§1. Multi-Hierarchy Simulation Studies of Magnetic Reconnection by MHD-PIC Interlocking

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A fusion plasma contains various spatiotemporal scales from macroscopic transports to microscopic processes relating to the dynamics of each electrons and ions. In fusion plasma studies with simulations, different hierarchies or physics are treated by different models so far. Studies on each hierarchy or physics are advancing, on the other hand interactions between hierarchies or physics are not understood. We believe that the complete understanding of fusion plasmas requires a simulation model which deals with multiple hierarchies or physics self-consistently and simultaneously.

We have developed a multi-hierarchy simulation model which couples an MHD code and a PIC code [1]. Using our model, we study on collisionless magnetic reconnection, since magnetic reconnection is one of typical multi-hierarchy processes and is considered to be involved with sawtooth oscillations. Our multi-hierarchy model is based on the domain decomposition method. Real space in a simulation domain is divided into three parts: an MHD domain to treat macroscopic dynamics away from reconnection points, a PIC domain to solve microscopic physics in the vicinity of the neutral sheet, and an interface domain to interlock the two domains by commuting the MHD and PIC information. This method enables us to express kinetic effects not by introducing any electrical resistivity models in insufficient grounds.

We report the first results on analysis of collisionless driven reconnection with our multi-hierarchy model. The influence of macroscopic dynamics on microscopic physics of magnetic reconnection is investigated [2]. The simulation domain is one-dimensionally divided in the upstream direction as follows. The MHD domain: $19.875<|y/(c/\omega_{ce})|<57.375$; the interface domain: $17.875<|y/(c/\omega_{ce})|<19.875$; and the PIC domain: $|y/(c/\omega_{ce})|<17.875$. We carry out simulation runs with different spatial patterns of plasma inflows imposed at the upstream boundary. The plasma inflows begin to grow first around the center of the upstream boundary (x=0), and the inflow region expands with the velocity v_w.

In Fig. 1, we display the spatial profiles of the magnetic field lines at $\omega_{ce}t$=1500 and at = $\omega_{ce}t$=1980 in the case of v_w =0.6v_A, where v_A is the Alfvén speed. Magnetic flux is injected from the MHD domain to the PIC domain and magnetic reconnection with a single X-point at the almost center of the PIC domain is driven. The system is likely to relax to the steady state.

Figure 2 shows the spatial profiles of the magnetic field lines at $\omega_{ce}t$=1500 and at = $\omega_{ce}t$=1980 in the case of v_w =4.0v_A. In other words, the inflow region more quickly expands into the x direction. We can see that magnetic reconnection with multiple X-points is driven and a magnetic island is formed. It seems that intermittent reconnection continues and the system does not relax to the steady state.

Furthermore, we have found that if the width of an inflow region increases as $v_w < v_A$, magnetic reconnection with a single X-point is driven, while in cases of $v_w > 2.0\ v_A$, multiple X-points appear. This tendency indicates that the expanding speed of an inflow controls the aspect ratio of the current sheet. When an inflow region expands slowly, the current sheet pushed by the inflow is short and reconnection with only single X-point trends to take place. On the other hand, if the expanding speed of an inflow region is large, the current sheet pushed is long, where multiple X-points could appear.

In this work, we have reported the influence of macroscopic dynamics on microscopic physics of magnetic reconnection. In the near future, by means of multi-hierarchy simulations with a hierarchy-interlocking algorithm in the upstream and downstream directions, we plan to investigate how microscopic physics affect global dynamics, and would like to clarify interaction between macro- and micro hierarchies in magnetic reconnection.

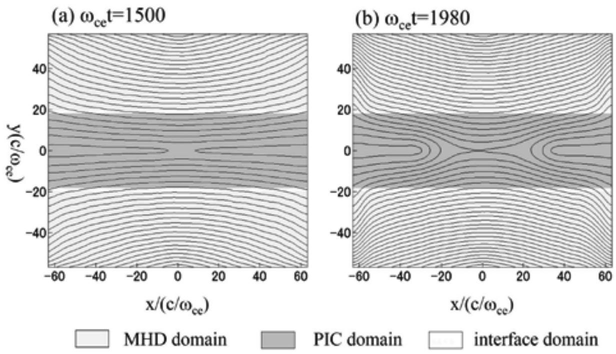

Fig. 1: Spatial profiles of the magnetic field lines in the case of v_w =0.6v_A.

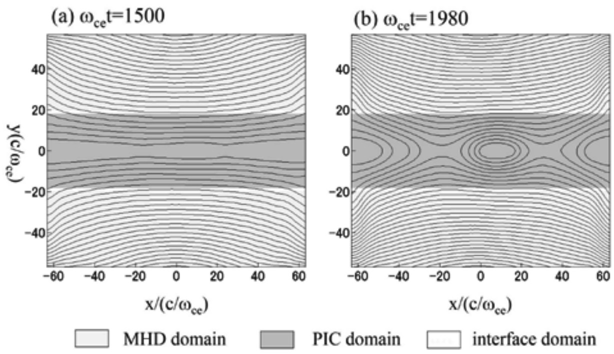

Fig.2: Spatial profiles of the magnetic field lines in the case of v_w =4.0v_A.

1) S. Usami, R. Horiuchi, H. Ohtani, and M. Den, Phys. Plasmas **20** (2013) 061208.
2) S. Usami, R. Horiuchi, H. Ohtani, and M. Den, Journal of Physics: Conference Series **561** (2014) 012021.