

Transport Property of Energetic Electrons in Transition Layer of Quasi-perpendicular Shock

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For many decades, the acceleration of high-energy charged particles has been of great interest in astrophysics and space physics. The standard paradigm of the origin of galactic cosmic rays is that shock waves driven by supernova explosions convert roughly ten percent of their kinetic energies to cosmic rays. The theory of diffusive shock acceleration (DSA) provides a solid basis. Indeed, observations of synchrotron emission from ultra-relativistic electrons in shell-type young supernova remnants support the scenario. However, since DSA is known to be inefficient for low-energy electrons, there must be a pre-acceleration mechanism that energizes electrons in the thermal pool to the threshold energy for DSA. The efficiency of electron injection is crucial in predicting the synchrotron emission power from the particle acceleration sites.

The theory of stochastic shock drift acceleration (SSDA) has emerged recently and provides a possible solution to the electron injection problem. It assumes that low-energy electrons are scattered by waves and are accelerated efficiently while they are confined within the transition layer of collisionless shocks. In the limit of strong scattering, the electron transport obeys the diffusion-convection equation, and the particle acceleration happens in a manner very similar to DSA, except that it occurs within a thin shock layer. However, it is not entirely clear when and where the assumption of strong scattering for low-energy electrons is appropriate.

This study uses two-dimensional Particle-In-Cell (PIC) simulations to investigate the property of energetic electron transport within the shock transition layer. In particular, we test whether the diffusion approximation adequately describes the electron transport. We have found that strong high-frequency whistler turbulence is generated in quasi-perpendicular shocks with moderate Mach numbers (Alfven Mach number of ~ 7). The electrons are efficiently scattered in highly oblique shocks and are effectively confined within the transition layer. As a result, a power-law-like energy spectrum forms in the downstream region. The resulting spatial profile of energetic electrons is consistent with the steady-state solution of the diffusion-convection equation, which was previously confirmed with spacecraft observation at the Earth's bow shock. We will also investigate the pitch-angle anisotropy and the statistical property of accelerated particle trajectories in the shock.

Keywords: plasma, particle acceleration, shock