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Auroral growth and self-excitation of kinetic Alfven waves: a cross-disciplinary study for space and fusion plasmas

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Auroral structure formation and its dynamics are considered to be closely related to the kinetic Alfven waves in the Earth's magnetosphere. Spontaneous growth of auroral arc structures, their nonlinear deformation, and transition to turbulence have been investigated in terms of magnetohydrodynamic (MHD) instabilities in the magnetosphere-ionosphere (M-I) system [1, 2], where the shear Alfven waves propagating in the magnetosphere are amplified with growth of auroral structures through the feedback M-I coupling. In the course of the auroral growth, the wave surfaces are strongly deformed through the Kelvin-Helmholtz type instability due to the $E \times B$ flow shear [2]. Simultaneously, nonlinear interactions of the upward and downward propagating Alfven waves with the energy cascades leads to transition to the Alfvenic turbulence [2] in consistent to observations of Alfvenic auroras by the FAST spacecraft [3].

When the perpendicular scale length of auroral structures is as small as the ion gyro-radius or the electron skin depth, the kinetic or dispersive Alfven waves play a leading role in the M-I coupling, instead of the shear Alfven waves. Extension of the reduced MHD model with the electron inertia has been applied to the feedback instability, providing generation of dispersive Alfven wave turbulence and the field-aligned electric field in the magnetosphere [4]. Figure 1 shows the kinetic (dispersive) Alfven turbulence found in a simulation of M-I feedback instability by means of the reduced MHD model extended with the electron inertia effect. The parallel electric field responsible to the electron acceleration is generated in the dispersive Alfven wave turbulence.

While the extended MHD model is useful for nonlinear simulations of the auroral dynamics, it cannot directly elucidate the electron acceleration process in the Alfvenic auroras. A unified theoretical model of the M-I coupling is, thus, constructed by means of the gyrokinetic equations, including the kinetic Alfven wave dynamics, and simultaneously explains self-excitation of kinetic Alfven waves, growth of auroral structures, and field-aligned acceleration of auroral electrons [5], providing a self-consistent description of the Alfvenic auroras observed by the FAST spacecraft.

Not only the theoretical model but also a numerical method involves a lot of difficulties in a self-consistent simulation of auroral growth and electron acceleration. A novel numerical method for solving the drift kinetic electron dynamics and the kinetic Alfven waves [6], which was developed for study of fusion plasma turbulence, has opened a pathway to a kinetic simulation of auroral M-I coupling.

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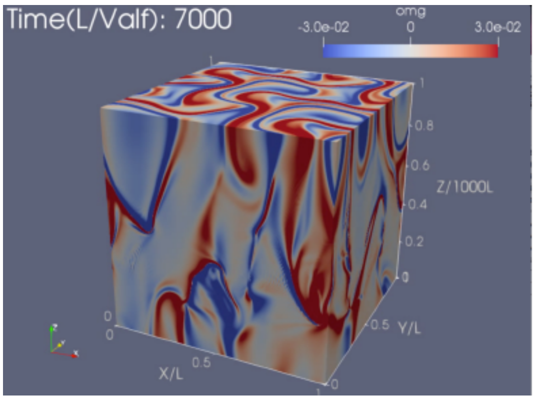

Figure 1: Kinetic (dispersive) Alfven turbulence driven by the feedback instability in magnetosphere-ionosphere coupling [4].