2 次元 PIC シミュレーションによるケルビン・ヘルムホルツ不安定のマルチスケール現象

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Multi-scale physics of the Kelvin-Helmholtz instability : 2D PIC simulation

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The formation mechanism of the low latitude boundary layer (LLBL) of the magnetosphere is a long standing issue of the magnetospheric physics and in-situ observations have indicated possible solar wind transport mechanisms other than the magnetic reconnection model. The Kelvin-Helmholtz instability (KHI) driven by the velocity shear at the magnetopause is one of the candidate mechanisms.

We have recently shown by 2D MHD simulations of the KHI in a highly asymmetric density layer in a large simulation domain that rapid formation of a plasma mixing layer can be achieved by forward and inverse energy cascades of the KHI. The forward cascade is triggered by the growth of the secondary Rayleigh-Taylor instability (RTI) [Matsumoto and Hoshino, 2004, 2006] excited during the nonlinear evolution. The inverse cascade is accomplished by a nonlinear coupling of the fastest growing mode of the KHI and its neighboring unstable modes. We suggested that the proposed mechanism well explained the observational requirements and is therefore responsible for the LLBL formation [Matsumoto and Seki, 2009], although some issues are remained to be understood. One major issue, which is not treated accurately in the simulation, is the mixing process itself. Since the result is based on the MHD simulation, the mixing of plasmas is due to the diffusion term introduced in the momentum equation.

To understand all the mechanisms ranging from the dissipating scale to the scale of the largest vortex in a self-consistent manner, we have carried out a 2D fully kinetic particle-in-cell (PIC) simulation of the KHI in a large simulation domain which allows growth of multiple KH unstable modes. As a result, we have successfully reproduced the inverse energy cascade among the KH unstable modes as have been shown by the 2D MHD simulation. In this presentation, we show that the direct and inverse energy cascades of the KHI indeed contribute to a formation of a large scale plasma mixing layer in a time scale much faster than we expect from the linear theory. The plasma mixing process and the resultant diffusion coefficient are also discussed in detail.