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# Electron Injection via Stochastic Shock Drift Acceleration: Theory, Simulation, and Observation

**Takanobu Amano**
(amano@eps.s.u-tokyo.ac.jp)

The acceleration of high-energy charged particles is common both in heliophysics and astrophysics. Although the diffusive shock acceleration (DSA) has been the well-accepted standard mechanism for particle acceleration at shocks, the fundamental issue is that DSA does not predict the number of accelerated particles. In other words, it relies on an unprescribed injection mechanism that provides a seed population from which the particle acceleration proceeds. Resolving the so-called injection problem is more challenging for electrons than ions because scattering low-energy electrons requires high-frequency waves, which are usually much lower in intensity than low-frequency fluctuations.

We have proposed stochastic shock drift acceleration (SSDA) as a plausible electron injection mechanism that can take place within the transition layer of quasi-perpendicular shocks [Katou & Amano, 2019]. The energy gain mechanism of SSDA is essentially the same as the conventional shock drift acceleration (SDA), but the presence of stochastic pitch-angle scattering makes the acceleration more efficient. We will show that the theoretical predictions nicely explain in-situ observations by Magnetospheric MultiScale (MMS) spacecraft [Amano et al. 2020]. Recent fully kinetic Particle-In-Cell (PIC) simulation results will also be shown, in which we found signatures of SSDA [Matsumoto et al. 2017, Kobzar et al. 2021]. We will also present an extended theoretical model that unifies SSDA and DSA. The model predicts a wide range of the energy spectrum from sub-relativistic and relativistic energies. The particle acceleration in the sub-relativistic energy will be dominated by SSDA, which has a spectral index steeper than the standard DSA. Under certain conditions, the particle acceleration mechanism may smoothly transition from SSDA to DSA, and the spectral index approaches the canonical DSA prediction. Therefore, the model can consistently describe the whole particle acceleration process, including the injection by SSDA and the main acceleration to cosmic-ray energies by DSA. We argue that the electron injection scheme through SSDA is realized preferentially at shocks with higher Alfven Mach numbers defined in the Hoffmann-Teller frame.