3-2. Simulation Science

§1. 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 and it is often said that a plasma is a treasure trove of multi-hierarchy processes. Some dynamics extend over the entire system size, while in the final analysis such global processes are generated based on microscopic motions of individual particles. In this research subject, as part of fundamental studies supporting the Numerical Simulation Research Project in NIFS, we promote studies on hierarchical structures of such multiple physics systems as magnetic reconnection, macroscopic instabilities, and plasma blob dynamics with theories and simulations.

Result

1. Magnetic reconnection Studies with theories and simulations

(1) In order to understanding the entire picture of magnetic reconnection as a multi-hierarchy phenomenon, we have developed a multi-hierarchy simulation model based on real-space decomposition. In this model, macroscopic physics is expressed by a magnetohydrodynamic (MHD) code and microscopic physics is solved by a PIC code. We had already succeeded in multi-hierarchy simulations of magnetic reconnection by coupling hierarchies in the upstream direction, in which plasmas and magnetic flux injected from an MHD domain drove magnetic reconnection in a PIC domain [1]. In order to apply our model to much wider systems of reconnection, we would like to extend it to one with a 2D hierarchy-interlocking scheme in the both upstream and downstream directions. In FY2013, we have implemented 2D hierarchy-interlocking for the upstream condition to our model. For checking its physical reliability, we perform multi-hierarchy simulations of plasma flow injection from the surrounding MHD domain to the central PIC domain. We can see that plasmas and magnetic flux smoothly and continuously propagate and the mass density and magnetic field increase in the PIC domain.

(2) When we perform a large-scale simulation with the multi-hierarchy model, we will face a problem that huge computer memory is necessary. In order to reduce the memory, we have coupled an AMR MHD code and a PIC code. In an AMR MHD model, the grid spacing dynamically changes depending on physical situations. In FY2013, we have successfully simulated propagation of linear Alfvén waves with the AMR MHD – PIC coupling model [2].

(3) Meanwhile, laboratory plasmas have a strong guide magnetic field in general. We then have studied magnetic reconnection with a finite guide magnetic field with a PIC model. Also, for hierarchy-interlocking in the downstream, we need to comprehend outflow plasma behaviors in the downstream region in detail. We have observed velocity distributions in the downstream region by using 2D PIC simulations. We can see characteristic distributions which are different from shifted Maxwellian ones. In the future, we would like to research their generation mechanisms.

2. Investigation on macroscopic instabilities with extend MHD simulations

Small scale effects such as two-fluid and finite Larmor radius (FLR) effects on macroscopic instabilities have been investigated with the linear eigenmode analysis based on an extended MHD model. The eigenmode equations are derived under general conditions compared to those considered for previous linear theories. Solving numerically these equations by using a matrix code, complicated dependences of Rayleigh-Taylor and Kelvin-Helmholtz instabilities on the two-fluid and FLR effects and the plasma beta found in nonlinear extended MHD simulations are confirmed.

3. Particle simulations of plasma blob dynamics

As the first step toward the multi-hierarchy simulation of fusion peripheral plasmas, we focus on the transport dynamics of plasma blobs which are intermittent filamentary coherent structures along the magnetic field line in peripheral plasmas. Before developing the holistic blob simulation, we have developed a particle simulation code for studies of blob dynamics [3] and investigated kinetic dynamics on blobs with the code [4]. In this fiscal year, we have observed self-consistent particle flows, spiral current systems, and special properties of velocity distributions in a blob. Furthermore, it has been found that symmetry breaking in blob propagation occurs when the ion temperature is higher.

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