§7. Multi-Hierarchy Simulation Model with a 2D Interlocking Scheme for Magnetic Reconnection Studies

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Magnetic reconnection is a complex phenomenon controlled by multiple spatiotemporal scale physics. When magnetic reconnection takes place, the field topology is globally changed and a large-scale transport occurs. This macroscopic scale is the entire system size. On the other hand, some kinetic processes in the vicinity of reconnection points are needed as a trigger. Because such macroscopic and microscopic physics are not independent, but complexly and dynamically interact, a multi-hierarchy simulation is believed to be a very useful and indispensable tool to understand the entire picture of magnetic reconnection.

For this purpose, we have developed a multi-hierarchy model which solves macroscopic and microscopic physics simultaneously and self-consistently. In this model, macroscopic dynamics are expressed by an MHD code, and microscopic physics are solved by a PIC code. We have developed hierarchy-interlocking in the upstream direction, and successfully demonstrated multi-hierarchy simulations of collisionless driven reconnection [1, 2].

In order to apply our model to much wider systems, we extend it to one with a 2D hierarchy-interlocking scheme in the both upstream and downstream direction. We have implemented 2D hierarchy-interlocking for the upstream condition to our model. Figure 1 shows the simulation domain. Based on the domain decomposition method, our model consists of three domains. The central region is a PIC domain which expresses kinetic physics and its surrounding area is an MHD domain which describes global dynamics. Between the MHD and PIC domains, an interface domain with a finite width is located in order to couple the two domains smoothly. The physics in the interface domain is calculated by both the PIC and MHD algorithms. Macroscopic physical quantities such as fluid velocities are obtained by a hand-shake scheme,

$$Q_{\mathrm{interface}} = F\, Q_{\mathrm{MHD}} + (1-F)\, Q_{\mathrm{PIC}}, \qquad (1)$$

where Q_{MHD} and Q_{PIC} indicate values of Q calculated by the MHD and PIC algorithms, respectively. The parameter F is a function of the coordinates (x, y). Microscopic quantities such as individual particle velocities and positions in the interface domain are freshly loaded so as to satisfy macroscopic quantities obtained according to Eq. (1) at every time step, assuming shifted Maxwellian velocity distribution.

We applied it to plasma injection from the surrounding MHD domain to the central PIC domain for checking its physical reliability. The initial mass density and magnetic field are uniform in the entire region, thus they are not for reconnection configuration. In Fig. 2, we display the bird's eye view of the mass density and magnetic field B_z profiles at $\omega_{ce}t = 1050$, where ω_{ce} is the electron gyrofrequency. We can see that plasmas and magnetic flux smoothly and two-dimensionally propagate from the MHD to PIC domains and plasmas are accumulated in the PIC domain.

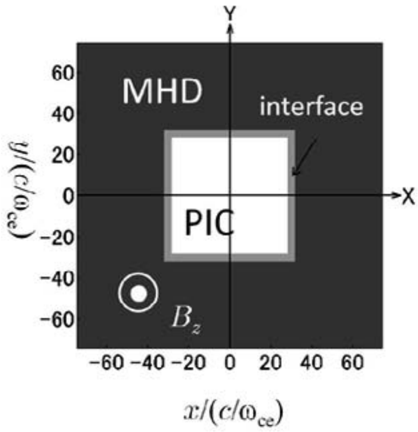

Fig. 1. Simulation domain for the 2D hierarchy-interlocking scheme.

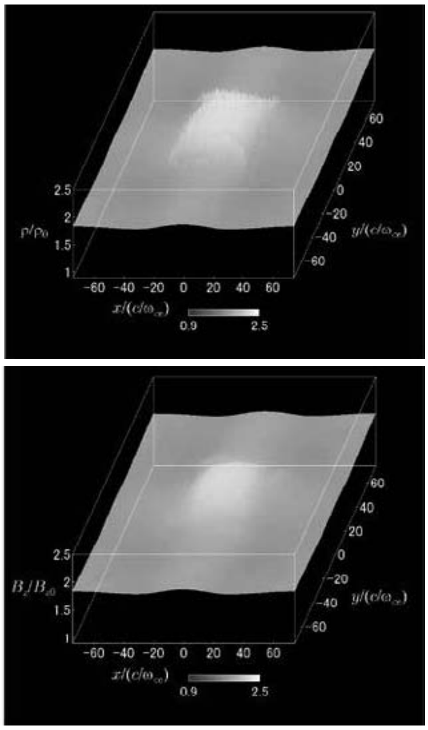

Fig. 2. Bird's eye view of the mass density (top) and magnetic field B_z (bottom) profiles at $\omega_{ce}t = 1050$. The quantities ρ_0 and B_{z0} represent the initial uniform mass density and magnetic field, respectively.

1) S. Usami, H. Ohtani, R. Horiuchi, and M. Den, Plasma Fusion Res. 4 (2009) 049.
2) S. Usami, R. Horiuchi, H. Ohtani, and M. Den, Phys. Plasmas 20 (2013) 061208.