Scaling Law of Relativistic Sweet-Parker Type Magnetic Reconnection

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Magnetic reconnection is one of the most important subjects in the studies of space, laboratory, and astrophysical plasmas. It plays an essential role in the understanding of energy conversion processes in high energy plasmas that characterize astrophysical compact objects.

While issues concerning the physical mechanisms and properties of magnetic reconnection remain unsettled in the relativistic regime, a few theoretical studies of relativistic effects have been made. Lyutikov & Uzdensky studied relativistic Sweet.Parker type reconnection within the framework of magnetohydrodynamics (MHD). They found that the reconnection-driven outflow can have an ultra-relativistic speed (Lorentz factor $\gamma \gg 1$) when the magnetic energy is preferentially converted to kinetic energy [1]. They concluded that the reconnection rate would be enhanced in the relativistic regime due to Lorentz contraction. In contrast, Lyubarsky concluded that the outflow cannot be accelerated to a relativistic speed ($\gamma \simeq 1$) because the magnetic energy should be converted into thermal energy [2]. The effect of the Lorentz contraction is then negligible and the reconnection rate would not be enhanced.

We performed the two-dimensional Relativistic Resistive Magnetohydrodynamic (R2MHD) simulations to determine the energy conversion rate of the Sweet-Parker type magnetic reconnection in the relativistic regime [3]. Figure 1 shows the numerical results of the R2MHD simulations. At the initial state, we give a small perturbation around the origin. Then, the magnetic field lines start to reconnect around the origin. The plasma inflowing in to the current sheet is evacuated in the ± y-direction (formation of the reconnection outflow). We can see that the plasma is heated up inside the current sheet. The magnetic energy is liberated in the diffusion region by the Ohmic dissipation. Most of the magnetic energy is converted not into the kinetic, but into the thermal energy. Then, the enhancement of the thermal energy density, which is larger than the rest mass energy density, contributes to the plasma inertia due to the relativistic effects. The increase in the plasma inertia leads to the slow outflow (Lorentz factor $\simeq 1$). This indicates the relativistic effects such as the Lorentz contraction on the energy conversion rate cannot be expected.

Next, we evaluate the reconnection rate $\mathcal{R}$, which characterizes the energy conversion rate. We confirmed that the reconnection rate relates with the magnetic Reynolds number $R_M = 4\pi L v_A / \eta$, where L, v_A, and η are the length of the current sheet, Alfvén velocity and electric resistivity, respectively. The reconnection rate in the relativistic reconnection is well fitted by $\mathcal{R} = R_M^{-0.5}$ as well as that in the non-relativistic plasma. Also we found that the reconnection rate is almost independent of the initial magnetic field strength. Thus, we conclude that the Sweet-Parker type magnetic reconnection is the slow process for the energy conversion not only in the nonrelativistic regime but also in the relativistic regime.

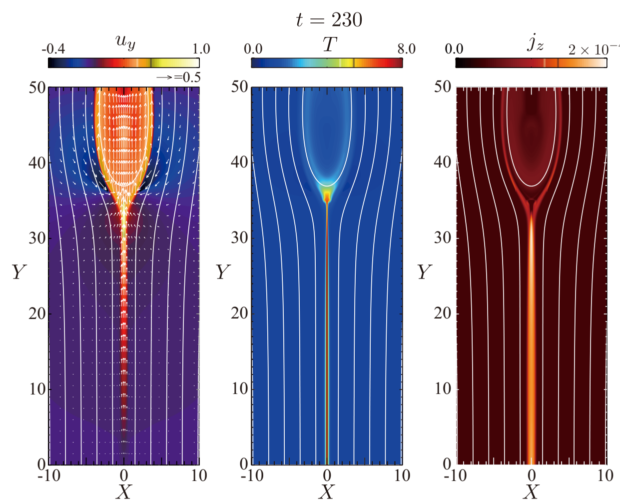

Figure 1: Numerical results of R2MHD simulations. Color shows the outflow (y-direction) four velocity, gas temperature, and the current density from left to right, respectively. Curves and arrows denote for the magnetic field lines and the velocity fields.

References

[1] Lyubarsky, Y. E.: 2005, *MNRAS*, **358**, 113.
[2] Lyutikov, M., Uzdensky, D.: 2003, *ApJ*, **589**, 893.
[3] Takahashi, H. R., Kudoh, T., Masada, Y., Matsumoto, J.: 2011, *ApJ*, **739**, L53.