Contribution ID: **42** Type: **oral**

Observational constraints on cosmic-ray escape from ultra-high energy accelerators

Tuesday, 26 July 2022 14:45 (15 minutes)

The energy spectrum and mass composition of ultra-high energy cosmic rays inferred at the Pierre Auger Observatory are used to derive a benchmark scenario for the emission mechanisms at play in extragalactic accelerators as well as for their energetics and for the abundances of elements in their environments. Assuming a distribution of sources following the density of stellar mass, the gradual increase of the cosmic ray mass number observed on Earth from $\simeq 2$\:EeV up to the highest energies is shown to call for nuclei accelerated up to an energy proportional to their electric charge and emitted with a hard spectral index. In addition, the inferred flux of protons down to $\simeq 0.6$\:EeV is shown to require for this population a spectral index significantly softer than that of heavier nuclei. This is consistent with in-source interactions that shape the energy production rate of injected charged nuclei differently from that of the secondary neutrons escaping from the confinement zone. Together with the inferred abundances of nuclei, these results provide constraints on the radiation levels in the source environments. Within this scenario, an additional component that falls off steeply with increasing energy up to the ankle feature is necessary to make up the all-particle flux in the sub-ankle energy range.

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Session Classification: Parallel 1

Track Classification: CRI