A hadronic synchrotron mirror model for blazars – Application to 3C279

Supervisor: Markus Böttcher

Laenita de Jonge

laenitaoberholzer@gmail.com

Abstract

Blazars show variability across the electromagnetic spectrum on a variety of time scales. In some cases, flaring events in one frequency band are not accompanied by flaring in other bands. Such events are 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 orphan gamma-ray variability, the hadronic synchrotron mirror model is suggested. We apply this model to a very-high-energy gamma-ray orphan flare of 3C279, which was observed by H.E.S.S. on the 28th of January 2018. A primary flare was observed 11 days earlier by Fermi-LAT. In our model, the Fermi-LAT spectrum is reproduced by proton synchrotron emission, which constrains the parameters of the ultra-relativistic proton population in the jet. A VHE orphan flare results from photo-pion interactions of this relativistic proton population with electron synchrotron radiation reflected back into the jet by a cloud acting as a mirror. We present both analytical estimates of the viability of the hadronic synchrotron mirror model and detailed numerical simulations. These demonstrate that a VHE orphan flare can be produced by this model, in accordance with observations, accompanied by only a very moderate Fermi-LAT flux enhancement. The photo-pion component of the spectrum is comparable in flux to that of the proton-synchrotron component in agreement with observations.

Background

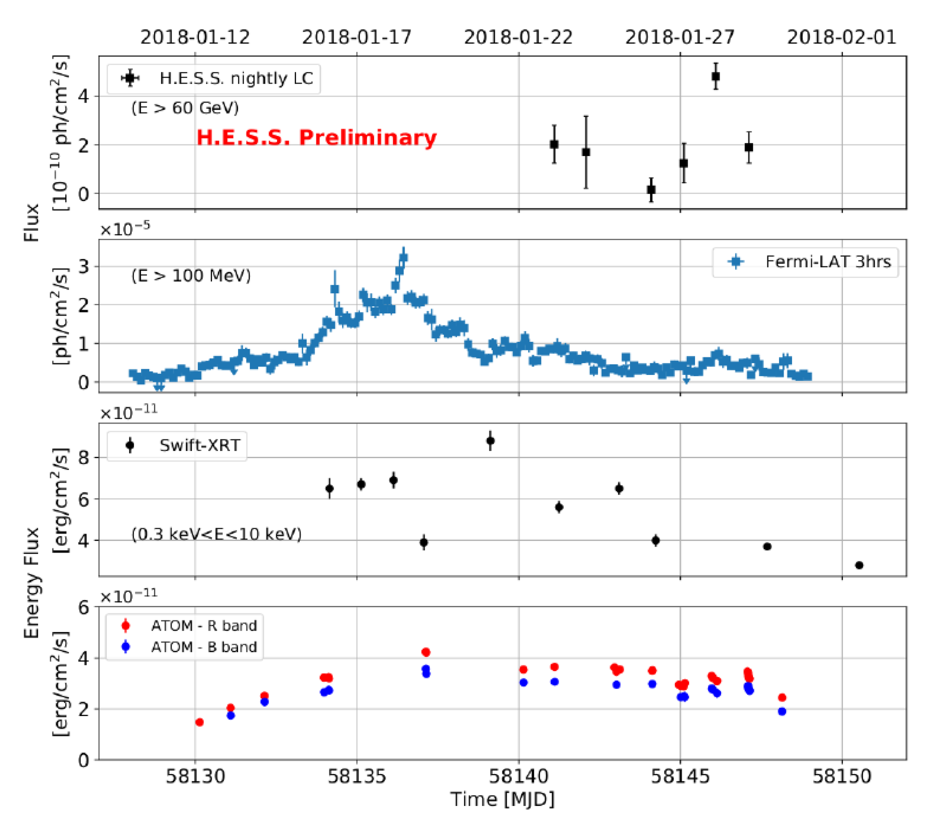
Hadronic model SED components:

- First Bump
  - Electron synchrotron
- Second Bump
  - Proton synchrotron and/or
  - Photo-pion production

$$p+\gamma \to p+\pi^0 \to p+\gamma+\gamma$$
$$or \to n+\pi^+ \to n+\mu^+ +\nu_\mu \to n+e^+ +\nu_\mu+\nu_e+\overline{\nu}_\mu$$

