Electromagnetic cascades propagating from low-redshift blazars

Orellana M.[1,2] Pellizza, L.J.[2,3] Romero, G.E.[2,3] Tueros, M.[2,3] Medina, M.C.[2,3] Pedrosa, S. [2,4]

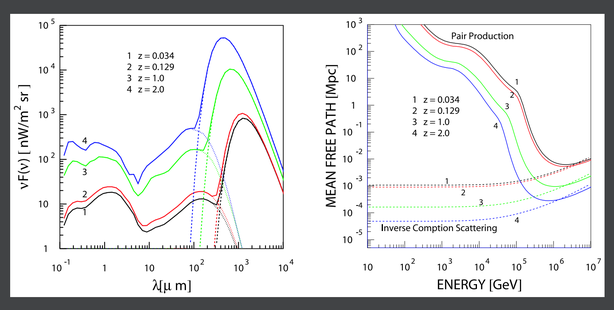
[1] Sede Andina de la Universidad Nacional de Río Negro [2] Consejo Nacional de Investigaciones Científicas y Tecnológicas (CONICET)
[3] Instituto Argentino de Radioastronomía (IAR) [4] Instituto de Astronomía y Física del Espacio (IAFE)

It has been established that the Extragalactic Background Light (optical to infrared wavelengths) attenuates the very high-energy photons emitted by blazars through pair production. The pairs are deflected by the Extragalactic Magnetic Field (EGMF) and cooled down by Inverse Compton scattering with the CMB photons while they develope an electromagnetic cascade. The originally emitted spectrum, the source extent and the arriving time of the photons are modified by such cascades. In order to study this problem we assume the blazar original emission to follow a power-law with exponential cutoff, and track the three-dimensional trajectories of each particle and photon in the cascade. Here we report on the status of our numerical simulations regarding the gamma-ray propagation through ~ 100 Mpc scales, making focus on the construction of the outcomming spectrum which is the result of the energy conservation and thus combines the information from the different channels of energy losses. Distinct spectra arise when varying the EGMF strength.

Gamma-ray opacity

Diffuse radiation fields permeate the Universe at all wavelengths. The diffuse light spanning the UV to far-IR wavelengths, termed the Extragalactic Background Light (EBL), is second in intensity only to the CMB. The EBL is a source of the VHE gamma-ray opacity in the Universe that results in $e^{\pm}$ pair creation. This is a largely studied problem (e.g. Protheroe 1986). Over a wider energy range the pairs interact with the CMB, as it is denser and there is no threshold energy for the Inverse Compton scattering. The gamma-ray optical depth is redshift dependent through

$$\tau\left(E_\gamma, z\right) = \int_0^z \mathrm{d}z' \frac{\mathrm{d}l}{\mathrm{d}z}(z') \int_0^{+\infty} \mathrm{d}E_{\mathrm{EBL}}\, n(E_{\mathrm{EBL}}, z') \times \int_{-1}^{1} \mathrm{d}\mu \frac{1-\mu}{2} \sigma(E_{\mathrm{EBL}}, E_\gamma \times (1+z'), \mu),$$

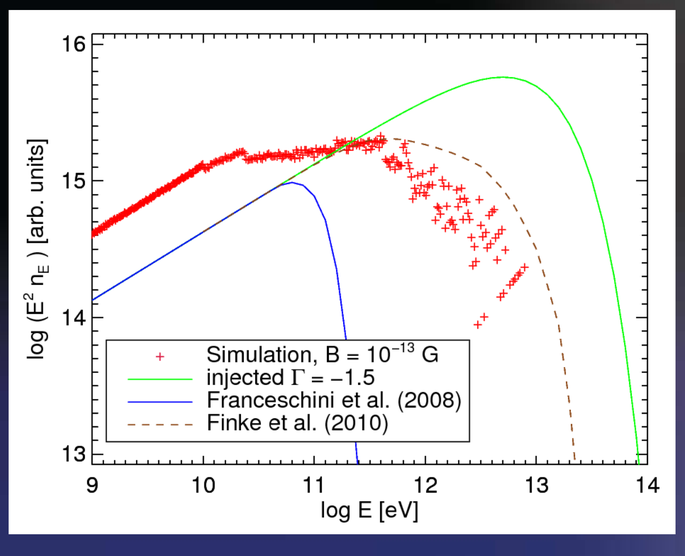


Results by Eungwanichayapant, A., & Aharonian, F. 2009. Left: EBL at different redshifts; Right: mean free paths of *gamma*-rays due to pair production and electrons due to the inverse Compton scattering at different epochs.

where the distance element is $\mathrm{d}l/\mathrm{d}z = c/H_0(1+z)\sqrt{\Omega_\Lambda + \Omega_m(1+z)^3}$ and , μ is the cosine of the angle between the momenta of two interacting photons, and σ is the pair creation cross section. A similar expression is valid for the IC. Note that a variety of EBL models do exist. The figure show opacity curves from the literature. But simple absorption calculations are often inadequate, because the secondary pairs continue to interact with background fields, developing cascades.

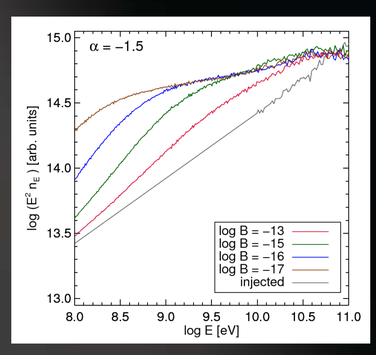
Simulations

Reprocessing of VHE photons from a putative blazar located at 600 Mpc, similar to the blazar 1ES 0229+200, which over recent years has become one of the primary sources used to put constraints on the EBL as it was detected by HESS, and has a weak Fermi detection. The injected spectrum follows a cut-off power-law with photon index $\Gamma = 1{,}5$ and $E_{\mathrm{cut}} = 10$ TeV, similar to the study performed by Vovk et al. (2012).



The injected and absorbed SEDs are shown in continuous lines. The EBL model by Franceschini et al (2008) was adopted in this case. The mean postprocessed spectra for an EGMF $B = 10^{-13}$ G is shown. It is expected to be more noisy at the highest energies considered. If a larger number of initial photons (in this case $\sim 10^4$) is considered, the noise can be reduced.

SED construction



The outcomming photons are binned in energy, being also posible to consider their temporal or spatial distributions. Total energy conservation is considered in order to plot in cosistent way the injected and reprocessed SEDs. The cooling of leptons through synchrotron radiation is responsible of the variation of the spectral distribution at GeV energies with the magnetic field stregth. Results from other testing runs illustrate this effect.

Prospects

Future observations with ground-base Cherenkov telescopes, such as MAGIC Stereo, HESS 2 and CTA, will dramatically improve the measurements of blazar spectra below 100 GeV, allowing much better constraints on the EGMF and EBL. According to these expectations we are currently engaged in the tune of our code for the investigation of VHE radiation reprocessing. The code will allow the simulation of the spectrum of gamma-ray sources in arbitrary environments, using ab-initio computations, eliminating as many simplifying assumptions as possible. We plan to use this tool to simulate different astrophysical sources.

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Contact: Mariana Orellana (morellana@unrn.edu.ar)