Intrinsic γ-ray luminosity, black hole mass, jet and accretion in
Fermi blazars

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ABSTRACT
We have analysed a large sample of clean blazars detected by Fermi Large Area Telescope (LAT). Using the literature and calculation, we obtained intrinsic γ-ray luminosity excluding beaming effect, black hole mass, broad-line luminosity (used as a proxy for disc luminosity), jet kinetic power from ‘cavity’ power and bulk Lorentz factor for parsec-scale radio emission, and studied the distributions of these parameters and relations between them. Our main results are as follows. (i) After excluding beaming effect and redshift effect, intrinsic γ-ray luminosity with broad-line luminosity, black hole mass and Eddington ratio have significant correlations. Our results confirm the physical distinction between BL Lacs and FSRQs. (ii) The correlation between broad-line luminosity and jet power is significant which supports that jet power has a close link with accretion. Jet power depends on both the Eddington ratio and black hole mass. We also obtain logL_{BLR} ∼ (0.98 ± 0.07)logP_{jet} for all blazars, which is consistent with the theoretical predicted coefficient. These results support that jets are powered by energy extraction from both accretion and black hole spin (i.e. not by accretion only). (iii) For almost all BL Lacs, P_{jet} > L_{disc}; for most of FSRQs, P_{jet} < L_{disc}. The ‘jet-dominance’ (parametrized as P_{jet}/L_{disc}) is mainly controlled by the bolometric luminosity. Finally, the radiative efficiency of γ-ray and properties of TeV blazars detected by Fermi LAT were discussed.

Key words: radiation mechanisms: non-thermal – galaxies: active – BL Lacertae objects: general – quasars: general – gamma-rays: general – X-rays: general.

1 INTRODUCTION
Blazars are the most extreme active galactic nuclei (AGNs) pointing their jets in the direction of the observer (Urry & Padovani 1995), and are the brightest and the most dominant population of AGN in the γ-ray sky (Fichtel et al. 1994; Abdo et al. 2010a). Their extremely observational properties are explained as being due to a beaming effect. Due to a relativistic beaming effect, the emissions from the jet are strongly boosted in the observer’s frame (Urry & Padovani 1995). Blazars are often divided into two sub-classes of BL Lacertae objects (BL Lacs) and flat spectrum radio quasars (FSRQs). FSRQs have strong emission lines, while BL Lac objects have only very weak or non-existent emission lines. The classic division between FSRQs and BL Lacs is mainly based on the equivalent width (EW) of the emission lines. Objects with rest frame EW > 5 Å are classified as FSRQs (e.g. Urry & Padovani 1995; Scarpa & Falomo 1997), Blandford & Rees (1978) had originally suggested that the absence of broad lines in BL Lacs was due to a very bright, Doppler-boosted synchrotron continuum. On the other hand, EW greater than 5 Å may be the results of a particularly low state of the beamed continuum in a source of intrinsically weak lines, and the jet electromagnetic output is often dominated by the emission at higher energies (Ghisellini et al. 2011; Sbarrato et al. 2012). Therefore, the EW alone is not a good indicator of the distinction between the two classes of blazars. By studying the transition between BL Lacs and FSRQs, Ghisellini et al. (2011) proposed a physical distinction between the two classes of blazars, based on the luminosity of the broad-line region (BLR) measured in Eddington units, and the dividing line is of the order of L_{BLR}/L_{Edd} ∼ 5 × 10^{-4}. The result also was confirmed by Sbarrato et al. (2012).

Many models have been proposed to explain the origin of the blazar γ-ray emission, including synchrotron self-Compton (SSC; e.g. Maraschi, Ghisellini & Celotti 1992), inverse Compton (IC) scattering on photons produced by the accretion disc (Dermer, Schlickeiser & Mastichiadis 1992; Zhang & Cheng 1997), scattered by ambient material, or reprocessed by the broad-line clouds (Sikora, Begelman & Rees 1994; Xie, Zhang & Fan 1997), synchrotron emission by ultrarelativistic electrons and positrons (e.g. Cheng, Yu & Ding 1993; Ghisellini et al. 1993) and electromagnetic

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cascade by collision of ultrarelativistic nucleons (e.g. Mannheim & Biermann 1992; Mannheim 1993; Cheng & Ding 1994). The most popular opinion is that γ-ray of powerful blazars is produced within the BLR via EC (e.g. Sikora et al. 1994; Ghisellini & Madau 1996) and γ-ray of low-power blazars is SSC (Maraschi et al. 1992). Since the launch of the Fermi satellite, we have entered in a new era of blazars research (Abdo et al. 2009, 2010a,b). Up to now, the Large Area Telescope (LAT) has detected hundreds of blazars because it has about 20-foles better sensitivity than its predecessor EGRET in the 0.1–100 GeV energy rang. The dramatically improved γ-ray data from Fermi LAT has opened up the possibility of testing results obtained from the EGRET era regarding the origin of γ-rays. Sbarrato et al. (2012) found a good correlation between the luminosity of the broad lines and the γ-ray luminosity. But the γ-ray luminosity in their sample did not consider the beaming effect; the sample studied in Sbarrato et al. (2012) was limited; most of BL Lacs from the Sbarrato et al. (2012) sample have been selected to be at $z < 0.4$.

The radiation observed from blazars is dominated by the emission from relativistic jets which transport energy and momentum to large scales (Blandford & Rees 1978). However, jet formation remains one of the unsolved fundamental problems in astrophysics (e.g. Meier, Koide & Uchida 2001). Many models have been proposed to explain the origin of jets. In current theoretical models of the formation of jet, power is generated via accretion and extraction of rotational energy of disc/black hole (Blandford & Znajek 1977; Blandford & Payne 1982), and then converted into the kinetic power of the jet. In both scenarios, the magnetic field plays a major role in channelling power from the black hole (BH) or the disc into the jet; in both cases, it should be sustained by matter accreting on to BH, leading one to expect a relation between accretion and jet power (Maraschi & Tavecchio 2003). The jet-disc connection has been extensively explored by many authors and in different ways (e.g. Rawlings & Saunders 1991; Falcke & Biermann 1995; Serjeant, Rawlings & Maddox 1998; Cao & Jiang 1999; Wang, Luo & Ho 2004; Liu, Jiang & Gu 2006; Xie, Dai & Zhou 2007; Ghisellini, Tavecchio & Ghirlanda 2009a; Ghisellini et al. 2009b, 2010, 2011; Gu, Cao & Jiang 2009; Sbarrato et al. 2012). More and more pieces of evidence show that the jet power of extragalactic radio loud sources is of the same order (or slightly larger than) of the disc luminosity (e.g. Rawlings & Saunders 1991; Ghisellini et al. 2009a,b). On a larger scale (radio-lobe size), one finds out the minimum jet power needed to sustain the radio-lobe emission via considering minimum energy and the lifetime of radio lobes (Rawlings & Saunders 1991). At smaller, but still very large, jet scales (on kpc to Mpc), one can use the recently discovered X-ray emission from resolved knots, to model it and to infer the total number of leptons needed to produce the observed radiation. Assuming a proton per emitting lepton, Tavecchio et al. (2000), Celotti, Ghisellini & Chiaberge (2001), Tavecchio et al. (2004), Sambruna et al. (2006) and Tavecchio et al. (2007) derived jet powers. At the very long baseline interferometry (VLBI) scale (pc or tens of pc), one takes advantage of the resolving power of VLBI to measure the size of the synchrotron emitting region (Celotti & Fabian 1993). This and gives an estimate of the jet power. A recent technique makes use of the cavities or bubbles in the X-ray emitting intra-cluster medium of the cluster of galaxies, and measures the energy required to inflate such bubbles. Assuming that this energy is furnished by the jet, one can calculate the associated jet power (e.g. Allen et al. 2006; Balmaverde, Baldi & Capetti 2008; Cavagnolo et al. 2010).

Blazars detected in the TeV or very high energy regime (VHE; $E > 100$ GeV) are still a small group but their number is rapidly increasing and are intensively studied (e.g. De Angelis, Mansutti & Persic 2008), because they are good laboratories to investigate particle acceleration and cooling, and to indirectly probe the extragalactic background light (EBL; e.g. Stecker, de Jager & Salamon 1992; Stanev & Franceschini 1998; Mazin & Raue 2007; Tavecchio et al. 2010, 2011). From TeVCat catalogue, the majority of the detected TeV blazars belong to high-frequency peaked BL Lacs (HBLs). There are three FSRQs detected in the TeV band (TSRQs; 4C +21.35, PKS 1510−089, 3C 279). Most of them have recently been detected also at MeV–GeV energies by Fermi LAT (Abdo et al. 2010a, 2012). The TeV observations have shown dramatic variability in some TeV blazars, which suggests extremely small emitting volumes and/or time compression by large relativistic Doppler factors (Aharonian et al. 2007; Wagner 2007). It is generally accepted that the SSC model can account for the observed Spectral Energy Distribution (SED) of TeV BL Lacs (TBL Lacs). However this may be an oversimplification, since, besides the jet region containing the energetic electrons responsible for the high-energy emission, other sites, both in the jet and externally to it (e.g. a molecular torus, a thin scattering plasma surrounding the jet, or the walls of the jet itself) may be important in producing the soft seed photons to be scattered at high energies (e.g. Costamante & Ghisellini 2002).

In this paper, through constructing a large sample of clean Fermi blazars and removing beaming effect, we studied the correlations between intrinsic γ-ray luminosity and black hole (BH) mass, between intrinsic γ-ray luminosity and the Eddington ratio, and revisited the correlation between the luminosity of the broad lines and the intrinsic γ-ray luminosity and physical distinction between the two classes of blazars. We estimated the jet kinetic power for the Fermi blazars from Nemmen et al. (2012) to study the jet-disc connection and properties of Fermi blazars detected in TeV band.

The paper is structured as follows: in Section 2, we present the samples; the results are presented in Section 3 and discussions are in Section 4; our conclusions are presented in Section 5. The cosmological parameters $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$ have been adopted in this work.

2 THE SAMPLES

We tried to select the largest group of clean blazars detected by Fermi LAT with reliable broad-line luminosity, γ-ray luminosity, redshift, BH mass and jet kinetic power. For the aim, we collected many very large samples of blazars to obtain broad-line data and BH mass and cross-correlated these sample with clean blazars detected by Fermi LAT. First, we considered the following samples of blazars to obtain the broad-line data: Cao & Jiang (1999), Wang et al. (2004), Liu et al. (2006), Sbarrato et al. (2012), Chai, Cao & Gu (2012), Shen et al. (2011), Shaw et al. (2012). We cross-correlated these sample with clean blazars detected by Fermi LAT in two years of scientific operation (Ackermann et al. 2011b, 2LAC; Abdo et al. 2012, 2FGL). Secondly, we considered the following samples of blazars to obtain BH: Woo & Urry (2002), Xie, Zhou & Liang (2004), Liu et al. (2006), Zhou & Cao (2009), Zhang et al. (2012), Sbarrato et al. (2012), Chai et al. (2012), Leon-Tavares et al. (2011a), Shen et al. (2011), Shaw et al. (2012). At last, we cross-correlated these Fermi blazars with sample of Nemmen et al. (2012) to obtain jet kinetic power and beaming factor. In total, we have a sample containing 248 clean Fermi blazars (191 FSRQs and 57 BL Lacs), including 20 TBL Lacs and 3 TSRQs.

1 http://tevcat.uchicago.edu
2.1 Intrinsic γ-ray luminosity

The *Fermi* satellite is detecting γ-ray emission from a large number of blazars. The second catalogue of AGN (2LAC) detected by the *Fermi* LAT in two years of scientific operation includes 1017 γ-ray sources located at high Galactic latitudes (|b| > 10°; Ackermann et al. 2011b). These γ-ray sources are detected with a test statistic (TS) greater than 25 and associated statistically with AGNs. However, some of these sources are affected by analysis issues and associated with multiple AGNs. Consequently, the clean sample includes 886 AGNs, comprising 395 BL Lacs, 310 FSRQs, 157 candidate blazars of unknown type, 8 misaligned AGNs, 4 narrow-line Seyfert 1 (NLS1s), 10 AGNs of other types and 2 starburst galaxies. Source detection is based on the average flux over the 24-month period and flux measurements are included in five energy bands (Abdo et al. 2012). We also note that 56 per cent of the BL Lacs have no measured redshifts.