Orphan Flares:

- Extreme variability and flaring in different bands
- Flaring in one frequency band unaccompanied by flaring in other bands
- Orphan flares are usually secondary flares

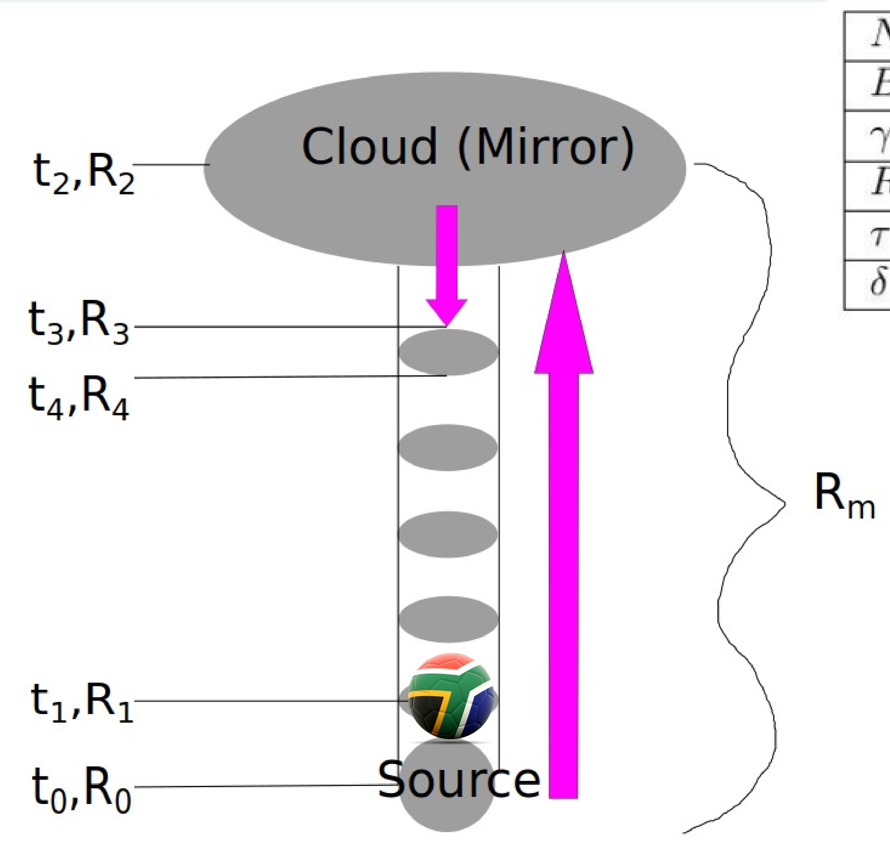


[Anton Dmytriiev, 2020]

3C279 orphan Flare:

- Eleven days after a Fermi-LAT flare was observed with counterparts in the X-ray and optical bands, an orphan flare in the VHE γ-ray band was detected.
- On 28th January 2018.
- ToO observation was ongoing because of the Fermi-LAT flare by Fermi, HESS, Swift-XRT and ATOM.
- 3C 279 is a FSRQ at a redshift of z = 0.536.

Model



N_0	2.5×10^{37}
B	$100\ G$
γ_b	9.8×10^{7}
R_{cl}	$5.5\times10^{15} cm$
τ	0.001
δ	10

