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Particle Acceleration in Colliding Two Shocks
近接・衝突する二つの衝撃波における粒子加速

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We have performed one-dimensional full particle-in-cell simulations of two colliding shocks. These shocks parameters are $M_A = 13, \beta_{i,e} = 0.5, \theta_{Bn} = 60^\circ$. We find that electrons are efficiently accelerated as they are repeatedly reflected by the shocks before two shocks collide. They also excite the large amplitude magnetic the structure (B_y) between two shocks. The structure cause pitch angle scattering of the energetic electrons and increase the possibility of the reflection. We get the self-consistent manner acceleration mechanism in the two oblique colliding shocks.

1. Introduction

Collisionless shock waves are ubiquitous in space. They occasionally interact with each other. For instance, it is observed that a coronal mass ejection driven shock collides with the earth's bow shock, and high energy ions are created during their approaching [1]. Colliding two shocks are observed also in high power laser experiments and the energy of self-emission from a plasma is increased during the shock-shock interactions [2]. Kinetic simulations regarding colliding two shocks have been performed with hybrid simulation [3]. However, hybrid simulations ordinarily treat ions as super-particles and electrons as a fluid. Therefore micro (electron) scale physics are not solved and we are unable to discuss an electron acceleration.

We use full Particle-in-Cell simulation which ions and electrons are treated as super-particles to overcome the above difficulty. We discuss the detailed structures of colliding two shocks and the accompanied particle acceleration process.

2. Simulation Method

We explain the method to produce the colliding two shocks in a simulation space. We perform numerical simulations using one dimensional full Particle-in-Cell (PIC) simulation. Initially, a homogeneous magnetized plasma, which follows a Maxwell distribution with the electron temperature T_e equal to the ion temperature T_i, and zero bulk velocity, is filled in the simulation system. The ambient magnetic field is given as $\vec{B}_0 = B_0(\cos\theta_{Bn}, 0, \sin\theta_{Bn})$, where B_0 is the strength of the ambient magnetic field and θ_{Bn} is the shock angle defined between the ambient magnetic field and the shock normal (x -axis). There are two boundaries at both sides of the system. By moving the walls inward with a constant speed, the walls specularly reflect the ambient plasma. Then the reflected and the ambient plasma interact with each other, a shock is formed and propagates inward. We set the velocity of the two walls to a same speed but in the opposite direction. Therefore, the two shocks are symmetric. The size of a spatial grid is $\Delta x = \lambda_{De}$ where λ_{De} is the electron Debye length. The time resolution is $\Delta t = 0.05\omega_{pe}^{-1}$ where ω_{pe} is the electron plasma frequency.

3. Results

We discuss the run whose parameters are $\theta_{Bn} = 60^\circ, M_A = 13, \beta_{i,e} = 0.5, \omega_{pe}/\omega_{ce} = 10 \, and \, m_i/m_e = 100$, where M_A is a Alfvén Mach number, $\beta_{i,e}$ is ion (electron) plasma beta, ω_{ce} is the electron cyclotron frequency and $m_{i,e}$ is ion (electron) mass.

Figure 1 shows the ion phase space and B_z (top panel), and the electron phase space, B_y and the ion (blue line) and the electron (black line) energy spectrum (bottom panel). The ion (electron) velocity and the magnetic field are normalized by the Alfvén velocity v_A and B_0 respectively. Before the collision, we find high energy electrons between two shocks (top panel) and large structure of B_y between two shocks (bottom panel). After the collision, these electrons are further accelerated and the energy spectrum of electron forms a power law spectrum whose the spectrum index is 2.4 in

