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Particle Simulation Studies on Effective Ion Heating during Magnetic Reconnection

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Magnetic reconnection is a ubiquitous and fundamental process of the energy rapid release, and one of the active research topics. In this work, the ion heating mechanism during magnetic reconnection in the presence of the toroidal (guide) magnetic field is investigated by means of particle simulations.

Figure 1 shows the spatial profiles of the ion temperature perpendicular to the magnetic field and magnetic field lines. The ion temperature is increased mainly in the downstream of reconnection as shown in plasma merging experiments of spherical tokamaks such as TS-3[1, 2] at the University of Tokyo, in which two torus plasmas are merged into a single torus plasma with higher temperature through magnetic reconnection. We display an ion velocity distribution at a local point of the downstream in Fig. 2. The ring-like structure of the velocity distribution is formed, i.e., the velocity distribution spreads compared with in the upstream [3]. This indicates that ions are effectively heated.

The formation process of the ring-like velocity distribution is as follows. The period of time during which ions cross the separatrix is shorter than the gyroperiod. The ions behave as nonadiabatic. Thus, the entry speed of the ions is less than the reconnection outflow speed to be regarded as zero. In the downstream, the toroidal magnetic field Bz and the convective electric field Ey The ions rotate around Bz while ExB drifting. The ion orbit in the velocity space is a circle. A large percentage of ions behave as the above motion. Thus, the ring-like velocity distribution is formed by such ions with different phases of the gyromotion.

This effective heating process explains the increment in the ion temperature reported in TS-3 experiments [1]. Figure 3 shows the profiles of the ion temperature by a T-3 experiment and a simulation of ours. The two profiles are in good agreement with each other [4]. Furthermore, we research the dependence of the ion temperature on the toroidal magnetic field. Our simulations show that the ion temperature decreases as the toroidal field is stronger, but the dependence becomes small for the high toroidal field. This tendency is consistent with that in TS-3 experiments [2].

Lastly, we point out that our effective heating process is similar to the pickup applied to magnetic reconnection by Drake et al. [5] (The original pickup was proposed for newly ionized particles in the solar wind [6].). However, the following points are totally different. A large percentage of protons as the main component ion are responsible for our effective heating, though only heavy ions as a minor component ion receive the pickup.

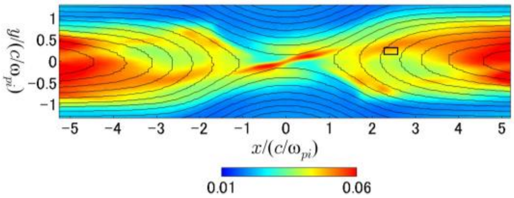

Figure 1: Spatial profile of the ion temperature perpendicular to the magnetic field and magnetic field lines. The temperature rises mainly in the downstream

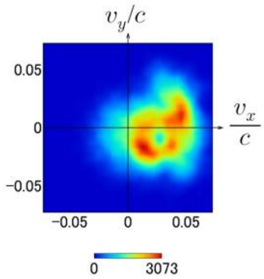

Figure 2: Ion velocity distribution at the boxed area of Fig.1. Ring-like structure is formed.

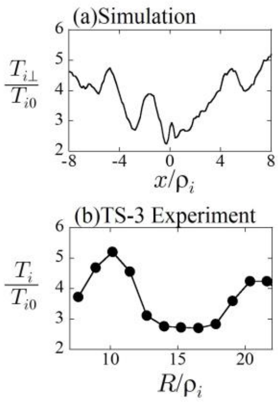

Figure 3: Profiles of the ion temperature of (a) a simulation and (b) a TS-3 experiment.

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