Nemmen et al. (2012) established a physical analogy between AGNs and γ-ray bursts (GRBs). A key point in their work was that γ-ray luminosity of blazars and GRBs considered beaming effect. They computed the intrinsic γ-ray luminosity *L* of blazars by correcting observation γ-ray luminosity *L_\text{obs}*(γ) for the beaming factor *f_0*, such that *L* = *f_0*L_\text{obs}*(γ). For blazars, *f_0* was estimated as 1 − cos(1/Γ), where Γ was the bulk Lorentz factor of the flow, since jet opening angle θ_j of AGNs obey θ_j < 1/Γ (Jorstad et al. 2005; Pushkarev et al. 2009). Using VLBI and Very Long Baseline Array (VLBA), Hovatta et al. (2009) and Pushkarev et al. (2009) calculated the variability Lorentz factors *Γ_\text{var}*. The bulk Lorentz factors of Nemmen et al. (2012) were from the results of Hovatta et al. (2009) and Pushkarev et al. (2009). Because θ_j was not available for the whole blazar sample, they used the power-law fit of *f_0* ≈ 5 × 10^{-4}(L_\text{2-30 GeV})^{-0.39±0.15} as an estimator for *f_0*. Nemmen et al. (2012) computed the K-corrected γ-ray luminosity at 0.1–100 GeV, uncertainty and the intrinsic γ-ray luminosity excluding beaming effect. The intrinsic γ-ray luminosity of some blazars from our sample are obtained from Nemmen et al. (2012).

If intrinsic γ-ray luminosity in our sample are not obtained from Nemmen et al. (2012), we follow a procedure similar of Nemmen et al. (2012) to calculate intrinsic γ-ray luminosity and use average uncertainty with 0.6 dex for them (we also use the power-law fit of *f_0* ≈ 5 × 10^{-4}(L_\text{2-30 GeV})^{-0.39±0.15} as an estimator for *f_0*).

2.2 Broad-line luminosity

The BLR luminosity given in Celotti, Padovani & Ghisellini (1997) were derived by scaling several strong emission lines to the quasar template spectrum of Francis et al. (1991), and used Lyα as a reference. Sbarrato et al. (2012) had taken the luminosity of emission lines of the blazars in Sloan Digital Sky Survey (SDSS) DR7 quasar sample. For calculating the total luminosity of the broad lines, they had followed Celotti et al. (1997). Specifically, they set Lyα flux contribution to 100, the relative weight of Hα, Hβ, Mg II and C IV lines, respectively, to 77, 22, 34 and 63. The total broad-line flux was fixed at 555.76. Their broad-line luminosity had been derived using these proportions. When more than one line was present, they calculated the simple average of broad-line luminosity estimated from each line. The rest of authors in our sample also adopted the method proposed by Celotti et al. (1997) and similar processes to gain broad-line luminosity.

Shaw et al. (2012) reported on optical spectroscopy of 229 blazars in the *Fermi* 1LAC sample and Shen et al. (2011) had spectrally analysed SDSS DR7 quasar sample. The luminosity of emission lines of some of our blazars are from Shaw et al. (2012) and Shen et al. (2011), and we use similar method of Sbarrato et al. (2012) to calculate broad-line luminosity. However, we find that some objects of broad-line luminosity are distinct from different samples with our results. The possible reasons are that using lines to calculate broad-line luminosity is different and variability also can cause the difference of them. In these sources, we use average broad-line luminosity instead.

2.3 BH mass

The traditional virial BH mass is estimated by using an empirical relation between BLR size and ionizing luminosity together with measured broad-line widths assuming the BLR clouds being gravitationally bound by the central BH. For most of FSRQs in our sample, the BH mass is estimated by traditional virial method (Woo & Urry 2002; Wang et al. 2004; Liu et al. 2006; Shen et al. 2011; Chai et al. 2012; Sbarrato et al. 2012; Shaw et al. 2012). When virial BH masses are attained from different lines, we simply average BH masses from different lines. In Shen et al. (2011), we obtain BH masses from Vestergaard & Peterson (2006) for Hβ and C IV, and Vestergaard & Osmer (2009) for Mg II. For some sources, especially BL Lac objects, the BH masses can be estimated from the properties of their host galaxies with either M_BH−σ or M_BH−L relations, where σ and L are the stellar velocity dispersion and the bulge luminosity of the host galaxies (Woo & Urry 2002; Zhou & Cao 2009; Leon-Tavares et al. 2011a; Chai et al. 2012; Sbarrato et al. 2012; Zhang et al. 2012). For a few sources, the BH masses are estimated from variation time-scale (Xie et al. 1991, 2004). For some blazars, when more than one BH masses are got, we use average BH mass instead.

2.4 Jet kinetic power

Cavagnolo et al. (2010) searched for X-ray cavities in different systems including giant elliptical galaxies and cD galaxies and estimated the jet power required to inflate these cavities or bubbles, obtaining a tight correlation between the ‘cavity’ power and the radio luminosity

\[
P_{\text{cav}} \approx 5.8 \times 10^{41} \left( \frac{P_{\text{radio}}}{10^{40} \text{erg s}^{-1}} \right)^{0.7} \text{erg s}^{-1},
\]

which is continuous over ~6–8 decades in *P_\text{jet}* and *P_\text{radio}* with a scatter of ~0.7 dex and *P_\text{jet} = P_\text{cav}*. While this method is limited to a small number of sources at present, the *P_\text{jet}* and *P_\text{radio}* relation covers over ~6–8 orders of magnitude in jet power, including both FR I and FR II sources. Making use of the correlation between *P_\text{jet}*_ and *P_\text{radio}*_ from Cavagnolo et al. (2010), Meyer et al. (2011) chose the low-frequency extended luminosity at 300 MHz as an estimator of the jet power for blazars. Following Meyer et al. (2011), Nemmen et al. (2012) estimated the jet kinetic power for a large sample of *Fermi* blazars and obtained the relation between intrinsic γ-ray luminosity and the kinetic power. The best-fitting parameters obtained from Nemmen et al. (2012) were α = 0.98 ± 0.02 and β = 1.6 ± 0.9 where log *P_\text{jet}*_ = α log *L_\text{2-30 GeV}*_ + β. The scatter about the best fit is 0.64 dex. Our sample’s jet powers are got from Nemmen et al. (2012). When jet powers of blazars from our sample are not directly got from Nemmen et al. (2012), we use the relation between intrinsic γ-ray luminosity and the kinetic power from Nemmen et al. (2012) to estimate the jet kinetic power. The uncertainty in *P_\text{jet}*_ is dominated by the scatter in the correlation of Cavagnolo et al. (2010) and corresponds to 0.7 dex.

The relevant data are listed in Table 1 with the following headings: column (1), name of the *Fermi* LAT catalogue; column (2),
## Table 1. The sample.

| Fermi name       | Other name | RA  | Dec  | Opt. type | SED type | Redshift | $\log L_{60}$ | $\log M_{BH}$ | $\log P_{BLR}$ | $\log L_{BLR}$ |
|------------------|------------|-----|------|-----------|----------|-----------|--------------|---------------|---------------|---------------|
| 2FGL J0004.7–4736 | PKS 0002–478 | 00 04 35.5 | 00 40 35.5 | bzq | 0.88 | 44.36 | 7.85 | 45.07 | 44.11 |
| 2FGL J0017.4–0018 | S3 0013–00 | 00 16 10.9 | 00 17 15.4 | LSP | 0.57 | 43.64 | 8.55,9.04 | 45.35 | 44.91 |
| 2FGL J0017.6–0510 | PMN 0017–0512 | 00 17 35.6 | 00 12 42.4 | LSP | 0.57 | 43.86 | 7.78 | 45.09 | 44.28 |
| 2FGL J0023.2+4454 | B3 0020+446 | 00 23 35.3 | 0.162 | 44.38 | 7.78 | 45.09 | 44.28 |
| 2FGL J0024.5+0346 | GB6 J0024+0349 | 00 24 45.1 | 0.545 | 43.79 | 7.76 | 45.41 | 43.80 |
| 2FGL J0043.7+3426 | GB6 J0043+3426 | 00 43 48.7 | 0.966 | 44.49 | 8.01 | 45.20 | 44.02 |
| 2FGL J0046.7–8416 | PKS 0044–84 | 00 44 25.2 | 1.032 | 44.44 | 8.68 | 45.15 | 44.88 |
| 2FGL J0047.9+2232 | NVSS J004802+22352 | 00 48 02.5 | 1.161 | 44.66 | 8.43,8.25 | 45.36 | 44.29 |
| 2FGL J0050.1–0452 | PKS 0047–051 | 00 50 21.4 | 0.92 | 44.22 | 8.20 | 44.93 | 43.35 |
| 2FGL J0057.9+3311 | MG3 J005830+3311 | 00 58 31.9 | 1.369 | 44.53 | 8.01,7.97 | 45.24 | 44.21 |
| 2FGL J0105.0–2411 | PKS 0102–245 | 01 04 58.1 | 1.747 | 44.77 | 8.85,8.97 | 45.48 | 44.95 |
| 2FGL J0108.6+0135 | 4C+01.02 | 01 08 38.8 | 2.107 | 45.43 | 8.83 | 46.46 | 46.13 |
| 2FGL J0113.7+4948 | 0110+495 | 01 13 27.0 | 0.389 | 43.72 | 8.34 | 44.44 |
| 2FGL J0136.9+4751 | OC 457 | 01 36 58.6 | 0.859 | 44.95 | 8.73,8.3 | 44.78 | 44.44 |
| 2FGL J0137.6–2430 | PKS 0135–247 | 01 37 38.3 | 0.835 | 44.33 | 9.11,9.13 | 45.57 | 45.34 |
| 2FGL J0158.0–4609 | PMN J0157–4614 | 01 57 50.8 | 2.287 | 44.84 | 7.98,8.52 | 45.55 | 44.73 |
| 2FGL J0204.0+3045 | B2 0200+30 | 02 03 45.3 | 0.955 | 44.31 | 8.02 | 45.03 | 43.41 |
| 2FGL J0217.5–0813 | PKS 0214–085 | 02 17 02.5 | 0.607 | 43.80 | 6.53 | 44.52 | 43.07 |
| 2FGL J0222.6+4302 | 0219+428 | 02 22 39.6 | 0.444 | 44.67 | 8.86 | 45.43 | 44.03 |
| 2FGL J0237.8+2846 | 4C+28.07 | 02 37 52.4 | 1.213 | 45.27 | 9.22 | 45.59 | 45.24,45.39 |
| 2FGL J0238.7+1637 | PKS 0235+164 | 02 38 38.9 | 0.94 | 44.72 | 9.12,22.8 | 44.72 | 43.92 |
| 2FGL J0245.1+2406 | B2 0242+23 | 02 45 16.7 | 2.247 | 45.13 | 9.12,9.18 | 45.83 | 45.34 |
| 2FGL J0245.9–4652 | PKS 0244–470 | 02 46 00.0 | 1.385 | 45.09 | 8.48,8.32 | 45.79 | 45.43 |
| 2FGL J0252.7–2218 | PKS 0250–225 | 02 52 48.0 | 1.419 | 45.14 | 9.40 | 45.50 | 44.73 |
| 2FGL J0257.7–1213 | PB 09399 | 02 57 40.9 | 1.391 | 44.51 | 9.22 | 45.22 | 44.14 |
| 2FGL J0259.5+0740 | PKS 0256+075 | 02 59 27.1 | 0.893 | 44.22 | 45.06 | 43.50 |
| 2FGL J0303.5–6209 | PKS 0302–623 | 03 03 50.8 | 1.348 | 44.72 | 9.76 | 45.43 | 45.65 |
| 2FGL J0310.0–6058 | PKS 0308–611 | 03 09 55.9 | 1.479 | 44.83 | 8.87 | 45.53 | 44.88 |
| 2FGL J0310.7+3813 | B3 0307+380 | 03 10 49.9 | 0.816 | 44.10 | 8.23 | 44.82 | 43.82 |
| 2FGL J0315.8–1024 | PKS 0313–107 | 03 15 56.9 | 1.565 | 45.50 | 7.17,8.33 | 44.88 | 44.67 | 44.67 |

