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ABSTRACTS (PH D THESIS)

Computer Simulations of Nonlinear Wave Instabilities Driven by Ion Temperature Anisotropy in Space Plasmas

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As one of the important phenomena in the space plasmas, instabilities driven by the temperature anisotropy of ions take place. For example, the ions are heated in the perpendicular direction to the ambient magnetic field due to the adiabatic heating in the downstream of the quasi-perpendicular shock. In the inner magnetosphere, there exists the inward transportation of the energetic plasmas due to the magnetic reconnections in the magnetotail. These phenomena form anisotropic velocity distribution functions of the ions in each region. The ion temperature anisotropy in the perpendicular direction drives mirror and electromagnetic ion cyclotron (EMIC) instabilities through the wave particle interactions. The mirror mode structures and the L-mode EMIC waves, which are excited through these instabilities, have large amplitude and scale size and thus they play a significant role for the energy transportations in the different parts of the geospace plasmas. We analyzed the nonlinear evolutions of these waves and interactions with the ions in the Earth's magnetosheath and the inner magnetosphere using the hybrid simulations which treat ions and electrons as particles and fluid, respectively.

The solar winds move through the bowshock, the proton temperature anisotropy causing the mirror and EMIC instabilities arises. Spacecraft observations show that the mirror instability dominates over the L-mode EMIC instability in the magnetosheath, although the theoretical linear EMIC growth rate is higher than that of the mirror mode waves. We performed two- and three-dimensional (2D and 3D) hybrid simulations with the periodic boundary to understand the competing process between the EMIC and mirror instabilities. In the 2D model, the energy of the EMIC waves is higher at the growth phase because of its higher growth rate. In the 3D model, however, the energy of the mirror mode waves is larger than that of the EMIC waves for all times because the wavenumber spectra of mirror mode waves form torus-like structures. As the mirror mode waves relax the temperature anisotropy effectively, the linear growth rates of the EMIC waves become smaller before saturation. The EMIC waves cause heating of protons trapped by the nonlinear potentials due to coexistence of forward and backward propagating waves. They terminate the growth of EMIC waves. Because of the heating, the temperature anisotropy decreases to the threshold of the mirror instability and thus the mirror mode wave saturates. At the nonlinear stage, coalescence of the mirror mode structures takes place in both models. The quick dissipation of the EMIC waves occurs due to the heating by the nonlinear processes. On the other hand, the coalescence is a much slower process than the nonlinear processes of EMIC waves, and thus the mirror mode waves remain.

We also performed 2D and 3D hybrid simulations in open boundary models. In the open systems, because of the propagation of EMIC waves, we obtain the clearer non-propagating mirror mode structures. We analyzed the relation between the mirror instability and the magnetic peaks and dips observed in the magnetosheath. In the 2D model with low beta ($\beta < 1$), we obtain fine structures of the magnetic dips at the nonlinear stage. In the 3D model, on the other hand, the mirror instability makes the magnetic peaks with the same parameters. The parametric analysis indicates that the magnetic peaks also arise in both 2D and 3D high beta cases ($\beta > 1$) as shown by the Cluster observations. In the high beta cases, the high mobility

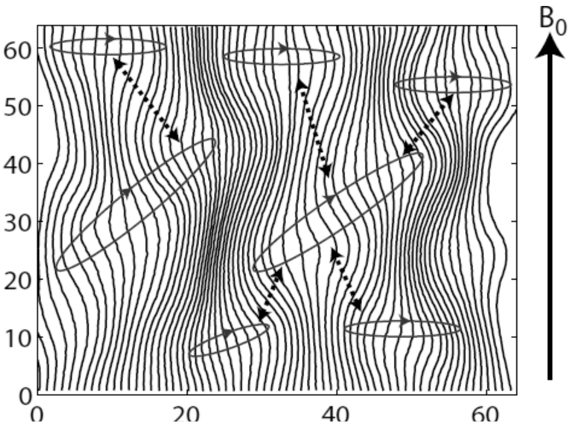

Fig. 1: 2D magnetic field lines of magnetic peak. Red circles show diamagnetic currents.

of the protons helps continuous coalescence of the diamagnetic currents inside the magnetic dips. The coalescence makes the magnetic dips larger and shallower. Between the large and shallow magnetic dips, the magnetic peaks appear in the high beta cases. In the 3D models, because degree of freedom increases in the perpendicular direction, the continuous coalescence can take place even in the low beta cases. Thus, the magnetic peaks appear in the 3D models in both cases.

In the Earth's inner magnetosphere, due to the inward transportation, the EMIC waves are driven. They cause the different nonlinear wave particle interactions because of the existence of the Earth's eigen dipole magnetic field. In a recent observation by the Cluster spacecraft, EMIC triggered emissions were discovered in the inner magnetosphere. We further modified the hybrid code to incorporate a cylindrical geometry of magnetic field modeling the inner magnetosphere to reproduce the EMIC triggered emissions and analyze the nonlinear wave particle interactions. We assume a parabolic magnetic field to model the dipole magnetic field in the equatorial region of the inner magnetosphere. As shown in Fig. 2, we reproduce rising tone emissions in the simulation space, finding a good agreement with the nonlinear wave growth theory. In the energetic proton velocity distribution we find formation of a proton hole, which is assumed in the theory. A substantial amount of the energetic protons are scattered into the loss cone, while some of the resonant protons are accelerated to higher pitch angles, forming a pancake velocity distribution.

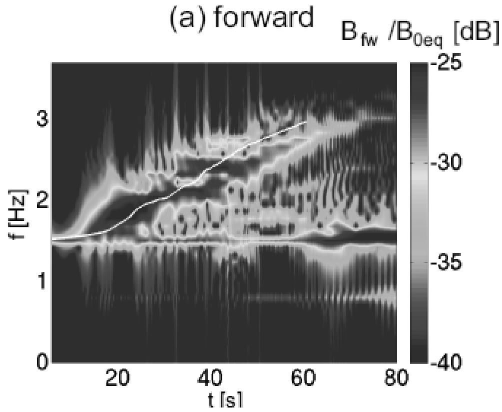

Fig. 2: Dynamic spectra of EMIC triggered emission.

Another type of EMIC wave with a constant frequency is occasionally observed below the He^+ cyclotron frequency after the multiple EMIC triggered emissions. In the presence of energetic protons with a sufficient density and temperature anisotropy, multiple EMIC triggered emissions are reproduced due to the nonlinear wave growth mechanism of rising-tone chorus emissions, and a constant frequency wave in the He^+ EMIC branch is subsequently generated. Through interaction with the multiple EMIC rising-tone emissions, the velocity distribution function of the energetic protons is strongly modified. Because of the pitch angle scattering of the protons, the gradient of the distribution in velocity phase space is enhanced along the diffusion curve of the He^+ branch wave, resulting in the linear growth of the EMIC wave in the He^+ branch.

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