Inhomogeneous SSC Model For The Quiet Gamma-Ray Emission State In BL Lacs

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Recent observations of BL Lacs clearly identify a persistent low level emission lasting months. Such a persistent emission can not be explained in terms of the homogeneous blob model since at the time scale of a month the parameters in the moving blob should change drastically. In order to explain this emission we develop the inhomogeneous model of the jet for a quiet state emission in BL Lacs.

1. Inhomogeneous Jet Model

We divide a part of the jet in which the acceleration of electrons occurs on several slabs. The plasma moves along the jet with the Lorentz factor Γ_{j}. The differetial spectrum of electrons is described by power law function with a spectral index β. Electrons are accelerated in the jet to maximum energies determined by the balance between acceleration energy gains and energy losses. The synchrotron energy losses of electrons are determined by the value of the magnetic field $B(x)$ at the distance x from the base of the jet. Electrons accelerated at the distance x along the jet comptonize the synchrotron radiation produced locally in the specific layer of the jet. As a result, γ-ray photons are produced in the SSC process. γ-rays, produced at the base of the jet, can be partially absorbed while propagating through the outer layers of the jet. Electrons accelerated at specific layer lose their energy only partially in this layer and move to the outer parts of the jet (i.e. to subsequent layers).

The model depends on: the magnetic field at the base of jet B_0, the maximum extent of acceleration region $x_{\max}$, the total power in relativistic electrons L_e, the spectral index of injected electrons β, the acceleration coefficient of electrons η, minimum energy of relativistic electrons $\gamma_{\min}$ and the black hole mass M_{BH}

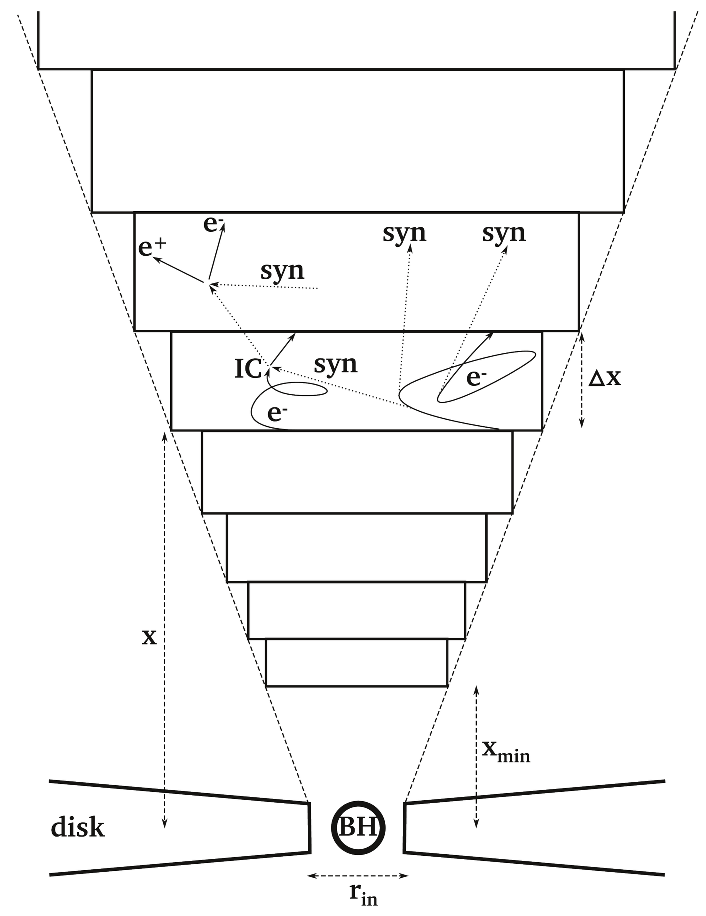

Figure 1. Schematic picture of the inhomogeneous SSC jet model.

