Three-dimensional nonlinear evolution of the K-H instability: Stability analysis of the vortex structure

Yosuke Matsumoto[1]; Kanako Seki[2]

[1] SELIS, Nagoya Univ.; [2] STEL, Nagoya Univ.

It has been well established that the geomagnetic activity is controlled by the orientation of the interplanetary magnetic field (IMF). While the magnetic reconnection model has been widely accepted as a standard model in the case of southward IMF, the solar wind energy transport mechanism has been still controversial in the case of northward IMF. The idea of the tail flank region of the magnetosphere as a primary transport region has been suggested by in-situ observations which have shown the mixture of the solar wind and magnetosphere origins.

The Kelvin-Helmholtz instability (KHI) driven by the fast solar wind plasma flow is one of the candidate mechanism that can be responsible for the mass transport of the solar wind plasma. In addition to the mass transport into the magnetosphere, the KHI may owe the energy transport to the ionosphere via closed magnetic field lines. Aurora, which is a reflection of dynamic motions in the magnetosphere, often shows the vortex pattern in association with appearances of auroral arcs. This kind of signature is thought to be a visual evidence of the KHI growing at the magnetospheric boundary. However, the detailed physical process that explains the observations still require the theoretical support. This motivates the authors to explore the energy transport mechanism through the 3-D nonlinear development of the KHI. The main objective is to elucidate the solar wind energy transport to the ionosphere along the magnetic field lines simultaneously to the magnetosphere across the velocity shear layer.

We have developed the 3-D MHD code to explore the nonlinear development of the KHI. The velocity shear is provided with a functional form of $Vx = -V0/2*\tanh(y/l)$. We fixed the shear strength with $V0/Vf = 1$, where Vf denotes the magnetosonic speed. The magnetic field is transverse to the velocity field which corresponds to a closed magnetospheric configuration. The pressure and the density is set uniformly. We changed plasma beta in order to explore the effect of the transverse magnetic field on the three-dimensional development, which is known to lead to 3-D turbulence in hydrodynamics case. The results show that in the early nonlinear stage, the 3-D secondary instability starts growing inside the vortex core even for the strong magnetic field case (beta=0.1). The Bx and By components of the magnetic field lead the two dimensional vortex motions to highly structured one. The spatial scale of the secondary instability is shorter for a higher beta case. In particular, the result for beta=0.1 shows that the secondary instability can collapse the two-dimensional vortex structure against the strong transverse magnetic field. Those results suggest that a simple 2-D KH evolution cannot be applied to the magnetospheric boundary and the 3-D evolution may owe the energy transport along the closed magnetic field lines.

The 3-D MHD simulations showed that the vortex core was susceptible to the 3-D secondary instability even for a strong transverse magnetic field case. To understand its nature, we modeled a one-dimensional axisymmetric vortex core, in which the centrifugal force was balanced with the gradient in the total pressure. Then we analyzed the linear response of the system. The resultant dispersion relation has a form similar to that of the Balbus-Hawley instability, while some differences arose due to the assumption of the strong magnetic field and the compressibility in the present study. For a strong magnetic field case, the dispersion relation indicated that the KH vortex core was unstable to the instability whose critical wave length was the order of the fastest growing mode of the KHI. The magnetic field acts for the destabilization in the buoyancy force as well as the stability effect in the magnetic tension force which characterizes the fastest growing mode. Further detailed eigen mode structure and the corresponding growth rate will be also presented.