**Notes:**
- RA and Dec are in J2000 coordinates.
- Opt. type: bzq = broad-line quasar, LSP = linearly polarized synchrotron.
- SED type: LSP = linearly polarized synchrotron.
- Redshift: measured from the optical restframe.
- $\log L_{60}$: the absolute 60 GHz flux density.
- $\log M_{BH}$: the black hole mass.
- $\log P_{BLR}$: the BLR photon luminosity.
- $\log L_{BLR}$: the BLR luminosity.
Table 1 – continued

| Fermi name  | Other name | RA Dec | Opt. type | Redshift | log$L^{\text{int}}_{\text{unc.}}$ | log$M_{\text{BH}}$ | log$P_{\text{int}}$ | log$L_{\text{BLR}}$ |
|-------------|------------|--------|-----------|----------|-------------------------------|-----------------|-----------------|-------------------|
| 2FGL J0319.6+1849 | 0317+185 | 03 19 51.8 | sbzb | 0.19 | 43.37 | 8.10 | 44.11 |
| 2FGL J0326.1+2226 | TXS 0322+222 | 03 25 36.7 | sbzb | 2.066 | 45.12 | 9.5,9.16 | 45.82 | 45.81 |
| 2FGL J0339.4–0144 | PKS 0336–01 | 03 39 30.9 | LSP | 0.852 | 43.93 | 8.89,8.98 | 45.31 | 45.00 |
| 2FGL J0342.4+3859 | GB6 J0342+3858 | 03 42 16.3 | sbzb | 0.945 | 44.40 | 7.42 | 45.11 | 43.87 |
| 2FGL J0405.8–1309 | PKS 0403–13 | 04 05 34.0 | sbzb | 0.571 | 43.78 | 9.08,9.07 | 45.68 | 45.25 |
| 2FGL J0407.7+0740 | TXS 0404+075 | 04 07 29.1 | LSP | 1.133 | 44.46 | 8.65 | 45.17 | 44.51 |
| 2FGL J0413.5–5332 | PMN J0413–5332 | 04 13 13.5 | sbzb | 1.024 | 44.50 | 7.83 | 45.21 | 44.14 |
| 2FGL J0416.7–1849 | PKS 0414–189 | 04 16 36.5 | sbzb | 1.536 | 44.70 | 45.41 | 44.54 |
| 2FGL J0422.1–0645 | PMN J0422–0643 | 04 22 10.6 | sbzb | 0.242 | 43.39 | 7.37 | 44.13 | 43.42 |
| 2FGL J0423.2–0120 | PKS 0420–01 | 04 23 15.8 | sbzb | 0.916 | 45.22 | 9.03,9.8,41 | 45.24 | 44.90 |
| 2FGL J0428.6–3756 | PKS 0426–380 | 04 28 40.4 | LSP | 0.26 | 43.57 | 8.60 | 45.53 | 44.94 |
| 2FGL J0430.4–2507 | PMN J0430–2507 | 04 30 16.0 | sbzb | 0.516 | 43.67 | 6.51 | 44.40 | 42.81 |
| 2FGL J0439.0–1252 | PKS 0436–129 | 04 38 34.9 | sbzb | 1.285 | 44.40 | 8.66 | 45.11 | 44.78 |
| 2FGL J0442.7–0017 | 0440–003 | 04 42 38.6 | sbzb | 0.844 | 44.84 | 8.81,8.1 | 45.41 | 44.81 |
| 2FGL J0453.1–2807 | PKS 0451–28 | 04 53 14.6 | sbzb | 2.56 | 45.46 | 46.15 | 46.26 |
| 2FGL J0457.0–2325 | PKS 0454–234 | 04 57 03.2 | sbzb | 1.003 | 45.12 | 45.82 | 44.41 |
| 2FGL J0501.2–0155 | PKS 0458–020 | 05 01 12.8 | sbzb | 2.291 | 45.28 | 9.27,8.66 | 46.30 | 45.30 |
| 2FGL J0507.5–6102 | PMN J0507–6104 | 05 07 54.4 | sbzb | 1.089 | 44.55 | 8.74 | 45.26 | 44.86 |
| 2FGL J0509.2+1013 | PKS 0506+101 | 05 09 27.4 | sbzb | 0.621 | 44.15 | 8.03,8.52 | 44.86 | 43.35 |
| 2FGL J0516.5–4601 | 0514–459 | 05 14 45.8 | sbzb | 0.087 | 43.16 | 8.02 | 43.89 |
| 2FGL J0516.8–6207 | PKS 0516–621 | 05 16 44.5 | sbzb | 1.3 | 44.83 | 7.93,8.52 | 45.53 | 44.35 |
| 2FGL J0526.1–4829 | PKS 0524–485 | 05 26 16.4 | sbzb | 1.3 | 44.65 | 9.15,8.46 | 45.36 | 44.87 |
| 2FGL J0530.8+1333 | 0532+134 | 05 30 56.4 | LSP | 2.06 | 45.36 | 10.2,9.4 | 45.92 |
| 2FGL J0531.8–3824 | PKS 0541–834 | 05 33 36.7 | sbzb | 0.774 | 44.25 | 7.40 | 44.97 | 43.74 |
| 2FGL J0532.7+0733 | OG 050 | 05 32 38.9 | sbzb | 1.254 | 44.98 | 8.43 | 45.57 | 44.86 |
| 2FGL J0538.8–4405 | PKS 0537–441 | 05 38 50.3 | sbzb | 0.892 | 45.29 | 8.8,8.33 | 45.53 | 45.02,44.84 |
| 2FGL J0539.3–2841 | PKS 0537–286 | 05 39 54.3 | sbzb | 3.104 | 45.43 | 46.13 | 45.36 |
| 2FGL J0601.1–7037 | PKS 0601–70 | 06 01 10.9 | sbzb | 2.409 | 45.24 | 7.36 | 45.93 | 44.69 |
| 2FGL J0608.0–0836 | PKS 0605–085 | 06 07 59.7 | sbzb | 0.872 | 44.02 | 8.43,8.825 | 45.42 | 44.60,45.33 |
| 2FGL J0608.0–1521 | PMN J0608–1520 | 06 08 01.5 | sbzb | 1.094 | 44.66 | 8.09 | 43.57 | 44.51 |
| Fermi name       | Other name          | RA Dec | SED type | Opt. type | Redshift | log $L_{BH}^{int}$ Unc. | log $M_{BH}$ ref | log $P_{BH}$ ref | log $L_{BLR}$ ref |
|------------------|---------------------|--------|----------|-----------|----------|------------------------|----------------|----------------|------------------|
| 2FGL J0635.5−7516 | PKS 0637−75         | 06 35 46.5 | bzbq     | LSP       | 0.653    | 44.40                  | 9.41,8.81     | 45.98          | 45.23            |
| 2FGL J0654.2+4514 | B3 0650+453         | 06 54 23.6 | bzbq     | LSP       | 0.928    | 44.70                  | 8.17          | 45.10          | 44.26            |
| 2FGL J0654.5+5043 | GB6 J0654+5042      | 06 54 22.0 | LSP       | LSP       | 1.253    | 43.27                  | 7.86,8.79     | 43.62          | 43.97            |
| 2FGL J0656.2−0320 | TXS 0653−033        | 06 56 11.1 | bzbq     | LSP       | 0.634    | 44.39                  | 8.82,8.77     | 45.10          | 45.68            |
| 2FGL J0710.5+5908 | 0706+591            | 07 10 30.1 | bzb     | LSP       | 0.125    | 42.96                  | 8.26          | 43.80          |                  |
|                  |                     |        |          |           |          |                        |               |                | −1.74            |
| 2FGL J0714.0+1933 | MG2 J071354+1934    | 07 13 55.6 | bzbq     | LSP       | 0.54     | 44.30                  | 7.33,7.91     | 45.02          | 43.93            |
| 2FGL J0721.5+0404 | PMN J0721+0406      | 07 21 23.8 | bzbq     | LSP       | 0.665    | 44.05                  | 8.49,9.12     | 44.77          | 45.33            |
| 2FGL J0721.9+7120 | 0716+714            | 07 21 53.4 | bzb     | LSP       | 0.3      | 44.46                  | 8.1,8.1       | 44.76          |                  |
| 2FGL J0738.0+1742 | 0735+178            | 07 38 07.4 | bzb     | LSP       | 0.424    | 44.19                  | 8.4,8.2       | 44.47          |                  |
| 2FGL J0739.2+0138 | PKS 0736+01         | 07 39 18.0 | bzbq     | LSP       | 0.189    | 42.91                  | 8.87,7.86     | 44.10          | 44.19            |
| 2FGL J0746.6+2549 | B2 0743+25          | 07 46 25.9 | bzbq     | LSP       | 0.191    | 42.65                  | 8.27          | 44.34          |                  |
| 2FGL J0747.7+4501 | B3 0745+453         | 07 49 06.4 | bzbq     | LSP       | 0.192    | 43.02                  | 8.54          | 43.87          | 44.34            |
| 2FGL J0750.6+1230 | PKS 0748+126        | 07 50 52.0 | bzbq     | LSP       | 0.889    | 44.47                  | 8.15          | 45.18          | 44.95            |
| 2FGL J0757.1+0957 | 0754+100            | 07 57 06.6 | bzb     | LSP       | 0.268    | 42.75                  | 8.20          | 44.34          |                  |
| 2FGL J0805.5+6145 | TXS 0800+618        | 08 05 18.1 | bzb     | LSP       | 0.303    | 45.48                  | 9.07          | 46.17          | 45.56            |
| 2FGL J0809.8+5218 | IES 0806+524        | 08 09 49.2 | bzb     | LSP       | 0.138    | 43.25                  | 8.90          | 43.29          |                  |
| 2FGL J0811.4+0149 | PKS 0808+019        | 08 11 26.7 | bzb     | LSP       | 1.148    | 45.46                  | 8.50          | 45.18          | 43.62            |
| 2FGL J0824.7+3914 | 4C +39.23           | 08 24 55.3 | bzb     | LSP       | 1.216    | 44.47                  | 8.55          | 45.18          | 44.83            |
|                  |                     |        |          |           |          |                        |               |                | −1.89            |
| 2FGL J0824.9+5552 | OJ 535              | 08 24 47.2 | bzbq     | LSP       | 1.418    | 44.80                  | 9.42,9.1      | 45.51          | 45.30,45.32      |
| 2FGL J0825.9+0308 | PKS 0823+033        | 08 25 50.3 | bzbq     | LSP       | 0.506    | 43.73                  | 8.8            | 44.45          | 43.37            |
| 2FGL J0830.5+2407 | B2 0827+24          | 08 30 52.1 | bzb     | LSP       | 0.980    | 44.07                  | 9.01,8.8,8.8  | 45.22          | 44.99,44.97      |
| 2FGL J0831.9+0429 | PKS 0829+046        | 08 31 48.9 | bzbq     | LSP       | 0.174    | 43.60                  | 8.8,8.46      | 44.18          | 42.57            |
| 2FGL J0834.3+4221 | OJ 451              | 08 33 53.8 | bzbq     | LSP       | 0.249    | 43.32                  | 9.68          | 44.18          | 43.07            |
|                  |                     |        |          |           |          |                        |               |                | −1.93            |
| 2FGL J0841.6+7052 | 4C+71.07            | 08 41 24.3 | bzb     | LSP       | 2.172    | 45.16                  | 9.36          | 45.97          | 46.43            |
| 2FGL J0854.8+2005 | OJ 287              | 08 54 48.9 | bzb     | LSP       | 0.306    | 43.89                  | 8.8,7.8,8.1   | 44.17          | 43.58,42.83      |
| 2FGL J0903.4+4651 | S4 0859+470         | 09 03 04.0 | bzbq     | LSP       | 1.466    | 44.44                  | 9.25          | 46.10          | 45.26            |
| 2FGL J0909.1+0121 | PKS 0906+01         | 09 09 10.1 | bzbq     | LSP       | 1.024    | 44.86                  | 9.32,8.5,9.14 | 45.25          | 45.1,45.24,45.27 |
| 2FGL J0910.9+2246 | TXS 0907+230        | 09 10 42.1 | bzb     | LSP       | 2.661    | 45.11                  | 8.70          | 45.81          | 45.21            |
| 2FGL J0912.1+4126 | B3 0908+41          | 09 12 11.5 | bzb     | LSP       | 2.563    | 44.89                  | 9.32          | 45.59          | 45.36            |
| 2FGL J0917.0+3900 | S4 0913+39          | 09 16 48.9 | bzb     | LSP       | 1.267    | 44.44                  | 8.62          | 44.18          | 44.80            |
|                  |                     |        |          |           |          |                        |               |                | −1.93            |
Table 1 – continued

