Exploring phase space turbulence in magnetic fusion plasmas

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Plasma turbulent transport is one of the most important issues in the magnetic fusion research, and the most challenging target in numerical simulations of fusion plasmas. While fusion plasma confinement has achieved the break-even condition or beyond, comprehension of the turbulent transport is still demanded toward more reliable prediction for future experiments. Direct numerical simulations of plasma turbulence are expected to provide physics-based understandings on the transport properties and its mechanism.

As the magnetic fusion plasma with high temperature of several keV is almost collisionless beyond applicability of the fluid approximation, gyrokinetic simulations solving time-evolution of distribution function on the phase space have been developed, extending a concept of turbulence onto the velocity space. Indeed, a drift wave turbulence simulation manifests cascades of fluctuations of the distribution function from macro to microscopic velocity scales.

The gyrokinetic turbulence simulation clarifies that optimization of a confinement magnetic field and particle orbits leads to turbulent transport reduction through enhancement of a self-generated sheared (zonal) flow, and confirms a theoretical guideline for designing non-axisymmetric toroidal confinement fields. More recent studies are devoted for validation of the gyrokinetic simulations against experiments, and demonstrate their reasonable agreements and feasibility for numerical prediction of transport.

The state-of-the-art peta-scale gyrokinetic simulations utilizing the K computer enable us to investigate multi-scale turbulent transport in fusion plasmas, where the two major topics are addressed; relaxation of a macro-scale temperature profile due to micro-scale turbulent transport, and ion- and electron-scale transport driven by plasma turbulence with a variety of spatio-temporal scales.