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Numerical Study of Ultra-High-Energy Cosmic-Ray Propagation and Cosmogenic Neutrinos

This work investigates the cosmological propagation of ultra-high-energy cosmic-ray (UHECR) protons and the associated production of cosmogenic neutrinos. We model the interaction of UHECRs with the cosmic microwave background (CMB) and the extragalactic background light (EBL), including adiabatic energy losses, electron–positron pair production, and photopion production. A Python-based numerical solver is developed to evolve the coupled proton and neutrino transport equations over cosmological redshift using vectorized matrix operations. The resulting spectra at Earth allow us to study the attenuation of the UHECR proton flux, the emergence of the high-energy suppression associated with photopion interactions, and the corresponding production of cosmogenic neutrinos. In addition, the contribution of different source-redshift intervals is analyzed to investigate the cosmological origin of the observed proton and neutrino fluxes.

Primary author(s) : Mr ZEGARRA CHAVEZ, Nick Samuel (Universidad Nacional de Ingeniería)

Co-author(s) : Dr BUSTAMANTE RAMIREZ, Mauricio (Niels Bohr Institute)

Presenter(s) : Mr ZEGARRA CHAVEZ, Nick Samuel (Universidad Nacional de Ingeniería)

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