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ORIGINAL ARTICLE

The magnetic structures of electron phase-space holes formed in the electron two-stream instability

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Abstract It is well known that the parallel cuts of the parallel and perpendicular electric field in electron phase-space holes (electron holes) have bipolar and unipolar structures, respectively. Recently, electron holes in the Earth's plasma sheet have been observed by THEMIS satellites to have detectable fluctuating magnetic field with regular structures. Du et al. (2011) investigated the evolution of a one-dimensional (1D) electron hole with two-dimensional (2D) electromagnetic particle-in-cell (PIC) simulations in weakly magnetized plasma ($\Omega_e < \omega_{pe}$, where Ω_e and ω_{pe} are the electron gyrofrequency and electron plasma frequency, respectively), which initially exists in the simulation domain. The electron hole is unstable to the transverse instability and broken into several 2D electron holes. They successfully explained the observations by THEMIS satellites based on the generated magnetic structures associated with these 2D electron holes. In this paper, 2D electromagnetic particle-in-cell (PIC) simulations are performed in the x–y plane to investigate the nonlinear evolution of the electron two-stream instability in weakly magnetized plasma, where the background magnetic field ($\mathbf{B}_0 = B_0\vec{\mathbf{e}}_x$) is along the x direction. Several 2D electron holes are formed during the nonlinear evolution, where the parallel cuts of E_x and E_y have bipolar and unipolar structures, respectively. Consistent with the results of Du et al. (2011), we found that the current along the z direction is generated by the electric field drift motion of the trapped electrons in the electron holes due to the existence of E_y, which produces the fluctuating magnetic field δB_x and δB_y in the electron holes. The parallel cuts of δB_x and δB_y in the electron holes have unipolar and bipolar structures, respectively.

Keywords Electron phase-space hole · Magnetic structure · Particle-in-cell stimulation · The transverse instability

1 Introduction

Electron phase-space holes (electron holes) have often been detected in different regions of the Earth's magnetosphere (Matsumoto et al. 1994; Ergun et al. 1998a; Franz et al. 1998; Bale et al. 1998; Cattell et al. 2002; Pickett et al. 2004) and the solar wind (Mangeney et al. 1999). In electron holes, the parallel cut of the electric field parallel to the ambient magnetic field has bipolar structures, while the signals of the electric field perpendicular to the ambient magnetic field are unipolar (Ergun et al. 1998a, 1998b; Franz et al. 1998). Electron holes are stationary Bernstein-Greene-Kruskal (BGK) solutions of the Vlasov-Poisson equations (Bernstein et al. 1957; Muschietti et al. 1999; Chen et al. 2005; Ng and Bhattacharjee 2005) and considered to be related to nonlinear Landau damping (Ng et al. 2006). Recently, electron holes in the Earth's plasma sheet, where the plasma is weakly magnetized ($\Omega_e < \omega_{pe}$, where Ω_e and ω_{pe} are the electron gyrofrequency and electron plasma frequency, respectively), have been observed by THEMIS satellites to have detectable fluctuating magnetic field (Andersson et al.

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