Effects of emission by electron-positron pairs from gamma-ray absorption in the BLR of gamma-ray blazars on the broadband SED

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Abstract

Blazars are a class of active galactic nuclei. These objects are bright sources of radiation throughout the entire electromagnetic spectrum. The spectral energy distributions (SEDs) of some blazars have a distinct dip feature occurring in the gamma-ray energy band of 10 - 200 GeV. We have investigated this feature in the known bright blazar 3C 279 by analysing its spectrum in earlier work. Results from this analysis suggest that the optical-ultraviolet emission lines of the broad-line region (BLR) of 3C 279 contribute to the absorption of gamma rays in the observed dip energy range. We have also calculated the synchrotron self-Compton (SSC) emission from secondary electron-positron pairs from absorbed gamma rays. We find that if the magnetic field inside the jet is sufficiently high, SSC emission from the pairs has the effect of filling the SED dip. Subsequently, we derive an upper limit on the jet magnetic field.

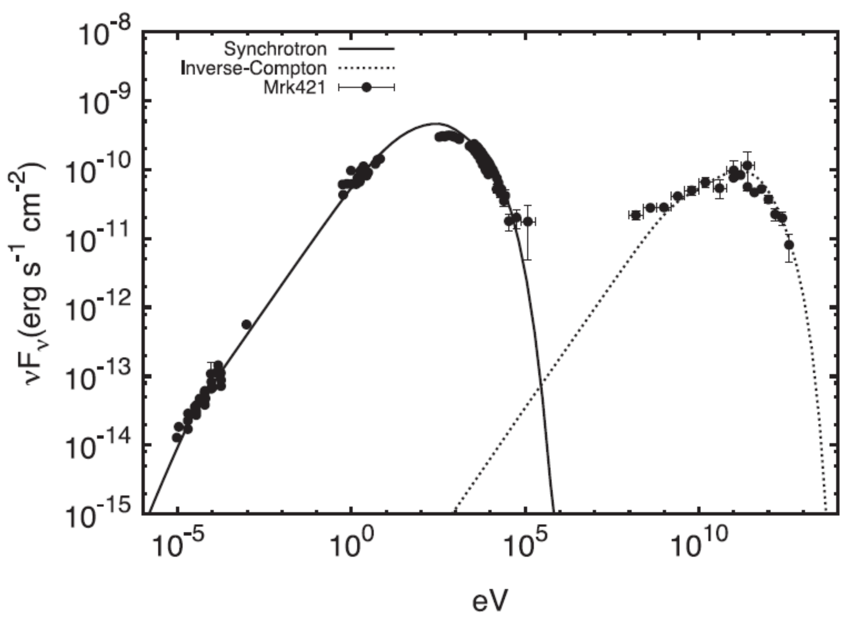
What are Blazars?

Blazars are a Subclass of Active Galactic Nuclei Characterised by:

- Extreme brightness
- Flux variability throughout EM spectrum.

Non-thermal emission with two broad peaks.

Infrared up to X-ray **Peak**	Low GeV **Peak**
• Synchrotron emission	• IC emission.

