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A simple diagnostic for the location of the blazar emission site

Markos Georganopoulos[1,2], Demosthenes Kazanas[2], and Eric S. Perlman[3]

[1] University of Maryland, Baltimore County
[2] NASA, Goddard Space Flight Center
[3] Florida Institute of Technology

Abstract. The distance between the supermassive black hole and the site where the blazar emission is radiated, is related to the blazar jet formation and collimation. Although it was thought that the blazar emission site resides within the broad emission line region, recent observations suggest otherwise. Here we present a simple diagnostic for the blazar location, that requires of GLAST and multiwavelength observations of blazars at γ-ray dominated states.

Key words. Galaxies: active – quasars: general – radiation mechanisms: nonthermal

1. Just before GLAST: moving the blazar out to pc scales?

It has always been assumed that the site that dominates the blazar emission is definitively at sub-pc distances from the central engine. This is mostly driven by variability arguments: for a jet of Lorentz factor Γ, its opening angle cannot be smaller than $1/\Gamma$. Significant variations (by a factor of at least $\sim$ 2), therefore, observed to last time Δt and corresponding to a comoving length $c\Delta t\Gamma$ have to be located at a distance of at most $c\Delta t\Gamma^2 \sim 10^{17-18}$ cm for $\Gamma \sim 10$, $\Delta t \sim 1$ day. This scale is very similar to the scale size of the broad line region (BLR), as reverberation mapping shows (Kaspi et al. 2000), and this has been used by Sikora, Begelman, & Rees (1994) to argue that the EGRET-detected GeV emission of powerful blazars is inverse Compton scattering off BLR optical-UV photons.

Recent observations, however, challenge this assumption, arguing that significant or even dominant energy dissipation in blazars takes place at pc scales. Jorstad et al. (2001a,b) based on statistics of VLBI and EGRET observations of blazars argued that the γ-ray flares take place in the superluminal radio knots in the parsec-scale jet, and not as close to the central engine as it was previously thought. Similar conclusions were reached by Lindfors et al. (2006) that argue that most of the energy dissipation in blazars takes blace well beyond the 10^{17-18} cm size of the broad line region. D'Arcangelo et al. (2007) studied the highly variable quasar PKS 0420-014 and found that the polarization angle of a standing feature (the 'pseudocore') at the upstream end of the jet in their 43 GHz VLBI image is closely correlated to the polarization angle of the optical emission and they use this to argue that the optical emission comes predominantly from the pseudocore and not from the vicinity of the central engine. Similar conclusions are reached by a large sample

