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Formation of Pancake, Rolling Pin, and Cigar Distributions of Energetic Electrons at the Dipolarization Fronts (DFs) Driven by Magnetic Reconnection: A Two-Dimensional Particle-In-Cell Simulation [1]

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Abstract

Energetic electrons in the magnetotail usually show anisotropic pitch angle distributions, such as Pancake, Cigar, and Rolling-pin distributions. All of the three kinds of pitch angle distributions are frequently observed to be related to dipolarization fronts (DFs). Pancake distribution is characterized by the enhancement of energetic electron flux with pitch angles around 90°; Cigar distribution is characterized by the enhancement of energetic electron flux with pitch angles around 0° and 180°; Rolling-pin distribution is characterized by the enhancement of energetic electron flux with pitch angles around 0°, 90°, and 180° [2]. It has been long accepted that electrons with pitch angles around 90° are generated by betatron acceleration, and electrons with pitch angles around 0° and 180° are generated by Fermi acceleration [3,4]. However, the differences in the conditions to form the three kinds of distributions are far less understood. In this work, we study when and where these distributions can be formed, and the detailed acceleration processes that lead the energetic electrons to form these distributions.

A two-dimensional particle-in-cell (PIC) simulation is performed to study the formation of the pitch angle distribution of energetic electrons at DFs driven by magnetic reconnection. The energetic electrons at DFs are originated from the lobe region, and experience a twostep acceleration process at the reconnection x-line and the DFs, respectively. Three kinds of pitch angle distributions commonly observed in the magnetotail, Pancake, Rolling-pin, and Cigar distributions, are formed in sequence during the propagation of the DFs. In the early stage, Pancake distributions are formed through betatron acceleration. During this stage, the flux of energetic electrons with pitch angles around 0° and 180° is low because these electrons have no time to be reflected many times at the DFs to obtain sufficient Fermi acceleration. However, the electrons with pitch angles around 90° are difficult to be trapped around the DFs for a long time, and their flux saturates quickly; while the electrons with pitch angles around 0° and 180° can be trapped inside the closed field lines and they get continuous Fermi acceleration during the propagation of the DFs. Therefore, in the later stage, the flux of energetic electrons with pitch angles around 0° and 180° gradually increases and at last exceeds that of energetic electrons with pitch angles around 90°, forming Rolling pin and Cigar distributions in sequence.

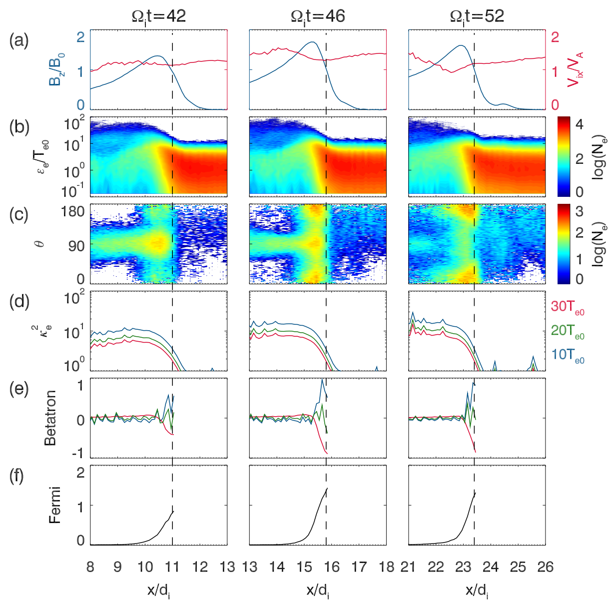

Figure 1
The distributions of some quantities around the DFs at $\Omega_i t$ =42, 46, and 52, respectively. (a) The magnetic field B_z/B_0, and the ion bulk velocity V_{ix}/V_A along z =0. (b) Electron energy spectra. (c) The pitch angle distributions for electrons with energy larger than $\sim 10T_{e0}$. (d) Adiabatic parameter κ_e^2 for electrons with perpendicular energy equal to 10, 20, and 30T_{e0}. (e) Power for betatron acceleration (green curves). (f) Power for Fermi acceleration. The vertical black dashed lines separate the region where the adiabatic assumption is valid. Power of Fermi and betatron acceleration is calculated from $dU_e/dt = E_\parallel J_\parallel + P_{e\perp}(\partial B/\partial t + \boldsymbol{u_E}\cdot\nabla B)/B + (P_{e\parallel} + m_e n V_e^2)\boldsymbol{u_E}\cdot\boldsymbol{\kappa}$ [5].

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