§9. Holistic Simulation of Quiet Auroral Arc Formation

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The large-scale structure of a quiet auroral arc is thought to be formed because of macroscopic interactions between the magnetosphere and ionosphere. Ionospheric feedback instability[1] is believed as one of the candidate to explain this phenomenon. Then, a number of magnetohydrodynamic (MHD) simulations on the basis of the feedback instability theory attempted to demonstrate the quiet auroral arc formation. In this kind of simulation study, the generation of high energy auroral electrons along the field lines is treated as a very simple parameterized model without solving the particle acceleration microscopic process. On the other hand, in recent studies with particle simulations, the microscopic mechanism of the spontaneous double layer formation by the current driven ion-acoustic instability and the electron acceleration by its potential difference have been found. The ion-acoustic double layer is a candidate to describe the production of auroral energetic electrons.

In this study, for the purpose of including microscopic processes in a MHD simulation rigidly, we have developed the integrated simulation code[2, 3], that consists of a three-dimensional MHD code for the magnetosphere-ionosphere (M-I) coupling system[4] and a one-dimensional electrostatic particle code with an open boundary system[5], using the "macro–micro interlocked (MMI) algorithm"[6]. Figure 1 shows the schematic diagram of the auroral MMI simulation. By this MMI code, such a microscopic process as particle acceleration is connected with the macroscopic process, that is, the auroral arc formation simultaneously and self-consistently without simple parameterization. With this MMI code, we have investigated the effect of accelerated electrons on the auroral arc formation.

As a first step, we have studied the dynamics of the feedback instability in a dipole geomagnetic field by means of the MHD code[4]. In this simulation, it is shown that multiple longitudinally striated structures of the ionospheric plasma density and the field-aligned current are created, resulting from nonlinear feedback instability. Such growth areas are consistent with the prediction by the integrated feedback theory that contains effects of spatially non-uniform electric field and non-uniform plasma density[4].

As a next step, we have developed an open system one-dimensional electrostatic particle code that adopts the new constant current generator model[5]. Using the new model, we have been able to investigate various phenomena at large electron drift velocities ($v_{\rm d} \gtrsim v_{\rm Te}$), in which the original model is not applicable[7], where $v_{\rm Te}$ is the electron thermal velocity. In the new model, the contribution of the ion flux, which is not considered in the original one, is included in the electric current. In test simulations, it is shown that the double layer creation by ion-acoustic instability also occurs in the vicinity of $v_{\rm d} \sim v_{\rm Te}$. Furthermore, the double layer produced by the Buneman instability in the case $v_{\rm d} \gtrsim 2.0\, v_{\rm Te}$ can be reproduced by the new code.

Finally, we have connected the MHD code and the new particle code using the MMI algorithm[2, 3]. Using the auroral MMI simulation code, a process of quiet auroral arc formation, in particular, the response of the magnetosphere to the effect of auroral energetic electrons, has been studied. Results of the auroral MMI simulation indicate that drastic variation in the ionospheric electric field, which is induced by auroral energetic electrons and propagates into the magnetosphere, influences the magnetospheric field-aligned current distribution[3]. Furthermore, based on the simulation results, aurora light has been rendered taking the emission from oxygen atoms excited by precipitating energetic electrons[2, 8].

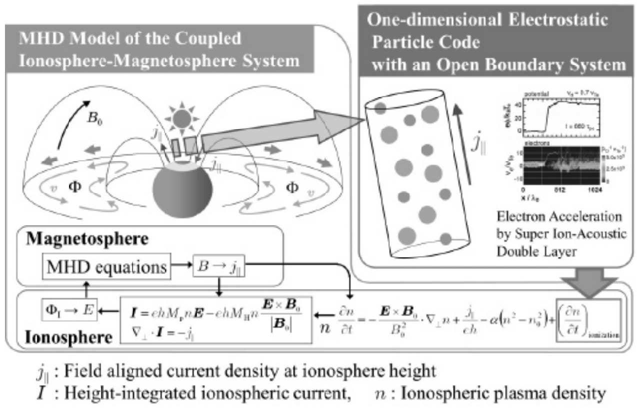

Fig. 1: Schematic diagram of the auroral MMI simulation.

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