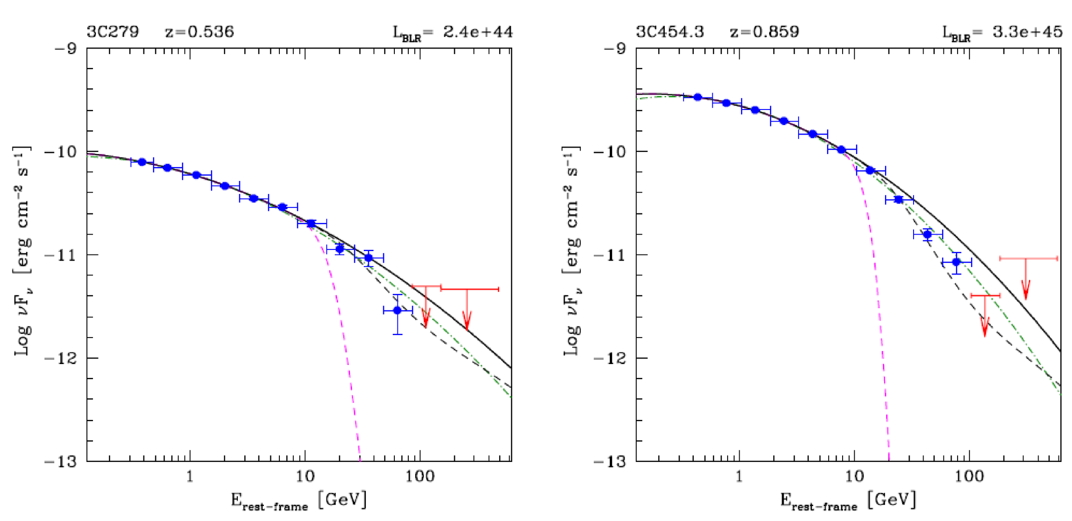


Blazars are subdivided into two subclasses: **BL-Lacertaes** and **Flat-Spectrum Radio Quasars**. Flat-Spectrum Radio Quasars (FSRQs) are characterised by:

Prominent broad emission spectral lines, pointing to the existence of a broad-line region (BLR).

"Dips" in Blazar Gamma-ray SEDs

In some blazar SEDs γ-ray absorption is observed at $\sim$ 10 to few 100 GeV.



Gamma-gamma Pair Production in the BLR

"Dips" hint to $\gamma - \gamma$ absorption of $\sim 10 - 100$ GeV gamma rays in the BLR. This interaction would produce energetic electron-positron pairs ($e^{\pm}$) that produce synchrotron self-Compton (SSC) radiation which has the potential of filling the gamma-ray "dips".

Analysis: Application to 3C 279

Consider the well-known bright FSRQ: 3C 279

- Redshift $z = 0.536$.
- $RA_{J2000} = 12^h 56^m 11.1^s$, $Dec_{J2000} = -05^d 47^m 22^s$

Analysis of 3C 279

BLR Model of 3C 279

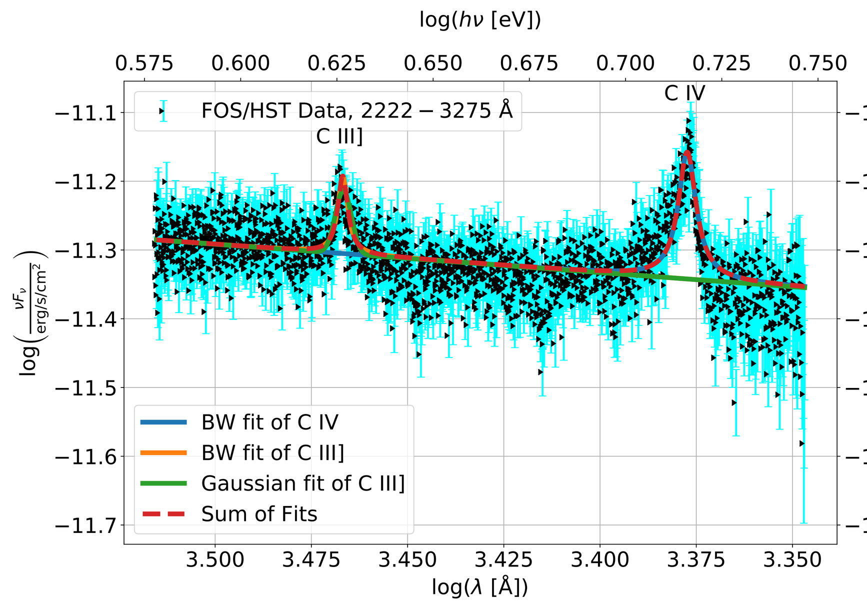
BLR fit with Breit-Wigner (BW), Gaussian (Ga) and power-law (PL).

