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Neutrinos and Gamma Rays from the First Ultra-High Energy Cosmic Rays in the Universe

Population III stars, the very first, metal-free stars to form in the Universe, may give rise to gamma-ray bursts (GRBs) with much greater energy compared to ordinary GRBs. Such Pop III GRBs can produce ultra-high energy cosmic rays (UHECRs) with a correspondingly larger energy budget. Despite their typically high redshifts (z˜10-20) and modest expected burst rates, the consequent cosmogenic neutrino flux due to the interactions of these UHECRs with cosmic background radiation fields may be potentially observable. Employing different available models for the Pop III GRB rate, we show that current upper limits from IceCube-40 may already rule out the most optimistic combinations of GRB energetics and formation rate. Future observations by the completed IceCube or KM3NeT may possibly detect the neutrinos and distinguish them from the lower-redshift contribution through their spectra. We also evaluate the accompanying flux of cascade gamma rays and discuss the constraints from current Fermi LAT measurements. Such neutrinos and gamma rays can provide a unique and important probe of the very first UHECRs that appear in the Universe.

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