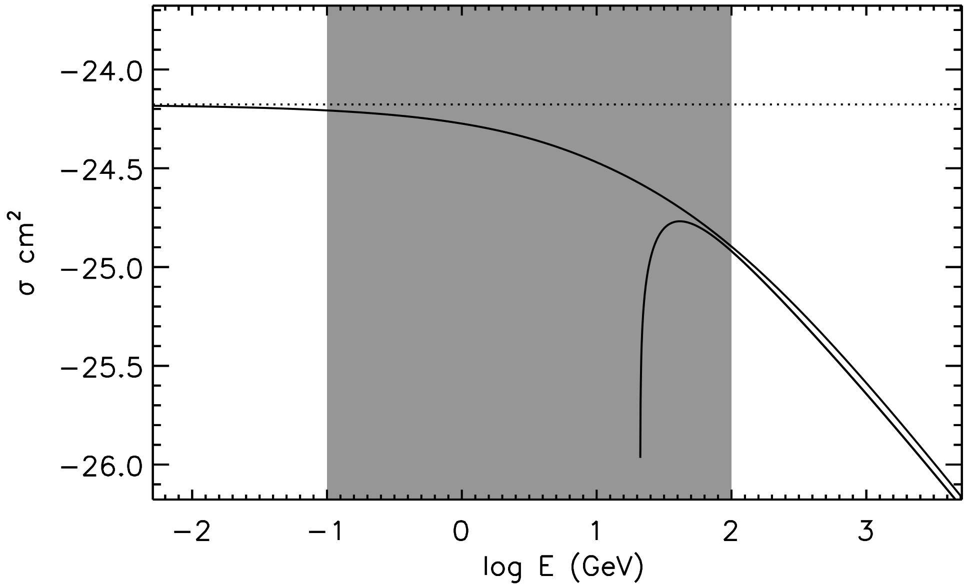

Fig. 1. The cross section for inverse Compton radiation (upper solid line) produced from line emission (in this particular case Ly α) seed photons starts in the Thomson regime (marked by the dotted line) for low final photon energies and gradually enters the Klein-Nishina regime for higher energy final photons. The pair production cross section of the produced radiation with the line emission is shown as the lower solid curve, with the low frequency cutoff corresponding to $1/\epsilon_0$ in units of $m_e c^2$, where ϵ_0 is the line photon energy. Note that the transition to the Klein-Nishina regime is mostly taking place at energies lower than the energy where the pair ablorption cross section becomes relevant. The gray background marks the 100 MeV - 100 GeV energy range of GLAST.

study by Jorstad et al. (2007). Very recent detailed multiwavelength observations of BL Lacertae, the archetypal lineless blazar, lend strong support to this picture (Marscher et al. 2008).

2. A parameter-free diagnostic for the relevance of the broad line region

The question of the location of the blazar emission relative to the BLR has important consequences on how relevant the absorption of the blazar γ-ray emission from pair production with the BLR photons is. Obviously, if the blazar is outside the BLR, the absorption will be negligible. Because this is a central consideration, we are currently working on developing a parameter-free diagnostic for the location of the blazar emission site relative to the BLR. The diagnostic is based on the fact that, although at energies below $\sim$ few GeV pair production absorption due to the BLR photons is irrelevant (Figure 1), the gradual transition from the Thomson to the Klein-Nishina regime will leave its imprint on the spectrum and the variability of the blazar in a unique way, particularly for blazars that are heavily Inverse - Compton dominated.

Cooling in the Klein-Nishina (KN) regime. In several cases, the Compton dominance can reach values as high as a few hundred (e.g. PKS 4C 38.31; Kubo et al. 1998). In such cases IC is the dominant energy loss mechanism, and to produce the $0.1 - 100$ GeV

