磁気リコネクションに起因する 3 次元アウトフロージェット

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3D outflow jets originated from magnetic reconnection

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The 3D dynamics of magnetic reconnection is one of the key issues in space and astrophysical plasmas. The observations in the Earth's magnetosphere, solar flares, and laboratory experiments have suggested that the reconnection processes are fully three-dimensional, accompanied by intense wave activities at the x-line and localized flow burst downstream of the x-line. In particular, the present study has focused on the 3D structure of the outflow jets generated by collisionless magnetic reconnection. The outflow structure of reconnection is considered to be three-dimensional from the observations, but the mechanism leading to the 3D reconnection jets has been poorly understood, mainly because of the limitation of computer resources.

We have challenged the 3D reconnection problem by means of the particle-in-cell (PIC) simulations with adaptive mesh refinement. Large-scale 3D PIC simulations have revealed that the thin current layer formed around the x-line is unstable to two types of the shear-driven modes in the anti-parallel configuration. One is a current sheet shear mode which has an intermediate scale between the ions and the electrons. This mode is generated due to the velocity shears in the inflow direction, so that the current sheet is perturbed in the inflow direction. The other is an electron shear mode driven by the electron velocity shear in the outflow direction. Since the shear scale in the outflow direction is much larger than that in the inflow direction, the wavelength of the electron shear mode is larger than that of the current sheet shear mode. The electron shear mode fluctuates the current sheet in the outflow direction. As a result, the flux ropes arising from the secondary tearing mode have a typical scale in the current density direction, corresponding to the wavelength of the electron shear mode. Because the flux ropes move downstream much slower than the ambient plasma, the reconnection jets tend to be blocked by the flux ropes and generate 3D flow channels between the flux ropes. Therefore, it is found that the reconnection outflow jets have a typical scale corresponding to the electron shear mode arising in the thin current layer. The interesting point is that the scale is roughly consistent with that of fast plasma flows termed the bursty bulk flows (BBFs) observed frequently in the Earth's magnetotail. It is surprising that the BBFs have an MHD scale (much larger than the ion inertia length), but they are originated from the electron instability where the electron inertia plays an important role.

In the presentation, we show the recent results of a large-scale 3D PIC simulation of magnetic reconnection and explain how the 3D reconnection jets are generated from turbulence arising at the reconnection x-line.