| Fermi name | Other name | RA Dec | SED type | Redshift | log$L_{\nu}^{int}$ Unc. | log$M_{BH}$ ref | log$P_{jet}$ ref | log$L_{BLR}$ ref |
|------------|------------|--------|----------|-----------|-----------------|----------------|----------------|---------------|
| 2FGL J0920.9+4441 | B3 0917+449 | 09 20 58.4 | LSP | 1.975 | 46.00 | 9.25,9.310.29 | 45.84 | 45.85,45.75 |
| 2FGL J0921.9+6216 | OK 630 | 09 21 36.1 | LSP | 1.453 | 44.71 | 8.93 | 44.42,45.05 |
| 2FGL J0923.2+4125 | B3 0920+416 | 09 23 31.1 | LSP | 1.732 | 44.80 | 7.68,8.16 | 45.50 | 43.75 |
| 2FGL J0924.0+2819 | B2 0920+28 | 09 23 51.5 | LSP | 0.744 | 44.20 | 8.8,8.825 | 44.91 | 44.41,44.63 |
| 2FGL J0937.6+5009 | CGRaBS J0937+5008 | 09 37 12.3 | LSP | 0.275 | 43.41 | 8.29,7.5 | 44.14 | 43.26,42.99 |
| 2FGL J0941.4+6148 | RX J0940.3+6148 | 09 40 22.3 | LSP | 0.211 | 43.20 | 8.36,8.25 | 43.93 |
| 2FGL J0945.9+5751 | GB6 J0945+5757 | 09 45 42.1 | LSP | 0.229 | 43.16 | 8.57,8.77 | 43.82 |
| 2FGL J0946.5+1015 | CRATES J0946+1017 | 09 46 35.1 | LSP | 1.007 | 44.48 | 8.52,8.47 | 45.19 | 44.81,44.75 |
| 2FGL J0948.8+4040 | 4C 40+24 | 09 48 55.3 | LSP | 1.249 | 43.71 | 8.95 | 45.65 |
| 2FGL J0956.9+2516 | B2 0954+25A | 09 56 49.9 | LSP | 0.707 | 44.25 | 9.34,9.8,7.46 | 44.80 |
| 2FGL J0957.7+5522 | 4C 55+17 | 09 57 38.2 | LSP | 0.896 | 44.93 | 8.96,7.8,7.07,8.45 | 45.63 |
| 2FGL J0958.6+6533 | CGRaBS J0958+6533 | 09 58 47.2 | LSP | 0.368 | 43.80 | 8.5,8.53 | 44.42 |
| 2FGL J1001.0+2913 | GB6 J1001+2913 | 10 01 10.1 | LSP | 0.558 | 43.99 | 7.31,7.64 | 45.51,45.06 |
| 2FGL J1012.1+0631 | PMN 1012+0630 | 10 12 13.3 | LSP | 0.727 | 44.01 | 8.50 | 45.32 |
| 2FGL J1012.6+2440 | MG 1012+2440 | 10 12 41.2 | LSP | 1.050 | 45.05 | 7.73,7.86 | 45.75 |
| 2FGL J1014.1+2306 | 4C 23+24 | 10 14 46.9 | LSP | 0.566 | 43.86 | 8.479,8.54 | 45.35 |
| 2FGL J1015.1+4925 | IES 1011+496 | 10 15 04.1 | LSP | 0.212 | 43.83 | 8.30 | 45.55 |
| 2FGL J1016.0+0513 | CRATES J1016+0513 | 10 16 03.1 | LSP | 0.173 | 45.09 | 9.11,7.99 | 45.79 |
| 2FGL J1017.0+3531 | B2 1015+35 | 10 18 10.9 | LSP | 1.228 | 44.50 | 9.10 | 45.23 |
| 2FGL J1033.2+4117 | B3 1030+415 | 10 33 03.7 | LSP | 1.117 | 44.59 | 8.65,8.61 | 45.35 |
| 2FGL J1037.5+2820 | PKS B1035+281 | 10 37 42.4 | LSP | 1.066 | 44.63 | 8.99 | 45.33 |
| 2FGL J1043.1+2404 | B2 1040+204 | 10 43 08.9 | LSP | 0.559 | 43.95 | 8.09 | 44.67,43.66 |
| 2FGL J1057.0−8004 | PKS 1057−79 | 10 58 43.3 | LSP | 0.581 | 44.19 | 8.80 | 44.90 |
| 2FGL J1058.4+0133 | PKS 1058+01 | 10 58 29.6 | LSP | 0.888 | 45.23 | 8.45,8.37 | 45.61 |
| 2FGL J1057.0+3531 | B2 1015+35 | 10 18 10.9 | LSP | 1.228 | 44.50 | 9.10 | 45.23 |
| 2FGL J1106.1+2814 | MG2 J110606+2812 | 11 06 07.2 | LSP | 0.843 | 44.23 | 8.85 | 44.94 |
| 2FGL J1112.4+3450 | CRATES J1112+3446 | 11 12 38.8 | LSP | 1.949 | 45.04 | 9.04,8.78 | 45.74 |
| 2FGL J1117.2+2013 | CRATES J1117+2014 | 11 17 06.2 | LSP | 0.139 | 43.30 | 8.62 | 44.04 |
| 2FGL J1120.4+0710 | MG1 J112039+0704 | 11 20 38.3 | LSP | 1.336 | 44.48 | 8.83 | 45.19 |
| 2FGL J1124.2+2338 | OM 235 | 11 24 02.6 | LSP | 1.549 | 44.63 | 8.79 | 45.34 |

References:

1. Sb12,Sh12
2. Sh12
3. S11
4. Sb12,Sh12
5. Sb12,Sh12
6. Sb12
7. Sh12
8. Sb12,Sh12

References for BH mass, jet and accretion in Fermi blazars:

- MNRAS 3375–3395 (2014)
Table 1 – continued

| Fermi name   | Other name | RA       | Opt. type | Redshift | log$L_{\text{jet}}$ Unc. | logM$_{\text{BH}}$ ref | log$P_{\text{jet}}$ ref | log$L_{\text{BLR}}$ ref |
|--------------|------------|----------|-----------|----------|--------------------------|-------------------------|-------------------------|-------------------------|
| 2FGL J1130.3−1448 | 1127−145 | 11 30 07.0 | bzb | 1.184 | 4.92 | 9.18 | 45.62 | 45.77 |
| 2FGL J1136.7+7009 | Mrk 180 | 11 36 26.4 | tsbzb | 0.045278 | 42.40 | 8.21 | 43.48 | 44.39 |
| 2FGL J1146.8−3812 | PKS 1144−379 | 11 47 01.4 | bzb | 1.048 | 44.58 | 8.50 | 44.89 | 44.36, 44.60 |
| 2FGL J1146.9+4000 | B2 1144+40 | 11 46 58.3 | bzb | 1.089 | 46.69 | 8.98,8.93 | 44.56 | 45.07, 45.06 |
| 2FGL J1152.4−0840 | PKS B1149−084 | 11 52 17.1 | bzb | 2.367 | 44.99 | 9.38 | 44.69 | 45.25 |
| 2FGL J1154.0−0010 | RXS J115404.9−001008 | 11 54 04.3 | bzb | 0.253 | 43.41 | 8.21,8.35 | 44.14 |
| 2FGL J1159.5+2914 | 4C+29.45 | 11 59 31.8 | bzb | 0.724 | 44.21 | 9.18, 9.8, 9.8, 375 | 45.43 | 44.71, 44.65 |
| 2FGL J1203.2+6030 | GB6 J1203+6031 | 12 03 03.4 | bzb | 0.066 | 42.47 | 8.09,8 | 43.45 | |
| 2FGL J1204.2+1144 | BZB J1204+1145 | 12 04 12.1 | bzb | 0.296 | 43.48 | 8.53,8.72 | 44.21 |
| 2FGL J1206.0−2638 | PKS 1203−26 | 12 05 33.2 | bzb | 0.789 | 44.33 | 8.59,9 | 45.70 | 44.07 |
| 2FGL J1208.8+5441 | CRATES J1208+5441 | 12 08 54.2 | bzb | 1.344 | 44.85 | 8.67,8.4 | 45.55 | 44.51, 44.54 |
| 2FGL J1209.7+1807 | CRATES J1209+1810 | 12 09 51.7 | bzb | 0.845 | 44.12 | 8.94,8.515 | 44.83 | 44.46, 44.48 |
| 2FGL J1214.6+1309 | 4C+13.46 | 12 13 32.0 | bzb | 1.139 | 44.42 | 8.69 | 45.13 | 44.94 |
| 2FGL J1217.8+3006 | 1215+303 | 12 17 52.1 | tsbzb | 0.133 | 43.28 | 8.12 | 43.92 | |
| 2FGL J1219.7+0201 | PKS J1219+02 | 12 20 12.3 | bzb | 0.241 | 43.25 | 8.87 | 44.37 | 44.83 |
| 2FGL J1221.3+3010 | IES J1218+304 | 12 21 21.9 | tsbzb | 0.184 | 43.56 | 8.60 | 44.49 | |
| 2FGL J1221.4+2814 | 1219+285 | 12 21 31.7 | tsbzb | 0.102 | 43.28 | 7.48 | 42.14 | 42.25 |
| 2FGL J1222.4+0413 | 4C+04.42 | 12 22 22.5 | bzb | 0.965 | 44.70 | 8.24,8.37 | 45.42 | 44.86, 44.97 |
| 2FGL J1224.9+2122 | 4C+21.35 | 12 24 54.4 | tsbzb | 0.432 | 43.90 | 8.87,8.44,8.9 | 45.38 | 45.21, 45.16 |
| 2FGL J1228.6+4857 | CRATES J1228+4858 | 12 28 51.8 | bzb | 1.722 | 44.75 | 9.22,8.255 | 45.45 | 44.77, 44.68 |
| 2FGL J1229.1+0202 | 3C 273 | 12 29 06.7 | tsbzb | 0.158 | 43.76 | 8.9,7.22,8.9,9.2 | 45.50 | 45.44, 45.53 |
| 2FGL J1239.5+0443 | CRATES J1239+0443 | 12 39 00.0 | bzb | 1.761 | 45.20 | 8.67,8.57 | 45.90 | 44.96, 44.83 |
| 2FGL J1246.7−2546 | 1244−255 | 12 46 46.8 | bzb | 0.633 | 44.67 | 9.04 | 45.14 | |
| 2FGL J1256.1−0547 | 3C 279 | 12 56 11.1 | tsbzb | 0.536 | 44.70 | 8.9,8.43,8.4,8.28 | 45.73 | 44.61, 44.38 |
| 2FGL J1258.2+3231 | B2 1255+32 | 12 57 57.2 | bzb | 0.806 | 44.15 | 8.74,8.255 | 44.86 | 44.54, 44.29 |
| 2FGL J1303.5−4622 | PMN J1303−4621 | 13 03 40.2 | bzb | 1.664 | 44.61 | 7.95,8.21 | 45.32 | 44.21 |
| 2FGL J1310.6+3222 | B2 1308+32 | 13 10 28.6 | bzb | 0.996 | 44.58 | 8.8,9.24,7.3,8.57 | 45.37 | 45.09, 44.92, 44.92 |
| 2FGL J1317.9+3426 | B2 1315+34A | 13 17 36.5 | tsbzb | 1.056 | 44.16 | 9.29,9.14 | 45.55 | 45.07, 45.09 |
| 2FGL J1321.1+2215 | CGRaBS J1321+2216 | 13 21 11.2 | tsbzb | 0.943 | 44.43 | 8.42,8.315 | 45.13 | 44.43, 44.99 |
| 2FGL J1326.8+2210 | B2 1324+22 | 13 27 00.8 | bzb | 1.4 | 44.92 | 9.24,9.25 | 45.11 | 44.90, 44.96 |

Notes:

- RA: Right Ascension
- Dec: Declination
- SED type: Spectral Energy Distribution type
- Redshift: Redshift value
- log$L_{\text{jet}}$ Unc.: Logarithm of jet luminosity uncertainty
- logM$_{\text{BH}}$ ref: Logarithm of black hole mass reference
- log$P_{\text{jet}}$ ref: Logarithm of jet power reference
- log$L_{\text{BLR}}$ ref: Logarithm of BLR luminosity reference