$$PL(\epsilon) = F_0 \left(\frac{\epsilon}{\epsilon_0}\right)^{-\alpha} \tag{1}$$

$$BW(\epsilon) = \frac{n_i w_i}{2\pi}\left[(\epsilon-\epsilon_i)^2 + (w_i/2)^2\right]^{-1} \tag{2}$$

$$Ga(\epsilon) = \frac{n_i}{\epsilon_i}\exp\left[-\frac{(\epsilon-\epsilon_i)^2}{2w_i^2}\right] \tag{3}$$

BLR Fit



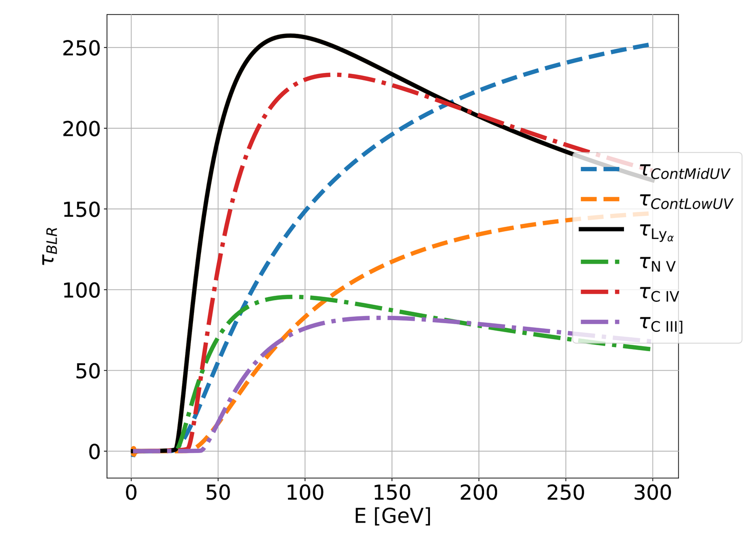
Gamma-gamma Opacity

$$R_{BLR} \propto \sqrt{\frac{L_{disk}}{10^{45}\mathrm{erg/s}}}\ \mathrm{pc} \approx 1.7\times10^{17}\ \mathrm{cm}. \tag{4}$$

where $L_{disk} = 3\times10^{45}$ erg/s for 3C 279.
Absorption per unit length from PL and BW respectively are

$$\frac{d\tau_{PL}(E)}{dx} = \frac{\pi r_e^2 L_0}{4\pi c R_{BLR}^2\epsilon_0^4}\left(\frac{m_e^2c^4}{E(1+z)}\right)^2\int_{\frac{m_e^2c^4}{E(1+z)}}^{\infty} d\epsilon\bar{\phi}[s_0(\epsilon)]\left(\frac{\epsilon}{\epsilon_0}\right)^{-(\alpha+2)} \tag{5}$$

$$\frac{d\tau_{BW,i}(E)}{dx} = \frac{r_e^2}{2}\left(\frac{m_e^2c^4}{E(1+z)}\right)^2 n_i w_i\int_{\frac{m_e^2c^4}{E(1+z)}}^{\infty}\frac{d\epsilon}{\epsilon^2}\frac{\bar{\phi}[s_0(\epsilon)]}{(\epsilon-\epsilon_i)^2+(w_i/2)^2} \tag{6}$$



Up to 180 GeV consistent with SED absorption, Ly_α line dominates all other line opacities. We use it as BLR opacity in our calculations

Gamma-ray Spectrum Model

We fit the intrinsic *Fermi* γ - ray spectrum (F_{intr}) with Log-parabola (LP).

$$F_{intr}(E) = LP(E) = F_0\left(\frac{E}{E_0}\right)^{-(\alpha+\beta\log\frac{E}{E_0})} \tag{7}$$