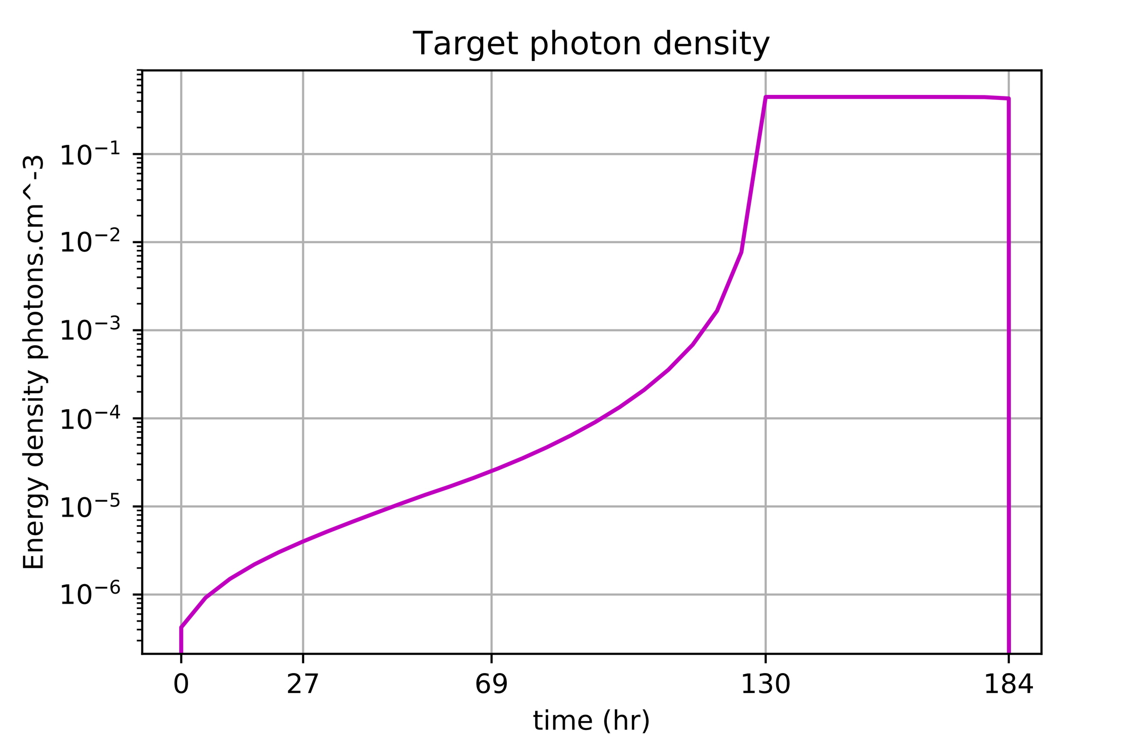
A list of the model parameters.

Important Parameters:

- The normalization of the proton spectrum
- Magnetic field
- The Lorentz factor that signifies the break in the spectrum
- Radius of the cloud
- Fraction of reflected photons
- The Doppler factor

Target photon density

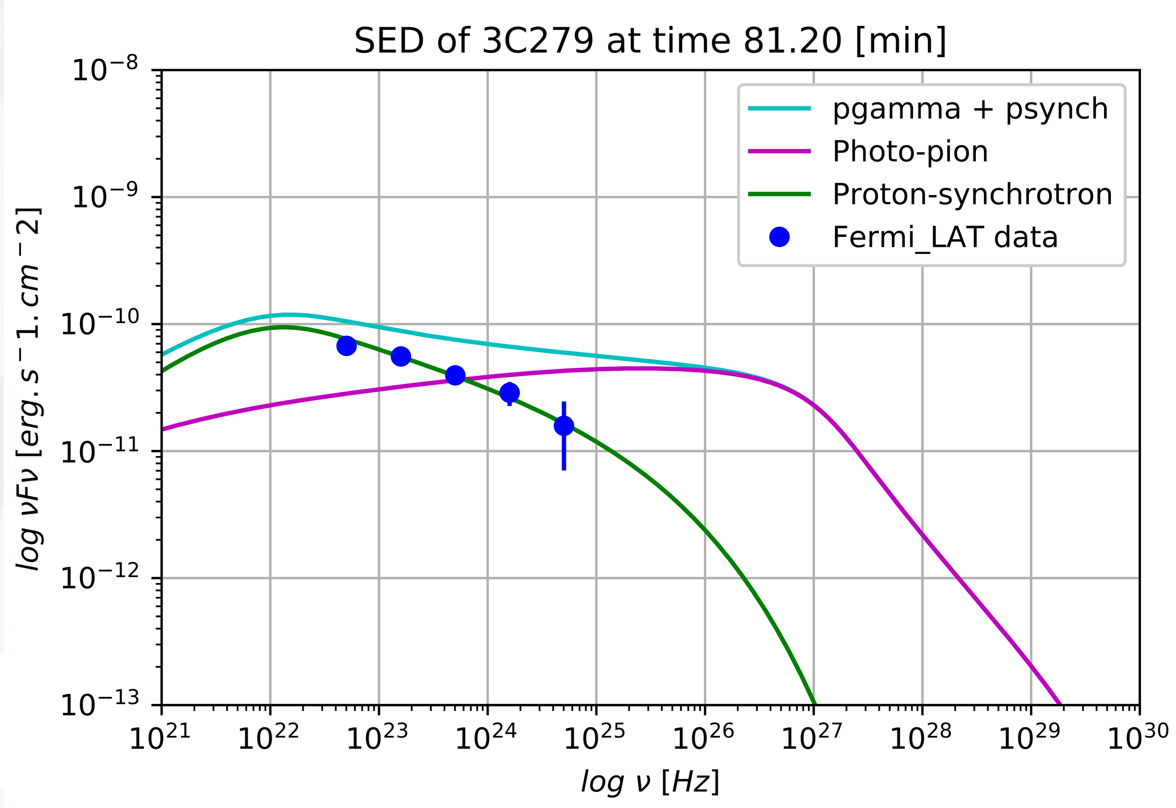
- The required target photon energy density: 280 erg·cm−3.
- Estimated target photon energy density: 35.2 erg ·cm−3
- Order of magnitude difference.
- Conclusively, the target photon field was dense enough for photo-pion production to take place.
- We can see the energy density shoot up after some time passes and then come down again after more time passes.

