Multiscale Simulations of Nonlinear Phenomena of Plasmas

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Plasmas observed in fusion experiments or in wide varieties of astrophysical situations such as the galaxy clusters, the interstellar medium, the solar corona, solor winds, the Earth's magnetosphere are typically in high temperature or in low density. Since collisions can be rare in such plasmas, deviations from thermal equilibrium can be maintained relatively long times. In thermally non-equilibrium plasmas, effects due to particle pictures of plasmas called kinetic effects play crucial roles on plasma dynamics. Examples of the kinetic effects include inertia of ions and electrons having intrinsic scales of inertial skin depths, and finite Larmor radius (FLR) effects of ions and electrons. These effects usually generate fine structures in velocity space, therefore enhance dissipations due to collisions even though collisionality is considered to be low.

Nonlinear phenomena in kinetic plasmas usually exhibit multiscale structures where various kinetic effects working at their intrinsic spatial scales are inter-related. The gyrokinetic approach is well-suited to study kinetic dynamics of plasmas. Gyrokinetics is a limit of kinetic model that describes the low-frequency dynamics of weakly collisional plasmas. It is derived by averaging the kinetic Vlasov-Landau equation and Maxwell's equation over the fast cyclotron motion, thus it omits the fast MHD waves, the cyclotron resonance, but retains FLR effects, and collisionless wave-particle interactions via the Landau resonance.

In this presentation, we discuss some recent results of large scale gyrokinetic simulations using `AstroGK`, astrophysical gyrokinetics code[1], which is developed to study fundamental aspects of kinetic plasmas and for applications mainly to astrophysical problems. Recent applications include magnetic reconnection[2], solar wind turbulence[3], fundamental studies of phase-space turbulence[4]. Brief summaries of the results are as follows:

- Simulations of the collisional–collisionless transitional regimes of the linear tearing instability are performed.
- Energy spectra of solar wind turbulence in dissipation range obtained from the simulation is confirmed to be consistent with spacecraft measurements.
- The entropy cascade in phase space is proposed as a universal mechanism for energy dissipation in magnetized plasma turbulence.

We also discuss the computational aspects of these works.

1. R. Numata *et al.*, J. Comput. Phys. **229**, 9347 (2010).
2. R. Numata *et al.*, Phys. Plasmas **18**, 112106 (2011).
3. G. G. Howes *et al.*, Phys. Rev. Lett. **107**, 035004 (2011).
4. T. Tatsuno *et al.*, Phys. Rev. Lett. **103**, 015003 (2009).