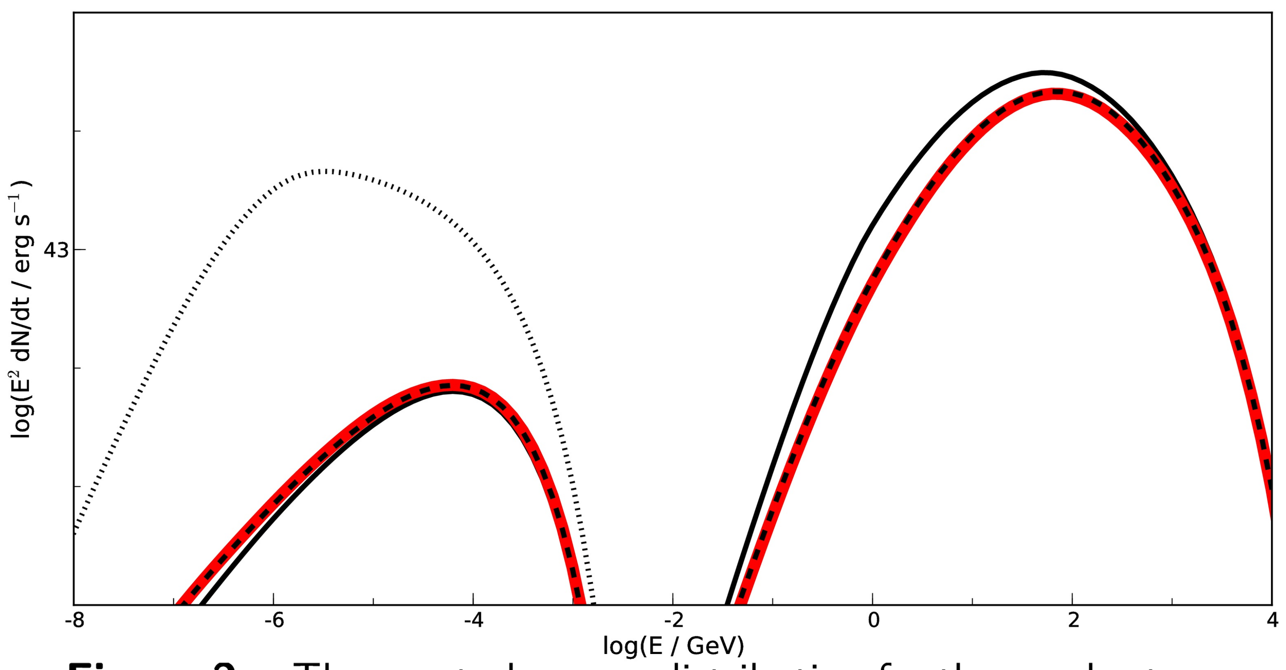

Figure 2. The spectral energy distribution for the synchrotron and IC γ-ray spectra produced in the 0th generation (black dotted curves), the 1st generation (black solid), the 3rd (black dashed) and 5th (red solid) for the examplary set of parameters.

2. Method To Calculate Spectra

In order to consider the energy losses of electrons on synchrotron and Inverse Compton process (and produced by them multifrequency spectrum) self-consistently we apply the iteration method. At first, we only calculate the synchrotron spectrum produced by injected electrons, assuming that they lose energy only on this synchrotron process (so called 0-th generation synchrotron spectrum). In the next generation injected electrons lose energy on the synchrotron process and on the IC process of the previous generation synchrotron spectrum. Based on this cooled electrons we calculate next generation of synchrotron and IC spectrum. This procedure is executed for every layer. In this way, after a few generations, we obtain a stationary spectrum (see Fig. 2).

3. Internal Absorption of γ-Rays

γ-rays produced in the inner part of the active region in the jet have to propagate through the synchrotron radiation produced in the more outer parts of the jet. In Fig. 3 we show the optical depth for γ-rays ($\gamma - \gamma \to e^{\pm}$), originated at distance x from the base of the jet, in the synchrotron radiation produced by electrons at larger distances. It is assumed that γ-rays are injected at small angles to the jet axis, i.e. smaller than the opening angle of the jet α. In such a case, γ-rays propagate completely within the jet volume filled with synchrotron radiation.

