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Studies on Magnetic Reconnection by Using the Multi-Hierarchy Simulation
多階層シミュレーションによる磁気リコネクション研究

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The first results on analysis of collisionless driven reconnection with a multi-hierarchy simulation model are reported. In the multi-hierarchy simulation model, real space in a simulation consists of three parts: a magnetohydrodynamics (MHD) domain to deal with macroscopic dynamics, a particle-in-cell (PIC) domain to solve microscopic kinetic physics from the first principle, and an interface domain to couple the two domains. The influence of macroscopic dynamics on microscopic physics of magnetic reconnection is investigated and an interesting tendency is found.

1. Introduction

As well known, a fusion plasma consists of multiple hierarchies. It contains multiple space-time scales from macroscopic transports to microscopic processes relating to the dynamics of individual particles. In simulation studies on fusion plasmas, such hierarchies are treated by different models. Studies on each hierarchies are advancing remarkably, while interactions between hierarchies or physics remain poorly understood. For the complete comprehension of fusion plasmas, simulation models which can deal with multiple hierarchies and physics self-consistently and simultaneously are required. In the first step, we have developed a multi-hierarchy model which couples a magnetohydrodynamics (MHD) code and a particle-in-cell (PIC) code. With the developed multi-hierarchy model, we study on collisionless driven reconnection is a typical multi-hierarchy phenomenon and is believed to be strongly involved with sawtooth oscillations.

2. Multi-Hierarchy Model

2.1 *Domain Decomposition Method*

Magnetic reconnection has hierarchical structure in the upstream direction that the characteristic space-time scales change with distance from the neutral sheet [1]. In the vicinity of the neutral sheet, microscopic kinetic physics play crucial roles, thus models based on the first principle are required. On the other hand, far away from the neutral sheet, plasma phenomena relax to large-scale and slow behaviors so that a one-fluid model can give a good approximation to express dynamics in a region outside the ion inertia length.

Based on the above feature, our multi-hierarchy model employs the domain decomposition method for real space [2-5]. The simulation domain consists of three parts; an MHD domain to express global dynamics, a PIC domain to describe kinetic physics, and an interface domain to couple the MHD and PIC domains. The PIC domain covers the region where microscopic kinetic effects play crucial roles. On the other hand, the MHD domain treats the region where MHD conditions are fully satisfied. Between the PIC and MHD domains, an interface domain with a finite width is inserted.

2.2 *Hand-Shake Scheme*

Physics in the interface domain is calculated by the PIC and MHD algorithms. Therefore MHD conditions need to be fully satisfied in the interface domain, too. Macroscopic physical quantities in the interface domain $Q_{\mathrm{interface}}$ are obtained by a hand-shake scheme, $Q_{\mathrm{interface}} = FQ_{\mathrm{MHD}} + (1-F)\, Q_{\mathrm{PIC}}$, where Q_{MHD} and Q_{PIC} indicate the values of Q calculated by the MHD and PIC algorithms, respectively. The interconnection function F is a function of the coordinates. On the other hand, individual particle velocities in the interface domain are newly determined so as to satisfy the (shifted) Maxwellian distribution at every PIC time step.

4. Simulation Results

By means of multi-hierarchy simulations, the influence of macroscopic dynamics on microscopic physics of magnetic reconnection is investigated.

We carry out simulation runs with different spatial patterns of plasma inflows, which are injected inward from the MHD domain. The inflow begins to be injected first around the center of the upstream boundary (x=0). The inflow region expands with the velocity v_w.

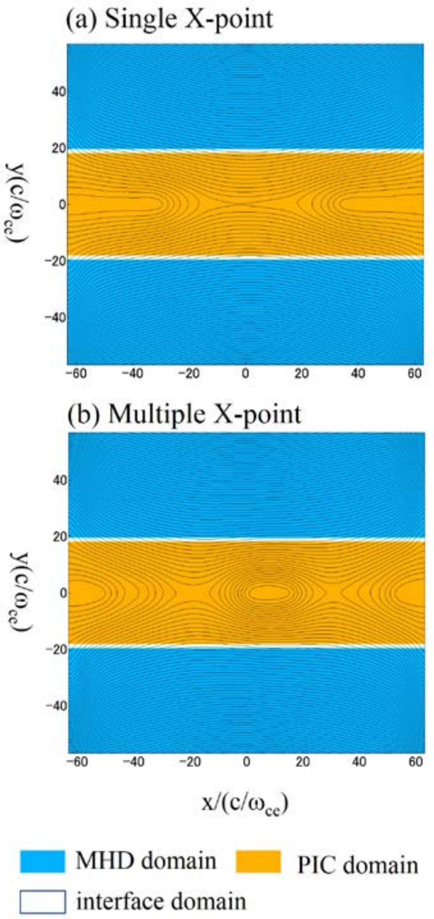

Fig.1. Spatial profiles of the magnetic field lines.

Figure 1 shows the spatial profiles of the magnetic field lines at $\omega_{ce}t$=1980 in cases of (a) v_w =0.6v_{A0} and (b) v_w =4.0v_{A0}, where v_{A0} is the Alfvén speed at the upstream boundary.

Dynamical behaviors of collisionless reconnection in the PIC domain depend strongly on plasma inflows from the MHD domain. We have found the following tendency. If the width of an MHD inflow increases as $v_w < v_{A0}$, magnetic reconnection has a single X-point at the almost center in the PIC domain, and this position is at rest. The system is likely to transit to the steady state. Meanwhile in cases of $v_w > 2.0\ v_{A0}$, reconnection with multiple X-points takes place. A magnetic island is formed, grows, and moves to the downstream boundary. It seems that the system does not relax to the steady state, but intermittent reconnection continues.

We can explain this tendency as follows. The expanding speed of an MHD inflow controls the aspect ratio of the current sheet. When the width of an MHD inflow increases slowly, the current sheet pushed by the MHD inflow is short. The region where reconnection points could emerge is limited to a small central region. Therefore, reconnection with only single X-point trends to take place. On the other hand, in cases in which an MHD inflow expands fast, the current sheet pushed by the MHD inflow, i.e., the region where reconnection points could emerge becomes long. Thus, multiple X-point reconnection occurs.

5. Summary

We have developed multi-hierarchy simulation model for a complete understanding of magnetic reconnection as a multi-scale phenomenon. In the multi-hierarchy simulation model, real space in a simulation consists of three parts: an MHD domain to treat global dynamics, a PIC domain to express kinetic physics, and an interface domain to interlock the two domains.

By means of multi-hierarchy simulations, the influence of macroscopic dynamics on microscopic physics of magnetic reconnection is investigated. Dynamical behaviors of collisionless reconnection in the PIC domain depend strongly on plasma inflows from the MHD domain. It is found that if the width of an MHD inflow increases as $v_w < v_{A0}$,, magnetic reconnection has only a single X-point, while in cases of $v_w > 2.0\ v_{A0}$, reconnection with multiple X-points takes place.

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