A hadronic synchrotron mirror model for blazars Application on 3C279

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Abstract

Blazars are a class of Active Galactic Nuclei (AGN) that are radio loud and have a small angle between the jet and the observer's line of sight, found in the centres of elliptical galaxies. In some cases, flaring events in one frequency band are not accompanied by flaring in other bands, termed - orphan flares. The causes of this variability and conditions in and location of the high energy emission region are not completely understood. As a possible explanation for rapid gamma-ray variability, the hadronic mirror model is suggested. A TeV orphan flare was observed on the 28th of January 2018 by the H.E.S.S. observatoty from 3C 279. A primary flare was observed 11 days earlier by Fermi-LAT. A broken power-law is applied to the Fermi-LAT spectrum preceding the orphan flare to constrain model parameters able to reproduce the proton-synchrotron SED through an analytical fit to the data. The high-energy component of the flare is modeled by the hadronic synchrotron mirror model. The model predicted a dense enough target photon field that is sufficiently efficient for photohadronic interactions to take place and the Fermi flux was not shifted by this model. The photo-pion component of the spectrum is comparable in flux to that of the proton-synchrotron component.

Introduction

The spectral energy distributions (SEDs) of blazars are characterized by two humps or components. The first hump is the low-frequency component that is caused by electron synchrotron emission. For the second hump, the high-frequency component in leptonic models is caused by Compton scattering [Maraschi et al., 1992, Dermer and Schlickeiser, 1993, Bloom and Marscher, 1996]. However, alternatively this component can also be caused by hadronic processes [Mücke et al., 2003, Mannheim and Biermann, 1992, Aharonian, 2000], where the dominant gamma-ray emission mechanisms are proton-synchrotron radiation and synchrotron emission from secondary particles produced by photo-pion production. These reactions are displayed by the following:

$$p + \gamma \rightarrow p + \pi^0 \rightarrow p + \gamma + \gamma \quad (1)$$

$$\text{or} \ \rightarrow n + \pi^+ \rightarrow n + \mu^+ + \nu_\mu \rightarrow n + e^+ + \nu_\mu + \nu_e + \bar{\nu_\mu} \quad (2)$$

Blazars show extreme variability across the electromagnetic spectrum. The central engines causing the relativistic jets have quiescent states and flaring states. In some cases, flaring events in one frequency band are not accompanied by flaring in other bands. Such events are termed orphan flares. Orphan flares are usually secondary flares following primary multi-wavelength flares, and are characterized by extreme variability [Krawczynski et al., 2004]. We are specifically looking at an orphan TeV flare in the frequency band $(E > 100\, GeV)$.

