

Proton synchrotron a plausible explanation of Orphan flare of 3C 279 in 2018

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An orphan very-high-energy gamma-ray flare from 3C 279 was reported on 28 January 2018, however, it was not accompanied by a Fermi-LAT flare. This VHE orphan flare was reported by the High Energy Stereoscopic System (H.E.S.S) telescope Eleven days after the Fermi-LAT flare. Distinct mechanisms from regular gamma-ray flares must produce orphan flares. A coherent explanation for this phenomenon, the proton synchrotron, and electron synchrotron with External Compton(EC) have been put forth.

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1. Introduction

3C 279, classified as a blazar, is a particularly remarkable FSRQ located approximately at the red-shift $z=0.536$ [1], away from Earth. Blazars are a specific type of AGN, characterized by their intense emissions across the entire electromagnetic spectrum, from radio waves to gamma rays. They are known for their highly variable and polarized emissions, originating from a supermassive black hole at the centre of their host galaxy. Sometimes flare in one frequency band does not occur with the flare in other wavelengths. Such events are defined as Orphan flares.

The term "orphan flare" here refers to a unique and intriguing event observed in 3C 279 in 2018 by the High Energy Stereoscopic System (H.E.S.S) in very-high-energy (VHE). The designation "orphan" arises from the absence of a corresponding flare detected in lower-energy wavelengths. H.E.S.S reported VHE observations from the direction of 3C 279 after the 11 days of the Fermi telescope observations in HE. The time period details for observations are given in Figure 1

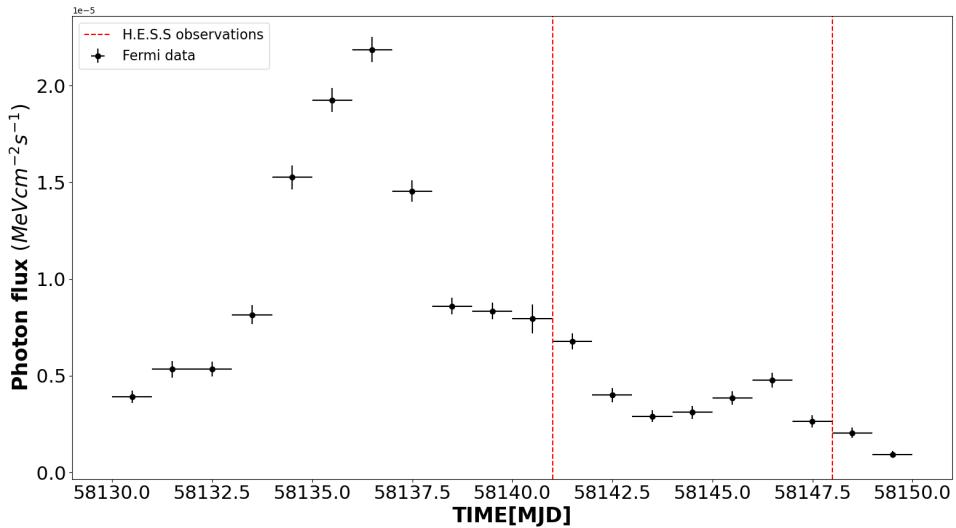


Figure 1: High-energy light curve from Fermi-LAT analysis of source during the time period MJD 58130 to MJD 58150 for the energy range 0.1 GeV to 300 GeV. The vertical red dash lines represent the time period of VHE observations reported by the H.E.S.S telescope (Atel #11239).

Many models have been put out to explain the orphan flares seen in various sources. The first TeV orphan flare energies were modelled by [2] utilising the synchrotron self-Compton (SSC) mode. A structured leptonic jet model for orphan flares was proposed by [3]. A -flare (0.1-200 GeV) from PKS 1510-089 in 2009 was subjected to the ring of fire model by [4]. Multi-wavelength modelling for orphan flares was recommended by [5]. [6] used the Hadronic Synchrotron Mirror Model for Orphan flares. Here, we propose that the proton synchrotron radiation contribution could be used to account for the temporal delay for VHE observations by the H.E.S.S telescope.

2. Methodology

We take into account a spherical blob of radius R' (prime for co-moving frame and un-prime for observer frame) in the jet where electrons and protons follow a power-law distribution with neutrality conditions. High energy FERMI-LAT analysis¹ motivated us to use log-parabola distribution for electrons.

$$N_e = N_0 (E'/E'_0)^{-(\alpha + \beta \ln(E'/E'_0))} \quad (1)$$

where N_0 normalization constant and E'_0 reference energy, these parameters are obtained from fitting. To model this source we use the "GAMERA Package"^[7]. GAMERA, an acronym for General Astrophysical Multi-purpose Environment for Research and Analysis, represents a comprehensive suite of astrophysics software that enables scientists to explore and model a wide range of astronomical phenomena. The Max Planck Institute for Nuclear Physics (MPIK) developed it. GAMERA solve the time-dependent transport equation for electrons

$$\frac{dN(E, t)}{dt} = Q(E, t) - \frac{\partial(b(E, t)N(E, t))}{\partial E} \quad (2)$$

where $Q(E, t)$ is injected spectrum and $N(E, t)$ is spectrum and $b(E, t)$ radiation loss term. To model the source for the time period MJD 58132 to MJD 58140 we take the contribution of electron synchrotron for low energy and Inverse Compton contribution from the Broad-line region and accretion disk for High-Energy (HE), and to explain the 11 days time delay from the peak of γ -rays HE Fermi flare for VHE observation by H.E.S.S telescope we consider proton synchrotron contribution from [8]. The protons follow the power-law distribution with exponential cut-off inside the blob

$$N_p(E) = N_0 (E_p/E_0)^{-\alpha_p} \exp(-E_p/E_0) \quad (3)$$

where N_0 obtain from proton luminosity and E_0 comes from fitting. The protons synchrotron cooling time is as follows

$$t_p = \frac{6\pi m_p^4 c^3}{\sigma_T m_e^2 E B} \quad (4)$$

The differential flux for proton synchrotron radiation is given as

$$J(\epsilon) = \frac{\epsilon^{-1}}{4\pi d^2} \int_0^\infty P(E, \epsilon) N_p(E) E \, dE \quad (5)$$

where $P(E, \epsilon)$ spectral distribution of synchrotron radiation from [8]

