NONLINEAR EVOLUTION OF ELECTRON TWO-STREAM INSTABILITY

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ABSTRACT

We study nonlinear evolution of electron two-stream instabilities in a two-dimensional system. Electron two-stream and bump-on-tail instabilities are considered to be the most probable generation mechanisms of electrostatic solitary waves/electron holes observed in various regions of the Earth's magnetosphere. To obtain detailed understanding on the nonlinear evolution of two-stream instability, we performed two-dimensional electromagnetic particle simulations with various sets of the electron cyclotron frequencies and the initial electron thermal velocities.

INTRODUCTION

Electrostatic Solitary Waves (ESW) were first observed by the GEOTAIL spacecraft in the Earth's magnetotail. ESW are bipolar electric pulses longitudinal to the ambient magnetic field. ESW can be modeled as electron phase-space density holes which are Bernstein-Greene-Kruskal (BGK) modes. Recently, electrostatic solitary waves are observed in various regions of the Earth's magnetosphere. Spatial structures and stability of multi-dimensional electron holes observed in the auroral region are issues of recent computer simulations. According to the previous multi-dimensional simulations of electron beam instabilities, electron holes are unstable under a very weak ambient magnetic field. When the ambient magnetic field is strong, electron holes are also unstable to excite electrostatic whistler waves. Under a weaker ambient magnetic field such that electron holes are stable and one-dimensional electron holes are formed through the coalescence process. The purpose of the present study is to obtain further understanding on the nonlinear evolution of electron two-stream instability in a two-dimensional system.

SIMULATION RESULTS

We found that nonlinear evolution of electron two-stream instability in the two-dimensional system falls into 4 categories. When the bounce frequency of electrons trapped by potential well of an electron hole is larger than the electron cyclotron frequency, electron holes are unstable to diffuse at the saturation stage, and there exist no potential structure at the nonlinear stage. However, under a slightly stronger ambient magnetic field we found the formation of stable two-dimensional electron holes isolated in both directions parallel and perpendicular to the ambient magnetic field. In the present simulations, two-dimensional electron holes persist for more than several thousands of electron plasma frequency, but the amplitude of two-dimensional electron holes gradually decreases. When the electron cyclotron frequency is larger than the electron plasma frequency, we found that the stability of electron holes is controlled by their amplitudes. When the potential energy of electron holes is smaller than or is comparable to the thermal energy of electrons, the two-stream instability develops to form one-dimensional electron holes. We confirmed that electron holes are stable for a long time as seen in the previous simulations. On the other hand, when the potential energy of electron holes is larger than the thermal energy of electrons, electron holes decay into electrostatic whistler waves. The electrostatic whistler modes are excited at an earlier stage as the initial electron thermal velocity becomes smaller. The present simulation results showed that the amplitude of electron holes is more essential for the excitation of electrostatic whistler waves.