§7. Study on Multi-Hierarchy Phenomena in Plasmas with Theory and Simulations

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Purpose

Plasmas consist of complex phenomena controlled by multiple spatiotemporal scale physics from macroscopic process, which cover the entire system, to microscopic motions of individual particles. In this research subject, as a part of fundamental studies supporting the Numerical Simulation Reactor Research Project in NIFS, we promote studies on hierarchical phenomena such as magnetic reconnection, macroscopic instabilities, and plasma coherent structures (blob dynamics) in fusion plasmas with theories and simulations.

Result

1. Magnetic reconnection Studies with theories and multi-hierarchy simulations

(1) By means of multi-hierarchy simulations, the hierarchy structure of driven magnetic reconnection has been investigated. In this multi-hierarchy model, real space in a simulation domain is divided [1]. The dynamics in the macroscopic hierarchy is expressed by an MHD algorithm and the physics in the microscopic hierarchy is solved by a PIC algorithm. The influence of dynamics in the macroscopic hierarchy on microscopic physics of magnetic reconnection is found [2]. It is observed that in one case, steady reconnection with a single X-point is driven, and in another case, intermittent reconnection with multiple X-points takes place. We have successfully obtained quantitative tendency on the above influence of macroscopic dynamics on microscopic physics of magnetic reconnection.

(2) We plan to perform a large-scale simulation such as the geomagnetosphere with the multi-hierarchy model. Large-scale simulations requires immerse computer memory In order to reduce the memory size, we have coupled an MHD code with Adaptive Mesh Refinement (AMR) method and a PIC code. In an AMR MHD model, the grid spacing dynamically changes depending on physical situations. In this fiscal year, we have successfully simulated plasma flow injection in the multi-hierarchy model and have confirmed that plasma and magnetic flux smoothly propagate from an AMR MHD domain to a PIC domain.

(3) On the other hand, in order to see the influence of microscopic phenomena on global structures, we have investigated geomagnetic substorms by using a multi-hierarchy simulation based on the parameter-interlocking method. In substorms, magnetic reconnection in the Earth's magnetotail plays an important role. It is believed that anomalous resistivity is originated from wave-particle interactions, particle meandering motions, etc. In this work, we however have introduced a resistivity model based on particle simulation results and have applied it to global MHD simulations. As a result, we can see that depolarization, propagation of flux rope, and increase in the auroral electrojet current show different behaviors, as a different resistivity model is employed.

2. Investigation on macroscopic instabilities with extend MHD simulations

(1) Linear analysis and nonlinear simulations of diamagnetic drift due to large pressure gradient on Rayleigh-Taylor instability have been carried out by an extended MHD model with two-fluid and finite Larmor radius (FLR) effects [3]. By linear stability analysis, we have examined the parameter dependence of the complete stabilization of large wavenumber modes and the ratio between real frequency and growth rate on the pressure and density gradients and beta value. We have shown by nonlinear simulations that when both of the two-fluid and FLR effects are included, the secondary Kelvin-Helmholtz instability appears due to strong flow shear and the mode structure is affected by the diamagnetic drift.

(2) Hall MHD simulations of ballooning instability in LHD have been carried out. The simulations have shown that the instability can be enhanced by the Hall effects and cause a large collapse of the pressure at the center of the plasma core. We have also carried out simulations of Hall MHD turbulence and shown that a transition from vortex sheets to vortex tubes is induced by the Hall term.

3. Particle simulations of plasma blob dynamics

In order to realize a holistic simulation of fusion peripheral plasma, we have investigated the kinetic (microscopic) dynamics on blob propagation with a three-dimensional electrostatic particle code as the first step. In this fiscal year, we have studied the microscopic dynamics on blob propagation in non-uniform grad-B plasmas. We then have found the propagation property and the potential and particle flow structures different from those observed in uniform grad-B plasmas.

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3) R. Goto, H. Miura, A. Ito, M. Sato and T. Hatori, Phys. Plasmas **22** (2015) 032115.