Model and Setup

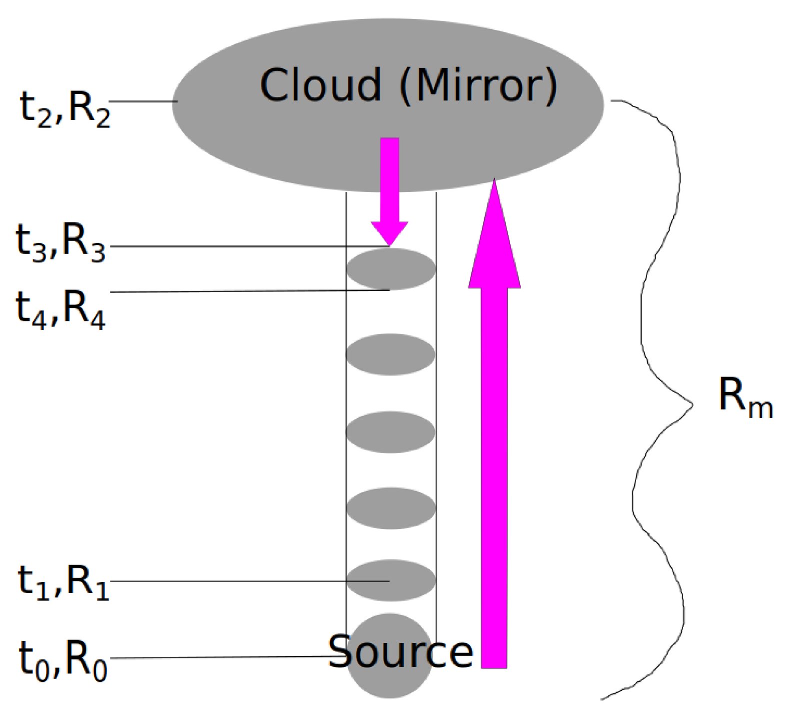

Figure 1: Geometry of the model. As from [Böttcher, 2007] a synchrotron flare is produced in the emission region at time t_1. The synchrotron emission is then reflected when it reaches the cloud, which acts as a mirror. A secondary flare is then produced when the primary synchrotron emission is reflected back into the emission region and the relativistic protons from the primary flare, at time t_3.

The geometry of the model setup is sketched in Figure 1. The observed time delay between primary and orphan flare is 11 days.

As seen in Figure 1, a blob of relativistic particles (protons and electrons) is propagating at relativistic speeds along the jet. The electron-synchrotron emission from the blob hits a gas cloud (e.g., of the broad line region of the quasar) that acts as a mirror and reflects the synchrotron photons back, which then enter the still emitting jet again, constituting an intense target photon field for photo-pion production ([Böttcher, 2005]). Basic principles and the Hadronic Synchrotron Mirror Model are used with the assumption that a fraction, $\tau = 0.1$, of the synchrotron flux from the moving emission region is reprocessed quasi-isotropically by the cloud and integrating the contributions from all points along the jet from the primary flare to the jet-cloud interaction (orphan flare), to calculate the target photon field. Figure 2 displays the target photon field for different timesteps:

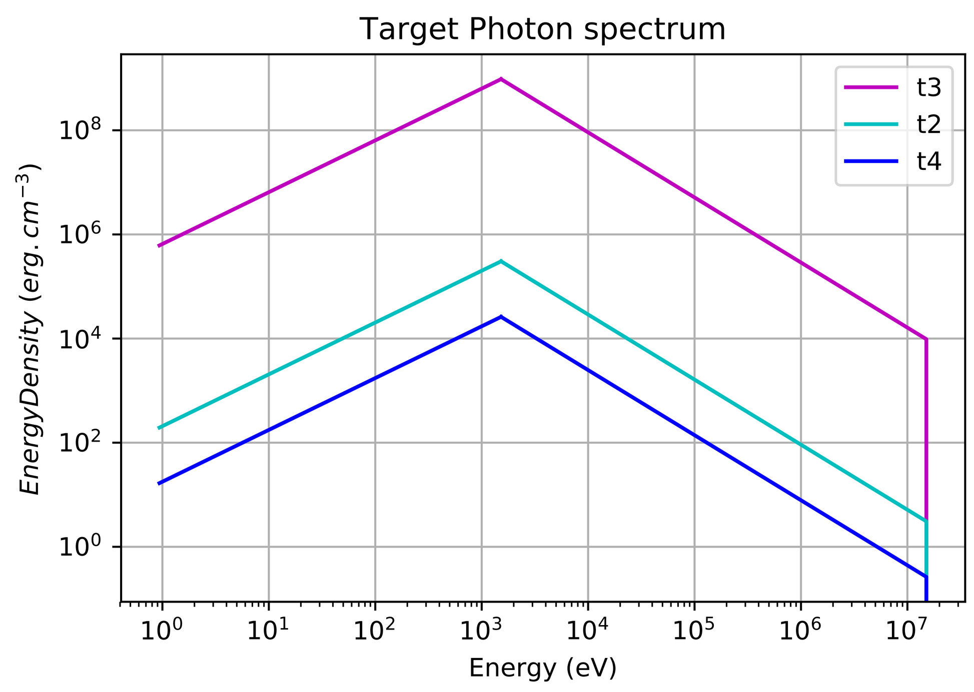

Figure 2: The target photon spectrum at time t_2 when the emitting jet reaches the cloud, t_3, the time at which the synchrotron emission is reflected back into the emission region, and t_4, the time at which the reflected particles pass completely through the emission region.

