Non-diffusive transport in plasma turbulence: a fractional diffusion approach

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Recent experimental and theoretical evidence indicates that transport in magnetically confined fusion plasmas deviates from the standard diffusion paradigm. Typical examples include the confinement time scaling in low confinement mode plasmas, perturbative experiments, and the non-Gaussianity and long-range correlations of fluctuations. The standard diffusion paradigm breaks down in these cases because it rests on restrictive assumptions including locality (i.e., Fick's law), Gaussianity, lack of long-range correlations, and linearity. The need to develop models that go beyond these restrictive assumptions, is the main motivation of this presentation that has two connected goals. The first goal is to show numerical evidence of non-diffusive transport of test particles in plasma turbulence. Based on these turbulent transport calculations, our second goal is to propose and test a macroscopic transport model for non-diffusive transport using fractional derivative operators [1]. To accomplish these goals, we integrate test particles in the **E**×**B** field obtained from a nonlinear, three-dimensional, pressure-gradient-driven turbulence model. In this system, changes in the pressure gradient trigger instabilities at rational surfaces that locally flatten the pressure profile and increase the gradient in nearby surfaces. This in turn, leads to successive instabilities and intermittent transport which causes anomalous diffusion [2]. We show that the probability density function (pdf) of particles is strongly non-Gaussian and exhibits algebraic tails. Also, the moments of the particles' displacements exhibit super-difussive scaling $\langle \delta x^n \rangle \sim t^{n\nu}$ with $\nu > 1/2$.The proposed macroscopic model is based on the use of fractional derivative operators in space and time. The model incorporates in a unified way non-Gaussianity, and space-time non-locality (i.e., non-Fickian transport) caused by the presence of long-wainting times, and large-spatial displacements (Levy flights) without a characteristic scale. These effects can have non-trivial consequences in transport. For example, Levy flights can lead to asymmetric, exponential acceleration of fronts [3]. Here we shown that the fractional model reproduces the shape and spatio-temporal scaling of the pdf obtained from the turbulence calculation. In particular, quantitative agreement is found for the exponents of the algebraic decaying tails of the pdf, and the super-diffusive scaling exponent.

[1] del-Castillo-Negrete D., B.A. Carreras, and V.E. Lynch, submitted to Phys. Rev. Lett. (2004).
[2] Carreras B.A., V.E. Lynch, *et al*., Phys. Plasmas **8**, 5096 (2001).
[3] del-Castillo-Negrete D., B.A. Carreras, and V.E. Lynch, Phys. Rev. Lett. **91**, 018302-1 (2003).