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Origins and Acceleration of Very- and Ultra-High-Energy Cosmic Rays

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The origin of cosmic rays (CRs) remains an open question. The CR spectrum is characterized by two main breaks: the knee at ˜3 PeV (1e15 eV) and the ankle at ˜3 EeV (1e18 eV). It is widely accepted that ultra-high-energy cosmic rays (UHECRs) above the ankle originate from extragalactic sources, with the transition energy between galactic and extragalactic components lying between the knee and the ankle. Recent observations suggest that the proton cutoff for UHECRs occurs at a few EeV, while higher energy CRs consist of higher mass atomic nuclei. Centaurus A, a nearby radio galaxy, is considered a major source of UHECR anisotropies, supporting the idea that radio galaxies (active galactic nuclei with kpc-scale jets) are sources of UHECRs. In this talk, I will present our analytical and numerical study using relativistic magnetohydrodynamic and particle-in-cell (RMHD-PIC) simulations of astrophysical jets. This study provides a self-consistent framework for understanding multi-wavelength observations and the acceleration of UHECRs. Furthermore, similar acceleration can take place in galactic ultra-luminous X-ray sources (ULXs), which can contribute to the CR flux between the knee and the ankle.

Presenter: WANG, Jieshuang

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