Time series analysis of electron acceleration in quasi-perpendicular shock transition regions

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Collisionless shock is believed to be an efficient accelerator of electrons in astrophysical and space plasma environments. In the shock transition, there coexist macroscopic shock structure and microscopic fluctuations due to various plasma instabilities (e.g.[1]). In particular, whistler waves play important role in electron scattering and acceleration at the shock. When the locally measured Alfvén Mach number falls below the so-called whistler critical Mach number, dispersive phase-standing whistler waves are excited in the shock transition region [2]. The modified two-stream instability also generates obliquely propagating whistler waves in the foot of quasi-perpendicular shocks [3]. Accordingly, electrons interacting with the shock transition layer exhibit complex behavior and are thought to be accelerated through multiple mechanisms. In this presentation, we perform particle simulations in the shock transition region, and develop a trajectory analysis method of accelerated electron to distinguish and quantify the wave and drift effects on the energy gain process.

Figure 1 shows the test particle trajectories in the quasi-perpendicular shock structure obtained by a one-dimensional particle-in-cell simulation. The shock parameters are as follows. The shock normal-magnetic field angle is 65 degrees, ion and electron betas, 0.15, upstream Alfvén Mach number, 5.3, which is below the whistler critical Mach number. Hence, the whistler wave trains are emitted in foot of the shock (the image of Fig.1a). Two different types of electron trajectories are shown in Fig.1 (a) in space and time, (b) in energy, (c) in pitch-angle defined at the de Hoffmanm-Teller frame, and (d) (e) in the momentum space. An electron labeled ‘1’ is reflected by the overshoot magnetic field and finally gain the parallel energy after the mirror reflection (Fig.1a and 1d). Thus, the main process seems to the shock-drift acceleration. Betatron acceleration is also candidate for the additional perpendicular energy increase seen in Fig.1(d), when the electron experiences the growing overshoot magnetic field. Another electron labeled ‘2’ is bounced and trapped in the magnetic trough produced by the phase-standing whistler wave embedded in the overshoot (Fig.1a). The bounce motion appears in the pitch-angle oscillation across 90 degrees (Fig.1c). During the trapping, the electron gradually gains the perpendicular energy (Fig.1b and 1e).

Time series data of the electron trajectory and the electromagnetic field experienced by the electron are separated into variations longer and shorter than the electron’s local gyro-period. Then we evaluate which electric field component contributes the most to electron energy gain. The time series analysis method distinguishes and identifies the effects on electron motion such as (1) the nonstationary cross-shock potential, (2) the motional electric field, (3) the betatron effect due to growing overshoot magnetic field, and (4) oblique whistler waves. We discuss electron acceleration mechanisms depending on the shock parameters with Alfvén Mach numbers ranging from 3 to 8 and shock normal-magnetic field angles from 65 to 85 degrees.

References

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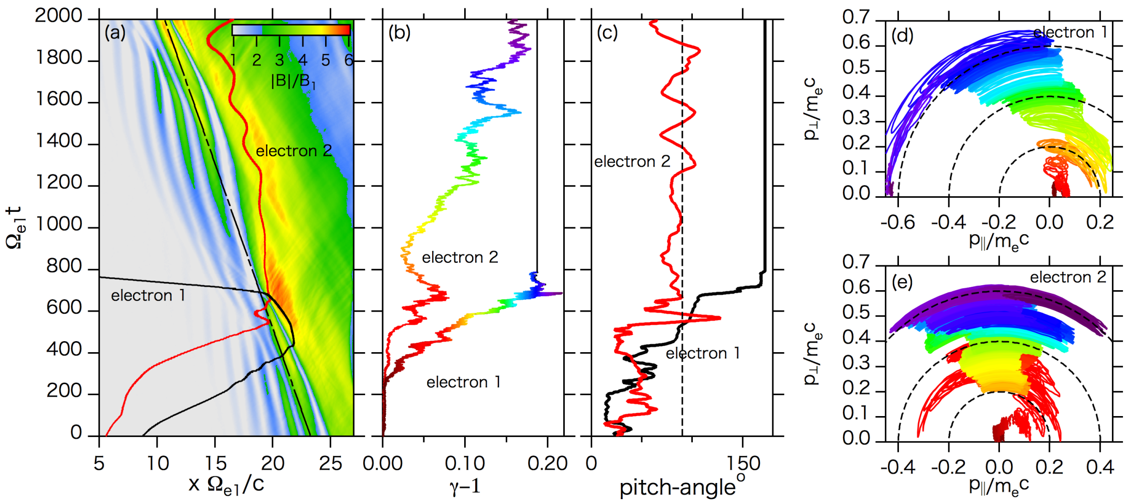

Figure 1: Test particle trajectories of electrons, in shock transition layer obtained from a one-dimensional PIC simulation in (a) space-time, (b) energy, (c) pitch-angle, and momentum space for (d) electron 1 and (e) electron 2.