7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

A nonlinear gyrokinetic model of the magnetosphere-ionosphere coupling system

Keiji Fujita[1], Tomo-Hiko Watanabe[1]
[1] Department of physics, Nagoya university
e-mail (speaker): fujita.keiji.x6@f.mail.nagoya-u.ac.jp

The auroral emission is known to result from collisions between neutral particles in the ionosphere and precipitating electrons from the magnetosphere. However, physical mechanisms behind a variety of auroral phenomenon have not been fully understood. For example, some fundamental questions, such as how the auroral electrons are accelerated and how the auroral structures develops, remain unresolved.

Since interactions between the magnetosphere and the ionosphere play important roles, numerous theoretical models of the magnetosphere-ionosphere (M-I) coupling system have been developed. Particularly, the feedback instability in the M-I coupling system has been discussed as a plausible model that can simultaneously address the issues mentioned above.

Since the original works in the 1970s [1,2], the feedback instability has been investigated with various models. In Refs. [3,4] the secondary growth of the Kelvin-Helmholtz instability in the M-I coupling system is investigated by nonlinear simulations using reduced magnetohydrodynamic (MHD) models, which elucidate spontaneous formation of auroral vortex structures. The left figure in Figure 1 shows the time history of electromagnetic energy of the magnetosphere obtained in Ref [4]. Around time=10, the nonlinear growth of the feedback instability saturates, and transition to turbulence due to the secondary instability occurs.

Nevertheless, the parallel electric field, which can accelerate the auroral electrons along field lines, is not included self-consistently in the MHD models. Thus, we need to extend the M-I coupling model to include kinetic effects, which can produce and sustain the parallel electric field.

The gyrokinetic theory is relevant to describe the magnetospheric dynamics self-consistently including the parallel electric field in the low-frequency regime. In Ref. [5], the linear feedback instability is successfully formulated by means of the gyrokinetic equations for the magnetospheric plasma, where the particle acceleration by kinetic Alfvén wave is confirmed in terms of the energy exchange rate through the wave-particle interaction. The dynamical evolution of the feedback M-I coupling is also simulated using a linearized gyrokinetic model [6]. However, to investigate the auroral vortex formation and the electron acceleration simultaneously, one needs to explore nonlinear evolutions of the feedback instability.

In the study, therefore, we develop the gyrokinetic simulation model for the magnetosphere including nonlinear effects of the $E \times B$ convection and the parallel advection terms. For this purpose, the gyrokinetic simulation code GKV has been extended with a plug-in module for the M-I coupling. The right figure in Figure. 1 shows the history of electromagnetic energy in the magnetosphere calculated with the gyrokinetic model. Although the initial conditions and background parameters are difference from those in the reduce MHD calculation, a qualitatively similar behavior to the reduced MHD result is observed in the gyrokinetic result. In the presentation, we will discuss the result in more detail as well as the boundary condition for the M-I coupling.

References
[1]. G. Atkinson, J. Geophys. Res. **75**, 4746 (1970).
[2]. T. Sato, J. Geophys. Res. **83**, 1042 (1978).
[3]. T.-H. Watanabe, Phys. Plasmas **17**, 022904 (2010).
[4]. T.-H. Watanabe, et al., New J. Phys. 18, 125010 (2016).
[5]. T.-H. Watanabe, Geophys. Res. Lett. **41**, 6071 (2014).
[6]. S. Nishimura and R. Numata, J. Phys. Soc. Japan **90**, 094901 (2021).

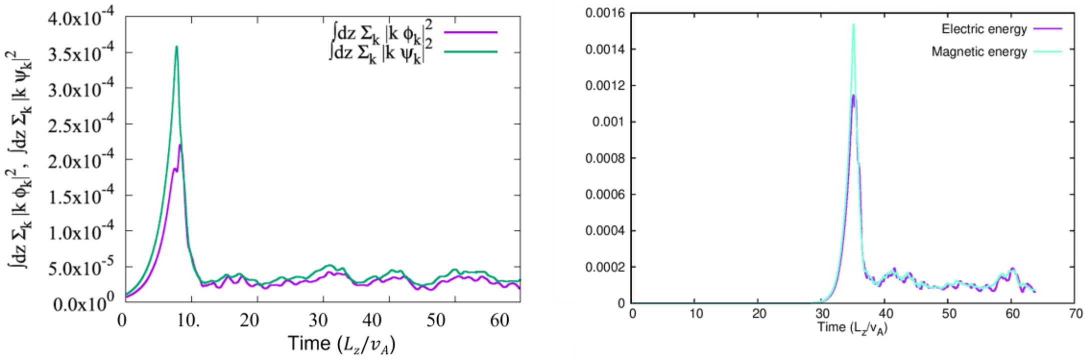

Figure 1: Time histories of electromagnetic field energy calculated with the reduce MHD model in Ref.[4] (left) and with the gyrokinetic model in the present study (right).