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Multi-Hierarchy Simulation of Collisionless Magnetic Reconnection

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Collisionless magnetic reconnection is a fundamental process to lead a rapid energy release and is considered to play an important role in solar flares, geomagnetospheric substorms, and tokamak discharge. Recently, magnetic reconnection attracts considerable attention as a phenomenon controlled by multi-scale physics with a different temporal and spatial scale. Indeed, when magnetic reconnection takes place, the field topology changes globally and the large plasma transport occurs, while as a trigger, electric resistivity controlled by microscopic kinetic process is needed, which leads to violation of the frozen-in constraint. Therefore, for complete understanding of collisionless magnetic reconnection mechanism, in the magnetic reconnection interlocked simulation (MARIS) project, we develop a multi-hierarchy simulation model which treats both microscopic and macroscopic physics self-consistently and simultaneously. In our multi-hierarchy model, PIC and MHD algorithms are used to solve microscopic and macroscopic physics, respectively.
The multi-scale structure of magnetic reconnection has a special feature that the characteristic space-time scales change with distance from the neutral sheet. Dynamics in the ion meandering orbit scale near the neutral sheet is controlled by kinetic physics, while plasma behaviors far away from the neutral sheet (outside the ion skin depth) relax to one-fluid.
Based on the above feature, the domain decomposition method is employed for our multi-hierarchy model, in which the domains differ in algorithm. The simulation domain is divided into three; the microscopic, the macroscopic, and the interface domains. The macroscopic domain surrounds the region where microscopic kinetic effects play crucial roles. Since physics in the microscopic domain is solved by particle-in-cell (PIC) algorithm, we refer to this domain as PIC domain. On the other hand, macroscopic domain treats the periphery of the PIC domain, and dynamics in this domain is expressed by magnetohydrodynamics (MHD) algorithm. Then we call this domain MHD domain. Between the PIC and MHD domains, a technical interface domain is put. Physics in the interface domain is calculated by the PIC and MHD algorithms.
For numerical tests, we simulated the propagation of linear Alfven waves under an uniform magnetic field (not anti-parallel) with our multi-hierarchy model. Waves were observed to propagate smoothly through three domains.
Then, we connect the PIC and MHD domain at the upstream boundary in order to simulate collisionless driven reconnection. The initial condition is given by a one-dimensional Harris-type equilibrium. Due to an external electric field applied at the outside boundary of the MHD domain, plasmas penetrate from MHD to PIC domain across the magnetic field. We have succeeded in the first demonstration of collisionless driven reconnection with multi-hierarchy simulation. Also it is found that the reconnection electric field is balanced with the pressure tensor due to the meandering motion moving across the neural sheet. This result is consistent with those obtained with pure PIC simulation by Ishizawa. et al. In our presentation, we will show multi-hierarchy simulation method, simulation results, and the future development.

Keywords: multi-hierarchy simulation, magnetic reconnection, PIC, MHD