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Particle Acceleration in Shock-Shock Interaction

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Collisionless shock waves play a crucial role in producing high energy particles. One of the most plausible acceleration mechanisms is the first order Fermi acceleration in which non-thermal particles statistically gain energy while scattered by MHD turbulence both upstream and downstream of a shock. Indeed, X-ray emission from energetic particles accelerated at supernova remnant shocks is often observed [e.g., Uchiyama et al., 2007].

Most of the previous studies on shock acceleration assume the presence of a single shock. In space, however, two shocks frequently come close to or even collide with each other. For instance, it is observed that a CME (coronal mass ejection) driven shock collides with the earth's bow shock [Hietala et al., 2011], or interplanetary shocks pass through the heliospheric termination shock [Lu et al., 1999]. Colliding shocks are observed also in high power laser experiments [Morita et al., 2013]. It is expected that shock-shock interactions efficiently produce high energy particles. A previous work using hybrid simulation [Cargill et al., 1986] reports efficient ion acceleration when supercritical two shocks collide. In the hybrid simulation, however, the electron dynamics cannot be resolved so that electron acceleration cannot be discussed in principle. Here, we perform one-dimensional full Particle-in-Cell (PIC) simulations to examine colliding two symmetric oblique shocks and the associated electron acceleration. In particular, the following three points are discussed in detail.

1. Energetic electrons are observed upstream of the two shocks before their collision. These energetic electrons are efficiently accelerated through multiple reflections at the two shocks (Fermi acceleration).

2. The reflected electrons excite large amplitude upstream waves. Electron beam cyclotron instability [Hasegawa, 1975] and electron fire hose instability [Li et al., 2000] appear to occur.

3. The large amplitude waves can scatters energetic electrons in pitch angle. The electrons gaining large pitch angles are easily reflected, hence accelerated, when they encounter a shock. The reflected electrons can sustain, or probably even strengthen, upstream large amplitude waves. The above series of process may give a positive feedback to the electron acceleration in converging two shocks.