A noteworthy plasma parameter on the shock acceleration/heating process

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Abstract

In addition to well known macro plasma parameters of Mach number (M_A) and plasma β (ratio of the plasma to the magnetic pressure), we would like to emphasize ω_{pe}/Ω_{ce} as another important parameter for the kinetics of the plasma heating/acceleration in the shock transition region. When $\omega_{pe}/\Omega_{ce} \leq 1$ any electron hole is not generated and we obtain mild heating with harder energy spectrum. When $\omega_{pe}/\Omega_{ce} \geq 20$ we observe strong heating and acceleration for the electron. In the parameter region of $\omega_{pe}/\Omega_{ce} > 5$ we observe a clear series of electron holes and, after that, ion holes generation in the resultant hot electrons. These ion holes help further electron energization.

1. Introduction

Although we would like to view shock behavior and their energetics on the unified view, various plasma conditions makes shock properties look much different. To know plasma parameters which controlling the shock heating and acceleration has been important issue for astrophysical problems. When considering electron dynamics (kinetics) in various plasma state, coupling strength of the response time scale between electrostatic and Lorentz force becomes a very important factor [1] in addition to well known macro parametersM_A and plasma β. This effect is measured by the frequency ratio of the electron plasma oscillation to electron gyration ($\omega_{pe}/\Omega_{ce} \equiv \Upsilon$).

We perform one-dimensional electromagnetic particle-in-cell simulation [2] of three component, incident ions and electrons, and reflected ions (reflection ratio is 0.2 here). The electron bulk flow speed (u_e) is decelerated compared to the incident ion flow (u_0) to meet no net current condition. The simulation coordinate nearly equal to the shock coordinate. Our plasma condition corresponds to M_A = 16 and β = 0.01. Mass ratio of the proton to the electron is set to the real value (1836). The initial temperature of the incident ion and electron are equal to T_0 and the reflected ion have 4 T_0. The velocity (V), magnetic field (B), and electric field (E) are normalized by u_0, initial B_0 (z), and $u_0(1-2\alpha)B_0/c$ (= E_{y0}, motional electric field), respectively. Time and space units are $2\pi/\omega_{pe}$ ($\equiv T_{pe}$)

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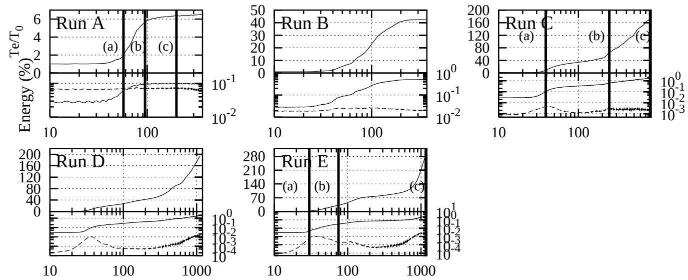

Fig. 1. Normlized electron temperature (each top panel) and energy history of the electron (solid) and electric field (dotted) measured by % (each bottom panel) for Run A $\sim$ E.

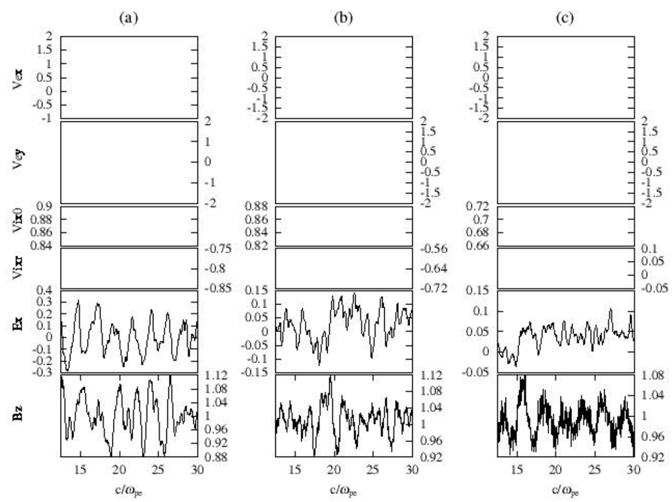

Fig. 2. Phase space diagrams and fields profiles for Run A at time sequences (a): 57 T_{pe}, (b): 95 T_{pe}, and (c): 200 T_{pe}. In each column electron velocity in the x and y direction (V_{ex}, V_{ey}), the incident ion and reflected ion velocity in the x direction (V_{i0x}, V_{irx}), electric field in the x direction (E_x), and magnetic field in the z direction (B_z) are plotted versus X.

and electron inertia length c/ω_{pe}.