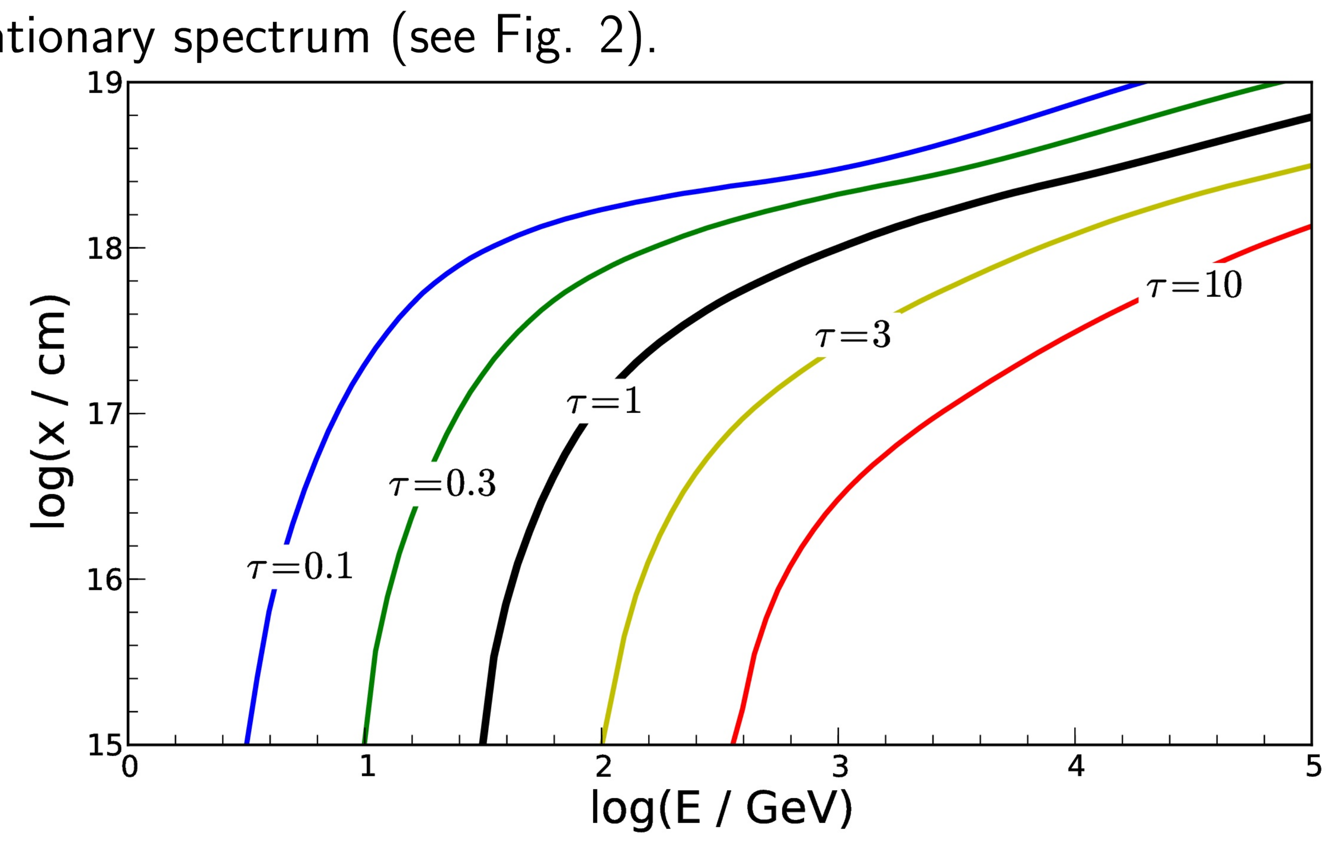

Figure 3. The optical depth τ as a function of γ-rays and distance from the base of jet for the examplary set of parameters.

