Modeling The Spectrum And Composition of Ultra-High-Energy Cosmic-Rays Using Two Extragalactic Source Populations

Saikat Das[a,*] · Soebur Razzaque[b] · Nayantara Gupta[a]

[a]Astronomy & Astrophysics Group, Raman Research Institute, Bangalore 560080, India
[b]Centre for Astro-Particle Physics (CAPP) and Department of Physics, University of Johannesburg, P.O. Box 524, Auckland Park 2006, South Africa

A mixed composition of light-to-heavy nuclei elements (^{1}H, ^{4}He, ^{14}N, ^{28}Si, ^{56}Fe) at injection fits the ultrahigh-energy cosmic ray (UHECR; $E > 10^{17}$ eV) spectrum data measured by the Pierre Auger Observatory, beyond the ankle, i.e., $E \gtrsim 5 \times 10^{18}$ eV. The simulated $\sigma(X_{\rm max})$ in the one-population model indicates that the addition of a light nuclei component up to the highest observed energies can improve the combined fit of the UHECR spectrum and composition. We consider the light nuclei to originate from a discrete source population consisting of protons (^{1}H). We constrain the maximum allowed proton fraction at the highest-energy bin at 3.5σ statistical significance, which ranges from 12.5% – 17.5% for proton injection spectral index $2.2 \leq \alpha \leq 2.6$. Thus, a non-zero proton fraction is inevitable. Although a positive evolution index is preferred in the one-population model, the best-fit value changes sign in the two-population model. Only the sources within $z \lesssim 1$ are considered because UHECRs from higher redshift contribute below the ankle due to increased photodisintegration. Including the redshift evolution of sources as a free parameter further improves the composition fit. We find that low-luminosity gamma-ray bursts match the best-fit evolution index in the case of the one-population model. Active galactic nuclei are the plausible candidates for light nuclei injection in the two-population model, whereas tidal disruption events can inject heavy nuclei composition. We also present the secondary neutrino flux in one- and two-population models, constraining the composition at highest energies. The cumulative neutrino spectrum in the two-population model at $E \gtrsim 0.1$ EeV is dominated by GZK neutrinos from $p\gamma_{\rm CMB}$ interactions due to the high values of $E_{\rm max}$ for protons, near the Δ-resonance threshold.

*Speaker