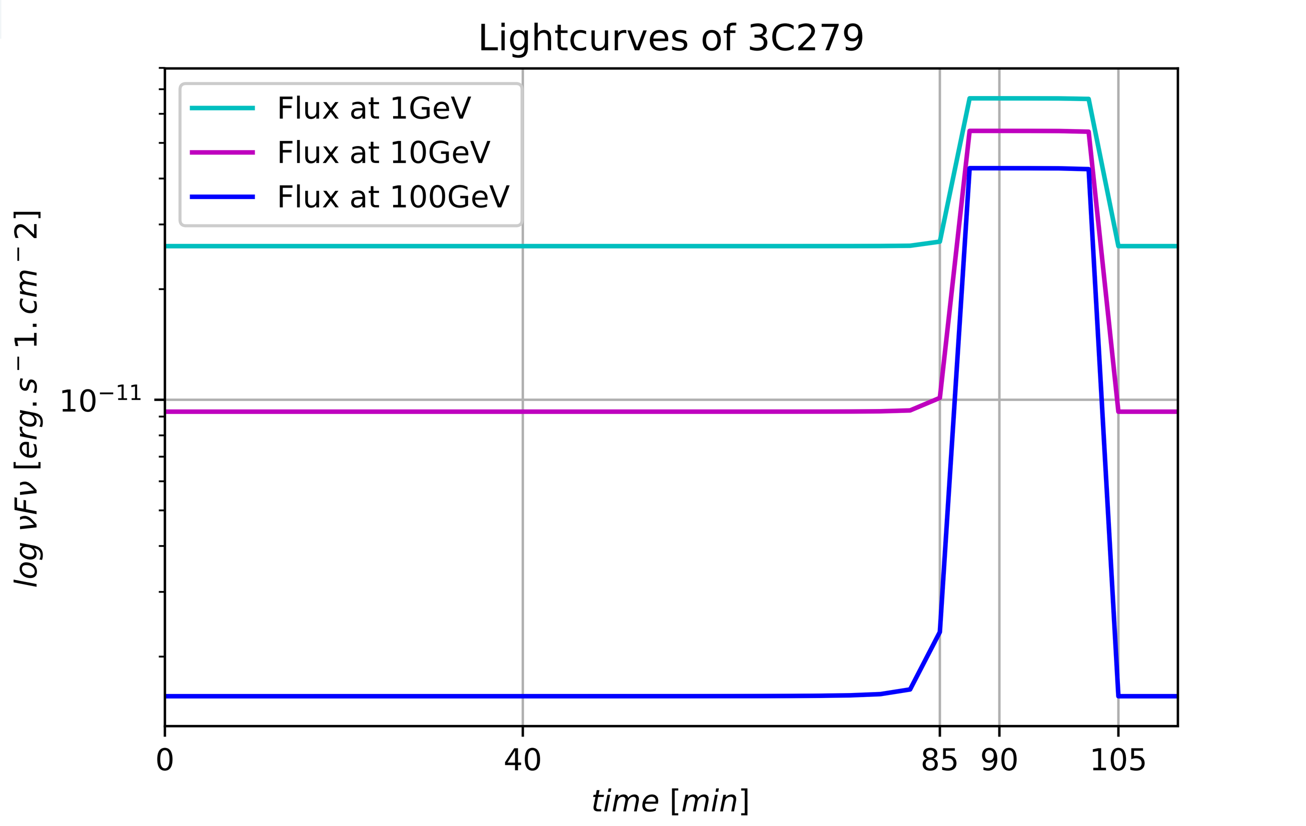


Results – SED and lightcurves

The programming steps:

1. Get the parameters describing the relativistic proton population from a proton synchrotron fit to the Fermi-LAT gamma-ray spectrum.
2. Numerical evaluation of the target photon field as a function of time.
3. Pion production and pion-decay products.
4. Calculate the γγ-opacity.
5. Calculate the resulting electromagnetic cascades to find the emerging SED.





1. $$N_p(\gamma_p)=N_0\left(\frac{\gamma_p}{\gamma_b}\right)^{-p_{1,2}}e^{-\frac{\gamma_p}{\gamma_c}}$$

2. $$\Delta u_{sy}=\frac{\Gamma^3F(t)A\Delta t}{V}$$

4. $$\tau_{\gamma\gamma}=\frac{2^{-\alpha}\sigma_T R_b n_0\epsilon_\gamma^\alpha}{3}$$

3. $$\dot{N_\gamma^{\pi_0}}(\epsilon)=\sigma_0 n_0\frac{cN_0E_\Delta}{2m_\pi c^2(\alpha+1)}\int_{max[\epsilon\frac{m_e}{m_\pi},\Gamma,\frac{E_\Delta}{2\epsilon_2 m_e c^2}]}^{\gamma_{cr,max}}d\gamma_\pi\gamma_\pi^{-(2+s)}\left(max\left[\epsilon_1,\frac{E_\Delta}{2\gamma_\pi m_e c^2}\right]-\epsilon_2^{-(\alpha+1)}\right)$$

5. $$N_e(\gamma)=\frac{1}{\nu_0\gamma^2}\int_\gamma^\infty d\tilde{\gamma}\left\{Q_e(\tilde{\gamma})+\dot{N}_e^{\gamma\gamma}(\tilde{\gamma})-\frac{N_e(\tilde{\gamma})}{t_{esc}}\right\}$$

[Böttcher and Dermer, 1998]

Luminosities

- Jet power slightly proton dominated
- Jet power is a little bit larger than the Eddington luminosity.
