Nonlocal phenomena associated with transport of heat flux and second sound in fusion plasmas

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The primary reason for heat and particle loss in fusion devices is the transport driven by microscale turbulence. The usual way to model this turbulent transport is to consider a linear relation between the fluxes and the gradients, with added pinch terms due to geometry and thermoelectric forces and a residual stress term in particular for angular momentum. This approach implies that the level of fluctuations at a given point in space is determined locally by the local values of temperature, velocity, density gradients, magnetic shear, safety factor, and other such plasma parameters. While these parameters clearly define local free energy injection, fluctuation levels at a given point in space depends not only those local parameters, but also the fluctuation levels in the neighbouring points.

Turbulence in nature, that may be generated locally almost never remains where it is generated, as it tends to spread in space by its own swirling motion. There are different approaches for including this tendency of the turbulence to spread itself in the formulation of turbulent transport from Fisher-Kolmogorov type spreading equations to fractional diffusion formulations. One interesting possibility that we will discuss is to consider, simple flux-gradient relations that involve time delay and radial coupling. Such a formulation leads to a rather simple description of avalanches and may explain breaking of gyroBohm transport scaling.

This generalization of the flux-gradient relation (i.e. constitutive relation), which involve both time delay and spatial coupling can be derived from drift-kinetic equation, leading to kinetic definitions of constitutive elements such as the flux of radial heat flux, which allows the possibility of numerical simulations to compute these cubic quantities directly. The formulation introduced here can be viewed as an extension of turbulence spreading to include the effect of spreading of cross-phase as well as turbulence intensity, combined in such a way to give the flux. The link between turbulence spreading and entropy production is highlighted. An extension of this formulation to general quasi-linear theory for the distribution function in the phase space of radial position and parallel velocity is also discussed.

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