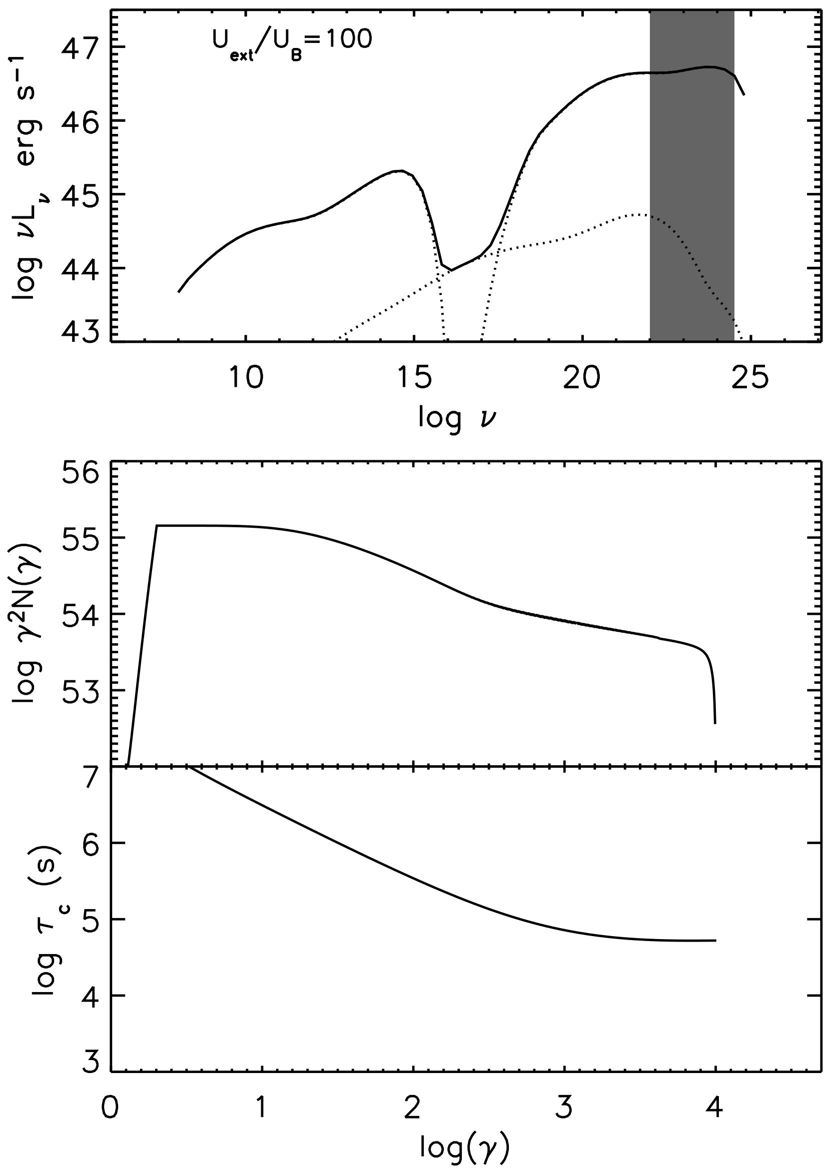

Fig. 2. Model of an EC dominated blazar. Bottom panel: the electron cooling time as a function of γ. Middle panel: the electron distribution.Top panel: the emitted power. Solid line for the total power, and dotted lines for the synchrotron (leftmost), SSC (central), and EC (rightmost and most powerful) components. The gray band is roughly the EGRET - GLAST regime.

photons ($\epsilon \sim 10^{3-5}$ in units of $m_e c^2$), electrons of at least the same Lorentz factor are required, $\gamma \sim 10^{3-5}$. Given that the typical BLR photon energy is $\epsilon_0 \sim 10^{-5}$, the GeV emission comes from scatterings in the transitional regime between the Thomson and Klein-Nishina regimes, since $\epsilon_0\gamma \sim 0.01 - 1$.

Consider now a case where the only loss mechanism we have is IC. In the Thomson regime ($\epsilon_0\gamma \ll 1$), the electron energy loss rate $\dot{\gamma} \propto \gamma^2$, and the electron cooling time $\tau_c = \gamma/\dot{\gamma} \propto 1/\gamma$. In the KN regime $\dot{\gamma} \propto \gamma^0$ (there is a slow logarithmic increase of $\dot{\gamma}$ with γ which we do not consider here), and $\tau_c = \gamma/\dot{\gamma} \propto \gamma$. So, while the cooling time decreases linearly with γ in the Thomson regime, it increases linearly in the KN regime. The behavior around $\epsilon_0\gamma \sim 1$ is flat, with a practically energy independent cooling time.

At progressively higher electron energies, the synchrotron cooling becomes important, even for highly Inverse Compton dominated blazars. A proper calculation requires the inclusion of the synchrotron and SSC losses, as well as the emission due to these processes and EC scattering. We present results of such a numerical calculation in Figure 2, for a source in which the ratio of the energy density U_{ext} in the jet comoving frame of the external (BLR) photon field is 100 times larger than the magnetic field energy density U_B. This guarantees that the EC emission will be much more powerful than the synchrotron component.

Note that the cooling time (bottom panel of Figure 2) for electrons with γ greater than $\sim 10^3$ is practically constant. This implies that if the GeV emission of heavily Inverse-Compton blazars takes place inside the BLR,

(*i*) the IR to UV variability, produced by the synchrotron emission of these electrons, should be achromatic

(*ii*) the GLAST variability should also be achromatic. Also, because the electron distribution, after it softens due to cooling in the Thomson regime, becomes harder due to the onset of the reduced efficiency KN cooling (middle panel of Figure 2),

(*iii*) The synchrotron SED at highly Inverse-Compton dominated states should exhibit a hump in the synchrotron component, and similarly, the GeV component should be flat/rising.

3. Conclusions

We presented a diagnostic test for localizing the blazar energy dissipation site relative to the BLR. The spectral and temporal characteristics we presented here, are independent of modeling parameters and are unavoidable for blazars with high Compton dominance, if the blazar emission is produced within the BLR. With the diagnostic we propose, GLAST observations, together with optical monitoring will provide a definite answer to the important question of the location or energy release in blazars.

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