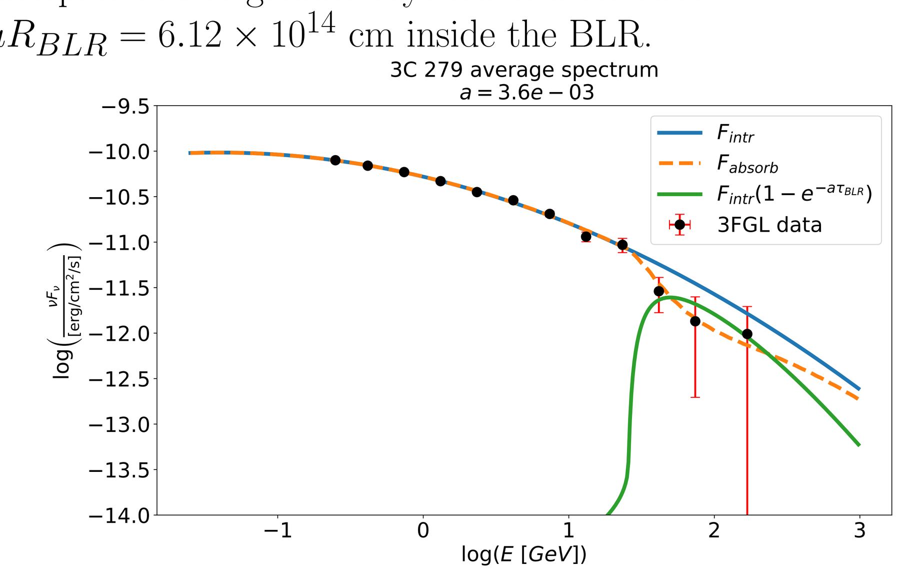
We fold with absorption, (F_{absorb}),

$$F_{absorb}(E) = LP(E)e^{-a\tau_{BLR}(E)} \tag{8}$$

where $\tau_{BLR}(E) = R_{BLR}\frac{d\tau_{BLR}(E)}{dx}$
and $0 < a < 1$ is a Free Parameter.
It is a fraction of R_{BLR} where gamma ray absorption takes place.
Gives indication about production zone of γ - rays.

Gamma-ray Fit

$a = 0.0036$ reproduces gamma-ray absorption quite well. We interpret this as gamma-rays travel a distance $aR_{BLR} = 6.12\times10^{14}$ cm inside the BLR.



$e^{\pm}$ Pair Spectrum

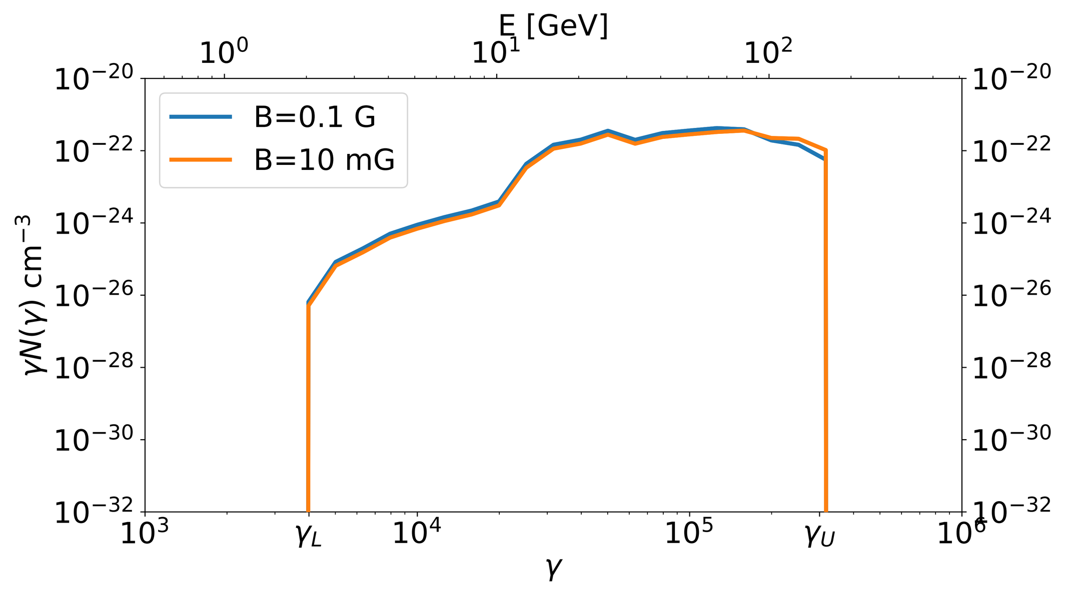
Differential electron-positron spectrum is calculated numerically from