2. Υ Dependence on the Electron Energization Process

Fig. 1 shows time (T_{pe}) variation of the electron temperature (each top panel) and energy history (each bottom panel) for the electron (solid line) and the electric field (dotted line) for Run A $\sim$ E ($\Upsilon = 0.5$, 1, 5, 10, and 20, respectively). We set time range to include all of the characteristic features and not to excess the time for taking pass the shock foot region. Since the temperature variation

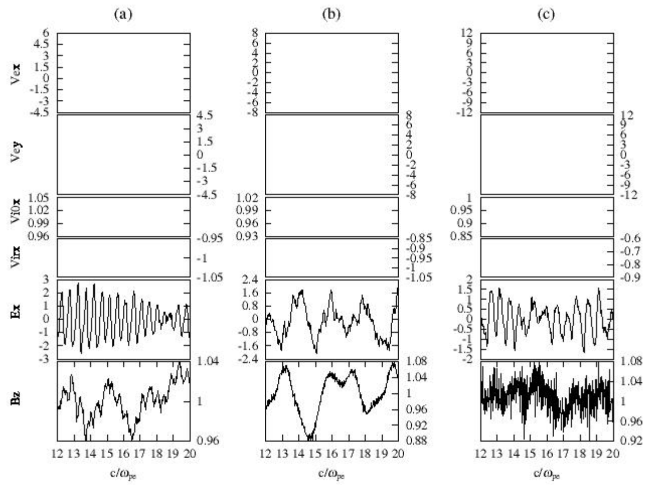

Fig. 3. Same format with Fig. 2 but for Run C at time sequences (a): 39 T_{pe}, (b): 245 T_{pe}, and (c): 794 T_{pe}.

of the ion components has little characteristic feature, we do not discuss here about it. Lines (a)-(c) in each panel are the time sequence discussed below (see figure captions). In Run A and B the electron energy and temperature increase are small compared to the larger Υ runs. In Run C $\sim$ E, the electric field energy increases apparently and energy of the electron reach up to several % at the last of the simulation. First increase of the electric field after $\sim$ 20 T_{pe} in Run C $\sim$ E is brought by nonlinear evolution of Buneman instability between the electron and reflected ion. Second increase of the electric field after $\sim$ 600 T_{pe} seen in Run D and E is due to the incident ion modulation. Strong electron heating and acceleration is accompanied by this ion modulation. Fig. 2 shows phase diagrams and field profiles at the time sequences (a) $\sim$ (c) in Run A (strong magnetization condition). The electron bulk flow undergoes strong modification by the electrostatic force as well as Lorentz force. No electron hole is formed because of fast oscillation of the electric field. Thermalization is not so strong ($\sim$ 6.5 T_0 at the last) but nonthermal electron generation occurs strikingly. Time sequences at (a) and (b) the both ion populations (incident and reflected) has wavy structure due to the friction with the electron, which fades out by the time of (c). Fig. 3 shows the same picture format with Fig. 2 but for Run C. Electron hole formation is incomplete ((a)). Around time (b) the reflected ion is strongly modified as a longer wavelength wavy structure. This structure is caused by ion-acoustic instability in the hot electron due to the positive gradient of the reflected ion distribution function. At the later time (c) the electric field sustaining wavy structure seen in the reflected ion becomes faint while the electric field accompanied by the incident ion modulation is amplified. They present little

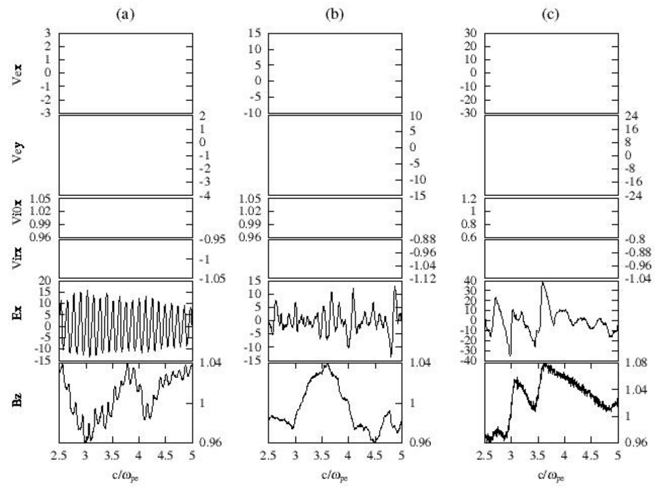

Fig. 4. Same format with Fig. 2 but for Run C at time sequences (a): 30 T_{pe}, (b): 75 T_{pe}, and (c): 1160 T_{pe}.

nonthermal component and much softer spectra than the spectra of Run A. Fig. 4 shows the picture for Run E. In this case electron holes are formed completly and they have a long life time. The most striking feature is strong modification of the incident ion observed at time (c). Such strong modification of the incident ion can not be observed when lower mass ratio is utilized. The modulation in the incident ion is triggered by the coupling between electron hole and ion-acoustic mode [3]. Ion coupling with the electron hole amplifies the electric field. In the panel (c) small depressions seen in the incident ion (for example at $x \sim 3.5$) corresponds to the separatrics of the ion hole as well as to the center of the original electron hole. Some electrons are trapped at the depressions and move toward $+x$ faster than the electron drift velocity. As a result, trapped electrons feel the effective motional electric field toward $-y$ direction (see two peak in V_{ey} panel at $x \sim 3$ and 3.5). This process energize electron efficiently. Energy spectra is harder than Run C and have some nonthermal population. Energy ratio of the electron to the incident bulk flow is the highest of all the runs we presents here.

3. References

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