§35. Current-Driven Instabilities in a Multi-Ion-Species Plasma

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Energetic heavy ions are often observed in space plasmas. Current-driven instabilities are believed to play an essential role in the heavy-ion heating. In order to study the nonlinear evolution of instabilities and energy transport among different particle species through unstable waves, we have carried out simulations using a two-dimensional (two space and three velocity components), electrostatic particle code.

We considered a plasma consisting of H, He, and electrons with the density ratio, $n_{He}/n_H = 0.1$. The electron temperature was taken to be higher than the ion temperature. The electron velocity parallel to the magnetic field was equal to the electron thermal speed. For the initial simulation parameters, the linear theory predicts that ion acoustic waves and H cyclotron waves are unstable, while He cyclotron waves are stable. The ion acoustic waves have the largest growth rates.

Figure 1 shows typical time evolution of an ion acoustic wave and H cyclotron waves. The dotted line (a), dashed line (b), and solid line (c) represent an ion acoustic wave, fundamental and second harmonic H cyclotron waves, respectively. The ion acoustic wave (a) initially grows fastest. However, it is quickly saturated with small amplitudes. The fundamental H cylotron wave (b) then begins to grow rapidly. After its saturation, the second harmonic wave (c) is destabilized. It grows to the largest amplitude, even though it is only marginally unstable in the initial state.

The waves and electron velocity distribution function strongly affect each other. Figure 2 shows the evolution of the distribution function for parallel electron velocity, $f_e(v_\parallel)$. The vertical lines (a), (b), and (c) show parallel phase velocities, $\omega/k_\parallel$, of the ion acoustic wave, fundamental and second harmonic H cyclotron waves depicted in Fig. 1, respectively. Initially, $f_e(v_\parallel)$ is a shifted Maxwellian. The ion acoustic waves grow firstly. This flattens $f_e(v_\parallel)$ around their phase velocities, i.e., around line (a), and makes the slope steep around line (b). Then, the fundamental waves grow and make $f_e(v_\parallel)$ flat around line (b) and steep around line (c). Finally, therefore, the second harmonics are destabilized. They make $f_e(v_\parallel)$ flat around line (c). In this way, $f_e(v_\parallel)$ has a quite large plateau region.

The second harmonics heat He ions perpendiculaly to the magnetic field through cyclotron resonance. We show in Fig. 3 distribution functions of perpendicular He velocity at various times. The number of high-energy particles increases with time. The helium was observed to be heated more than the hydrogen.

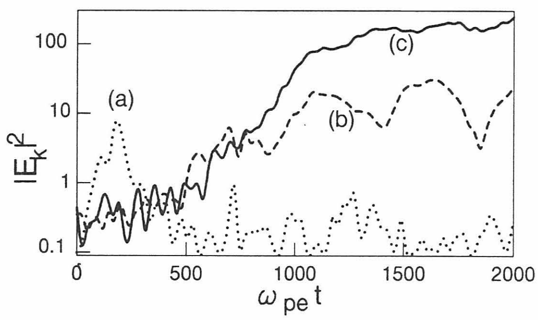

Fig. 1. Time variations of typical unsable waves.

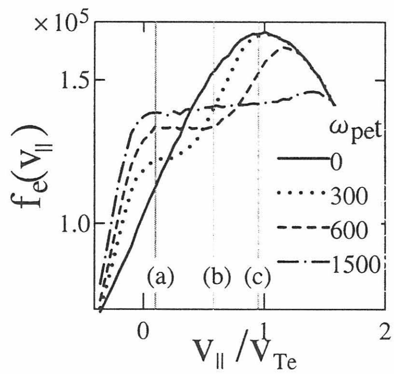

Fig. 2. Evolution of electron distribution function.

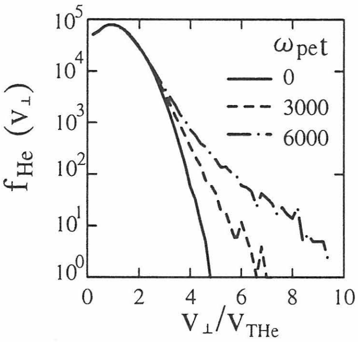

Fig. 3: Distribution functions of perpendicular He velocity.