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Modelling TXS0506+056 with internal $\gamma - \gamma$ secondaries

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A flare in 2017 from TXS0506+056 has 3.5σ spatial as well as temporal correlation with IceCube-170922A neutrino event above energy 290 TeV. The multi-wavelength modeling of the source is one of the viable way to figure out its energetics to produce neutrino. Several models on considering lepto-hadronic channels to produce the gamma rays and neutrino from this blazar have already been done. We report here the secondary contribution resulted from the $\gamma - \gamma \rightarrow e^+e^-$ interaction between self synchrotron (SSC) and synchrotron photon in the blazar TXS0506+056. This study would help in understanding the maximum energy of the electrons produced at the source.

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1. Introduction

Blazar is a class of Active galactic nuclei with a jet along the direction of the observer[1]. Balzar is considered an energetic source of high-energy cosmic rays. Neutrinos and gamma rays produce when these high-energy cosmic rays interact with their surroundings. Neutrinos production can demonstrate by two-mode of interaction :

$$p+\gamma \rightarrow p+n \tag{1}$$

$$p+p \rightarrow \pi^0 \rightarrow \gamma+\gamma \tag{2}$$

$$p+p \rightarrow \pi^+ \rightarrow \nu_\mu+\mu^+ \rightarrow \nu_\mu+e^++\nu_e+\nu_\mu^-$$
$$p+p \rightarrow \pi^- \rightarrow \nu_\mu^-+\mu^- \rightarrow +e^-+\nu_e^-+\nu_\mu$$

Neutrino production accompanied by gamma rays can elucidate the energetic and acceleration mechanisms of astrophysical objects.

TXS0506+056 is the first known astrophysical object which has 3.5σ temporal and spatially coincident with IceCube neutrino event 170922A[2]. Multi-wavelengths observations for the flaring state of TXS0506+056 blazar reported by Fermi-LAT[4], Magic[5], Agile[6], Hess[7], integral[13], Kanata[14], swift[11], NuStar[12]telescopes. Magic observed VHE gamma-ray between 28 September to 4 October 2017. In the initial observation, no VHE gamma was observed by magic. Magic gave an upper limit of 90 GeV for photon energy. Beyond 90 GeV statistics is not significant. Many lepto- hadronic[8][9] models have been examined for the modeling of TSX0506+056 blazar so far. However, there are many unanswered questions.

We emphasize the secondary contribution of $\gamma-\gamma$ absorption from low energy photons and high-energy photons could give information about very high-energy photons. We use the lepto-hadronic model to study the kinematics of TXS0506+056 blazar. Low energy photons are from the leptonic part of the spectral energy distribution(SED) and high-energy photons from the proton synchrotron.

2. Methodology

We consider a spherical region of radius R' inside the moving jet called a blob. The time-dependent evolution of the particles inside the blob describes as:

$$\frac{\delta N}{\delta t}=Q(E,t)-\frac{\delta(bN)}{\delta E}-\frac{N}{t_{esc}} \tag{3}$$

Where $N(E,t)$ is the number of particles at time t and b is energy loss rate and $Q(E,t)$ is source term and t is escape time of particles. The Gamera Package can use to study the time-dependent evolution of particles. The various interactions of electrons and protons can examine using the Gamera package. Gamera[16] is C++ library to study high energy astrophysical sources. It is created by Max Planck Institute for Nuclear Physics (MPIK). Doppler factor for the moving jet is

$$\delta=\Gamma_j^{-1}(1-\beta_j cos\theta)^{-1} \tag{4}$$

where θ is angle between jet axis and direction of observer and Γ_j is Lorentz factor. Prime parameters are used for the jet frame and unprime parameters are used for the observer frame.
The injected spectrum of electrons in the jet is defined as a power law

$$\frac{dN}{dE} = l_0 \left(\frac{E}{E_0}\right)^{-\alpha} \tag{5}$$

where dN/dE is number of particles in the spectrum with respect to energy and α is index parameter for electron spectrum and l_0 is the number of injected electrons particles. In the blob charge neutrality condition is valid. The spectrum of the accelerated proton is defined as power-law with the exponential cut-off.