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| Fermi name                  | Other name | RA       | Dec     | Opt. type | SED type | Redshift | log10Unc. | logMBH | logPjet | logEBLR |
|-----------------------------|------------|----------|---------|-----------|----------|----------|-----------|--------|---------|---------|
| 2FGL J1332.5−1255           | PMN J1332−1256 | 13 32 39.1 | 0.175   | bzq       |          | 1.492    | 45.05     | 8.96,8.61 | 45.75  | 45.26   |
| 2FGL J1332.7+4725           | B3 1330+476  | 13 32 45.2 | 0.668   | bzq       | LSP      | 1.362    | 44.71     | 7.95    | 45.42  | 44.37   |
| 2FGL J1333.5+5058           | CLASS J1333+5057 | 13 33 53.8 | 0.57    | bzq       | LSP      | 0.539    | 44.16     | 7.98    | 45.15  | 44.18   |
| 2FGL J1337.7−1257           | PKS 1335−127 | 13 37 39.8 | 0.57    | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1344.2−1723           | PMN J1344−1723 | 13 44 14.4 | 2.506   | bzq       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1345.4+4453           | B3 1343+451  | 13 45 33.1 | 2.534   | bzq       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1345.9+0706           | TXS 1343+073 | 13 45 49.3 | 1.093   | bzq       | LSP      | 1.3      | 44.56     | 7.95,8.62 | 45.27  | 44.67   |
| 2FGL J1347.7−3752           | PMN J1347−3750 | 13 47 40.3 | 0.57    | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1354.7−1047           | 1352−104     | 13 54 46.5 | 0.332   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1358.1+7644           | S5 1357+76   | 13 57 55.3 | 1.585   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1359.4+5541           | 87GB 135720.6+555936 | 13 59 05.8 | 2.354   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1408.8−0751           | 1406−076     | 14 08 56.5 | 1.494   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1419.4+3820           | B3 1417+385  | 14 19 46.5 | 1.831   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1428.0−4206           | PKS 1424−41  | 14 27 56.3 | 1.522   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1428.6+4240           | 1426+428     | 14 28 32.6 | 0.129139 | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1436.9+2319           | PKS 1434+235 | 14 36 41.0 | 1.548   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1442.7+1159           | 1440+122     | 14 42 48.3 | 0.163058 | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1444.1+2500           | PKS 1441+25  | 14 43 56.8 | 0.939   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1504.3+1029           | PKS 1502+106 | 15 04 25.0 | 1.839   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1510.9−0545           | 1508−055     | 15 10 53.6 | 1.185   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1512.2+0201           | PKS 1509+022 | 15 12 15.7 | 0.219   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1512.8−0906           | PKS 1510−08  | 15 12 50.5 | 0.361   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1514.6+4449           | BZQ J1514+4450 | 15 14 36.6 | 0.57    | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1517.7−2421           | 1514−241     | 15 17 41.8 | 0.049   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1522.0+4348           | B3 1520+437  | 15 21 49.3 | 2.171   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1522.7−2731           | PKS 1519−273 | 15 22 37.7 | 1.294   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1535.4+3720           | RGB J1534+372 | 15 35 47.2 | 0.142   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1539.5+2747           | MG2 J153938+2744 | 15 39 39.1 | 2.191   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| 2FGL J1549.5+0237           | PKS 1546+027 | 15 49 29.4 | 0.414   | LSP       |          | 0.57     | 1.06      | 45.77   | 45.22  | 45.18   |
| Fermi name | Other name | RA Dec | Opt. type SED type | Redshift | log $E_{\gamma}$ int ref | log $M_{BH}$ ref | log $P_{\gamma}$ ref | log $L_{BLR}$ ref |
|-----------|------------|--------|--------------------|----------|-------------------------|----------------|----------------|----------------|
| 2FGL J1550.7+0526 | 4C+05.64 | 15 50 35.3 | bzbq | 1.422 | 44.69 | 9.38,8.98 | 45.79 | 45.06,45.08 |
| 2FGL J1553.5+1255 | PKS 1551+130 | 15 53 32.7 | LSP | 0.57 | 12,12,12 | 0.57 | 12,12,12 | 45.79,45.06,45.08 |
| 2FGL J1608.5+1029 | 4C+10.45 | 16 08 46.2 | LSP | 1.226 | 44.70 | 8.64,9.8,7.7 | 45.20 | 45.07,45.08 |
| 2FGL J1613.4+3409 | B2 1611+34 | 16 13 41.0 | LSP | 0.26 | 12,12,12 | 0.26 | 12,12,12 | 45.20,45.07,45.08 |
| 2FGL J1625.7−2526 | PKS 1622−253 | 16 25 46.9 | LSP | 0.28 | 12,12,12 | 0.28 | 12,12,12 | 45.20,45.07,45.08 |
| 2FGL J1626.1−2948 | 1622−297 | 16 26 06.0 | LSP | 0.37 | 12,12,12 | 0.37 | 12,12,12 | 45.20,45.07,45.08 |
| 2FGL J1635.2+3810 | 4C+38.41 | 16 35 15.5 | LSP | 0.31 | 12,12,12 | 0.31 | 12,12,12 | 45.20,45.07,45.08 |
| 2FGL J1637.7+4714 | 4C+47.44 | 16 37 45.2 | LSP | 0.31 | 12,12,12 | 0.31 | 12,12,12 | 45.20,45.07,45.08 |
| 2FGL J1653.9+3945 | Mkn 501 | 16 53 52.2 | LSP | 0.31 | 12,12,12 | 0.31 | 12,12,12 | 45.20,45.07,45.08 |
| 2FGL J1703.2−6217 | CGRaBS J1703−6217 | 17 03 36.3 | bzbq | 1.147 | 45.17 | 8.0,8.5 | 45.4 | 45.08 |
| 2FGL J1709.7+4319 | B3 1708+433 | 17 09 41.0 | LSP | 0.57 | 12,12,12 | 0.57 | 12,12,12 | 45.4 | 45.08 |
| 2FGL J1727.1+4531 | 1726+455 | 17 27 27.6 | LSP | 0.31 | 12,12,12 | 0.31 | 12,12,12 | 45.4 | 45.08 |
| 2FGL J1728.2+0429 | PKS 1725+044 | 17 28 24.9 | LSP | 0.31 | 12,12,12 | 0.31 | 12,12,12 | 45.4 | 45.08 |
| 2FGL J1728.2+5015 | B2 1728+5015 | 17 28 18.6 | bzbq | 0.453 | 44.39 | 8.6 | 45.07 | 45.08 |
| 2FGL J1733.1−1307 | I Zw 187 | 17 33 02.7 | LSP | 0.57 | 12,12,12 | 0.57 | 12,12,12 | 45.07 | 45.08 |
| 2FGL J1734.3+3858 | B2 1734+3858 | 17 34 20.6 | bzbq | 0.57 | 12,12,12 | 0.57 | 12,12,12 | 45.07 | 45.08 |
| 2FGL J1740.2+5212 | B3 1740+5212 | 17 40 37.0 | LSP | 0.57 | 12,12,12 | 0.57 | 12,12,12 | 45.07 | 45.08 |
| 2FGL J1751.5+0938 | 4C+09.57 | 17 51 32.8 | bzbq | 0.321 | 44.16 | 8.7,8.2,8.3 | 44.86 | 45.08 |
| 2FGL J1800.5+7829 | S5 1803+78 | 18 00 45.7 | LSP | 0.26 | 12,12,12 | 0.26 | 12,12,12 | 45.08,45.08 |
| 2FGL J1806.7+6948 | 3C 371 | 18 06 50.7 | LSP | 0.26 | 12,12,12 | 0.26 | 12,12,12 | 45.08,45.08 |
| 2FGL J1818.6+0903 | MG1 J181841+0903 | 18 18 40.0 | LSP | 0.26 | 12,12,12 | 0.26 | 12,12,12 | 45.08,45.08 |
| 2FGL J1824.0+5650 | 4C+56.27 | 18 24 07.1 | bzbq | 0.57 | 12,12,12 | 0.57 | 12,12,12 | 45.08,45.08 |
| 2FGL J1830.1+0617 | TXS 1827+062 | 18 30 05.8 | LSP | 0.26 | 12,12,12 | 0.26 | 12,12,12 | 45.08,45.08 |
| 2FGL J1848.5+3216 | B2 1846+32 | 18 48 22.0 | LSP | 0.26 | 12,12,12 | 0.26 | 12,12,12 | 45.08,45.08 |
| 2FGL J1902.5−6746 | PKS 1902−6746 | 19 03 00.7 | LSP | 0.254 | 43.47 | 7.5 | 45.08,45.08 |
| 2FGL J1924.8−2912 | PKS B1921−293 | 19 24 51.0 | bzbq | 0.353 | 44.04 | 9.0,8.3 | 44.76 | 45.08,45.08 |
| 2FGL J1954.6−1122 | TXS 1951−115 | 19 54 41.0 | LSP | 0.57 | 12,12,12 | 0.57 | 12,12,12 | 45.08,45.08 |
| 2FGL J1958.2−3848 | PKS 1954−388 | 19 57 59.8 | LSP | 0.57 | 12,12,12 | 0.57 | 12,12,12 | 45.08,45.08 |
Table 1 – continued

| Fermi name | Other name | RA Dec | SED type | Unc. ref | log $L_{\text{int}}/\text{BH}$ | log $M_{\text{BH}}$ ref | log $P_{\text{jet}}/\text{BH}$ ref | log $M_{\text{BLR}}$ ref |
|------------|------------|--------|----------|----------|-----------------|---------------------|-------------------------|---------------------|
| 2FGL J2000.0+6509 IES 1959+650 | 19 59 59.8 | tbzb | 0.047 | 42.97 | 8.10 | 43.71 |
| 2FGL J2000.8−1751 PKS 1958−179 | 20 00 57.1 | bzq | 0.65 | 44.37 | 45.08 | 44.15 |
| 2FGL J2009.5−4850 PKS 2005−489 | 20 09 25.4 | LSP | 0.071 | 43.10 | 8.5,9,03,8.1 | 43.84 | 42.04 |
| 2FGL J2031.7+1223 PKS 2029+121 | 20 31 55.0 | bzq | 1.215 | 44.63 | 7.59 | 45.34 | 43.87,43.76 |
| 2FGL J2035.4+1058 PKS 2032+107 | 20 35 22.3 | bzq | 0.601 | 44.25 | 7.74,8,26 | 44.88† | 44.17 |
| 2FGL J2109.9+0807 PMN J2110+0810 | 21 10 09.6 | bzq | 1.58 | 44.71 | 8.82 | 45.42 | 45.09 |
| 2FGL J2115.3+2932 B2 2113+29 | 21 15 29.4 | LSP | 0.57 | 8.74 | 45.49 | 44.78 |
| 2FGL J2120.1+1901 OX 131 | 21 20 03.0 | LSP | 0.57 | 8.74 | 45.82 | 44.26 |
| 2FGL J2133.8−0154 2131−021 | 21 34 10.3 | bzq | 1.285 | 44.59 | 45.67 | 43.66 |
| 2FGL J2135.6−4959 PMN J2135−5006 | 21 35 20.0 | bzq | 2.181 | 45.07 | 8.31,8,4 | 45.77 | 45.26 |
| 2FGL J2143.5+1743 OX 169 | 21 43 35.5 | LSP | 0.211 | 43.82 | 8.6,8,7,4,8.1 | 44.38† | 44.26 |
| 2FGL J2144.8−3356 PMN J2145−3357 | 21 45 01.0 | LSP | 0.56 | 8.31 | 45.49 | 44.18 |
| 2FGL J2148.2+0659 4C+06.9 | 21 48 05.4 | LSP | 0.99 | 44.77 | 8.87 | 45.10† | 45.77 |
| 2FGL J2157.4+3129 B2 2155+31 | 21 57 28.8 | LSP | 0.28 | L06 | 42.10* | C99 |
| 2FGL J2157.9−1501 PKS 2155−152 | 21 58 06.3 | bzq | 0.672 | 44.11 | 7.9 | 45.34† | 43.68 |
| 2FGL J2158.8−3013 PKS 2155−304 | 21 58 52.0 | LSP | 0.57 | 8.70 | 43.90† | C99 |
| 2FGL J2201.9−8335 PKS 2155−83 | 22 02 19.7 | LSP | 1.865 | 45.09 | 9.0,2,9,16 | 45.79 | 45.19 |
| 2FGL J2204.6+4216 BL Lac | 22 04 17.6 | LSP | 0.027 | 41.91 | 8.10 | 43.38† | C99 |
| 2FGL J2211.9+2355 PKS 2209+236 | 22 12 05.9 | LSP | 1.125 | 44.39 | 8.46 | 45.10 | 44.79 |
| 2FGL J2219.1+1805 MG1 J221916+1806 | 22 19 13.9 | LSP | 1.071 | 44.19 | 7.65,7,66 | 45.72† | 45.62 |
| 2FGL J2225.6−0454 3C 446 | 22 25 47.2 | LSP | 1.404 | 45.11 | 8,8,1,5,4,7,9 | 46.29† | 45.60 |
| 2FGL J2229.7−0832 PKS 2227−08 | 22 29 40.1 | LSP | 1.56 | 45.96 | 8.9,5,8,6,2 | 45.17† | 45.66,45.45 |
| 2FGL J2232.4+1143 CTA 102 | 22 32 36.4 | LSP | 1.037 | 44.89 | 8.7,8,6,4,9 | 45.72† | 45.87,45.62 |
| 2FGL J2236.4+2828 B2 2234+28A | 22 36 22.5 | LSP | 0.795 | 44.57 | 8.35 | 45.28 | 45.40,45.37 |
| 2FGL J2237.2−3920 PKS 2234−396 | 22 37 08.2 | LSP | 0.297 | 43.36 | 7.77,7,9,5 | 44.09 | 43.87 |
| 2FGL J2243.2−2540 PKS 2240−260 | 22 43 26.4 | LSP | 0.774 | 44.35 | 8.60 | 45.33† | 43.5,43.46 |
| 2FGL J2244.1+4059 TXS 2241+406 | 22 44 12.7 | LSP | 1.171 | 44.76 | 8.28 | 45.46 | 44.32 |
| 2FGL J2253.9+1609 3C 454.3 | 22 53 57.7 | LSP | 0.859 | 45.91 | 8.7,9,17,8,6,8,3 | 45.86† | 45.65,45.52 |
| 2FGL J2258.0−2759 PKS 2255−282 | 22 58 06.0 | LSP | 0.926 | 44.70 | 8.9,2,9,16 | 45.35† | 45.84 |
other name; column (3) is right ascension (the first entry) and declination (the second entry); column (4), classification of source – the first entry: bzb = BL Lacs, bszq = FSRQs, tbzb = BL Lacs detected in the TeV or VHE regime and tbzq = FSRQs detected in the TeV or VHE regime; the second entry: classification of SED proposed by Abdou et al. (2010c) and Ackermann et al. (2011a); the synchrotron peak frequency $\nu_{\text{peak}} < 10^{14}$ Hz for low-synchrotron-peaked blazar LSP, $10^{14} \text{ Hz} < \nu_{\text{peak}} < 10^{15}$ Hz for intermediate-synchrotron-peaked blazar ISP, $10^{15} \text{ Hz} < \nu_{\text{peak}}$ for high-synchrotron-peaked blazar HSP; column (5), redshift; column (6), logarithm of intrinsic $\gamma$-ray luminosity excluding beaming effect in units of erg s$^{-1}$ and uncertainty; column (7), logarithm of BH mass in units of $M_\odot$ and references; column (8), logarithm of jet kinetic power with 0.7 dex uncertainty in units of erg s$^{-1}$ and logarithm of beaming factor; column (9), logarithm of broad-line luminosity in units of erg s$^{-1}$ and references.

