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Hard VHE γ-ray spectra in blazars

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In this contribution we discuss the problem of the hard-spectrum VHE sources and their possible interpretation within leptonic models. Blazars can be strong TeV emitters and these TeV photons can interact with the infrared photons of the extragalactic background light (EBL) via the process $\gamma\gamma \rightarrow e^+e^-$, as they travel over cosmological distances to the observer. This mechanism results in a modification of the observed flux with respect to the intrinsic one in the sense that the observed spectrum appears softer than it is intrinsically. The problem is that in some cases the unabsorbed, EBL-corrected spectrum seems very hard, even when only corrected for low EBL flux levels.

Characteristic cases concern the blazars 1ES 1101-232 at $z = 0.186$ and 1ES 0229+200 at $z = 0.14$ for which, intrinsic photon indices $\Gamma \lesssim 1.5$, ($\Gamma = \alpha + 1$, where α is the spectral index, $F_\nu \propto \nu^{-\alpha}$) have been inferred. In addition, a recent analysis of Fermi LAT data for the nearby TeV blazar Mkn 501 reported a hard γ-ray flare spectrum ($\Gamma \simeq 1.1$) at lower (10- 200 GeV) energies, thereby providing strong evidence for hard intrinsic spectra independently of questions related to the EBL.

Here we investigate possible interpretations within a standard leptonic approach. Methodologically, it seems necessary for us to first examine "conventional" radiation and acceleration mechanismsm that have often been successful in interpreting blazar observations, before adopting very different and often more extreme solutions. In the leptonic scheme, hard spectra should derive from hard electron distributions. This could occur in particle acceleration scenarios where a power-law index less than 2 is generated, or if one considers particle distributions with a high value of the low-energy cut-off γ_{min}. In the latter case the hardest possible TeV spectra follows $F_\nu \propto \nu^{1/3}$ in standard synchrotron self-Compton scenarios, as the Compton spectrum reflects the synchrotron emissivity for energies related to the cut-off and lower. In an External Compton model the limiting case is $F_\nu \propto \nu$, revealing the behavior of the Compton emissivity function.

However, any hard injection spectrum of electrons, even a monochromatic one, is normally expected to quickly undergo radiative (synchrotron or Thomson) cooling and thereby develop a standard E_e^{-2}–form with corresponding IC (Thomson) γ-ray photon spectrum $E_\gamma^{-1.5}$. However, for the TeV regime suppression of the cross-section due to Klein-Nishina effects usually leads to even steeper spectra ($\Gamma > 1.5$) at TeV energies. A time-depended approach is needed in order to examine the possibilities fir mainting a hard electron distribution in the presence of energy losses.

As it turns out, one promising possibility is to take adiabatic losses due to an expansion of the source into account. When the energy scale at which adiabatic losses start to dominate over radiative losses is close to the minimum cut-off, then a flat electron distribution $N_e \propto \gamma^0$ can be formed. In such a case the emission of the $\gamma_{\rm min}$-electrons dominates at low energies for all times and the hard TeV spectrum is maintained while energy losses modify the injected electron distribution.

Perhaps the most interesting possibility in the presence of radiative losses is represented by stochastic acceleration scenarios. When acceleration is balanced by synchrotron or Thomson losses, then a relativistic Maxwell-like distribution arises as steady-state solution of the corresponding Focker-Planck equation. Remarkably, these distributions produce spectra similar to the ones obtained for δ-functions. In this case, hard steady-state TeV spectra can be achieved, capable of successfully interpreting even the most extreme sources known to date.

Our results illustrate that even within a leptonic synchrotron-Compton approach relatively hard intrinsic TeV source spectra can be accounted for under a variety of conditions. This outcome

PoS(AGN 2011)005

is likely to be of interest for CTA and plans to disentangle the effects of instrinsic and extrinsic absorption.

More details on the results presented here can be found in: Lefa, E. et al. 2011, ApJ 740, 64.

PoS(AGN 2011)005