Results and Discussion

A condition for the model to work was that there should be a dense enough target photon field for photo-pion production to take place. Figure 3 reveals that as the photons are reflected back into the jet, there is a steep increase in the photon density.

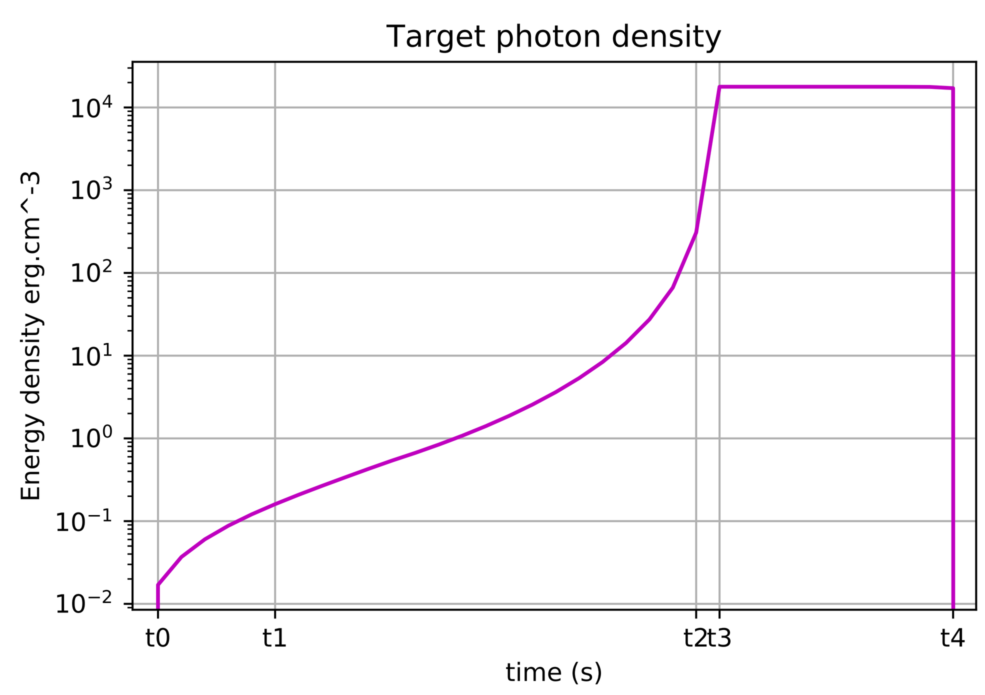

Figure 3: The target photon density in the jet, as the electron-synchrotron emission is reflected back into the still emitting jet at each timestep. t0 denotes the start of the flare when the density is > 0. t1 is the time when the proton synchrotron emission is produced, t2 is the time when the emitting jet reaches the cloud that acts as a mirror. t3 is the time at which the synchrotron emission is reflected back into the emission region and t4 denotes the reflected particles as they pass completely through the emission region, thus the flare has moved beyond the cloud.

The spectral energy distribution is obtained by photo-pion-induced cascade emission with contributions from proton-synchrotron radiation. The cascade component requires a very large jet power to accurately represent the energy density spectra; for relativistic proton luminosities this is $L_p \sim 10^{47} - 10^{49}\, erg.s^{-1}$ [Böttcher et al., 2013]. The jet power for this flare was estimated as:

$$L_p \sim \pi R_b^2 c \Gamma^2 \gamma_b^2 m_p c^2 N_0 \sim 7 \times 10^{46}\, erg.s^{-1} \quad (3)$$

The SED of the Fermi-LAT spectrum for 3C 279 is presented by a superposition between the proton-synchrotron and photo-pion contributions. Figure 3 displays that the Fermi-LAT flux is not significantly affected by the addition of the photo-pion contribution during the VHE flare, with the peak of the flux at $\nu F_\nu = 2 \times 10^{-11}\, erg.cm^{-2}.s^{-1}$. The photo-pion component can be seen becoming more prominent at timestep 3, where the reflected photons reach the top of the emission region. The Fermi-LAT data was taken from [Böttcher et al., 2013].