3. Result

The multi-wavelength modelling for the source using the GAMERA package is shown in Figure 2. The HE gamma-ray light curve for the energy range .1 GeV to 300 GeV during the time period 58130 MJD to 58150 MJD suggests a time delay for VHE observations reported by H.E.S.S telescope during the time MJD 58142 to 59148. The leptonic contribution to model low energy contribution from radio to HE contribution from FERMI telescope from electron synchrotron and

¹<https://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/>

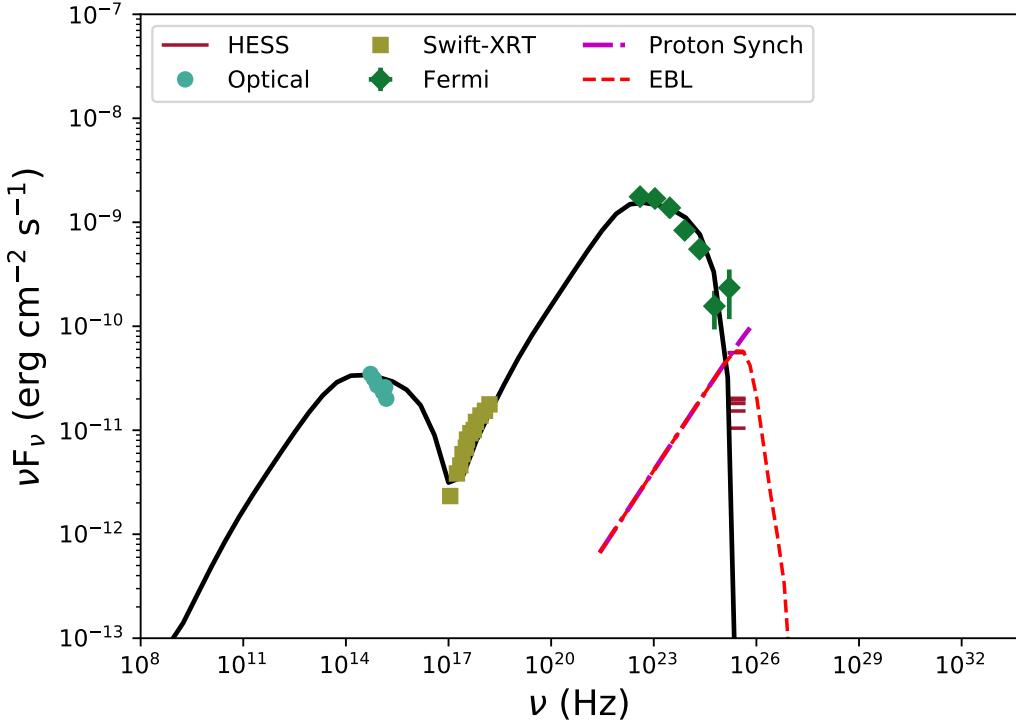


Figure 2: Lepto-hadronic modelling of source shown in the figure. The black solid line indicates the total leptonic contribution from the electron synchrotron plus external inverse Compton from the BLR region and accretion disk region photons. The Cyan sphere represents optical observation and light green rectangles are X-ray observations taken from [9]. The dark green rectangles are high-energy Fermi observations from Fermi-LAT analysis. VHE observations were taken from the light curve of 3C 279 given in [6] and we multiplied photon flux with 60 GeV and assumed constant differential flux for the whole H.E.S.S energy range(red solid-state lines). The red dashed line represents 11 days of delayed VHE observations by proton synchrotron contribution with EBL correction.

inverse Compton from BLR and accretion disk region require $\alpha_e = 1.8$, $\beta_e = .10$, $\gamma_{mine} = 400$, and $\gamma_{maxe} = 1.2 \times 4$ and radius of the blob $R' = 2 \times 16$ cm. The proton synchrotron requires $B = 2.3$ Gauss, for 11 days of delayed VHE observations. From equation (4) we found proton synchrotron cooling time is 12 days and 8 days in the observer frame for the proton energy $E'_p = 2.8 \times 10^{19}$ and $E'_p = 4.03 \times 10^{19}$ respectively.

4. Summary

On 28 January 2018, the H.E.S.S telescope reported VHE observations from the direction of FSRQ 3C 279 after 11 days of HE FERMI-LAT flare. Without any sightings in other wavelength bands, this flare was identified as a distinct flare. As a result, this is known as a TeV VHE orphan flare. In order to comprehend this TeV Orphan flare and the 11-day interval following the peak of the Fermi-LAT flare, we took proton synchrotron radiation into account. We discovered that for

magnetic field $B = 2.3$ Gauss and for the proton energy $E'_p = 2.8 \times 10^{19}$ and $E'_p = 4.03 \times 10^{19}$ in the jet frame proton synchrotron cooling time is 12 days and 8 days respectively in the observer frame.

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