3 THE RESULTS

3.1 The distributions

The redshift distributions of the various classes are shown in Fig. 1. They are very similar with complete 2LAC sample. The redshift distributions for all blazars are $0 < z < 3.1$ and mean value is 1.006 $\pm$ 0.04. Mean values for FSRQs and BL Lacs are 1.17 $\pm$ 0.05 and 0.45 $\pm$ 0.05, respectively. Compared with normal GeV BL Lacs (NBL Lacs, $z = 0.62 \pm 0.07$), blazars detected in the TeV or VHE regime (TBL Lacs) have much smaller mean redshift (0.13 $\pm$ 0.02). The mean redshift of TeV FSRQs (TFSRQs) is 0.44 $\pm$ 0.09. Through non-parametric Kolmogorov–Smirnov (KS) test, we find that the redshift distributions between TBL Lacs and NBL Lacs are significant difference (chance probability $P < 0.0001$, significant difference with $P < 0.05$ confidence level); the redshift distributions among HBLs (HSP BL Lacs), IBLs (ISP BL Lacs) and LBLs (LSP BL Lacs) are significant difference ($P = 0.003$, $P < 0.0001$, $P = 0.006$).

The BH mass distributions of the various classes are shown in Fig. 2. The BH mass distributions for all blazars mainly are $10^{7.5} - 10^{10}$ $M_\odot$ and mean value is $10^{8.54 \pm 0.03}$ $M_\odot$. Mean values for FSRQs and BL Lacs are $10^{8.55 \pm 0.04}$ $M_\odot$ and $10^{8.34 \pm 0.06}$ $M_\odot$, respectively. There are similar mean BH masses for NBL Lacs and TBL Lacs ($10^{8.36 \pm 0.08}$ $M_\odot$, $10^{8.31 \pm 0.09}$ $M_\odot$). The mean BH mass of TFSRQs is $10^{8.53 \pm 0.11}$ $M_\odot$. The BH mass distributions between TBL Lacs and NBL Lacs are not significant difference ($P = 0.345$). The BH mass distributions among HBLs, IBLs and LBLs are not significant difference ($P = 0.4$, 0.77, 0.1). We note three blazars with a very low mass of the central BH ($J0217.5-0813: 10^{6.53 \pm 0.01}$ $M_\odot$;
BH mass, jet and accretion in Fermi blazars

Figure 2. BH mass distributions for NBL Lacs, TBL Lacs, NFSRQs and TFSRQs. The meanings of different lines are as same as Fig. 1.

Figure 3. Jet kinetic power distributions for NBL Lacs, TBL Lacs, NFSRQs and TFSRQs. The meanings of different lines are as same as Fig. 1.

J0430.4−2507: $10^{6.51±0.77} M_\odot$; J1954.6−1122: $10^{6.73±0.39} M_\odot$. The BH mass of the three blazars are directly from Shaw et al. (2012) in which the BH masses were estimated by traditional virial method. Shaw et al. (2012) have urged caution in BH mass of their blazars sample because of non-thermal dominance. We also note that the FWHM of Mg II for the three blazars are small (1200 ± 400, 1200 ± 200, 1500 ± 600 km s$^{-1}$). So the BH masses of the three blazars require further study. If the BH masses of the three blazars are indeed small, then it is very important for studying jet of AGN, since the only known jetted AGN with low masses are narrow-line Seyfert 1 galaxies.

The jet kinetic power distributions of the various classes are shown in Fig. 3. The jet kinetic power distributions for all blazars are $10^{42} - 10^{47}$ erg s$^{-1}$ and mean value is $10^{45.08±0.04}$ erg s$^{-1}$. Mean values for FSRQs and BL Lacs are $10^{45.28±0.04}$ and $10^{44.4±0.11}$ erg s$^{-1}$, respectively. Compared with NBL Lacs ($10^{44.72±0.11}$ erg s$^{-1}$), TBL Lacs have much smaller mean jet kinetic power ($10^{43.80±0.15}$ erg s$^{-1}$). The jet kinetic power distributions between TBL Lacs and NBL Lacs are significant difference ($P < 0.0001$). The mean jet kinetic power of TFSRQs is $10^{45.35±0.23}$ erg s$^{-1}$. The jet kinetic powers among HBLs, IBLs and LBLs are significant difference ($P = 0.026$, $P < 0.0001$, $P = 0.023$).

Figure 4. Intrinsic $\gamma$-ray luminosity distributions for NBL Lacs, TBL Lacs, NFSRQs and TFSRQs. The meanings of different lines are as same as Fig. 1.

The intrinsic $\gamma$-ray luminosity distributions of the various classes are shown in Fig. 4. The intrinsic $\gamma$-ray luminosity distributions for all blazars are $10^{42} - 10^{47}$ erg s$^{-1}$ and the mean value is $10^{44.37±0.05}$ erg s$^{-1}$ (as a comparison, the observational $\gamma$-ray luminosity distributions for all blazars is $10^{43.11} - 10^{49.12}$ erg s$^{-1}$ and the mean value are $10^{46.85±0.07}$ erg s$^{-1}$). Mean values for FSRQs and BL Lacs are $10^{43.54±0.04}$ and $10^{43.78±0.11}$ erg s$^{-1}$, respectively. Compared with NBL Lacs ($10^{44.05±0.13}$ erg s$^{-1}$), TBL Lacs have smaller mean intrinsic $\gamma$-ray luminosity ($10^{44.28±0.13}$ erg s$^{-1}$). The mean intrinsic $\gamma$-ray luminosity of TFSRQs is $10^{44.37±0.24}$ erg s$^{-1}$. The intrinsic $\gamma$-ray luminosity distributions between TBL Lacs and NBL Lacs are significant difference ($P = 0.001$). The intrinsic $\gamma$-ray luminosity distributions among HBLs, IBLs and LBLs are significant difference ($P = 0.033$, $P < 0.0001$, $P = 0.007$).

The $\gamma$-ray photon index distributions of the various classes are shown in Fig. 5. The $\gamma$-ray photon index distributions for all blazars are 1.3–3 and mean value is 2.29 ± 0.02 (for FSRQs the $\gamma$-ray photon index distribution is 1.9–3 and 1.3–2.5 for BL Lacs). Mean values for FSRQs and BL Lacs are 2.37 ± 0.02 and 2.02 ± 0.03, respectively. From complete 2LAC clean sample with $F[\varepsilon > 100\,\text{MeV}] > 1.5 \times 10^5\,\text{Ph cm}^{-2}\,\text{s}^{-1}$ (see their fig. 18), the $\gamma$-ray photon index distributions for FSRQs and BL Lacs are
1.9–3 and 1.6–2.5, respectively. The average photon spectral indexes for FSRQs and BL Lacs are 2.42 and 2.06, respectively. In our sample, there are four BL Lacs in the 1.3–1.6 interval because the four BL Lacs have $F(E > 100\, \text{MeV}) < 1.5 \times 10^{-7}\, \text{ph}\, \text{cm}^{-2}\, \text{s}^{-1}$. To sum up, the $\gamma$-ray photon index distributions of our sample are very similar to complete 2LAC sample. Compared with NBL Lacs (2.15 ± 0.03), TBL Lacs have much smaller mean $\gamma$-ray photon index (1.79 ± 0.05). The mean $\gamma$-ray photon index of TFSRQs is 2.21 ± 0.05. The $\gamma$-ray photon index distributions between TBL Lacs and NBL Lacs are significant difference ($P < 0.0001$). The $\gamma$-ray photon index distributions between HBLs and IBLs, between HBLs and IBLs are significant difference (both $P < 0.0001$) but not significant difference between IBLs and LBLs ($P = 0.64$).

The bulk Lorentz factor $\Gamma$ distributions of the various classes are shown in Fig. 6 (for the blazars without direct estimates of $\Gamma$, we estimate bulk Lorentz factor by the relation $f_0 = 1 - \cos \theta$). The bulk Lorentz factor distributions for almost all blazars are 0–30 and mean value is 13.76 ± 0.44. Mean values for FSRQs and BL Lacs are 15.18 ± 0.5 and 9.03 ± 0.65, respectively. Compared with NBL Lacs (10.52 ± 0.86), TBL Lacs have smaller mean bulk Lorentz factor (6.27 ± 0.58). The mean bulk Lorentz factor of TFSRQs is 28.87 ± 8.13 (their bulk Lorentz factors are directly from the radio measurements). The bulk Lorentz factor distributions between TBL Lacs and NBL Lacs are significant difference ($P = 0.001$). The bulk Lorentz factor distributions between HBLs and IBLs, between HBLs and IBLs are significant difference ($P = 0.004, P < 0.0001$) but not significant difference between IBLs and LBLs ($P = 0.18$). We also compare our bulk Lorentz factor from the radio measurements ($\Gamma_R$) with bulk Lorentz factor calculated by modelling the SED from Ghisellini et al. (2010) ($\Gamma_G$). Apart from our sample, we also include 10 blazars from Nemmen et al. (2012) because they are included in both Ghisellini et al. (2010) and Nemmen et al. (2012; J0120.4–2700, J0449.4–4350, J1719.3+1744, J0205.3–1657, J0217.9+0143, J0221.0+3555, J1332.0–0508, J2056.2–4715, J2147.3+0930, J2203.4+1726). But the blazars are not included in our sample because their BH mass and BLR data cannot be obtained. The result is shown in Fig. 7. From Fig. 7, we can see that for all HBLs, $\Gamma_R < \Gamma_G$; for most of IBLs and LBLs, $\Gamma_R < \Gamma_G$; for most of NFSRQs and TFSRQs, $\Gamma_R > \Gamma_G$. At the end of this section, we cross-check the sample of blazars in Meyer et al. (2011) and Nemmen et al. (2012) with that of Ghisellini et al. (2010), and compare the kinetic jet power as measured with the two methods. The result is shown in Fig. 8. From Fig. 8, we can see that on average, the jet power from Ghisellini et al. (2010) is slightly larger than the ‘cavity’ power from Meyer et al. (2011) and Nemmen et al. (2012). The difference can be due to the strong difference of time-scales.

### 3.2 Intrinsic $\gamma$-ray luminosity versus BH mass

Fig. 9 shows BH mass as a function of intrinsic $\gamma$-ray luminosity. Different symbols correspond to blazars belonging to different classes. Pearson analysis is applied to analyse the correlations between BH mass and intrinsic $\gamma$-ray luminosity for all blazars (Padovani 1992; Machalski & Jamrozy 2006; Ackermann et al. 2011a). The result shows that the correlation between BH mass and intrinsic $\gamma$-ray luminosity is significant (number of points $N = 239$, significance level $P < 0.0001$, coefficient of correlation $r = 0.369$, significant correlation $P < 0.05$ confidence level). Because there are
correlations between BH mass and redshift, and between intrinsic γ-ray luminosity and redshift, Pearson partial correlation analysis excluding the dependence on the redshift is applied to analyse the correlations between BH mass and γ-ray luminosity. The result shows that the correlation between BH mass and intrinsic γ-ray luminosity is significant at 0.05 level when excluding redshift effect ($N = 239$, $P = 0.035$, $r = 0.136$, significant correlation $P < 0.05$ confidence level). In Fig. 9, we note that there are some objects out of main zone, which have BH mass above $10^{8.5} \text{M}_\odot$ and below $10^7 \text{M}_\odot$. After excluding these objects, we find a much better significance between BH mass and intrinsic γ-ray luminosity ($P = 0.017$).

### 3.3 Intrinsic γ-ray luminosity versus broad-line luminosity and the Eddington ratio

Fig. 10 shows broad-line luminosity as a function of intrinsic γ-ray luminosity. Because there is also correlation between broad-line luminosity and redshift, Pearson partial correlation analysis is applied to analyse the correlation. The result of Pearson partial analysis shows that when excluding the dependence on the redshift, there is still significant correlation between broad-line luminosity and intrinsic γ-ray luminosity ($N = 217$, $P < 0.0001$, $r = 0.321$).

