Electron Heating Process at Quasi-Perpendicular Shocks

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Abstract

One-dimensional full particle simulations are performed in order to investigate a kinetic effect of electrons on the dissipation process at a quasi-perpendicular shock. It is now considered that the kinetic effects of electrons increase as Alfvén Mach number (M_A) increases. That is, there appears a strong interaction between protons and electrons in the higher Mach number case. Here, we have taken a low proton to electron mass ratio as 25 because we can see the interaction even in the lower Mach number case. The results would give some informations about the electron kinetics in collosionless shocks. In the case of $M_A = 4.4$, the upstream electrons are adiabatically heated up from upstream to downstream region. Ions are reflected at the shock surface as reported in hybrid simulation runs. In the case of $M_A = 7.1$, ions are still reflected at the shock surface by the same way as in the low Mach number case. In addition electrons are reflected at the upstream end of the reflected ions. Both reflected electrons and ions are accelerated by the upstream motional electric field, and then convected to the downstream region. The electric field which can reflect the incoming upstream electrons are excited by the modified two-stream instability between the incoming ions and reflected ions. The larger wave amplitude in the higher Mach number case brings the electron reflection.

1. Introduction

Characteristics of the dissipation processes in collisionless plasma shocks change as Alfvén Mach number M_A increases. Above the first critical Mach number M_{c1} (~ 3, which depends on the upstream parameters), the fluid resistivity is inadequate to provide the jump of plasma quantities from the upstream region to the downstream region, and some anomalous dissipation mechanisms are necessary. The observational results from satellites around the earth's bow shock and the numerical results from hybrid simulations make it clear, that is, the multi

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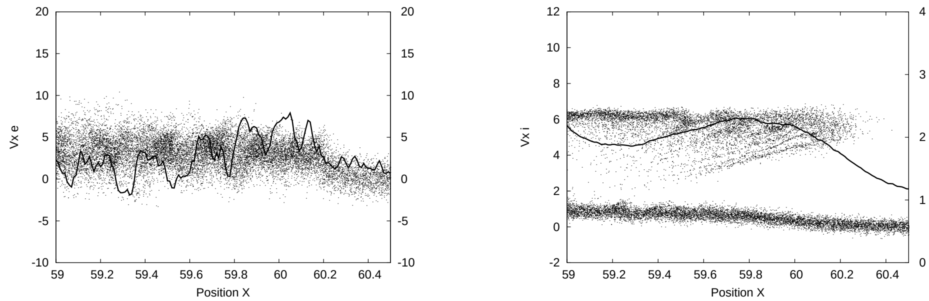

Fig. 1. Results from $M_A = 4.4$ case. Time is 12.9 Ω_i^{-1}. Left: The electron phase plot (dots, left-axis) with the X component of the electric field (lines, right-axis). Right: the ion phase plot (dots, left-axis) with the intensity of the magnetic field (lines, right-axis). Electrostatic waves are observed in the region where reflected ions exist.

ion-distribution in velocity space which consists of the incoming upstream ions and the reflected ions at the shock can represent a significant amount of the dissipation (e.g. Sckopke et al. 1983; Leroy et al. 1982). In these results, however, the electrons are not considered as particles but as fluid. How the electrons contribute to the shock dissipation processes? The electron kinetics would begin to be important under the condition where the dissipation process by only protons is inadequate in much higher Mach number as the discussed at M_{c1}. It is called the second critical Mach number M_{c2}. Here we have shown the kinetic process around the Mach number where the electron kinetics acts an important role to dissipation processes.

2. Simulation Model

The simulations are one-dimensional in space (shock normal direction x: positive x directed upstream) but fully three-dimensional in velocity. To create a shock in the simulation system, we have used the magnetic piston method at $X = 0$. The created shock propagates to positive x region where both electrons and protons are uniformly distributed in the system without bulk flow. Hereafter, magnetic field is normalized by the upstream value B_0. Density is normalized by the upstream proton density N_{p0}. Velocity, time, and length, are by, the Alfvén velocity V_{A0}, the inverse of proton gyro-frequency Ω_i^{-1}, and, the ion inertia length $\lambda_i \equiv V_{A0}/\Omega_i$, respectively, based on the upstream parameters. The realistic mass ratio of proton to electron is too large ($\sim$ 1836) to investigate the interaction between these two species in a full particle simulation, especially in the high Mach number shocks, because a longer simulation box size is necessary to simulate the time evolution of the shock structure, otherwise the launched shock from one side of the simulation box has arrived at the other side of the box before the system will be well matured. Here we have taken the lower mass ratio as 25 because we can see the interaction even in the lower Mach number case. The ratio of the electron plasma frequency (ω_{pe}) to the electron cyclotron frequency (Ω_{ce}) is $\omega_{pe}/\Omega_{ce} = 4$. The shock angle is 70 deg. with the ambient magnetic field on the x-y plane.

