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Whistler waves associated with magnetic reconnection

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Magnetic reconnection is one of the key processes playing an important role in the magnetospheric substorm and solar flares. 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 the diffusion region formed around the magnetic X-line, where the ideal magnetohydrodynamics (MHD) constraints break down. Especially, in collisionless plasmas consisting of electrons and ions, the diffusion region develops a two-scale structure in which the electron-scale diffusion region is embedded in the ion-scale diffusion region. The motions of electrons and ions decouple in the ion-scale diffusion region, so that only the electrons are frozen into the magnetic field. It has been suggested that whistler waves play a significant role in the electron acceleration in this region, and control the structure of the electron-scale diffusion region so as to provide sufficient dissipation to support the fast reconnection. This indicates that electron-scale whistler waves influence the global reconnection processes. However, several numerical simulations achieved the fast reconnection by using a hybrid code without the Hall effects or full particle code in an electron-positron system, in both of which whistler waves are not incorporated. Furthermore, recent full kinetic simulations performed in a large system have revealed that the electron-scale diffusion region becomes elongated in the outflow direction and as a result the reconnection processes are significantly slowed down, even though whistler modes are involved.

Whistler waves are frequently observed in the Earth magnetopause and magnetotail associated with magnetic reconnection. Some of the researchers have argued that the detection of whistlers demonstrates the theory of the whistler-mediated reconnection. However, it is still difficult by using a few-point satellite data to identify the causality between whistler waves and reconnection. Numerical simulations are also challenging, because the scale of whistler modes is the electron scale so that the electron-scale fine cells are required in order to resolve the waves sufficiently.

In this study, we investigated the mechanism for the emission of whistler waves associated with magnetic reconnection, by performing full kinetic 2D simulations in a large system. The code employs the adaptive mesh refinement (AMR), which subdivides the computational cells according to the refinement criteria and enables high-resolution simulations around the diffusion region. The longitudinal and transverse components of the electric field are separately solved so that one can easily distinguish whistler modes, which are purely electromagnetic. The finding is that whistler waves are emitted in the downstream region of the electron outflow jet, where the electron temperature anisotropy (where Te_perp is greater than Te//) arises. Indeed, it is well known that such temperature anisotropy can drive whistler waves easily. This result indicates that it seems that whistler modes are generated as a consequence of magnetic reconnection, and we could not find the evidence that the whistlers control the structure of the electron-scale diffusion region.

In this paper, we compare whistler waves observed in the simulations with the linear theory, and discuss the role of the waves in magnetic reconnection.