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

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We investigate ultra-fast outflows (UFOs) in active galactic nuclei (AGN) as potential sources of ultra-high-energy cosmic rays (UHECRs), focusing on cosmic-ray nuclei, an aspect not explored previously. These large-scale, mildly-relativistic outflows are a common feature of AGN. We study the cosmic-ray spectrum and maximum energy attainable in these environments with 3D CRPropa simulations and apply our method to 87 observed UFOs. Nuclei can be accelerated up to 100 EeV at the wind-termination shock in some UFOs, but their escaping flux is strongly attenuated due to photonuclear interactions with intense AGN photon fields. In the most extreme $\sim 10\%$ of UFOs in our sample, nuclei can escape with energy exceeding ~ 500 PeV. In contrast, protons typically escape UFOs with only mild attenuation, with half of the observed UFOs reaching ultra-high energies. We show that UFOs can explain the observed UHECR flux in the transition region below the ankle and potentially contribute to the flux of cosmic-ray nuclei up to the highest energies. An important multimessenger signature is provided by the PeV astrophysical neutrinos expected from interactions of the accelerated cosmic rays in the UFOs.

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