§23. Multi-Hierarchy Simulation of Collisionless Driven Reconnection

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Magnetic reconnection is believed to play an important role in solar flares, geomagnetic substorms, and tokamak disruptions. Furthermore, magnetic reconnection has an aspect of cross-hierarchy phenomenon. When magnetic reconnection occurs, the field topology changes on a macroscopic scale and global plasma transport takes place. On the other hand, an electrical resistivity controlled by a microscopic kinetic process is necessary as a trigger. Therefore, for complete understanding of magnetic reconnection, we develop a multi-hierarchy simulation model, which calculates both microscopic and macroscopic physics consistently and simultaneously.

It is seen that space-time scale changes with distance from the neutral sheet in magnetic reconnection. Dynamics within the ion-meandering orbit scale is controlled by kinetic physics, while plasma behaviors outside the ion skin depth can be expressed by a one-fluid model. Based on this features, we employ the domain decomposition method for our multi-hierarchy model. Physics in the domain where microscopic kinetic effects play crucial roles is solved by PIC algorithm [1]. This domain is called PIC domain. On the other hand, dynamics in the periphery of the PIC domain is expressed by MHD algorithm. We refer to this domain as MHD domain. To interlock these two models, we insert an interface domain with a finite width between the PIC and MHD domains.

The physics in the interface domain is calculated by both the PIC and MHD algorithms. Macroscopic physical quantities in the interface domain (for instance, magnetic field and fluid velocities) are obtained by a hand-shake scheme, $Q_{\mathrm{interface}} = a \ Q_{\mathrm{MHD}} + (1 - a)\, Q_{\mathrm{PIC}}$, where Q_{MHD} and Q_{PIC} indicate the values of Q calculated by the MHD and PIC algorithms, respectively. The parameter a is a function of the coordinates. Individual particle velocities in the interface domain are newly determined so as to satisfy the (shifted) Maxwellian distribution using the obtained macroscopic quantities at every time step.

We have first examined applicability of our multi-hierarchy model. Multi-hierarchy simulations of Alfvén wave propagation and plasma flow injection were discussed [2,3]. Next, we apply our multi-hierarchy model to collisionless driven reconnection [4]. Figure 1 shows a schematic diagram of our multi-hierarchy model. The PIC domain covers the central region close to the neutral sheet, and the MHD domains are outside the PIC domain. The interface domain is located between the PIC and MHD domains. Figure 2 displays the magnetic lines of force in the (x, y) plane. Plasma flows come from MHD to PIC domains and drive magnetic reconnection at the center in the PIC domain. The lines of force are smoothly connected between two hierarchies. The multi-hierarchy simulation of collisionless driven reconnection was first done in the world.

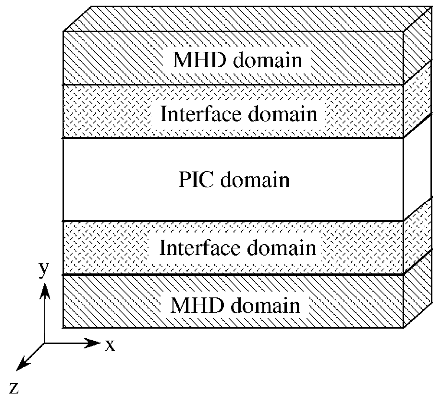

Fig. 1: Schematic diagram of the multi-hierarchy simulation model.

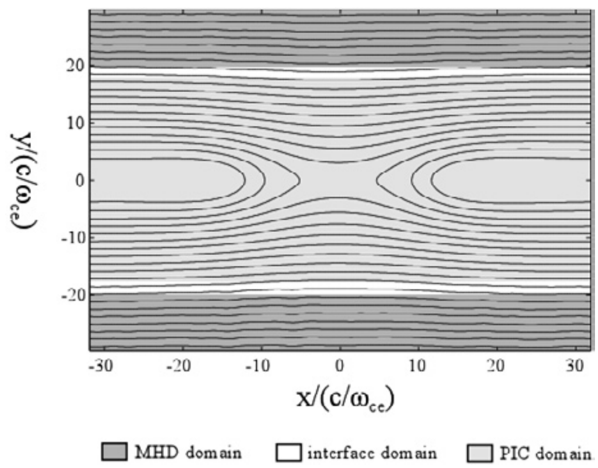

Fig. 2: Magnetic field lines of force in multi-hierarchy simulation.

1) H. Ohtani and R.Horiuchi, Plasma Fusion Res. **4** (2009) 024.
2) S. Usami, H. Ohtani, R. Horiuchi, and M. Den, Comm. Comput. Phys. **4** (2008) 537.
3) S. Usami, H. Ohtani, R. Horiuchi, and M. Den, J. Plasma Fusion Res. **85** (2009) 585.
4) S. Usami, H. Ohtani, R. Horiuchi, and M. Den, Plasma Fusion Res. **4** (2009) 049.