$$\frac{dn(\gamma)}{dV\,dt\,d\gamma} = \frac{3}{32}c\sigma_T\int_\gamma^\infty d\epsilon_1\frac{n_{SED}(\epsilon_1)}{\epsilon_1^3}\int_{\frac{\epsilon_1}{4\gamma(\epsilon_1-\gamma)}}^\infty d\epsilon_2\frac{n_{BLR}(\epsilon_2)}{\epsilon^2}g(\epsilon_2,\epsilon_1,\gamma) \tag{9}$$

where

$$g(\epsilon_2,\epsilon_1,\gamma) = \frac{4\epsilon_1^2}{\gamma(\epsilon_1-\gamma)}\ln\frac{4\epsilon_2\gamma(\epsilon_1-\gamma)}{\epsilon_1} - 8\epsilon_1\epsilon_2 + \frac{2\epsilon_1^2(2\epsilon_1\epsilon_2-1)}{\gamma(\epsilon_1-\gamma)} - \left(1-\frac{1}{\epsilon_1\epsilon_2}\right)\frac{\epsilon_1^4}{\gamma^2(\epsilon_1-\gamma)^2}$$

We plot $t(\gamma,B)\gamma\frac{dn}{dV\,dt\,d\gamma}$



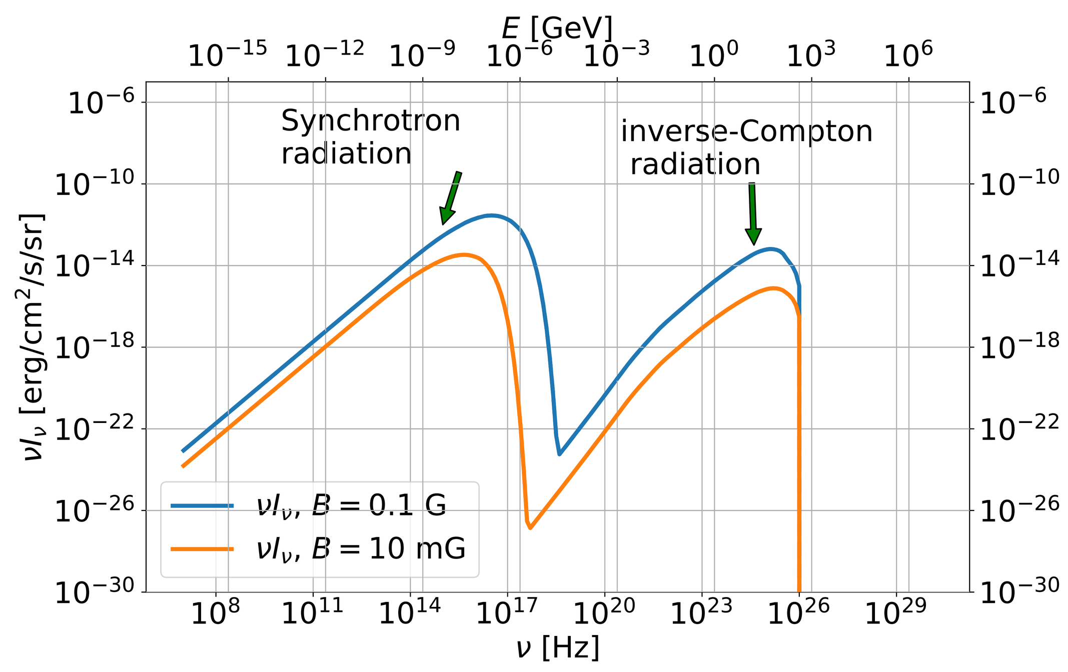
where $t(\gamma,B) = \min[t_{inj}, t_{cool}(\gamma,B)]$.

