Contribution ID: **44** Type: **Contributed Talk**

From Fermi to Fractals: Stochastic Particle Acceleration in Strong MHD Turbulence

Wednesday 17 September 2025 16:00 (15 minutes)

Since Enrico Fermi first proposed the stochastic acceleration of protons due to multiple scatterings off of parsec-scale interstellar magnetic fields as a method of cosmic ray acceleration around the time of the 1950s, the theoretical framework of stochastic acceleration in magnetohydrodynamic (MHD) turbulence has undergone significant refinement, although these traditional models often fail to capture and incorporate the complex nature of MHD turbulence. Recent numerical simulations of stochastic acceleration incorporating realistic multifractal MHD turbulence yielded previously unknown effects, such as intermittent particle energization characterized by large jumps in particle momentum.

Here we present a Monte Carlo framework in which the stochastic particle acceleration of an instantaneously injected electron population is modelled as a continuous-time random walk based on the methodology developed in previous studies. In a parameter study, our Monte Carlo code simulates the effects of intermittent particle energization due to interactions with strong MHD turbulence on the electron particle spectrum, and incorporates synchrotron cooling in a self-consistent manner in the theoretical and computational models. Our findings suggest sharply peaked particle spectra exhibiting distinct high-energy power law tails, differing significantly from the log-parabolic spectra predicted by the standard Fermi theory.

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Session Classification: AGN

Track Classification: Other High-Energy Sources