Extragalactic jets from every angle
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Beaming effect for Fermi/LAT blazars

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Abstract. In this talk, we will show the beaming effect for Fermi/LAT blazars, then we discuss the correlations between γ-ray luminosity and other parameters, such as radio Doppler factors, superluminal motions, and core-dominance parameters. We also compare the Doppler factors determined from the γ-ray luminosity, X-ray emissions, and the short-term time scales with those from other methods. Our discussions suggest that γ-ray emissions may be strongly beamed.

Keywords. galaxies: active, BL Lacertae Objects, quasars: general, galaxies: jets

1. Introduction

Blazars are a special subclass of active galactic nuclei (AGN) with some extreme observation properties, rapid and high amplitude variability, high and variable polarization, superluminal radio components, non-emission line feature or have strong emission lines, or strong γ-ray emissions (see Fan 2005, Fan *et al.* 2011a, Fan *et al.* 2013a, Abdo *et al.* 2010, Nolan *et al.* 2012, Lott *et al.* 2014, Berecca González 2014).

Blazars have two subclasses, namely BL Lacertae objects (BL Lacs) and flat spectrum radio quasars (FSRQs). From surveys, BL Lacs can be divided into radio selected BL Lacertae objects (RBLs) and X-ray selected BL Lacertae objects (XBLs). They can also be divided into three subclasses from their spectral energy distributions (SEDs), namely low-frequency-peaked BL Lacertae objects (LBLs), intermediate-frequency-peaked BL Lacertae objects(IBLs), and high-frequency-peaked BL Lacertae objects (HBLs). From the synchrotron peak frequency, there is a sequence $\nu_{FSRQs} < \nu_{LBLs} < \nu_{IBLs} < \nu_{HBLs}$, but their synchrotron peak luminosity follows a sequence of $L_{FSRQs} > L_{LBLs} > L_{IBLs} > L_{HBLs}$ (Fossati *et al.* 1998).

Since the launch of Fermi/LAT, one of the most important results of the mission is the discovery of blazars (i.e., FSRQs and BL Lacs), which emit most of their bolometric luminosity in the high energy range γ-rays (0.1 - 100 GeV) (Abdo *et al.* 2010, Ackermann *et al.* 2011, Nolan *et al.* 2012, Fan *et al.* 2014a, Fan *et al.* 2014b). The γ-rays found may be strongly beamed since γ-ray emissions are correlated with radio emissions, the Fermi/LAT detected sources show high states in radio flux and polarization, the Fermi/LAT detected sources show higher brightness temperature than those non-Fermi-detected sources, and the γ-ray bright sources show narrower co-moving viewing angle than the γ-ray weak sources (Kovalev *et al.* 2009, Hovatta *et al.* 2010, Savolainen *et al.* 2010, Giroletti *et al.* 2012, Massaro *et al.* 2013a, Massaro *et al.* 2013b, Giovannini *et al.* 2014, Fan *et al.* 2014b, Wu *et al.* 2014, Lisakov & Kovalev 2014, and reference therein).

In this work, we also discuss the beaming effect in the Fermi/LAT sources. In section 2, we will show some correlations between γ-ray luminosity and other parameters. In section

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3, we will give some discussions and a brief conclusion. We adopt $H_0 = 73\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$, and the spectral index, α is defined as $f_\nu \propto \nu^{-\alpha}$ through this work.

2. Some results

Now, we will show the correlations between γ-ray luminosity and other parameters (radio Doppler factor, superluminal velocity, and core-dominance parameter), the statistical results for Fermi/LAT blazars are based on the 2FGL (Nolan *et al.* 2012). We also show our determination of γ-ray Doppler factors and compare them with those by others.