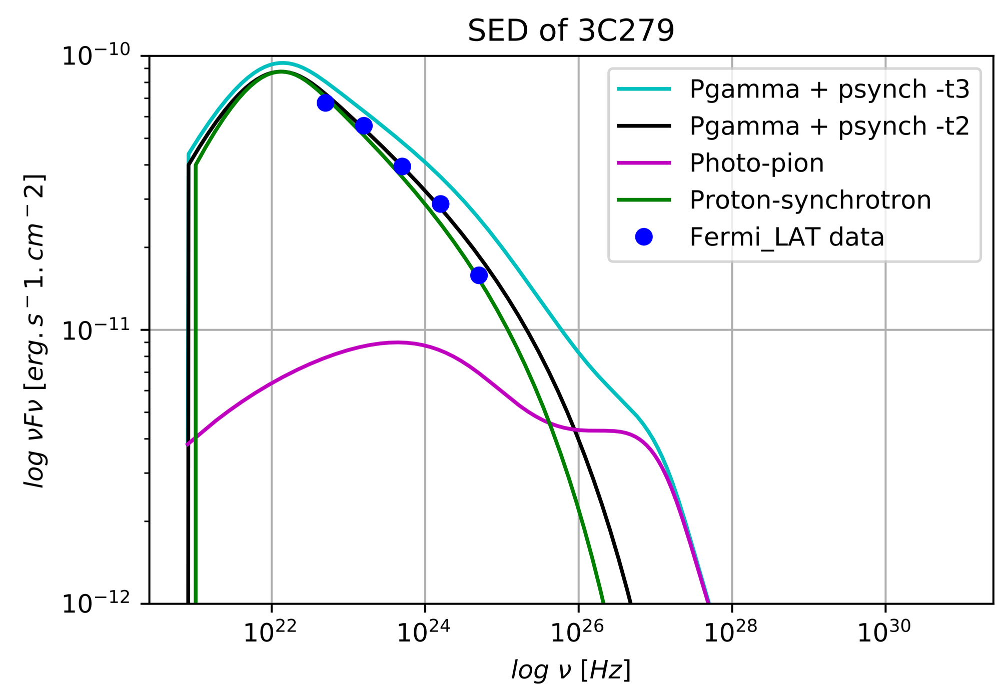

Figure 4: The SED of 3C279 produced by the pair cascades of the UHE γ-rays from the photo-pion interactions (pink line) and the proton-synchrotron component (green line), the sum of the two components (cyan line) at timestep t3, the sum of the two components (black line) at timestep t2, and the Fermi-LAT data points are plotted for reference (blue dots).

Conclusions

The expected target photon density was calculated as $280\ erg.cm^{-3}$. The target photon field was given by $35.2\ erg.cm^{-3}$ with an order of magnitude difference. Conclusively, the target photon field was dense enough for photo-pion production to take place sufficiently for its emission to be comparable to that of the Fermi-LAT flux if some of the parameters are adjusted. The BLR gas cloud acting as mirror could have a larger area or there could be a larger reflective fraction of the cloud; then, there would be no order of magnitude difference.

A numerical code was developed to evaluate the hadronic synchrotron mirror model and explore the free parameter space to look for plausible solutions that would produce the observed orphan flare. Consequently, the synchrotron mirror scenario induces a dense enough target photon field without affecting the proton-synchrotron dominated Fermi-LAT spectrum. This suggests that protons are accelerated to ultra-relativistic energies. From Figure 4 we can see how the photo-pion component is coming out above the constant proton-synchrotron radiation, consequently the hadronic synchrotron mirror model is plausible for modeling the orphan flare.

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