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External blob radiation model for the TeV gamma-ray emission in radio galaxies

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Abstract. We propose that two emission regions are present in the decelerating jet of radio galaxy at this same moment. Isotropic electrons, in the farther blob as counted along the jet, up-scatter mono-directional soft radiation, from the closer blob, at a relatively large angles to the jet axis. Such model can naturally explain the large angle gamma-ray emission observed from radio galaxies.

Keywords. Galaxies: active, galaxies: jets, radiation mechanisms: non-thermal, gamma-rays: galaxies

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The inner radio jets in radio active galaxies observed at TeV γ-ray energies are inclined at large angles to the line of sight. We consider the standard blob in a jet scenario for the variable, high energy emission from the inner jet in radio galaxies. It is assumed that two emission regions are present within the jet at this same moment. The inner region (called blob I) moves fast and emits highly collimated radiation towards the outer, slowly moving region (called blob II). Isotropically distributed relativistic electrons, in the blob II reference frame, up-scatter collimated radiation from the inner blob I, preferentially in the direction opposite to the jet propagation. Therefore, γ-rays, produced in the blob II, are emitted at larger angles to the observer's line of sight than expected in the case of the isotropic emission region. On the other hand, radiation produced in blob I is highly collimated along the jet axis. This emission is characteristic for the BL Lac type objects observed at a small viewing angles. We discuss the basic emission features of such external blob radiation model. We argue that the model can describe the high energy emission from radio galaxies viewed at large angles. The details of the model can be found in Banasiński & Bednarek (2019).

Our calculations show that the large angle emission can be significantly enhanced if the relativistic electrons in the blob II inverse Compton up-scatter mono-directional soft radiation produced in the blob I. Therefore, the existence of such two regions in the jet, either well localized or quite extended, seems to provide natural mechanism for the γ-ray emission observed from radio galaxies.

We calculate the γ-ray spectra produced by isotropic electrons with the equilibrium spectrum, $dN_{\rm e}/dE_{\rm e}$, which scatter mono-directional soft radiation with the spectrum, $n(\varepsilon)$, in the blob II reference frame, by integration the following formula,

$$\frac{dN}{d\varepsilon_\gamma dt' d\Omega'} = \int_{E_{\rm L}}^{E_{\rm U}} \frac{dN_{\rm e}}{dE_{\rm e}} \int_{\varepsilon_{\rm L}}^{\varepsilon_{\rm U}} \frac{dN(\theta', \varepsilon, E_{\rm e})}{d\varepsilon_\gamma d\varepsilon dt' d\Omega'} d\varepsilon dE_{\rm e}, \tag{1}$$

where $dN(\theta', \varepsilon, E_{\rm e})/(d\varepsilon_\gamma d\varepsilon dt' d\Omega')$ is the γ-ray spectrum produced by the mono-energetic electrons by scattering soft photons with energy ε. It is expressed by the convenient formulas obtained by Aharonian & Atoyan (1981). These spectra depend on the angle, θ', which is the angle between the directions of the soft photon and the γ-ray as measured in the blob II reference frame. In our geometrical case this angle is measured from the jet axis. In order to produce γ-ray photon with energy, ε_γ, the electron, soft photon, and γ-ray has to fulfill the following minimum kinetic condition given by, $\varepsilon_{\rm min} = 0.5\varepsilon_\gamma m_{\rm e}c^2/[(1-\cos\theta)E_{\rm e}^2(1-\varepsilon_\gamma/E_{\rm e})]$ (see Appendix A in Moderski *et al.* 2005). If $\varepsilon_{\rm min}$ is greater than the lower range of the soft photon spectrum, $\varepsilon_{\rm L}$, the integration is performed only over the energy range of soft photons above $\varepsilon_{\rm min}$. $\varepsilon_{\rm U}$ is the upper energy range of the soft radiation. We assume that electrons in the blob have the energies in the range $E_{\rm min}$ and $E_{\rm max}$. The lower limit on the energy of the electron, $E_{\rm L}$, which is able to produce γ-ray with energy, ε_γ, is also obtained from the above kinetic condition by introducing in the above formula $\varepsilon = \varepsilon_{\rm U}$. This lower limit has to be below the maximum energy of available electrons in the blob, $E_{\rm max}$. If $E_{\rm L}$ is above $E_{\rm min}$ then we integrate the electron spectrum only from $E_{\rm L}$. We assume that electrons in both blobs have the equilibrium spectra well described by the power law function, i.e. $dN_{\rm e}/dE_{\rm e} = AE_{\rm e}^{-\beta}$.

The model has been applied to the radio galaxy, NGC 1275. We perform the example calculations of the γ-ray spectra assuming two limiting values for the observation angles of the jet in NGC 1275, i.e. $\theta = 30°$ and $50°$. These γ-rays have to propagate through the synchrotron radiation field produced by electrons within the blob II. To find out whether their absorption is important, we calculate the optical depths for the γ-rays in the radiation field of the homogeneous blob II. The absorption effects in the soft radiation field of the blob II has to be taken into account for the case of the blob II. We include them by introducing the reduction factor equal to $R(E_\gamma) = \{1-\exp[-\tau(E_\gamma)]\}/\tau(E_\gamma)$.

We conclude that the spectrum observed simultaneously by the *Fermi*-LAT and the MAGIC telescopes, in the GeV-TeV energy range (Aleksić *et al.* 2014), can be well described for the reasonable power in the low energy soft photons emitted from the blob I, equal to the isotropic equivalent synchrotron power of the order of a few 10^{45} erg s^{-1}. Such emission power is within the range of the powers (a few $\sim10^{45} - 10^{46}$ erg s^{-1}) observed from the BL Lac type objects, e.g. Mrk 501 (Ahnen *et al.* 2017), Mrk 421 (Aleksić et al. 2012b) or PKS 2155-304 (Aharonian *et al.* 2009, Abramowski *et al.* 2012). In the case of a relatively small optically thick blob ($R = 3\times10^{15}$ cm), the total energy in the relativistic electrons in the blob II, able to explain the γ-ray emission from NGC 1275, should be equal to $\sim10^{48}$ ergs, for the viewing angles not far from $\sim30°$. However, the absorption effects for the small blob II viewed at the angle $50°$ are too strong to provide correct description of the NGC 1275 spectrum. In the large blob II model ($R = 3\times10^{16}$ cm), the absorption effects are small enough to provide correct description of the observed spectrum for the whole range of the observation angles $30° - 50°$. However, in this case the energy in relativistic electrons should be much larger, i.e. of the order of a few 10^{49} erg, which is still acceptable in the case of blobs in jets of AGNs.

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