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Formation of Non-Maxwellian Distribution and Its Role in Collisionless Driven Reconnection

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Abstract. The dynamical evolution of collisionless driven reconnection is investigated by using an electromagnetic particle simulation code in a microscopic open system. Strong in-plane electrostatic field is excited in the central region of current sheet under the influence of an external driving field. As a result of the amplification of unmagnetized meandering motion by the electrostatic field particle distribution function is modified from the shifted Maxwellian to an anisotropic one in the current sheet. An ion hole appears at the center of current sheet in the phase space, where distribution becomes two-peaked and no ions exist in low velocity region between two peaks. The strong modification of distribution function leads to the generation of off-diagonal components of pressure tensor term, which is one of major causes to violate frozen-in constraint and trigger collisionless reconnection.

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Key words: Collisionless reconnection, particle simulation, open system, multi-scale physics.

1 Introduction

Magnetic reconnection plays an important role in the dynamics of the solar flare, the magnetosphere, and laboratory experiments [1]. There are two key issues in considering magnetic reconnection. One is a local or microscopic issue. The excitation of magnetic reconnection needs a microscopic process, which leads to the generation of electric resistivity, such as wave-particle interaction [2–4], binary collisions, and so on. The other issue is a global or macroscopic issue. Magnetic reconnection results in global plasma transport and global change of field topology. Thus, magnetic reconnection is a multi-scale phenomenon bridging between macroscopic and microscopic hierarchies, and its whole

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picture should be clarified by solving both microscopic physics and macroscopic physics consistently and simultaneously. We are now developing the multi-hierarchy simulation model for magnetic reconnection under MARIS (Magnetic Reconnection Interlocked Simulation) project. The simulation model consists of three parts, i.e., MHD model to describe global dynamics of reconnection phenomena, electromagnetic PIC model to describe the microscopic processes in the vicinity of reconnection point [5], and interface model to describe the interaction between micro and macro hierarchies [6].

Because microscopic reconnection system is just only a part of macroscopic system, microscopic open model is needed even for understanding of microscopic mechanism of magnetic reconnection. We have developed Particle Simulation code for Magnetic reconnection in an Open system (PASMO) [7–9], which is subject to an external driving source. This code is designed to be connected with a code for macroscopic system under the MARIS project, i.e., the information of macroscopic system is introduced into microscopic system through the system boundary. In this paper we discuss the microscopic physics of collisionless driven reconnection clarified by using PASMO code.

2 Open boundary model

Particle simulation code relies on the explicit electromagnetic PIC algorism [5]. As an initial condition we adopt a one-dimensional equilibrium with the Harris-type anti-parallel magnetic configuration as

$$\mathbf{B}(y) = (B_x(y),0,0), \tag{2.1}$$

$$B_x(y) = B_0 \tanh(y/L), \tag{2.2}$$

$$P(y) = B_0^2/8\pi \,\mathrm{sech}^2(y/L), \tag{2.3}$$

where B_0 is a constant and L is the scale height along the y-axis. There is a magnetically neutral sheet at $y=0$ in the initial equilibrium. The initial particle distribution is assumed to be a shifted Maxwellian with spatially constant temperature and average particle velocity, which is equal to the diamagnetic drift velocity.

In order to study the dynamical evolution of collisionless driven reconnection in an open system under the influence of an external driving source we have developed a new open boundary model, in which a free condition is used at the downstream boundary ($x=\pm x_b$) and an input condition is used at the upstream boundary ($y=\pm y_b$)) [7–10]. The boundary condition for the z-axis is assumed to be periodic. The plasma inflows are symmetrically driven from two upstream boundaries by the external electric field imposed in the z direction under the assumption that the frozen-in condition is satisfied for both ions and electrons. The driving field $E_{zd}(x,t)$ used for this simulation is the same as that in the previous simulations [7–10], which is controlled by two parameters, i.e., maximum flux input rate E_0 and the spatial size of initial bell-shaped profile x_d (input window size). The distribution function of incoming particles at the upstream boundary is assumed to