§3. Particle Acceleration in Large-amplitude MHD Waves Created by Strong Disturbances

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We have studied the evolution of magneto-hydrodynamic waves created by a strong disturbance in a collisionless plasma and particle acceleration caused by these waves: specifically, 1) evolution of large-amplitude Alfven waves produced behind a magnetosonic shock front and ultrarelativistic electron acceleration occurring there, 2) effects of the inhomogeneity of the external magnetic field on positron acceleration in a shock wave in an electron-positron-ion plasma, 3) effects of ion composition on nonlinear evolution of oblique magnetosonic waves in two-ion-species plasmas, and 4) multi-dimensional effects on electron trapping and acceleration in an oblique shock wave.

1) Evolution of large-amplitude Alfven waves behind a magnetosonic shock front and associated ultrarelativistic electron acceleration

A strong disturbance in a magnetized plasma produces a magnetosonic shock wave. Moreover, large-amplitude Alfven waves are generated behind the shock front. We have observed the evolution of these waves with one-dimensional, fully kinetic, relativistic, electromagnetic simulations. Furthermore, we have recognized three types of ultrarelativistic electron acceleration caused by these Alfven waves [1]. These energization processes can take place in both weak and strong external magnetic fields.

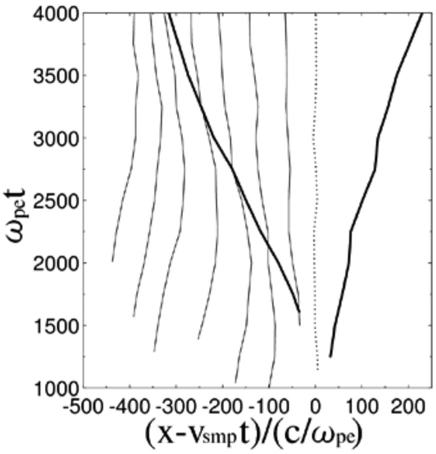

Fig. 1. Wave trajectories.

Figure 1 shows the trajectories of the waves created by a strong disturbance. The two thick lines indicate forward (right going) and backward (left going) shock fronts, while the thin lines represent the trajectories of Alfven waves; the dotted line is the trajectory of a strong-magnetic-field (SMF) pulse, which is thought to be developing into the Alfven wave.

Figure 2 displays magnetic-field profiles (the top and second panels), electron density (third panel), and electron phase space (x, γ) (bottom panel), where γ is the Lorentz factor. In this figure, the forward and backward shock fronts are near $x/(c/\omega_{pe})$=2370 and 2020, respectively. The SMF pulse is near $x/(c/\omega_{pe})$=2230, and Alfven waves are on its left. In the Alfven wave region including the SMF pulse, we find ultrarelativistic electrons with γ~300.

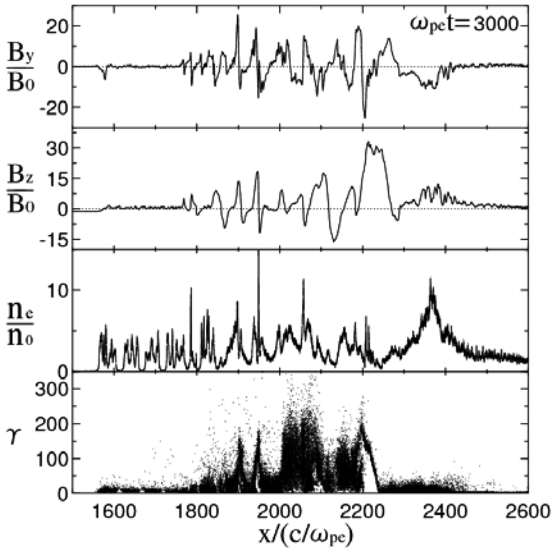

Fig. 2. Snap shots of magnetic and density profiles and electron phase space (x, γ).

2) Positron acceleration

Positron acceleration to γ~10^4 by a shock wave has been demonstrated with particle simulations with real ion-to-electron mass ratio, m_i/m_e=1836. Furthermore, effects of the spatial gradient of the external magnetic field on the acceleration has been investigated in detail [2].

3) Oblique magnetosonic waves in two-ion-species plasmas

The study of the effects of ion composition on perpendicular magnetosonic waves [3] has been extended to oblique waves [4].

4) Multi-dimensional simulation of electron trapping

Multi-dimensional effects on electrons in an oblique shock wave have been investigated in detail by means of two-dimensional electromagnetic particle simulations and test particle calculations. It has been shown that whistler wave instabilities can cause detrapping of energetic electrons from the shock wave [5].

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