Role of whistler waves in magnetic reconnection

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Magnetic reconnection is one of the key processes playing an important role in magnetic substorms, solar flares, and fusion devices. It facilitates the fast conversion of energy stored in a compressed magnetic field into plasma kinetic and thermal energies. However, the magnetic dissipation mechanism to support a fast reconnection is poorly understood. The magnetic dissipation takes place in a microscopic region, so-called the diffusion region, where the ideal magnetohydrodynamic (MHD) constraints break down. In collisionless plasmas consisting of electrons and ions, the electron diffusion region develops in the vicinity of the magnetic X-line, where the electrons are accelerated due to the reconnection electric field and are ejected as a consequence of the meandering/Speiser motion, which gives rise to the inertia resistivity. It has been suggested that whistler waves invoked outside the electron diffusion region control the electron acceleration and the structure of the electron diffusion region, so that the electron inertia resistivity alone provides sufficient dissipation to support the fast reconnection. This indicates that electron-scale waves essentially influence the global reconnection processes. It is argued that this model was demonstrated by satellite observations which detected whistler waves associated with reconnection. However, it is difficult by using only a few-point satellite data to identify the causality between whistlers and reconnection. Furthermore, recent full kinetic simulations in large systems have pointed out that the electron diffusion region becomes elongated in the outflow direction, leading to a drop in the reconnection rate, even though the whistler physics is incorporated into the system. Nevertheless whistler waves are frequently observed in the Earth's magnetosphere associated with reconnection.

The present study clarifies the generation mechanism and role of whistler waves in magnetic reconnection by using 2D full kinetic simulations in a large system. It is demonstrated that the whistlers are driven by the electron temperature anisotropy formed in the downstream region of the electron outflow, where the magnetic field is intensified due to the pileup of the field lines. The anisotropic electrons are mainly produced by the adiabatic heating in the perpendicular direction. The present results indicate no evidence that the whistler waves control the dissipation processes in the electron diffusion region, while they scatter the electrons in the pitch-angle distribution and somewhat contribute to the electron momentum transport along the field lines. The wave properties in the present simulation are well consistent with recent Cluster observations.

In this paper, we will show the generation mechanism of whistler waves during magnetic reconnection and discuss their role in the reconnection processes.