequence \( \nu_s - L_s \) inverse correlation, but is still consistent with the sequence \( \nu_s - U_{\text{tot}} \) inverse correlation. Here, we call \( \nu_s - L_s \) the phenomenological sequence and \( \nu_s - U_{\text{tot}} \) the theoretical sequence (see Ghisellini & Tavecchio 2008). As suggested by Ghisellini & Tavecchio (2008), blazars with smaller black holes can have jet energy dissipated within the BLR. Following the theoretical sequence, the high-energy electrons in the jet will suffer greater cooling, and then smaller \( \nu_s \). This results in a lower synchrotron peak frequency and lower luminosity. So, our result can be regarded as a departure from the phenomenological sequence, but is consistent with the theoretical sequence. The \( \nu_s - U_{\text{tot}} \) relation has different slopes from different studies, ranging from 1/2 to 1 (see Celotti & Ghisellini 2008; Ghisellini et al. 1998, 2002, 2009b, 2010). The reason for this is not clear. Ghisellini et al. (2002) suggest that \( \nu_s \propto U_{\text{tot}}^{-1} \) implies a constant cooling time at peak frequency, which may correspond to a constant light crossing time. The relation \( \nu_s \propto U_{\text{tot}}^{-1/2} \) may denote a constant heating rate (see Ghisellini 1999).

The correlation between the ratio \( r_{\text{CD}} \) and CD is a new result. These two parameters are independent of redshift or beaming effect. They may be related to the jet conditions and radiative processes. Within the leptonic model, the relation between IC and synchrotron components implicates the relative importance of EC to SSC, at least on statistics. Here we have given an explanation: it may be the result of EC dominance. This is consistent with the detailed SED modeling (see Ghisellini et al. 2009b, 2010). Some blazars exhibit long-term outbursts. Given a blazar, the emission regions of different outburst/quiet states may be surrounded by a similar external radiation field, e.g., BLR photons. In this case, the EC and synchrotron emissions will follow Equation (4). For some extreme blazars, e.g., 3C 279, if we have SEDs at different outburst/quiet states, these combined with Equation (4) will yield interesting results. The caveat is that the equation is derived from a one-zone symmetrical model. Enlarging the sample to check the above correlation is of course necessary.

In summary, we have presented the log \( \nu_s - \log L_s \) plane for bright Fermi blazars. The plane shows an inverse correlation statistically, but some low-\( \nu_s \)-low-\( L_s \) blazars appear. These blazars may be characterized by relatively smaller black hole masses rather than by weaker beaming. The ratio \( r_{\text{CD}} \) correlates with the Compton dominance CD. This may indicate that in most blazars the high energy emission is dominated by the EC process.

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