Fig. 11 represents the Eddington ratio as a function of γ-ray luminosity ($L_{\text{bol}}/L_{\text{Edd}} = 1.3 \times 10^{28} (\text{M}_\odot/\text{G}_\odot) \text{erg s}^{-1}$, $L_{\text{bol}} \approx 10 L_{\text{BLR}}$ from Netzer 1990). The result of Pearson partial analysis also shows that after excluding the dependence on the redshift, there is still significant correlation between the Eddington ratio and γ-ray luminosity ($N = 208$, $P = 0.001$, $r = 0.23$).

### 3.4 Jet power versus broad-line luminosity and disc luminosity

Fig. 12 shows broad-line luminosity as a function of jet power (bottom panel) and disc luminosity as a function of jet power (top panel, $L_d \approx 10 L_{\text{BLR}}$). Linear regression is applied to the relevant data to analyse the correlation between broad-line luminosity and jet power. The results show a strong correlation between broad-line luminosity and jet power ($r = 0.7 \pm 0.6$, $P < 0.0001$, $N = 226$). We also obtain $\log L_{\text{BLR}} \sim (0.98 \pm 0.07) \log P_{\text{jet}}$. The result of Pearson partial analysis shows that there is still significant correlation between broad-line luminosity and jet power ($N = 217$, $P < 0.0001$, $r = 0.483$). From the top panel of Fig. 12, we find that the distribution of data points is close to $L_d = P_{\text{jet}}$. For almost all BL Lacs, the jet power is larger than the disc luminosity while the jet power is much smaller than the disc luminosity for most of FSRQs.

We use multiple linear regression analysis to obtain the relationship between the jet power and both the Eddington luminosity and the BLR luminosity with 99 per cent confidence level and $r = 0.71$ (Fig. 13):

$$\log P_{\text{jet}} = 0.52(\pm 0.04) \log L_{\text{BLR}} - 0.02(\pm 0.06) \log L_{\text{Edd}} + 23.09(\pm 2.4).$$

(2)

After excluding these objects with BH mass above $10^{8.5} \text{M}_\odot$ and below $10^7 \text{M}_\odot$, we obtain

$$\log P_{\text{jet}} = 0.51(\pm 0.04) \log L_{\text{BLR}} + 0.02(\pm 0.07) \log L_{\text{Edd}} + 21.5(\pm 2.8).$$

(3)

Following Wang et al. (2004), we define the ‘jet-dominance’ factor (the relative importance of the jet power compared to the disc luminosity) as $F_j = P_{\text{jet}}/L_{\text{bol}}$, Eddington ratio $L_{\text{bol}}/L_{\text{Edd}}$, and
This implies that ‘jet-dominance’ is mainly controlled by, and is inversely dependent on, the bolometric luminosity.

In addition, equations (2) and (3) can be also expressed in a different form as

$$\log P_{\text{jet}} = 0.52\log L_{\text{bol}}/L_{\text{Edd}} + 0.5\log \left( \frac{M}{M_\odot} \right) + 41.62, \quad (6)$$

$$\log P_{\text{jet}} = 0.52\log L_{\text{bol}}/L_{\text{Edd}} + 0.54\log \left( \frac{M}{M_\odot} \right) + 43.15. \quad (7)$$

Theoretically, Heinz & Sunyaev (2003) have presented the dependence of jet power on BH mass and accretion rate in core-dominated jets: for standard accretion, $F_j \sim M^{17/12}$; for radiatively inefficient accretion modes, $F_j \sim (mM)^{17/12}$. The observational evidence has been provided by many authors. There was the BH fundamental plane given by Merloni et al. (2003) and Falcke et al. (2004): $\log L_R = (0.6^{+0.11}_{-0.11})\log L_X + (0.78^{+0.11}_{-0.09})\log M + 7.33^{+0.05}_{-0.07}$. Foschini (2014) reported about the unification of relativistic jets from compact objects. An important result from Foschini (2014) was the discovery of powerful relativistic jets from radio-loud NLS1s, which made it evident that the existence of a secondary branch in AGN is similar to what was already known in Galactic binaries. From Foschini (2014), in radiation-pressure-dominated accretion disc, the jet power can be scaled as $\log P_{\text{jet}} \propto \frac{L}{L_{\text{bol}}}$ in gas-pressure-dominated accretion disc, $\log P_{\text{jet}} \propto \frac{L_{\text{bol}}}{L}$ + $0.5\log M + 0.65(\pm 0.25)\log L_{\text{bol}} + 5.07(\pm 10.05)$. We compare our results with these results from other authors, and find that our results are similar to results from other authors, i.e. the dependence of jet power on both the Eddington ratio and BH mass. From equations (6) and (7), we can see that there are very close coefficients between BH mass and Eddington ratio. But from other results, the coefficient from BH mass is larger than that from Eddington ratio/X-ray luminosity. This difference can be due to jet power calculated by different methods and different sample.

### 3.5 Jet power versus BH mass and the Eddington ratio

We further analyse the correlations between jet power and BH mass, between jet power and Eddington ratio for all blazars (Figs 14 and 15). Similarly, excluding the redshift effect and using Pearson partial analysis, we find that there are significant correlations between jet power and BH mass ($r = 0.163$, $P = 0.012$, $N = 239$), between jet power and Eddington ratio ($r = 0.378$, $P < 0.0001$, $N = 208$).

### 3.6 Divide between BL Lacs and FSRQs

Ghisellini et al. (2011) and Sbarrato et al. (2012) have studied the relation between $L_{\gamma}/L_{\text{Edd}}$ and $L_{\text{BLR}}/L_{\text{Edd}}$, and proposed a physical distinction between the two classes of blazars that division of blazars into BL Lacs and FSRQs is controlled by the line luminosity in Eddington units. The dividing line is of the order of $L_{\text{BLR}}/L_{\text{Edd}} \sim 5 \times 10^{-4}$, in good agreement with the idea that the presence of strong emitting lines is related to a transition in the accretion regime, becoming radiatively inefficient below a disc luminosity of the order of 1 per cent of the Eddington one. With enlarged sample and $\gamma$-ray excluding beaming effect, we revisit the divide between BL Lacs and FSRQs proposed by Ghisellini et al.
BH mass, jet and accretion in Fermi blazars

Figure 14. The BH mass as a function of jet power. The uncertainty of jet kinetic power is 0.7 dex. The meanings of different symbols are as same as Fig. 7.

Figure 15. The Eddington ratio as a function of jet power. The uncertainty of jet kinetic power is 0.7 dex. The meanings of different symbols are as same as Fig. 7.

Figure 16. Broad-line luminosity as a function of γ-ray luminosity both in Eddington units. The meanings of different symbols are as same as Fig. 7. The horizontal solid line indicates the luminosity divide between FSRQs and BL Lacs at $L_{BLR}/L_{Edd} \sim 10^{-3}$ and dashed line is $L_{BLR}/L_{Edd} \sim 5 \times 10^{-4}$ from Ghisellini et al. (2011) and Sbarrato et al. (2012).

Figure 17. Distributions of the accretion rates in Eddington units $\dot{M}/\dot{M}_{Edd}$. For FSRQs, $\dot{M}$ is given by $\dot{M} = L_d/(\eta c^2)$, with $\eta = 0.1$ (black continuous line) and for BL Lacs, $\dot{M} = P_{jet}/c^2$ (green dashed line) and $\dot{M} = L_d/(\eta c^2)$ (red dotted line).

(2011) and Sbarrato et al. (2012). Fig. 16 represents broad-line luminosity as a function of γ-ray luminosity both in Eddington units. Fig. 16 shows that the divide between BL Lacs and FSRQs is of the order of $L_{BLR}/L_{Edd} \sim 10^{-3}$ corresponding to $\dot{M}/\dot{M}_{Edd} = 0.1$ ($L_d \approx 10 L_{BLR}$, $\dot{M}_{Edd} = L_{Edd}/c^2$, $L_d = \eta M/c^2$, $\eta = 0.1$). In Fig. 16, we can see some transition sources with $L_{BLR}/L_{Edd} > 10^{-3}$ (transition sources are classified as BL Lacs with an SED appearing as intermediate between BL Lacs and FSRQs, and also have relatively weak broad emission lines and small EW). In addition, Ghisellini et al. (2010) studied general physical properties of bright Fermi blazars and found that there is a divide between BL Lacs and FSRQs occurring at $\dot{M}/\dot{M}_{Edd} = 0.1$. Following Ghisellini et al. (2010), we give the ratio $\dot{M}/\dot{M}_{Edd} \approx \frac{L_d^2}{1.3 \times 10^{14} M(M/M_\odot)}$. For FSRQs, $\dot{M}$ is given by $\dot{M} = L_d/(\eta c^2)$, with $\eta = 0.1$ and for BL Lacs, $\dot{M} = P_{jet}/c^2$. Our result is given in Fig. 17 (black and green dashed lines). Meanwhile, we consider $\dot{M} = L_d/(\eta c^2)$ for BL Lacs. The result also is given in Fig. 17 (black and red dotted lines). From Fig. 17, we can see that the results are very similar to Fig. 16 that the divide between BL Lacs and FSRQs occurs at $\dot{M}/\dot{M}_{Edd} = 0.1$ and some BL Lacs with $\dot{M}/\dot{M}_{Edd} > 0.1$ can be transition sources. Therefore, the results from our sample (not related to a particular model) confirm the idea proposed by Ghisellini et al. (2010, 2011) and Sbarrato et al. (2012), and that the divide between BL Lacs and FSRQs is of the order of $L_{BLR}/L_{Edd} \sim 10^{-3}$ corresponding to $\dot{M}/\dot{M}_{Edd} = 0.1$.

3.7 Radiative efficiency of γ-ray versus redshift, BH mass and the Eddington ratio

The radiative efficiency of γ-ray is estimated as $\varepsilon = L_\gamma/(L_\gamma + P_{jet})$ (Nemmen et al. 2012). When calculating radiative efficiency of γ-ray, we only use jet power directly from Nemmen et al. (2012). Radiative efficiency of γ-ray $\varepsilon = L_\gamma/(L_\gamma + P_{jet})$ as a function of redshift (middle panel), BH mass (top panel) and Eddington ratio...
4 DISCUSSIONS

4.1 The \(\gamma\)-ray luminosity

The relation between \(\gamma\)-ray and broad-line luminosity is important for the origin of \(\gamma\)-ray. Sbarrato et al. (2012) studied a Fermi sample and found a good correlation between the luminosity of the broad lines and the \(\gamma\)-ray luminosity. But they cannot consider beaming effect for \(\gamma\)-ray luminosity and the number of sample is still limited. Therefore, through constructing a large sample of Fermi blazars and removing beaming effect, we re-visit the correlation and our results show that there is significant correlation between intrinsic \(\gamma\)-ray and broad-line luminosity. Ghisellini & Madau (1996) assessed non-thermal Comptonization models for the high-energy emission of the EGRET blazar sources, and found that the radiation produced by BLR clouds illuminated by the relativistically moving plasma ‘blob’ provides the bulk of the seed photons to be Comptonization to \(\gamma\)-ray energies. Through studying the connection between \(\gamma\)-ray emission and millimetre flares, Leon-Tavares et al. (2011b) found that the mean observed delay from the beginning of a mm flare to the peak of the \(\gamma\)-ray emission is about 70 d, corresponding to an average distance of 7 pc along the jet. At these distances, well beyond the canonical BLR, the seed photons could originate either from the jet itself, from a dusty torus, or from an outflowing BLR. Arshakian et al. (2010) suggested that the continuum emission from the jet and counterjet ionizes material in a sub-relativistic outflow surrounding the jet, which results in a formation of two conical regions with broad emission lines (in addition to the conventional BLR around the central nucleus) at a distance \(\geq 0.4\) pc from the central engine. The existence of a non-virial, outflowing BLR can make EC models possible even at distances of parsecs down the jet, which was first proposed by Leon-Tavares et al. (2011b). Thus, the significant correlation between intrinsic \(\gamma\)-ray and broad-line luminosity suggests that the radiation mechanism of the \(\gamma\)-ray in Fermi blazars of existing BLR is likely to be IC scattering of ambient photons from BLR or outflowing BLR. However, this result cannot totally exclude that the seed photons originate from other sites. In addition, we also find significant correlations between intrinsic \(\gamma\)-ray luminosity and BH mass, between intrinsic \(\gamma\)-ray luminosity and Eddington ratio, which are consistent with the results of jet power. According to relativistic jet theory, the radiative jet power can be calculated by dividing the observed \(\gamma\)-ray luminosity by the square of the bulk Lorentz factor. Therefore, it is known that \(\gamma\)-ray luminosity can be used as a proxy for the jet power.