γ-ray luminosity and radio Doppler factor: From 2FGL, we compiled available radio Doppler factors from the works (Ghisellini *et al.* 1993, Huang *et al.* 1999, Lahteenmaki & Valtaoja 1999, Fan *et al.* 2010) for some sources, and calculated their γ-ray luminosity between 1.0 and 100 GeV,

$$L_\gamma(erg/s) = 4\pi d_L^2(1+z)^{(\alpha_{ph}-2)}f,$$

here α_{ph} is the photon spectral index, f is the flux expressed as

$$f = N_{(E_L\sim E_U)}\frac{E_\mathrm{U}-E_\mathrm{L}}{E_\mathrm{U}\times E_\mathrm{L}}\ln\frac{E_U}{E_L}\ \text{if}\ \alpha_\mathrm{ph}=2, \text{otherwise}$$

$$f = N_{(E_L\sim E_U)}\frac{1-\alpha_{ph}(E_U^{2-\alpha_{ph}}-E_L^{2-\alpha_{ph}})}{2-\alpha_{ph}(E_U^{1-\alpha_{ph}}-E_L^{1-\alpha_{ph}})},$$

where f is in units of GeV$\cdot$ cm$^{-2}\cdot$s^{-1}, and $N_{E_L\sim E_U}$ stands for the integral photons with units of photons$\cdot$ cm$^{-2}\cdot$s^{-1} in the energy range from E$_L$ to E$_U$. Then we adopted the linear regression to the luminosity and radio Doppler factor, and found a close linear correlation (Fan *et al.* 2013b),

$$\mathrm{logL}_\nu \sim\ 0.8\log\delta^3.$$

Core-dominance parameter and superluminal motion: Core-dominance parameter can be defined as the ratio of the core emission, S_{core} (or L_{core}), to the extended emission, S_{ext} (or L_{ext}), $\mathrm{logR} = \log(\mathrm{S_{core}}/\mathrm{S_{Ext}})$. From our previous paper (Fan *et al.* 2011b) and the blazar catalogue (Massaro *et al.* 2011), we can get a sample of 563 blazars with available core-dominance parameters. Out of them, 124 sources are detected by Fermi/LAT, they show higher core-dominance parameter, $< logR|_{Fermi-blazars} >= 0.96 \pm 0.81$ than the rest, $< logR|_{non-Fermi-blazars} >= 0.26 \pm 0.97$.

When linear regression fitting is adopted to γ-ray luminosity and core-dominance parameter, there is no correlation between them. However, there is a close correlation between the ratio of γ-ray luminosity to extended radio luminosity and the core-dominance parameter (also see Wu *et al.* 2014),

$$\log(\mathrm{L}_\gamma/\mathrm{L}_{\mathrm{Ext.}}) = (0.946\pm0.158)\log(1+\mathrm{R}) + (2.74\pm0.212).$$

The close correlation suggests that γ-ray emissions be composed of two components as are radio emissions. Fortunately, γ-ray emissions are really observed from the lobes of Cen A (Massaro & Ajello 2011, Kataoka 2014).

For γ-ray luminosity and superluminal velocity, we found a tendency that the brighter γ-ray emissions, the higher superluminal velocity as shown in Fig. 1.

γ-ray Doppler factor: The particular observation properties of blazars can be explained by a relativistic beaming model. The high-energy γ-rays detected from blazars imply the existence of the beaming effect in those sources, otherwise, the γ-rays should have been

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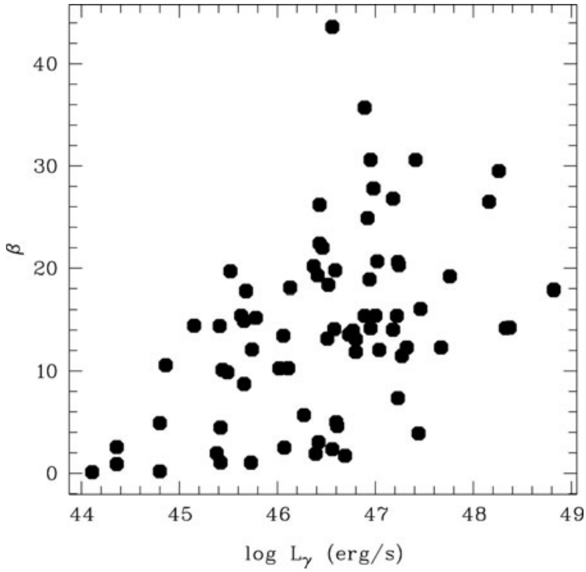

Figure 1. Plot of superluminal velocity against γ-ray luminosity.