3. Simulation Results

Figure 1 shows the result from $M_A = 4.4$ case. The electron phase space plot, the X component of the electric field, the ion phase space plot and the intensity of the magnetic field are shown. The reflected ions are observed with $V_x \sim 6$. Shock front which is defined from the overshoot of the magnetic field intensity is located at $X = 58.6$. Upstream directs to the right (positive X) direction. An electrostatic waves are observed in the region where reflected ions exist. The wave field, however, doesn't strongly modify the electron dynamics. Electrons are weakly heated up as the magnetic field intensity increases. These weak electron kinetics bring the consistent results with hybrid simulations. Figure 2 shows the result from $M_A = 7.1$ case in the same format as Figure 1. Shock front is located at $X = 86.9$. Ions are still reflected at the shock surface by the same way as in the low Mach number case. In addition electrons are also reflected at the upstream end of the reflected ions ($X = 90 - 90.1$). The intensity of the electric field is strong enough for electrons to be reflected to the upstream direction. The reflected electrons are accelerated by the upstream motional electric field and make a halo distribution in the downstream region ($89 < X < 90$). Resultantly, the downstream temperature in the downstream region is higher than that of the lower Mach number case. This dissipation process is quite similar with the mechanism of protons.

4. Summary and Discussion

We have investigated the interaction phenomena between protons and electrons in quasi-perpendicular shocks. Especially, by choosing the small mass ratio between electron and ion (= 25) we can see how the electron works kinetically in a quasi-perpendicular shock. The way is the reflection process at the upstream end of the reflected ions. Although it is not clear if the kinetic effects shown in this study works in the high Mach number shocks in the realistic mass ratio case, this is one of the candidates to heat up the electron temperature at quasi-perpendicular shocks. The excited electrostatic waves which modify the electron dynamics are the results of the instability between the incoming electrons and the reflected ions. The modified two-stream instability excites the waves. Since the growth rate of the wave gets larger as the velocity difference between these two

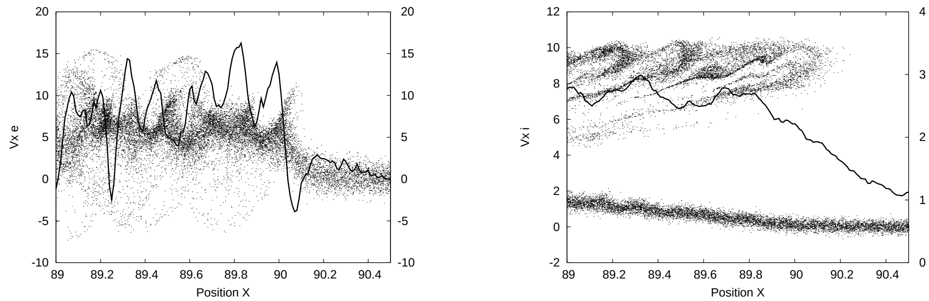

Fig. 2. Results from $M_A = 7.1$ case in the same format as Figure 1. Time is 13.6 Ω_i^{-1}. The electrostatic waves are also observed. Moreover, the intensity of the electric field is strong enough for electrons to be reflected.

components, the wave amplitude gets larger in the higher Mach number case.

Bessho and Ohsawa (2002) has already reported that a part of electron are reflected at the back of the shock front, and then those electron are strongly accelerated by a spatial trapping process at the shock front. However, their process is different from our results because the initial upstream frequency ratio ω_{pe}/Ω_{ce} in their simulations is less than unity. From both our results and results of Bessho and Ohsawa (2002), the importance of the frequency ratio are suggested for the electron dynamics. In the case of $\omega_{pe}/\Omega_{ce} = 20$, the reflected electrons can not be observed even in $M_A = 20$. In this case, electron holes in velocity space is observed.

5. References

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