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Blazar Sequence in Fermi Era

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Abstract. In this paper, we review the latest research results on the topic of blazar sequence. It seems that the blazar sequence is phenomenally ruled out, while the theoretical blazar sequence still holds. We point out that black hole mass is a dominated parameter accounting for high-power-high-synchrotron-peaked and low-power-low-sychrotron-peaked blazars. Because most blazars have similar size of emission region, theoretical blazar sequence implies that the break of Spectral Energy Distribution (SED) is a cooling break in nature.

Key words. BL Lacertae objects: general—glaxies: jets—quasars: general.

1. Blazar sequence and validity

Blazars present two bumps in the $\log\nu - \log\nu L_\nu$ diagram, which are believed to be non-thermal emissions from relativistic jet. Fossati *et al.* (1998) showed that the first bump luminosity anticorrelates with peak frequency, which is called a phenomenal blazar sequence. Through SED modelling, Ghisellini *et al.* (1998) presents a theoretical blazar sequence: $\gamma_0 - U_{\rm t}$ anticorrelation, where γ_0 is the electron energy emitting at peak and $U_{\rm t}$ is the summation of the magnetic and radiative energy densities within the Thomson regime. Blazar sequence plays an important role in understanding many AGN physics: radiative mechanism, particle acceleration, emission region location, etc. Therefore, many works focus on its validity.

The phenomenal blazar sequence seems to be ruled out by clear evidences (see Padovani 2007; Chen & Bai 2011 for summary). (1) $\log\nu_{\rm p} - \log(\nu L_\nu)_p$ anticorrelation is not confirmed by larger sample. (2) Blazar sequence predicts high-peaked-BL Lacs more numerous than low-peaked-BL Lacs. However, luminosity functions do not confirm this. (3) High-power-high-peak blazars are found (Padovani *et al*. 2012).

Multi-band SEDs of many larger blazar samples, including simultaneous data are modelled (see Ghisellini *et al*. 2010 and references therein). These results exhaustively validate the theoretical blazar sequence.

2. Why HP-HSP or LP-LSP?

Powerful blazars usually imply very large radiative energy density. This yield effective inverse Compton cooling of relativistic electrons. The cooled electrons emit at lower frequency. But the discovery of high-power-high-synchrotron-peaked (HP-HSP) blazars indicates that this simple analysis should be problematic. So does the discovery of numerous low-power-low-sychrotron-peaked (LP-LSP) blazars.

If a blazar has a less beaming jet, its synchrotron bump should peak at lower frequency and lower power. Therefore, beaming effect may account for HP-HSP and LP-LSP blazars. Radio galaxies, which are believed to be less beaming, actually locate at LP-LSP region (see Meyer *et al*. 2011). However, if we take out the radio galaxies, one cannot find less beaming for LP-LSP blazars. Chen & Bai (2011) showed that $\log(\nu_s^{1/4} L_s)$ correlates with a beaming independent parameter $\log(L_C/L_s)$. This result indicates that the beaming effect is not the dominated role for LP-LSP and HP-HSP blazars. In fact, we study a large blazar sample based on Fermi/LAT γ-ray catalogue, and showed that LP-LSP blazars have lower black hole mass. This result is supported by 4 γ-ray narrow line Seyfert 1 (NLS1), who are LP–LSP in nature and have lower black hole mass (see Chen & Bai 2011).

One can assume that the jet dissipation location is proportional to the black hole mass $R_{\rm diss} \sim \Gamma^2 R_0 \propto M_\bullet$, while the radius of the Broad Line Region (BLR) is proportional to the square root of the black hole mass $R_{\rm BLR} \propto L_{\rm disk}^{1/2} \propto M_\bullet^{1/2}$. The luminosity can be assumed to be proportional to the black hole mass $L_{\rm jet} = \eta_{\rm rad} P_{\rm jet} = \eta_{\rm rad}\eta_{\rm jet}\dot{m} M_\bullet$. Therefore, for low $M_\bullet$, jet dissipates inside the BLR, electrons cool more effectively, and then emit at low frequency. This may account for the LP-LSP blazars. For large $M_\bullet$, jet dissipates outside the BLR, electrons cool less effectively, and then emit at high frequency. This may account for HP-HSP blazars (see Ghisellini & Tavecchio 2008; Chen & Bai 2011 for more details).

3. Nature of theoretical blazar sequence

Despite the phenomenal blazar sequence, theoretical blazar sequence still holds. This provides an opportunity to understand the nature of the break of the bump. One possibility is that it could be a cooling break. Through simple analysis of cooling process, one can expect $\gamma_0 \sim (3m_e c)/(4\sigma_T U_t t_c) \sim (3m_e c^2)/(4\sigma_T U_t R)$. Many studies show that most blazars have similar size of the emission region ($R \sim 10^{16}$ cm, see for e.g., Celotti & Ghisellini 2008; Ghisellini *et al*. 2010; Zhang *et al*. 2012). Therefore, one can expect the sequence $\gamma_0 \propto U_t^{-1}$.

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