§21. Multi-Hierarchy Simulation of Magnetic Reconnection with Non-uniform Mesh

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Collisionless magnetic reconnection is one of the fundamental processes in which energy is rapidly converted from magnetic field energy to kinetic energy. It plays an essential role in the rapid energy release in laboratory fusion device and astrophysical plasmas. Furthermore, magnetic reconnection has an aspect of cross-hierarchy phenomenon. When magnetic reconnection takes place, the global change in field topology and large plasma transport occur, while electrical resistivity controlled by microscopic process is necessary in the vicinity of reconnection points as trigger. For comprehension of magnetic reconnection process as a cross-hierarchy phenomenon, we have developed the multi-hierarchy simulation model which solves macroscopic and microscopic physics simultaneously and self-consistently.

In our multi-hierarchy model, we employ the domain decomposition method; the domains differ in algorithm [1-3]. Physics in the domain where some microscopic dissipation mechanisms are required is solved 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.

We have performed the simulation of collisionless driven reconnection with the multi-hierarchy model, namely plasma inflows come from the MHD domain and drive magnetic reconnection in the PIC domain [4]. It was confirmed that reconnection process found in the multi-hierarchy model is true physics.

In FY 2011, we have improved our multi-hierarchy model to adopt non-uniform grid spacing in the upstream (y) direction. The simulation domain is divided as Fig. 1(a). The PIC domain covers the central region close to the neutral sheet $|y/(c/\omega_{ce})|<17.875$, the MHD domains are outside the PIC domain ($19.875 < |y/(c/\omega_{ce})| < 57.375$), and the interface domain is located between the PIC and MHD domains ($17.875 < |y/(c/\omega_{ce})| < 19.875$). Here c is the speed of light, and ω_{ce} is the electron gyrofrequency. Figure 1(b) displays grid spacing in the y direction Δ_y versus space coordinate y. The grid spacing Δ_y is 1.0 at the boundary of MHD domain ($|y/(c/\omega_{ce})| = 57.375$) and decreases to 0.25 as $|y|$ becomes smaller. On the other hand, the grid spacing is 0.25 in the PIC and interface domains. (Regarding the x and z directions, the grid spacing is 0.25 in the whole domains.)

Figure 2 shows magnetic field lines (left) and fluid velocity vectors (right) in the (x, y) plane at $\omega_{ce}t = 2340$. Both plasma and magnetic flux are smoothly supplied to the PIC domain through the interface domain (white) from the MHD domain. Magnetic reconnection is driven at the center of the PIC domain. Furthermore, we confirmed that the magnetic reconnection phenomena found in the new multi-hierarchy model with the non-uniform grid spacing exhibit true physics as with the uniform grid spacing.

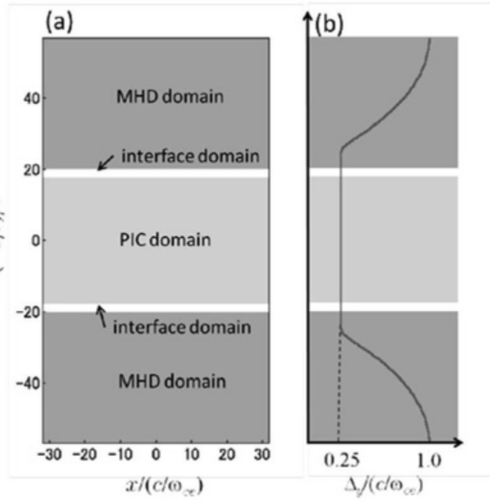

Fig. 1: (a) Simulation domain in the multi-hierarchy model for magnetic reconnection. (b) The grid spacing versus space coordinate y.

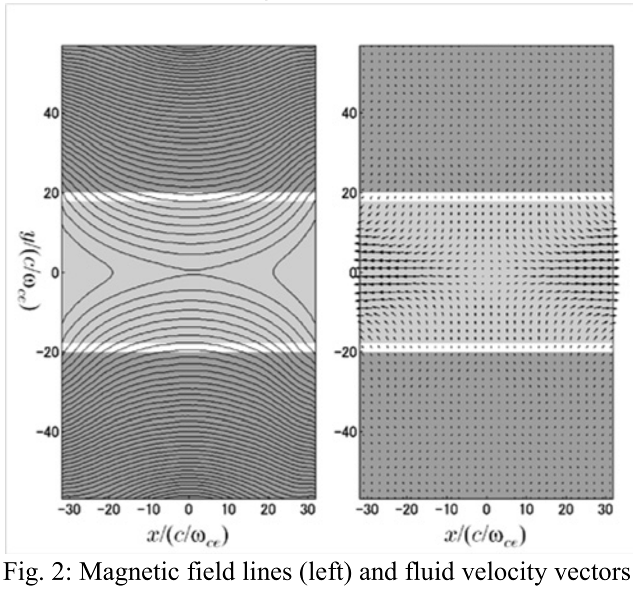

Fig. 2: Magnetic field lines (left) and fluid velocity vectors (right) in the (x, y) plane.

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2) S. Usami, H. Ohtani, R. Horiuchi, and M. Den, J. Plasma Fusion Res. **85** (2009) 585.
3) S. Usami, H. Ohtani, R. Horiuchi, and M. Den, Comm. in Comput. Phys. **12** (2012) 1006.
4) S. Usami, H. Ohtani, R. Horiuchi, and M. Den, Plasma Fusion Res. **4** (2009) 049.