Particle description of the dissipation processes in collisionless magnetic reconnection

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Magnetic reconnection is a common process in space and laboratory plasmas, facilitating fast release of magnetic energy into plasma kinetic and thermal energy. However, it has been paradoxical that fast magnetic dissipation occurs in collisionless plasmas where the classical collision frequency is much lower than the plasma frequency. In steady-state reconnection, the magnetic dissipation relies on the electron momentum transport due to some collision effect. Since in 2D system there are no waves responsible for the electron scattering, it is considered that the momentum transport is carried out by the electron meandering/Speiser motion generating the electron inertia resistivity. On the other hand, particle-in-cell (PIC) simulations have revealed that the reconnection electric field at the X-line is supported by the electron viscosity resulting from the electron off-diagonal pressure. However, the origin of the electron viscosity is not clearly understood in terms of the electron dynamics.

The present study investigates the dissipation mechanism in association with collisionless magnetic reconnection, based on the single particle trajectories of the electrons. We have derived analytically the profile of the electron pressure tensor term in the generalized Ohm's law, using a simplified but realistic model on the particle motions. The model assumes that the electrons are accelerated without thermalization in the electron diffusion region, are oscillated around the X-line, and are ejected away from the X-line. The particle ejection occurs at the turning points of the oscillation, which causes the y momentum transport to the z direction and gives rise to the electron viscosity, where the current density is in the y direction and the magnetic field is in the x direction. It is confirmed that the theoretical profile is in good agreement with the 2D PIC simulations, which demonstrates that the magnetic dissipation due to the electron viscosity in the fluid picture is equivalent to that due to the inertia resistivity in the particle description.

In this paper, we introduce the theoretical model and clarify the dissipation mechanism, that is, the momentum transport mechanism, based on the single particle motions of the electrons. The application to the 3D dissipation processes will be discussed.