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Bursty electron acceleration associated with a quasi-perpendicular shock reformation

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Energetic, non-thermal electrons are directly observed in the vicinity of Earth's quasi-perpendicular bow shock. Shock Drift Acceleration (SDA) model [1] has been considered important for producing non-thermal electrons out of the solar wind thermal population. However, the SDA alone does not seem to explain all observed features. Here we show, using 1D PIC simulations of a quasi-perpendicular collisionless shock (Alfvén Mach number 7.1, shock angle 70 degrees, plasma beta 0.3, and ion-to-electron mass ratio 625), that there are additional electron acceleration mechanisms associated with the periodic, self-reformation process of supercritical shocks. The orbit analysis is performed by separating and quantifying all acceleration and deceleration processes.

Figure 1(a) shows a typical trajectory of an accelerated electron near the shock in space and time, indicated by the colored curve. In the panel, the background image with gray scale indicates the magnetic field magnitude. The simulation is in a one-dimensional space along the *x*-axis, and in the downstream frame of reference. The shock travels in the negative *x*-direction toward the upstream region, where the shock front indicated by the red dotted line. The time interval shown here covers almost one cycle of the shock self-reformation. Figure 1(b) shows the trajectory in the velocity space, where the velocity is defined in the normal incidence frame (NIF) in which the shock is at rest, and decomposed into parallel and perpendicular to the upstream magnetic field lied in the *x*-*z* plane. Figure 1(c) shows the kinetic energy of the electron. Here, the rainbow colors in (a-c) indicate the corresponding time, $t\omega_{pe}$. In (c) the horizontal dashed line indicated the energy calculated from the SDA alone. Namely, the energy gain is calculated from the time integration of $-eE_{y1}v_{yd}/m_ec^2$, where E_{y1} denotes the upstream motional electric field and v_{yd} the drift velocity along the shock surface calculated from the simulation data. The kinetic energy is more than twice as large as that estimated by the SDA alone. Figure 1(d-f) show the electromagnetic field felt by the electron, where the values are averaged over the several gyro-periods defined by the local magnetic field.

In (a) the incoming electron is trapped in a thin magnetic trough, formed as a local whistler wave, embedded in the time-evolving overshoot magnetic field in the reformation cycle. During the trapping, the electron feels the increased magnetic field (d), resulting in the energy gain of the gyro-motion perpendicular to the ambient field (b). The orbit analysis reveals that the perpendicular energy gain is caused by non-adiabatic betatron acceleration. In (f) the dashed line indicates E_{y1}. Our simulation shows the electron feels time-evolving E_y larger than E_{y1}, resulting in a further energy gain. At the end of the reformation cycle, the accelerated electron is released upstream with the small amount of the energy loss as the overshoot magnetic field decreases rapidly, resulting in a bursty nature of electron acceleration.

References

[1] M.M. Leroy and A. Mangeney, *Ann. Geophys.*, 2, 4, 449-456 (1984)

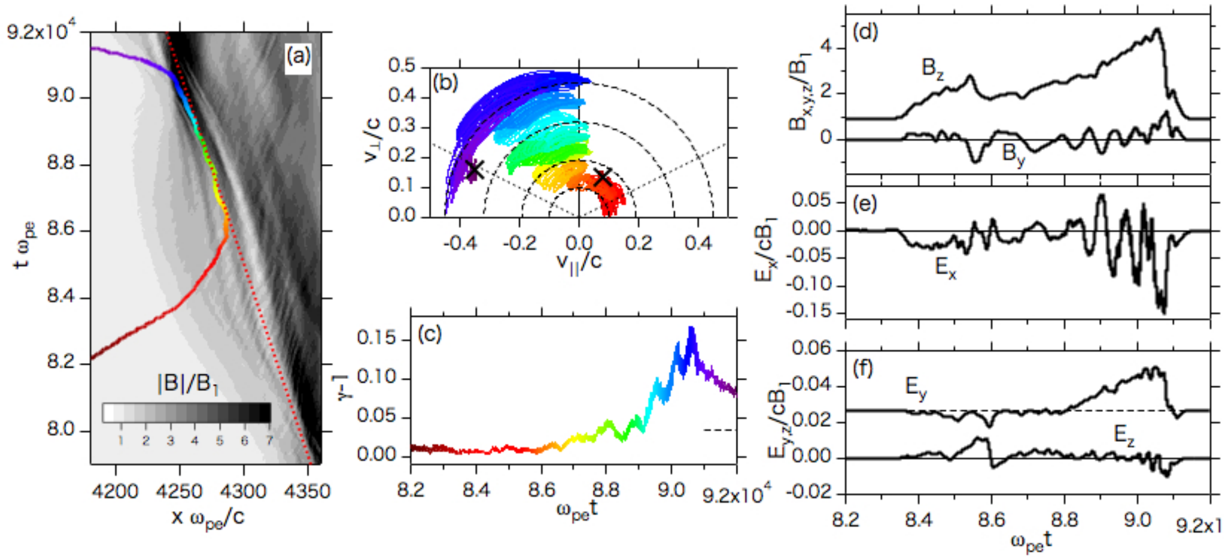

Figure 1: (a) Accelerated electron trajectory in (x-t) space and (b) in velocity space of the NIF. (c) Kinetic energy of the electron. (d) to (f) Electromagnetic field experienced by the electron.