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Ultra-high-energy cosmic rays from ultra-fast outflows of active galactic nuclei

We investigate ultra-fast outflows (UFOs) of active galactic nuclei (AGN) as potential sites for the production of the highest-energy cosmic rays, focusing on cosmic-ray nuclei, a previously unexplored aspect. These mildly-relativistic large-scale outflows, with velocities reaching up to half the speed of light, are ubiquitous in AGN. We numerically study the processes that affect the maximum energy of the cosmic rays with 3D CRPropa simulations of the vicinity of the AGN. We then apply our method to 87 observed UFOs. We find that the studied UFOs can accelerate iron nuclei to $\sim 10^{20}$ eV, but only a small fraction of these sources allow the nuclei to escape, owing to photonuclear interactions with the intense photon fields within the AGN. The expected flux suppression limits the viability of UFOs as the sources of the observed ultra-high-energy cosmic-ray nuclei, although an intermittent escape during low emissivity states of the associated AGN may be possible. The vast majority of the investigated outflows mainly allows protons and neutrons, which are either primary or byproducts of photodisintegration, to escape due to a lower number of interactions. We conclude that UFOs can supply the protons below the ankle of the cosmic-ray spectrum, making them intriguing source candidates for this component of the observed flux.

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