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Testing cascade models of extragalactic gamma-ray propagation using observations of extreme TeV blazars with imaging Cherenkov telescopes

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Recent observations made by imaging Cherenkov telescopes have found a pile-up in the TeV region of some blazar spectra in the optically thick regions (optical depth in this case is the measure of absorption of primary gamma rays on extragalactic background light (EBL) due to the $\gamma\gamma \rightarrow e+e-$ process). This pile-up is not consistent with the predictions of the commonly-used models which include only absorption of primary photons and adiabatic losses. We believe that this "anomaly" may be accounted for if certain mechanisms such as electromagnetic (EM) cascade development are taken into consideration. There are three distinct regimes of cascade development depending on the energy of the incident particle. If this energy is high enough, then there are several generations of cascade particles and the observable spectrum is practically independent of the energy and type (electron/photon) of the primary particle but it depends on the distance to the source (the so-called universal regime). If that energy is comparatively low, the number of generations decreases and the spectrum becomes dependent on both energy and type of the primary particle (one-generation regime). The third possible regime is the "extreme Klein-Nishina regime" in which electrons transfer most of their energy to the background photons via inverse Compton scattering process (this regime may take place at ultrahigh energies of primary photons, E>1 EeV). In our work we, for the first time, consider in detail the "one-generation regime", the universal regime and the transition between them. In this talk we will mainly focus on the so-called hadronic cascade models, in which primary protons create secondary photons by means of pair-production and photopion processes and these photons, in turn, initiate EM cascades. We will compare the results obtained in hadronic and electromagnetic cascade models (in the latter primary particles are photons instead of protons) and provide formal best fits for these models to the widely available data from the HESS and VERITAS experiments (which has never been done before). The sample of observations used in our work includes 6 blazars with hard spectra. In addition to that, to calculate observable spectra for the case of hadronic models, we will introduce a fast and reasonably accurate hybrid method using a large pre-computed database of cascades from primary electrons and photons. We also, for the first time, consider a possibility that the beam of primary protons is affected by an intervening galaxy clusters near the source and on the way from the source to the observer. For the first case, we perform a detailed statistical analysis for the case of blazar 1ES 0229+200 using the emission model of Tavecchio (2013) and show that this model is excluded with significance > 5σ unless the magnetic field strength near the source of protons is much lower than 100 nG. Finally, we show that the intermediate cluster may significantly affect both shape and normalization of the observable spectrum.

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