SSC from $e^{\pm}$ Pairs

We calculate secondary SSC emission by adapting SSC Model for Blazars developed by Chiaberge and Ghisellini, 1999 to our models.
Where $\mathbf{I}_{S/C}(\nu)$ is **intensity** of synchrotron or inverse-Compton radiation resulting from cooling of $e^{\pm}$ pairs.

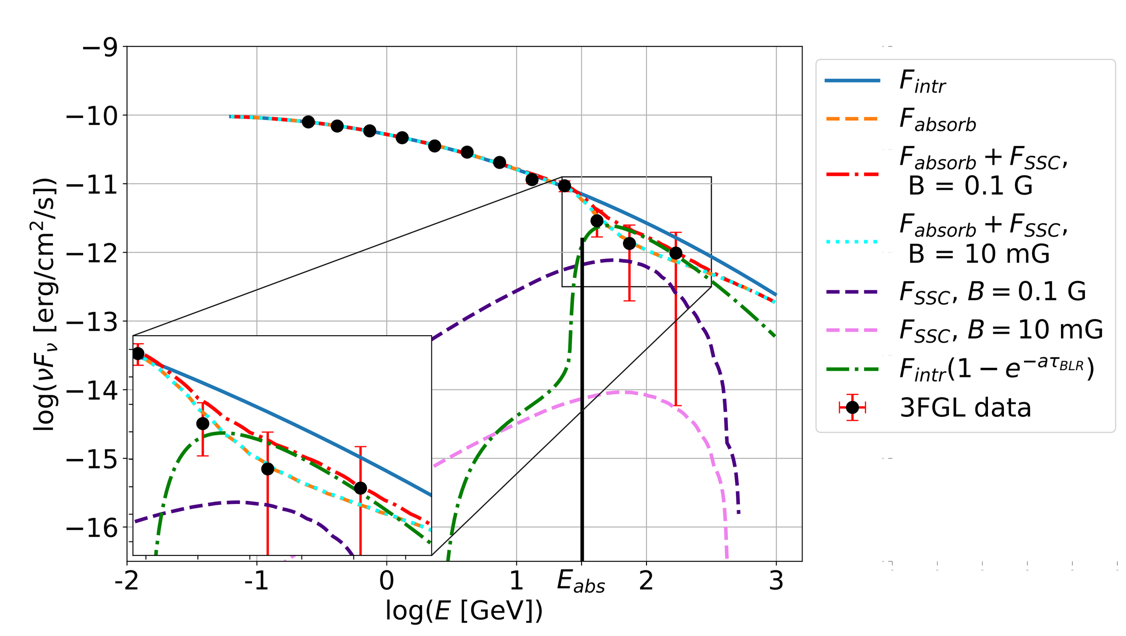
$$I_S(\nu) = \frac{R_{BLR}}{4\pi}\int_{\gamma_{min}}^{\gamma_{max}} d\gamma\frac{dn(\gamma)}{dV\,dt\,d\gamma}t(\gamma,B)P_S(\nu,\gamma) \tag{10}$$

$$I_C(\nu_1) = R_{BLR}\frac{\sigma_T}{4}\int_{\nu_0^{min}}^{\nu_0^{max}}\frac{d\nu_0}{\nu_0}\int_{\gamma_1}^{\gamma_2}\frac{d\gamma}{\gamma^2\beta^2}\frac{dn(\gamma)}{dV\,d\gamma}f(\nu_0,\nu_1)\frac{\nu_1}{\nu_0}I_S(\nu_0) \tag{11}$$



Effect of $e^{\pm}$ SSC Emission

$F_{intr}(E) \geq F(E) \equiv F_{absorb}(E) + F_{SSC}(E)$



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