Spectral Approach to Anomalous Diffusion in Plasma from Lab to Space

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Here we introduce a novel spectral approach [1], [2], [3] to the study of anomalous diffusion across various plasma regimes, including microgravity dusty plasma, magnetized low temperature plasma, fusion plasma, and space plasma. Anomalous diffusion occurs due to non-local collisions and correlations that lead to energetic and/or sub-diffusive particles. The spectral approach combines fractional operators and random disorder distributions to model non-local processes and stochasticity.

We first consider the strongly coupled collisional regime by applying the model to data from the Plasmakristall-4 (PK-4) facility on board the International Space Station, where dust particles self-organize in filamentary structures in DC plasma with external electric fields. We use these experiments to validate scaling relations between non-Maxwellian distributions and exponents on the fractional operators. We then apply the spectral approach to data from the Magnetized Duty Plasma Experiment (MDPX) at Auburn where anomalous dust diffusion is caused by plasma filamentation in magnetic fields of ~2T in collisional low temperature plasma.

Next, we apply the model to collisionless cases using data from the DIII-D tokamak, where electrons with energies ~20MeV were observed to become confined in magnetic islands and de-confined during island bifurcation [4]. We argue that the island dynamics during the experiment lead to electron acceleration through Fermi process. Finally, we discuss the implication of this effect to plasma disruptions in fusion and the generation of geomagnetic storms in Earth's magnetosphere during solar flares.

In the spectral approach, correlations and stochasticity are incorporated in a Hamiltonian operator, which uses a fractional Laplacian for the kinetic energy and a distribution of random disorders for the potential energy. The operator is iteratively applied to an initial energy state to advance the energy in an infinitely-dimensional Hilbert space. In the limit of many iterations, one obtains information on the spectrum of possible energy states for that system, including the probability for continuous spectrum corresponding to extended states.

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