§30. Holistic Simulation – Auroral Arc Formation as the First Trial –

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The organizing system of the nature including industrial products are governed by the plural physical processes which are weakly but firmly interacting to each other. The "Holistic Simulation" can deal with such the organizing system

Suppose, for simplicity, a system that two processes, microscopic and macroscopic processes, are mutually interacting to each other. Weakness of the mutual interaction allows us to make simulations of both processes rather independently. Therefore, we need to exchange the information (data) between macroscopic and microscopic processes for the weak interaction. From the standpoint of the macroscopic process, data are not necessary at every microscopic unit time step to be transferred from the microscopic part, because there would be no appreciable macroscopic change of state in such a tiny time scale. On the other hand, from the microscopic standpoint, data are not necessary to be transferred at every macroscopic unit time step from the macroscopic part, because in such a short time scale the macroscopic state would not suffer any meaningful change at all. A reasonably small macroscopic time would be a reasonable data exchange period, because the microscopic process could be appreciably influenced by an appreciable change in the macroscopic state in a small macroscopic time step and also the macroscopic process could be influenced by an appreciable change in the microscopic state in that time step. By this way one can drastically reduce the data transfer rate.

Generally, an interesting phenomenon where the microscopic process plays an important role in macroscopic evolution is when the macroscopic (environmental) state is changed drastically at local regions, consequently the microscopic process also being strongly activated. We do not have to make microscopic simulations at all grid points, but that it would be enough to pick up several featuring grid points of the macroscopic grid system. Thus, we can reduce drastically the number of grid points that should be subjected to microscopic simulation.

As the first trial of the holistic simulation, we started by the quiet auroral arc formation. The fundamental origin of the quiet auroral arc is the feedback interaction between the magnetosphere and ionosphere, of which scale is of the order of 100,000 km. Due to the macroscopic interaction, the striated structure of the electric current is formed in the ionosphere. When the electric current exceeds some critical value in somewhere near the ionosphere, the large potential gap, in other words, the large electric field along the geomagnetic field line is created by the microscopic instability through the particle interaction among electrons and ions of which scale is 10 cm. Such large electric field accelerates the low energy (100 eV) electrons up to 1 keV, which collide with the neutral atoms in the atmosphere to make auroral green(oxygen) or red(nitrogen) light. And also, such accelerated electrons ionized neutral atoms in the ionosphere, so that the ionospheric condition, therefore, the condition of the macroscopic interaction would be changed.

We employed MHD simulation for the macroscopic interaction between the magnetosphere and ionosphere, and the particle simulation in the open boundary condition for the microscopic interaction. Here, we also developed a new coordinate system, the dipole coordinate system, for the MHD simulation to get more realistic configuration of the magnetosphere.

As the boundary condition of the MHD simulation, we employed the fixed magnetospheric equatorial plane with a Heppner-type twin vortex plasma flow that works for the driving force of the feedback coupling between the magnetosphere and ionosphere. The ionosphere is described by the height-integrated ionospheric equations in which the Pedersen and Hall conductivities are taken into account. For the particle simulation, the open boundary condition is employed, where ions and electrons can freely flow into the simulation box and go out.

Starting the MHD simulation, we observed the striated structure of the electric current in the ionosphere as the time goes by, and the electron beam velocity exceeded the critical value that corresponds to 70% of the electron thermal speed. Then, using the information of the electron beam velocity, we made a shifted Maxwellian distribution function as an initial electron velocity distribution as well as the boundary condition on the upstream side, and started the particle simulation. During the execution of the microscopic (particle) simulation, we continued the macroscopic (MHD) simulation, because the macroscopic data is changed in the macroscopic time scale, in other words, the microscopic boundary condition on the upstream side is not changed in the microscopic time scale. After the electrostatic potential was formed due to the microscopic interaction and saturated, the information of the accelerated electrons was transferred to the macroscopic simulation, and was put into the ionospheric equation of the macroscopic simulation. Such simulation procedure was repeated, and thus, the simulation of the aural arc formation was done self-consistently from both macroscopic and microscopic viewpoints.

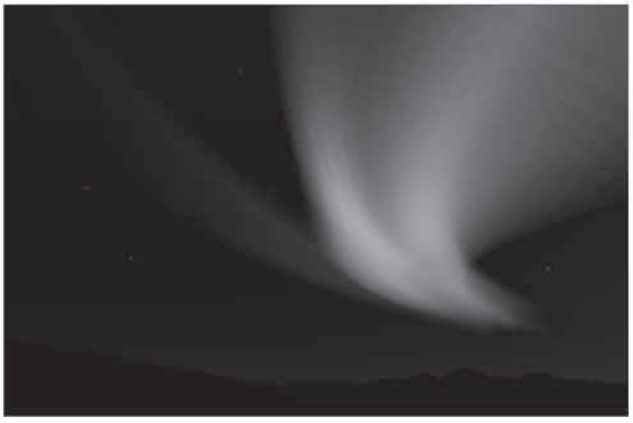

Fig. 1 The simulation results of auroral arc formation