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Electron surfing acceleration in two-dimensional perpendicular shocks

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Particle acceleration in collisionless shock waves is one of the most important issues in space and astrophysical plasma physics. While first order Fermi acceleration is the standard theory for particle acceleration in collisionless shocks, several theoretical difficulties remain yet to be answered.

The central issue in the Fermi acceleration theory at collisionless shocks is the so-called injection problem: Since the Fermi process is not efficient for thermal particles, injection from a thermal pool to nonthermal energy by some other mechanism is required. We think that particle heating and acceleration within the shock structure are important for the injection. It is well-known that a fraction of upstream ions are reflected off the shock front, which play a role for the dissipation required for collisionless shocks. For a strong shock with a Mach number typical of supernova remnants (SNRs), the reflected ions give rise to the Buneman instability through the interactions with upstream electrons. It has been discussed that large amplitude electrostatic waves produced by the instability play an important role for the electron injection to the Fermi acceleration process. Namely, energetic electrons produced by the so-called shock surfing acceleration (SSA) can be a seed population for the subsequent Fermi acceleration. Actually, we have recently showed that the electron injection can be achieved through the SSA followed by shock drift acceleration in quasi-perpendicular shocks with Mach number typical of SNR shocks (Amano & Hoshino, 2007). We showed that the estimated efficiency of the electron injection is consistent with X-ray observations of a nearby SNR.

So far, most studies considering the electron acceleration in high Mach number shocks have been employed one-dimensional (1D) particle-in-cell (PIC) simulation codes. Since the injection efficiency of electrons depends strongly on the electron energization in the shock transition region, understanding of the electron energization in multidimensions are needed for a more accurate estimate of the injection efficiency.

In this report, we discuss an electron acceleration mechanism in perpendicular high Mach number shocks simulated by a two-dimensional (2D) PIC simulation code. We find that strong electron acceleration occurs in the shock transition region even in 2D. The observed electron energy spectrum exhibits a power-law distribution with a index of about 2. The energetic electrons are generated at the leading edge of the shock transition region where large amplitude electrostatic waves are produced by the Buneman instability. From a detailed analysis of accelerated electron trajectories, we conclude that the acceleration mechanism in 2D can also be considered as SSA that is modified by the multidimensionality. The impact of the multidimensionality on the electron injection will be discussed.