CRA 2023
sixth Cosmic Ray Anisotropy Workshop
May 16-19, 2023
Loyola University - Chicago

Contribution ID: **47** Type: **not specified**

The curious maximum-rigidity distribution of ultra-high-energy-cosmic-ray accelerators

Thursday, 18 May 2023 12:15 (30 minutes)

A standard assumption among models of candidate source populations of ultra-high energy cosmic rays (UHECRs) is that all sources in a candidate source population accelerate particles to the same maximum energy. Motivated by the fact that candidate astrophysical accelerators exhibit a vast diversity in terms of their relevant properties, such as luminosity, Lorentz factor, and magnetic field strength, we study the compatibility of a population of sources with non-identical maximum cosmic-ray energies with the observed energy spectrum and composition of UHECRs at Earth. For this purpose, we compute the UHECR spectrum emerging from a population of sources with a power-law, or broken-power-law, distribution of maximum energies applicable to a broad range of astrophysical scenarios. We find that for a wide range of studied models, the maximum energies of the UHECR accelerators must be nearly identical in order to be compatible with the UHECR data, in stark contrast to the variance expected for the astrophysical source models considered. A substantial variance of the maximum energy is only consistent with the UHECR data if the maximum energies of the UHECR sources follow a broken power-law distribution with a very steep spectrum above the break. However, in this scenario, the individual source energy spectra must be unusually hard with increasing energy output as a function of energy. These findings have implications for the arrival-direction distribution of UHECRs.

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