$$N_p(E) = N_0 E_p^{-\alpha_p} exp(-E_p/E_0) \tag{6}$$

Proton synchrotron[3] can be understood by the simple replacement of m_e to m_p and E to E_p in the comprehensive study of electrons synchrotron[10]. Proton synchrotron[3] becomes a prime contribution as compared to other losses for the conditions $t_{var}\delta \geq t_{sy}$ and $t_{var}\delta \geq t_{acc}$ where t_{var} is variability time, and t_{sy} synchrotron cooling time of a proton and t_{acc} acceleration time of particles. The characteristic energy and synchrotron cooling time of a proton is

$$\epsilon_c \simeq 87\ B_{100}\ E_{19}^2\ GeV \tag{7}$$

$$t_{sy} \simeq 4.5 \times 10^4\ B_{100}^{-2}\ E_{19}^{-1}\ s \tag{8}$$

General form of acceleration time of particles is

$$t_{acc} \simeq 1.36 \times 10^4\ E_{19}\ B_{100}^{-1}\ \eta(E)\ s \tag{9}$$

where: $B_{100} = \dfrac{B}{100}\ G$ and $E_{19} = \dfrac{E}{19}\ GeV$

The characteristic radiation time of synchrotron photon is defined as

$$t_{sy}(\epsilon) = 2.5 \times 10^5\ B_{100}^{-3/2}\ (\epsilon/1GeV)^{-1/2}\ s \tag{10}$$

Differential synchroton radiation flux in delta approximation:

$$J(\epsilon) = A\ \epsilon^{-\Gamma}\ \exp(-(\epsilon/\epsilon_0)^{1/2}) \tag{11}$$

$$A = \left(\frac{N_0}{48\ \pi^2\ d^2}\right)\left(\frac{\sigma_T\ B^2\ m_c^2}{m_p^4\ c^3}\right)\ a^{(\alpha_p+1)/2}\ \delta_j^{(\alpha_P+5)/2}$$

The number density of photons inside the blob can be calculated from photon flux

$$n'_j(\epsilon'_j) = \frac{2\ d_L^2}{c\ R_b'^2\ \delta^2\ \Gamma^2} \frac{f_{\epsilon_j}}{m_e\ c^2\ \epsilon_j'^2} \tag{12}$$

where $\epsilon_j = \delta\ \epsilon'_j\ /(1+z)$
ϵ is photon energy in the unit of $m_e c^2$ in observer frame and ϵ'_j is photon energy in jet frame in the

unit of $m_e c^2$ and z is redshift of blazar and d_l is the distance of blazar from earth.

Emissivity calculation:[15] To calculate the number of electrons per unit volume per unit time from the interaction of low energy γ of the leptonic part of SED with high energy γ of proton synchrotron.

$$Q'_{e,\gamma\gamma}(\gamma'_e) = \frac{3\,\sigma_T\,c}{32}\int_{\gamma'_e}^{+\infty} d\epsilon'_\gamma \frac{n'_\gamma(\epsilon'_\gamma)}{\epsilon'^3_\gamma}\int_a^{+\infty} d\epsilon'_j \frac{n'_j(\epsilon'_j)}{\epsilon'^2_j} \times \left[\frac{4\,\epsilon'^2_\gamma}{\gamma'_e(\epsilon'_\gamma-\gamma'_e)}\ln\left(\frac{4\gamma'_e\epsilon'_\gamma(\epsilon'_\gamma-\gamma'_e)}{\epsilon'_\gamma}\right) - 8\epsilon'_\gamma\epsilon'_j + \frac{2\epsilon'^2_\gamma(\epsilon'_\gamma\epsilon'_j-1)}{\gamma'_e(\epsilon'_\gamma-\gamma'_e)} - \left(1-\frac{1}{\epsilon'_\gamma\,\epsilon'_j}\right)\left(\frac{\epsilon'^2_\gamma}{\gamma'_e\,(\epsilon'_\gamma-\gamma'_e)^2}\right)\right] \tag{13}$$