- This can be explained by the fact that the jet is not in a steady state, so the jet power is only larger for the duration of the flare, and then reverts back to a lower value.

$$L_p\sim\pi R_b^2c\Gamma^2\gamma_b^2m_pc^2\frac{N_0}{V_b}\sim2.1\times10^{47}\ \mathrm{erg.s}^{-1}$$

$$L_B\sim\pi R_b^2c\Gamma^2\frac{B^2}{(8\pi)}\sim9.4\times10^{46}\ \mathrm{erg.s}^{-1}$$

$$L_{Edd}=1.3\times10^{47}\ \mathrm{erg.s}^{-1}$$

Summary

- The synchrotron mirror scenario induces a dense enough target photon field.
- This model does predict a moderate flare in Fermi-LAT, but with a much smaller amplitude than that of the VHE flare.
- This suggests that protons are accelerated to ultra-relativistic energies.
- The flare duration is predicted to be about half an hour long, the runtime of one H.E.S.S. observational run.
- Fermi-LAT typically needs longer integration times than half an hour to get a significant detection of 3C279, which could explain why no flare was seen in the Fermi-LAT light curve.

[1] Anton Dmytriiev. Exploring Active Galactic Nuclei at extreme energies: analysis and modeling of multi-wavelength flares and preparation of CTA. PhD thesis, November 2020.
[2] Markus Böttcher and Charles D Dermer. High-energy gamma rays from ultra-high-energy cosmic-ray protons in gamma-ray bursts. The Astrophysical Journal Letters, 499(2):L131, 1998.