4.2 Jet power

From our results, we can see that the correlation between broad-line luminosity and jet power is significant which supports that jet power has a close link with accretion. According to Ghisellini (2006), if relativistic jets are powered by a Poynting flux, under some reasonable assumption, the Blandford-Znajek (BZ) jet power can be written

\[
L_{\text{BZ, jet}} \sim \left( \frac{a}{m} \right)^2 \frac{R_0^3}{H^2} \frac{\varepsilon_B}{\eta} \frac{L_{\text{disc}}}{\beta_i},
\]

where \(a/m\) is the specific BH angular momentum; \(R_0 = \frac{2GM_{\text{BH}}}{c^2}\) is the Schwarzschild radius; \(H\) is the disc thickness; \(R\) is the radius; \(\varepsilon_B\) is the fraction of the available gravitational energy; \(\eta\) is the accretion efficiency; \(L_{\text{disc}}\) is the observed luminosity of accretion disc; \(\beta_i\) is...
the radial infalling velocity. The maximum BZ jet power can then be written as (Ghisellini 2006)

\[ L_{\text{jet}} \sim \frac{L_{\text{disc}}}{\eta}. \quad (9) \]

In addition, in view of current theories of accretion discs, the BLR is ionized by the radiation of the accretion disc. We have

\[ L_{\text{disc}} \approx 10 L_{\text{BLR}}. \quad (10) \]

From equations (9) and (10), we have

\[ L_{\text{BLR}} \sim 0.1 \eta L_{\text{jet}}. \quad (11) \]

From equation (11), we can write

\[ \log L_{\text{BLR}} = \log L_{\text{jet}} + \log \eta + \text{const.} \quad (12) \]

From equation (12), we can find that the theoretical predicted coefficient of \( \log L_{\text{BLR}} - \log L_{\text{jet}} \) relation is 1. Using linear regression analysis, we obtain \( \log L_{\text{BLR}} \sim (0.98 \pm 0.07) \log L_{\text{jet}} \) for all blazars, which is consistent with the theoretical predicted coefficient of \( \log L_{\text{BLR}} - \log L_{\text{jet}} \) relation. Our results suggest that Fermi blazar jets are also powered by energy extraction from a rapidly spinning BH through the magnetic field provided by the accretion disc, which supports the hypothesis provided by Xie et al. (2006, 2007). The extraction of energy from BH rotation was well established by Blandford & Znajek (1977). In addition, we find that the jet power depends on both the Eddington ratio and BH mass. Heinz & Sunyaev (2003) have presented the theoretical dependence of jet power on Eddington ratio and BH mass. The observational evidence has been provided by many authors (see Section 3.4). The massive BHs will be spun up through accretion, as the BHs acquire mass and angular momentum simultaneously through accretion (Chai et al. 2012). Volonteri, Sikora & Lasota (2007) investigated how the accretion from a warped disc influences the evolution of BH spins with the effects of accretion and merger being properly considered and concluded that within the cosmological framework, most supermassive BHs in elliptical galaxies have on average higher spins than BHs in spiral galaxies, where random, small accretion episodes (e.g. tidally disrupted stars, accretion of molecular clouds) might have played a more important role. If this is true, the correlation between BH mass and jet power implies that jet power is probably governed by the BH spin. So from above discussion, we can conclude that for Fermi blazars, jets are powered by energy extraction from both accretion and BH spin (i.e. not by accretion only).

From top panel of Fig. 12, we find that for almost all BL Lacs, the jet power is larger than the disc luminosity while the jet power is much smaller than the disc luminosity for most of FSRQs. For BL Lacs, our result is consistent with result of Ghisellini et al. (2010), whereas for FSRQs, our result is different from result of Ghisellini et al. (2010) in which jet power is still larger than the disc luminosity. In their work, the jet power and disc luminosity are related with the model described in detail in Ghisellini & Tavecchio (2009). However, our results are model independent and much larger sample. A reasonable explanation about our results is as follows. FSRQs occur in the earlier phase. They have powerful disc and jet, high accretion and \( L_{\text{d}} > P_{\text{jet}} \). With time, the FSRQs will have lower accretion rate, a less efficient disc, shrinking BLR. It is possible that some transitions between FSRQs and BL Lacs appear with moderate BLR luminosity. When the accretion rate decreases below the critical value (i.e. \( m_\text{c} = M_{\text{ej}}/M_{\text{bd}} \approx 10^{-1} \)), the accretion changes mode, becoming radiatively inefficient and thus FSRQs become BL Lacs. BL Lacs have weak disc and weaker lines emitted closer to the BH. Dissipation in the jet occurs outside the BLR (if it exists at all). So it is possible that BL Lacs have \( L_{\text{d}} \approx P_{\text{jet}} \) and the explanation is in line with BL Lacs, TBL Lacs have much smaller redshift, jet kinetic power, intrinsic \( \gamma \)-ray luminosity, \( \gamma \)-ray photon index and bulk Lorentz factor. We find that compared with NBL Lacs, TBL Lacs have very small redshift, jet kinetic power, intrinsic \( \gamma \)-ray luminosity, \( \gamma \)-ray photon index and bulk Lorentz factor. And the distributions of these parameters between TBL Lacs and NBL Lacs suggest that BH mass is not the main factor for difference between them. Due to most of TBL Lacs classified into HBLs, we also compare the distributions of these parameters among HBLs, IBLs and LBLs. The results show that except BH mass distributions, there are significant differences for these parameters distributions between HBLs and IBLs, and between HBLs and LBLs. The TBL Lacs are relatively nearby blazars (\( z < 0.5 \), \( z \approx 0.1 \) for most of them) because of TeV \( \gamma \)-ray absorbed by EBL. No significant differences of BH masses between TBL Lacs and NBL Lacs suggest that BH mass is not the main factor for difference between them. For TBL Lacs, \( \gamma \)-ray photon index \( \Gamma_{\text{GRV}} < 2.2 \), which is consistent with the results of Senturk et al. (2013). Compared with NBL Lacs, TBL Lacs have much smaller jet kinetic power and intrinsic \( \gamma \)-ray luminosity which suggests that TBL Lacs contain a low power sources and there are different jet structures between TBL Lacs and NBL Lacs. In our sample, the mean radio bulk Lorentz factor of TBL Lacs is \( 6.27 \pm 0.58 \). Compared with NBL Lacs, TBL Lacs have much smaller bulk Lorentz factor. Many authors have studied the parsec-scale jets of the TBL Lacs and found a lower Doppler factor, bulk Lorentz factor and slower apparent jet pattern speeds (e.g. Chiaberge et al. 2000; Giroletti et al. 2004b; Kovalev et al. 2005; Piner, Pant & Edwards 2008, 2010; Piner & Edwards 2013). For TBL Lacs, there is 'bulk Lorentz factor crisis'. Doppler factors from SSC models are in strong disagreement with those deduced from the unification models between blazars and radio galaxies. When corrected from extragalactic absorption by the diffuse infrared background, the SSC one-zone models require very high Lorentz factor (around 50) to avoid strong \( \gamma \)–\( \gamma \) absorption. However, the statistics on beamed versus unbeamed objects, as well as the luminosity contrast, favour much lower Lorentz factor of the order of 3 (Henri & Sauge 2006). An obvious explanation for the 'bulk Lorentz factor crisis' is that the radio and \( \gamma \)-ray emissions are produced in different parts of the jet with different bulk Lorentz factors and several models have been invoked, including decelerated jets, spine-sheath structures, faster moving leading edges of blobs and 'minijets' within the main jet (Piner et al. 2013). All models suggest that jets of TBL Lacs have significant velocity structures. The velocity structures may show an observational signature in the VLBI image of jet, such as limb brightening or limb darkening. Limb brightening has been observed in VLBI images of Mrn 501 and Mrn 421 (e.g. Giroletti et al. 2004a; Piner, Pant & Edwards

4.3 TeV blazars

In this subsection, we discuss the properties of TeV blazars detected by Fermi LAT. Figs 1–6 are distributions of redshift, BH mass, jet kinetic power, intrinsic \( \gamma \)-ray luminosity, \( \gamma \)-ray photon index and bulk Lorentz factor. We find that compared with NBL Lacs, TBL Lacs have very small redshift, jet kinetic power, intrinsic \( \gamma \)-ray luminosity, \( \gamma \)-ray photon index and bulk Lorentz factor. And the distributions of these parameters between TBL Lacs and NBL Lacs suggest that BH mass is not the main factor for difference between them. For TBL Lacs, \( \gamma \)-ray photon index \( \Gamma_{\text{GRV}} < 2.2 \), which is consistent with the results of Senturk et al. (2013). Compared with NBL Lacs, TBL Lacs have much smaller jet kinetic power and intrinsic \( \gamma \)-ray luminosity which suggests that TBL Lacs contain a low power sources and there are different jet structures between TBL Lacs and NBL Lacs. In our sample, the mean radio bulk Lorentz factor of TBL Lacs is \( 6.27 \pm 0.58 \). Compared with NBL Lacs, TBL Lacs have much smaller bulk Lorentz factor. Many authors have studied the parsec-scale jets of the TBL Lacs and found a lower Doppler factor, bulk Lorentz factor and slower apparent jet pattern speeds (e.g. Chiaberge et al. 2000; Giroletti et al. 2004b; Kovalev et al. 2005; Piner, Pant & Edwards 2008, 2010; Piner & Edwards 2013). For TBL Lacs, there is 'bulk Lorentz factor crisis'. Doppler factors from SSC models are in strong disagreement with those deduced from the unification models between blazars and radio galaxies. When corrected from extragalactic absorption by the diffuse infrared background, the SSC one-zone models require very high Lorentz factor (around 50) to avoid strong \( \gamma \)–\( \gamma \) absorption. However, the statistics on beamed versus unbeamed objects, as well as the luminosity contrast, favour much lower Lorentz factor of the order of 3 (Henri & Sauge 2006). An obvious explanation for the 'bulk Lorentz factor crisis' is that the radio and \( \gamma \)-ray emissions are produced in different parts of the jet with different bulk Lorentz factors and several models have been invoked, including decelerated jets, spine-sheath structures, faster moving leading edges of blobs and 'minijets' within the main jet (Piner et al. 2013). All models suggest that jets of TBL Lacs have significant velocity structures. The velocity structures may show an observational signature in the VLBI image of jet, such as limb brightening or limb darkening. Limb brightening has been observed in VLBI images of Mrn 501 and Mrn 421 (e.g. Giroletti et al. 2004a; Piner, Pant & Edwards
corresponding to $L_{\gamma}$ for all $L_{\text{satellite}}$. Our main results are the following:

(i) After excluding beaming effect and redshift effect, there is significant correlation between intrinsic $\gamma$-ray and broad-line luminosity, which suggests that the radiation mechanism of the $\gamma$-ray in Fermi blazars of existing BLR is likely to be IC scattering of ambient photons from BLR or outflowing BLR. And there are significant correlations between intrinsic $\gamma$-ray luminosity and BH mass, between intrinsic $\gamma$-ray luminosity and Eddington ratio.

(ii) The results from our sample (not related to a particular model) confirm the idea proposed by Ghisellini et al. (2010, 2011) and Sbarbaro et al. (2012), and that the divide between BL Lacs and FSRQs is of the order of $L_{4\text{BLR}}/L_{\text{edd}} \sim 10^{-10}$ corresponding to $M_{\gamma}/M_{\text{edd}} = 0.1$.

(iii) The correlation between broad-line luminosity and jet power is significant which supports that jet power has a close link with accretion. Jet power depends on both the Eddington ratio and BH mass. We also obtain $\log L_{\text{BLR}} \sim (0.98 \pm 0.07)\log P_{\text{jet}}$ for all blazars, which is consistent with the theoretical predicted coefficient of $\log L_{\text{BLR}} \sim -\log L_{\text{jet}}$ relation. These results support that for Fermi blazar, jets are powered by energy extraction from both accretion and BH spin (i.e. not by accretion only).

(iv) For almost all BL Lacs, the jet power is larger than the disc luminosity while the jet power is much smaller than the disc luminosity for most of FSRQs. The ‘jet-dominance’ is mainly controlled by, and is inversely dependent on, the bolometric luminosity.

(v) There are no correlations between radiative efficiency of $\gamma$-ray and redshift, between radiative efficiency of $\gamma$-ray and BH mass, between radiative efficiency of $\gamma$-ray and Eddington ratio.

(vi) Compared with NBL Lacs, TBL Lacs have much smaller redshift, jet kinetic power, intrinsic $\gamma$-ray luminosity, $\gamma$-ray photon index and bulk Lorentz factor for parsec-scale radio emission. There are not significant differences of BH masses between them. TFSRQS have small redshift but large bulk Lorentz factor for parsec-scale radio emission.

5 CONCLUSIONS

In this work, we have analysed a large sample of blazars detected in the Fermi satellite. Our main results are the following:

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