where $a = \dfrac{\epsilon'_\gamma}{4\,\gamma'_e\,(\epsilon'_\gamma-\gamma'_e)}$

σ_T is Thomson scattering cross-section and c is speed of light and γ'_e is Lorentz factor from $\gamma-\gamma$ pair production and $n'_\gamma(\epsilon'_\gamma)$ is number density of Photons of energy ϵ'_γ using total leptonic contribution and $n'_j(\epsilon'_j)$ is number density of photons of energyϵ'_j using proton synchrotron and ϵ'_γ is low-energy Photons energy in the unit of $m_e\ c^2$(Hz) and ϵ'_γ is high-energy Photons energy in the unit of $m_e\ c^2$(Hz)and $f_{\epsilon j}$ is Observed photon flux in the unit $(erg\ cm^{-2}\ s^{-1})$

3. Result

The secondary contribution of low energy photons from the leptonic part of the SED and high energy photons from the proton synchrotron is shown in fig(1)

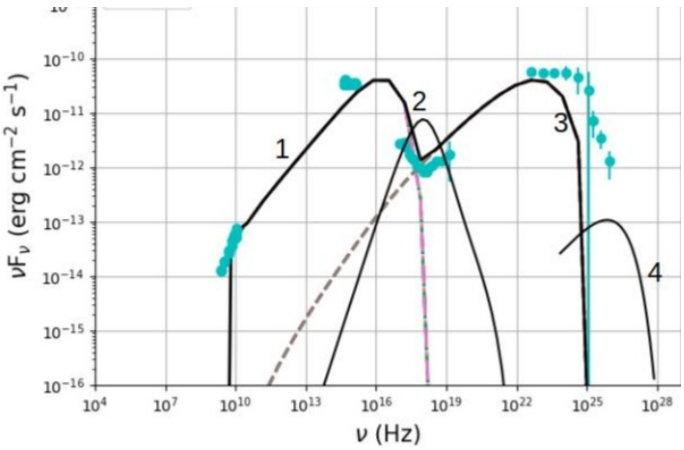

Figure 1: [The first curve characterizes electron synchrotron and the second curve denotes secondary contribution of gamma-gamma absorption and the 3rd curve shows SSC contribution and the 4th curve illustrates proton synchrotron contribution]

The protron synchrotron time equation(8) $t_{sy} \simeq 3.2\times10^5\ sec$ and the particle acceleration time equation (9) $t_{acc} \simeq 3.67\times10^4\ sec$ for $E_p = 10^{19}\ GeV$ and B= 36 $Gauss$. Hence $t_{var}\ \delta \geq t_{sy}$ and $t_{var}\ \delta \geq t_{acc}$.

Parameters used in the lepto-hadronic model are

Parameters	Value	Parameters	Value
α	1.02	$l_0\ (1/erg)$	5×10^{45}
γ'_{emin}	1300	γ'_{emax}	7×10^{3}
δ	21.5	$B\ (Gauss)$	36
z	.3365	d(pc)	1.79×10^{9}
R (cm)	9.3×10^{14}	$N_0(1/erg)$	1.31×10^{42}
γ'_{pmin}	1	γ'_{pmax}	1.06×10^{10}
α_p	2	$t_{var}\ (days)$	60

4. Summary

TSX0506+056 has been the only source to study hadronic modelling of blazar due to correlation with neutrino event. Here, we tried to understood proton synchrotron and cascade in blazars using Gamera Package.

We first modeled the low energy photons from radio to GeV γ-rays with leptonic channel. From the leptonic total energy we calculated the proton energy budget. Due to magnetic field of 36 Gauss from the modelling the proton also cool down through synchrotron. We calculated the cascade photons from these synchrotron photons and found it will contribute at the x-rays energy range.

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