# §5. Hierarchy-Interlocking Model in the Downstream Direction for Simulation Studies of Magnetic Reconnection

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Collisionless magnetic reconnection is one of the fundamental processes in which magnetic field energy is converted to kinetic and thermal energies. It plays an essential role in the rapid energy release in laboratory fusion device and astrophysical plasmas such as solar flare. Also magnetic reconnection has an aspect of typical complex phenomenon controlled by multiple spatiotemporal scale physics. In order to clarify the complete picture of magnetic reconnection as a multi-hierarchy phenomenon, we have developed a multi-hierarchy simulation model which deals with macroscopic and microscopic physics simultaneously and self-consistently [1-4].

In our multi-hierarchy model, we employ the domain decomposition method; the domains differ in algorithm. Physics in the domain where some microscopic dissipation mechanisms are required is solved in the first principle by full particle-in-cell (PIC) algorithm. We call this domain PIC domain. On the other hand, dynamics outside the PIC domain is expressed by magnetohydrodynamics (MHD) algorithm, in which the ideal MHD equations are calculated as the basic equation, since electrical resistivity is assumed to be generated self-consistently by microscopic kinetic process only in the PIC domain. We refer to this domain as MHD domain. Between the PIC and MHD domains, an interface domain with a finite width is inserted in order to interlock two domains smoothly.

With the hierarchy-interlocking in the upstream direction, we have performed the multi-hierarchy simulations of driven reconnection, namely plasma inflows come from the MHD domain and drive magnetic reconnection in the PIC domain [3,4]. It was confirmed that reconnection process found in the multi-hierarchy model is true physics.

Aiming to apply our multi-hierarchy model to a larger region of the magnetic reconnection system, we develop the hierarchy-interlocking model in the downstream direction, in which the improved interlocking method is adopted. First, we consider the configuration that the upstream region (PIC domain) is located in the left side and the downstream region (MHD domain) is in the right side. As the hand-shaking scheme for physical quantities except for pressure, the following relation

$$Q = F(x)\, Q_{\mathrm{MHD}}(x) + [1\text{-}F(x)]\, Q_{\mathrm{PIC}}(x),$$

is used. On the other hand, for pressure $P$ we employ

$$P = F(x)\, P_{\mathrm{MHD}}(x) + [1\text{-}F(x)]\, P_{\mathrm{PIC}}(x\text{-}\Delta x),$$

where $\Delta$x can be regard as for instance one grid spacing. This improved method can suppress unphysical noises in the interface domain.

Using this new model, we perform a multi-hierarchy simulation in which plasma flow satisfying a shifted Maxwellian velocity distribution propagates from PIC to MHD domains. Figure 1 shows the bird's eye view of the profiles of plasma mass density at $\omega_{ce}t$=1300 and at $\omega_{ce}t$=2000. The simulation domain is divided as follows. PIC domain: $0<x/(c/\omega_{ce})<88.0$, interface domain: $88.0<x/(c/\omega_{ce})<96.0$, MHD domain: $96.0<x/(c/\omega_{ce})<344.0$. We can see that plasmas are smoothly and continuously ejected from PIC to MHD domains via the interface domain. Now, we are constructing a two-dimensional hierarchy-interlocking model, in other words a hierarchy-interlocking model in the upstream and downstream directions as shown in Fig. 2 and are examining its physical reliability.

We furthermore consider that a particle domain with Coulomb collision effect is inserted between PIC and MHD domains.

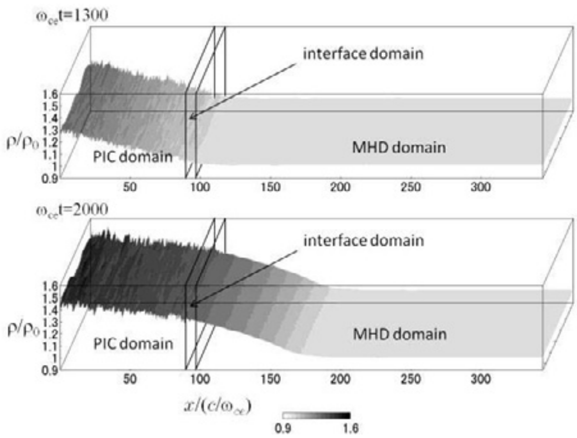


Fig. 1: Bird's eye view of the spatial profile of plasma mass density at $\omega_{ce}t$=1300 and at $\omega_{ce}t$=2000. Plasmas smoothly propagate from the PIC to MHD domains.

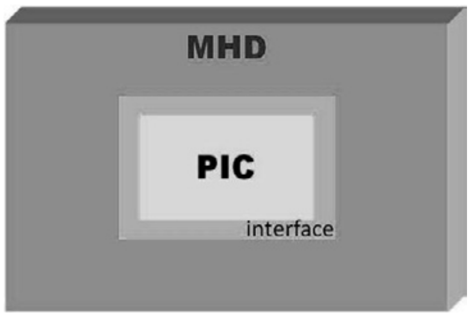


Fig. 2: Schematic diagram of the two-dimensional hierarchy-interlocking model.


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4) S. Usami, H. Ohtani, R. Horiuchi, and M. Den, Phys. Plasmas, accepted.