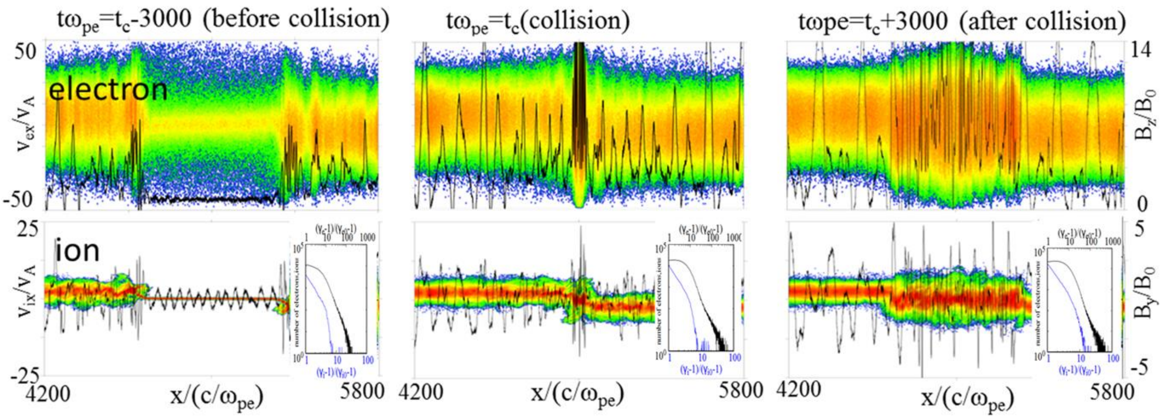

Fig.1. Electron phase space and B_z (top panel) and ion phase space, B_y and energy spectrum(bottom panel)

high energy region.

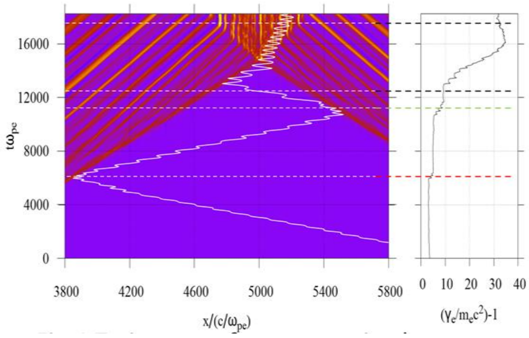

Fig.2. Time-space evolution of B_z and the electron trajectory and energy

We focus on how electrons are accelerated. Figure 2 shows the time-space evolution of B_z and the trajectory of a well-accelerated electron (left panel), and the time evolution of the electron energy (right panel). From this figure, the electron is repeatedly reflected between two shocks and accelerated only when interacts with the shocks. This acceleration mechanism of one time reflection is so-called shock drift acceleration (SDA) [4] in which a particle is moved along y direction by $\nabla \times \mathbf{B}$ drift and accelerated by the motional electric field (E_y).

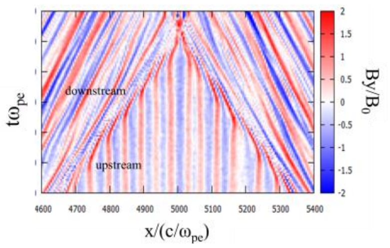

Fig.3.Time-space evolution of B_y

Moreover, reflected electrons excite the large amplitude structure (B_y) in the upstream via fire hose instability [5] since the electrons reflected via SDA tend to make anisotropy of temperature ($T_{e\parallel} > T_{e\perp}$). $\parallel, \perp$ denote parallel and perpendicular to the ambient magnetic field. Figure 3 shows the time-space evolution of the structure. From this figure, the wave frequency ω is zero and the wave number k is $45(\omega_{pe}/c)$.

This structure causes pitch angle scattering of the reflected electrons. The scattered electrons are easy to be reflected by the shocks since a reflection via SDA occurs for electrons whose the perpendicular velocity is larger than the parallel velocity. So, the structure gives the positive feedback to the particle acceleration.

4. Summary

Using one dimensional full PIC simulation, we investigate the colliding two shocks. Main results are (1) the electrons are reflected and accelerated via SDA. This acceleration mechanism is equal to Fermi acceleration (2) the reflected electrons excite structure upstream via fire hose instability (3) this structure scatters the pitch angle of energetic electrons and increase the reflection possibility.

5. References

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