Microinstabilities in collisionless shocks: recent simulation results

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Microinstabilities in a foot of a supercritical (quasi-)perpendicular shock wave are investigated. A two dimensional full particle simulation with periodic boundary conditions show that a variety of different instabilities get excited in a time period shorter than ion gyro period. The most dominant instability is the modified two-stream instability (MTSI) which leads to strong electron heating through the secondary generated electron acoustic instability (EAI). Influences of the MTSI on global shock structures are discussed by performing additional one dimensional full particle shock simulation.

INTRODUCTION

Recent high accurate simulation results reveal that in high Mach number quasi-perpendicular shock front various kinds of microinstabilities get excited and lead to strong plasma heating (e.g., [1]-[3]). The instabilities are driven by relative bulk velocities between incoming, reflected ions, and electrons. In one dimensional geometry, those instabilities can be separated from each other by choosing appropriate parameters. However, in a realistic space plasma, they may be simultaneously present in some cases. Therefore, a purpose of this study is to perform two dimensional simulation and discuss competing processes among those instabilities. Here, we especially pay attention to four instabilities: electron cyclotron drift instability (ECDI), Buneman instability (BI), and MTSIs. Furthermore, influences of the MTSI on a self-reformation process of a quasi-perpendicular shock are discussed by utilizing a one dimensional full particle code.

SIMULATION RESULTS

A part of a foot region is modeled by a two dimensional simulation box using periodic boundary conditions. In a time imediately after specular reflection of incoming ions at a ramp, the system is composed of three plasma species, i.e., incoming and reflected ions, and incoming electrons. The simulation is performed on the electron rest frame, and the incoming and the reflected ion beams are along parallel and antiparallel to the x-direction, while the ambient magnetic field is in the y-direction. Waves are allowed to propagate in the x-y plane. The Mach number of the shock is assumed as $M_A \lesssim 10$. The reflection ratio, the relative density of the reflected to the incoming ions, is 0.25. The plasma beta is

0.1. The mass ratio is 1836, and the ratio of electron plasma to cyclotron frequencies is $\omega_{pe}/\Omega_e = 2$.

First, the Bernstein modes of the fundamental and the second harmonics are driven by ECDI (or BI) through electron-reflected ion interactions. It leads to perpendicular electron heating during $400 < \omega_{pe}t < 1200$ in Fig.1. After that, two MTSIs get excited via electron-incoming ion interactions (MTSI-1) and electron-reflected ion interactions (MTSI-2), while the ECDI is kinetically damped in this stage. The MTSI-2 produces in v_y-y phase space large electron holes. As a result, local electron distribution function has two peaks in v_y so that EAI is driven as the so-called two step instabiliy. The EAI provides efficient parallel electron heating during $1200 < \omega_{pe}t < 1500$ in Fig.1.

In the two dimensional simulation, two MTSIs survive in the end of the run. Then, it is expected that reformation process of the shock is influenced by MTSI when generated waves have sufficiently large amplitudes. To examine it additional one dimensional shock simulation is performed. Because of the one dimensionality, only the MTSI-1 is generated in the foot. After a long time, a part of generated waves are reflected at the ramp and both the incoming and the reflected waves thermalize ions in the foot. Such strong ion thermalization might suppress the reformation.

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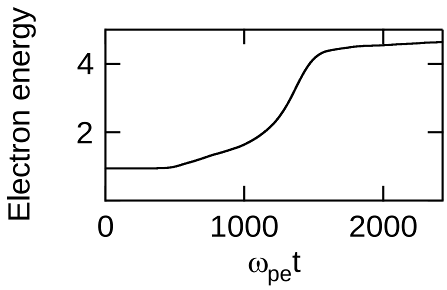

Fig.1 Energy time history of electrons of two dimensional simulation.