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Three-Dimensional Electrostatic Particle Simulation on Low-Frequency Instabilities Enhanced by Parallel Ion Flow Velocity Shears

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Field-aligned (parallel) plasma flow velocity shears play important roles in the generation of low frequency plasma instabilities in the space and fusion oriented plasmas. Recent theoretical works using kinetic treatment have predicted that the parallel flow velocity shear causes electrostatic ion-cyclotron and ion acoustic instabilities. According to the experimental results, on the other hand, it is demonstrated that the ion-acoustic, ion-cyclotron, and drift-wave instabilities are excited and suppressed by the parallel velocity shear, where the destabilizing and stabilizing mechanisms are explained by the kinetic theory. In the experimental investigation, however, it is difficult to change the shape and the location of the velocity shear, and the plasma parameters such as the ratio of the ion to electron temperature, which are very effective in the growth rate of the shear driven instabilities. In this sense, a particle simulation is very useful method to clarify the effects of the velocity shear, because the simulation can easily set these parameters. The purpose of this research is to perform the particle simulation in order to understand the experimental results and clarify the essential mechanism of the shear driven instabilities.

We employ a three dimensional electrostatic particle simulation with a periodic boundary model, where an external uniform magnetic field directs in the positive z direction. Our simulation code applies the particle-in-cell (PIC) method, which follows particle motions in the self-consistent electric field produced by charged particles. Full ion and electron dynamics in the external magnetic field and self-consistent electric field is followed. Ion flows are set along the magnetic field lines. The ion flow velocity shear is introduced by changing the ion drift velocity spatially across the magnetic filed lines. The time evolutions of various spatial Fourier modes of the potential and density fluctuations, and the velocity distribution functions of the electrons and ions are investigated.

In the case where the ion drift speed is so small that the low-frequency instabilities cannot take place, the ion acoustic wave is destabilized by introducing the ion flow velocity shear. The ion acoustic wave is locally destabilized in the large velocity shear region. On the other hand, the ion-cyclotron instability is also destabilized by the ion flow velocity shear. The velocity shear enhances not only the fundamental mode but also the high harmonic modes. As a result, the spiky fluctuations in the time domain are locally observed in the velocity shear region, which are caused by the simultaneous existence of several coherent ion-cyclotron harmonics. These results are qualitatively consistent with the experimentally obtained results and the analysis based on the local theory.