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Spontaneous excitation of auroral structures and Alfvenic turbulence

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Spontaneous generation and nonlinear deformation of auroral arc structures have been investigated from a point view of instability growth of shear (or kinetic) Alfven waves in the magnetosphere-ionosphere (M-I) coupling system. The feedback instability, which was originally proposed by Sato [1], has successfully described amplification of the shear Alfven waves which explains spontaneous formation and drift motion of auroral structures in the ionosphere. In the conference, we would like to present developments of the theoretical and numerical studies of the spontaneous excitation of auroral structures and their nonlinear evolution leading to the Alfvenic turbulence.

We have recently established theoretical formulation of the feedback M-I coupling by means of the reduced magnetohydrodynamic (MHD) equations (or the gyrokinetic equations) coupled with the two-fluid equations [2]. Being based on the theoretical model, we have carried out nonlinear simulation of the feedback instability, and have demonstrated formation of auroral structures, the secondary growth of the Kelvin-Helmholtz (K-H) type instability which spontaneously generates auroral vortex structures, and transition to the Alfvenic turbulence.

The feedback instability amplifies the shear Alfven waves carrying the field aligned current with $k_\perp \gg k_\parallel$ (where $k_\perp$ and $k_\parallel$ denote the perpendicular and parallel wavenumbers, respectively), produces density, current, and electric field perturbations on the ionosphere, and generates the auroral fine structures. Growth of the Alfvenic perturbations is accompanied with a strong shear flow generation which leads to the K-H instability and saturation of the instability growth [3]. Then, the M-I coupling system transits into the Alfvenic turbulence where the counter propagating shear Alfven waves nonlinearly interact with each other. Recent simulation of the M-I coupling with higher numerical resolution has demonstrated that the energy spectrum in the nonlinear stage of the feedback instability has the typical power law scaling of $\propto k_\perp^{-5/3}$ which is consistent with the scaling by Goldreich and Sridhar as well as the FAST spacecraft observations. It should be remarked that the spontaneous growth of auroral arcs, deformation of the auroral vortex structures, and nonlinear dynamics causing the power law scaling of Alfvenic turbulence are elucidated in a single theoretical framework describing linear and nonlinear evolutions of the feedback M-I coupling.

The ab-initio M-I coupling model based on the basic formulations of plasma physics has further been extended so as to investigate competition or coexistence of the feedback and ballooning instabilities in the M-I coupling, to introduce generation of the parallel electric field, and to unify the MHD and two-fluid descriptions of the magnetospheric and ionospheric plasma [4]. The recent successful extensions of the feedback M-I coupling theory manifest robustness and universality of the theoretical approach.

Furthermore, the feedback M-I coupling model has been extended by introducing the gyrokinetic description of the magnetospheric plasma [5]. The new theory provides ones a unified model of the auroral growth and the field aligned acceleration of electrons, and can simultaneously explain the two key ingredients in auroral physics.

References

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