absorbed due to pair-production on collision with the lower-energy photons populating the region. Following Mattox *et al.* (1993), we assume that: i) X-rays are produced in the same region of the γ rays, and that when the γ rays are observed X-ray and γ-ray intensities are similar; ii) the emission region is spherical; iii) the emission is isotropic, and the size of the emission region is constrained by the timescale of the time variations, ΔT, to be $R = c\delta\Delta T/(1+z)$, where c is the speed of light, δ is the Doppler factor and z is the redshift, and assume that the optical depth does not exceed unity as in Mattox *et al.* (1993), then the lower limit of δ can be expressed in the form (see Fan *et al.* 2014b):

$$\delta \geqslant \left[1.54\times10^{-3}(1+z)^{4+2\alpha}\left(\frac{d_{\rm L}}{\rm Mpc}\right)^2\left(\frac{\Delta T}{\rm hr}\right)^{-1}\left(\frac{F_{\rm KeV}}{\mu{\rm Jy}}\right)\left(\frac{E_\gamma}{\rm GeV}\right)^{\alpha}\right]^{\frac{1}{4+2\alpha}},$$

where α is the X-ray spectral index, ΔT is the time scale in units of hrs, $F_{\rm KeV}$ is the flux density at 1 KeV in units of μJy, E_γ is the energy at which the γ-rays are detected, in units of GeV (here we used the averaged γ-ray energy, $\langle E\rangle = \frac{\int E\,{\rm d}N}{\int {\rm d}N}$), while $d_{\rm L}$ is the luminosity distance in units of Mpc (Pedro & Priyamvada 2007).

We got X-ray data for a sample of 457 Fermi/LAT blazars, when $\Delta T = 6$ hrs is adopted to the sample, $\delta = 1.5$ - 59 for the whole sample. Out of the 457 sources, there are only 8 sources with $\delta > 20.0$. For the subclasses, we have following averaged values: $\langle\delta\rangle = 9.30\pm7.76$ for the 193 FSRQs, $\langle\delta\rangle = 5.32\pm2.55$ for the 264 BLs, $\langle\delta\rangle = 5.05\pm2.48$ for the 61 LBLs, $\langle\delta\rangle = 5.21\pm2.59$ for the 69 IBLs and $\langle\delta\rangle = 5.51\pm2.57$ for the 134 HBLs (Fan *et al.* 2014b).

3. Discussion and conclusions

Blazars show many special observation properties, which maybe caused by beaming effect. After the launch of Ferm/LAT, most isolated point sources detected by Fermi/LAT are AGN (see Abdo *et al.* 2010, Nolan *et al.* 2012, Lott *et al.* 2014). This discovery provides us with a good chance to study the emission mechanisms and some effects included

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in the emissions of AGNs. The beaming effect as an important role in blazars is discussed in the literature. We investigated the effect in γ-ray region using the correlations between γ-ray luminosity and other parameters. The core-dominance parameters in the Fermi/LAT sources are found higher on higher than that in the non-Fermi/LAT blazars. Superluminal motion velocity increases with γ-ray luminosity, which is also correlated with radio Doppler factors, δ_R. We determined the lower limit of γ-ray Doppler factors, compared our results with those (Ghisellini *et al.* 1993, Huang *et al.* 1999, Lahteenmaki & Valtaoja 1999, and Fan *et al.* 2010), and found that the Doppler factors determined here are consistent with those in the literature for the common sources. From our determination, we get the average Doppler factors $< \delta_\gamma >= 9.30 \pm 7.76$ for 193 FSRQs and $< \delta_\gamma >= 5.32 \pm 2.55$ for 264 BLs. It is interesting that our Doppler factors are consistent with the Lorentz factors, $\Gamma = 11.7^{+3.3}_{-2.2}$ for FSRQs (Ajello *et al.* 2012) and $\Gamma = 6.1^{+1.1}_{-0.8}$ for BLs (Ajello *et al.* 2014), extracted from the luminosity functions. For 1849+670, we can get $\delta_\gamma = 4.01$ ($\Delta T = 24$hrs) - 4.80 ($\Delta T = 6$hrs), which is consistent with $\delta = 4.2$ (Kharb *et al.* 2014). But it should be mentioned that ΔT may be different from one source to another, and time scales within one days are only for a handful of sources. It is better to use the detected short-term time scale to determine the Doppler factors. Our discussions suggest that γ-ray emissions may be strongly beamed.

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