Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

PEM29-08 Room:503 Time:April 30 11:15-11:30

Colliding Two Oblique Shocks: Shock Structures and Particle Acceleration

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Mechanisms of the particle acceleration at a collisionless shock have been intensively studied analytically, numerically, and observationally. Most of the previous studies assume that energetic particles interact with a single shock. However, shock waves are ubiquitous in space, and 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 [H. Hietala et al., 2011], or interplanetary shocks pass through the heliospheric termination shock [J. Y. Lu et al., 1999]. The detailed structures of such colliding shocks and the accompanied particle heating/acceleration processes have not been understood.

Cargill et al. [1986] performed one dimensional hybrid simulations to discuss the dynamic structure of colliding shocks and the accompanied ion acceleration. They showed that some ions are efficiently accelerated at the time of the collision of two supercritical shocks. However, since electron dynamics are neglected in a hybrid simulation, the microstructures of the colliding shocks, which may affect the early stage processes of particle acceleration, cannot be resolved.

Here, we perform full Particle-in-Cell (PIC) simulations to examine colliding two shocks. In particular, the following three points interacting with two colliding oblique shocks is 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). Moreover, a part of the accelerated electrons are farther energized by interacting with increasing magnetic field during the collision and/or one of the shocks after the collision.

2. Before two shocks collide, there is a large amplitude wave excited by electrons flowing out to the upstream. We discuss the excitation mechanism and the influence on particle propagation or shock structures.

3. After two shocks collide, we find that a plasma density and pressure in the downstream is lower than the value calculated by MHD. The reason is that energetic electrons run away to the upstream. In addition to this, we discuss kinetic influences by comparing PIC simulation's results with the value after two shocks collide (magnetic fields, the shock velocity and etc.) calculated by MHD.

Keywords: collisionless shock, multi-shock waves, particle acceleration, numerical simulation