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Gyrokinetic simulation of auroral arc growth in a dipole field

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Aurora is one of the most fascinating visible phenomena in space plasmas. Whereas auroral observation has a long history back to the 19th century, the auroral dynamics still provides open issues in studies of plasma physics. Among a variety of auroral phenomena, the most typical one is called a discrete auroral arc which extends around 1,000km in the east-west direction while having a few tens of km scales (or intervals) in the latitudinal direction.

Regarding the auroral arcs, one may remind several key questions. First, what is the physics mechanism characterizing the spatiotemporal scales of auroral arcs? Second, what is the primary energy source providing spontaneous auroral arc growth? Third, what is the mechanism leading to auroral vortex formation and deformation of arcs with curtain-like structures? Fourth, what is the mechanism of electron acceleration along the auroral field lines?

The feedback instability proposed by Sato [1] has explained the first and the second questions given above, where the ionospheric density and current perturbations coupled with the shear Alfven waves propagating in the magnetosphere can spontaneously grow by using a part of energy to be dissipated by Joule heating, when the convection electric field exceeds a critical threshold. The third question has been answered by nonlinear magnetohydrodynamic simulation of the feedback instability [2, 3], where the perpendicular flow shear enhanced by auroral arc growth nonlinearly causes the Kelvin-Helmholtz instability. The last question has been unveiled by the quasi-linear gyrokinetic theory [4] and the nonlinear gyrokinetic simulation of the feedback instability [5], where the parallel electric field of dispersive Alfven waves can accelerate electrons along the auroral field lines. The state-of-the-art of the gyrokinetic simulation of the magnetosphere-ionosphere (M-I) coupling is further extended in the present study by incorporating the dipole magnetic field geometry.

We have recently extended the flux tube gyrokinetic simulation code, GKV [6], by introducing the dipole field geometry, where the perturbed gyrokinetic equations for electrons and ions are numerically solved along with the two-fluid equations for the ionosphere. To overcome a numerical difficulty caused by the strongly inhomogeneous background magnetic field intensity, the perpendicular velocity space variable is chosen as one of the phase space coordinates.

By means of the newly developed code, we have carried out linear analyses of the feedback instability in the dipole field. The obtained real frequencies and growth rates are plotted in Figure 1 as functions of the perpendicular wavenumber normalized by the thermal ion gyro-radius on the magnetic equator, where the foot point latitude of field line is 60 degrees. One finds that the real frequency approaches a constant value as the wavenumber increases, which is a property of the field line resonance, while the linear growth rate peaks around $k_\theta \rho_i \approx 0.15$. This is the first identification of the feedback instability including kinetic ions and electrons in the dipole field, while the feedback instability tends to be weakly stabilized due to the strong mirror field in comparison to the case with straight field lines.

In addition to the feedback instability growth, we have also found wave-particle interactions in terms of the perturbed distribution functions on the phase space. More detailed simulation results will be reported at the conference.

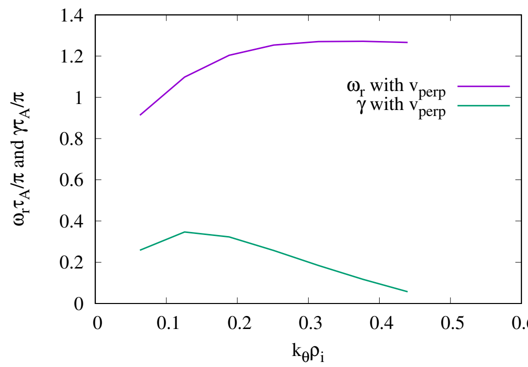

Figure 1: Dispersion relation of the feedback instability in a dipole field geometry. Computations are carried out by means of the gyrokinetic code GKV extended with the magnetosphere-ionosphere coupling module.

References

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