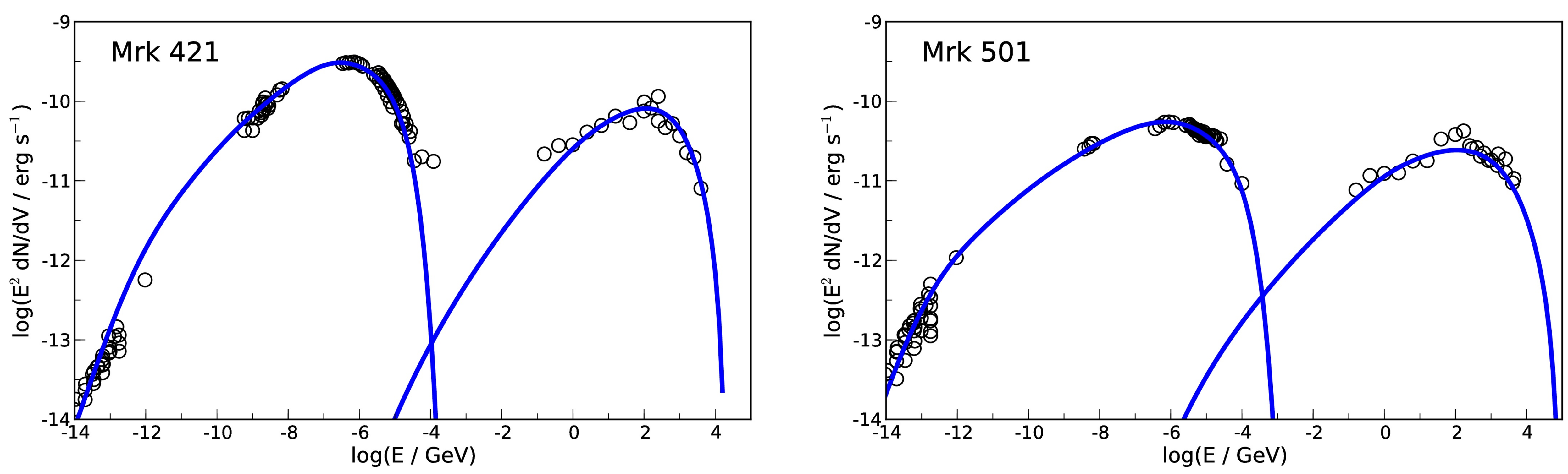

Figure 4. The comparison of multiwavelength spectrum observed during the quiscent state from Mrk 421 (on the left) with the spectrum culated in our inhomogeneous extended jet SSC model. The parameters of the model are the following: $B_0 = 12.5$ G, $x_{\max} = 10^{19}$ cm, $= 1.5 \times 10^{-5}$, $\beta = 2.0$, $L_e = 2 \times 10^{43}$, $M_{\mathrm{BH}} = 3 \times 10^8 M_{\odot}$, $\gamma_{\min}$, and Doppler factor of the jet $D = 5.1$. Interpretation of the spectrum of k 501on the right. The parameters of the model are the following: $B_0 = 2.5$ G, $x_{\max} = 3 \times 10^{19}$ cm, $\eta = 1.5 \times 10^{-4}$, $\beta = 2.3$, $L_e = 9 \times 10^{43}$, $_{\mathrm{BH}} = 10^9 M_{\odot}$, $\gamma_{\min}$, and Doppler factor of the jet $D = 3.5$.

4. Results

We apply our inhomogeneous jet model to the quiescent state of two well known BL Lacs Mrk 421 (Abdo et al. 2011a) and Mrk 501 (Abdo et al. 2011b). In Fig. 4 we compare computed spectra with observations above objects in low activity state in 2009.

5. Conclusion

- In the case of blazars, observed at small angle to jet axis, the effect of internal absorption of γ-rays is important for the extended jet. We conclude that in the case of BL Lacs the HE γ-ray produced in the inner part of jet is efficietnly absorbed.
- Computed spectra agree with the observed low activity state of selected BL Lacs.
- The model required relativistic boosting of emission with Doppler factor of a few, which agree with the radio observations of BL Lacs jet (eg. Lico et al. 2012).

References

Abdo, A.A. et al. 2011a ApJ 736, 131

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