A stochastic shock drift acceleration model of electrons in the shock transition region

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The acceleration of cosmic rays is one of the most important problems in astrophysics. Galactic cosmic rays with energies below 10^{15}eV are believed to be accelerated by the 1st order Fermi Acceleration at supernova remnant (SNR) shocks. The theory naturally reproduces a power-law spectrum roughly consistent with observations. However, it is well known that the 1st order Fermi acceleration is not efficient for non-relativistic electrons (<1MeV). Hence we need a pre-acceleration mechanism that injects thermal electrons to relativistic energies to explain electron fluxes estimated from observed radio and X-ray synchrotron radiations emitted by relativistic electrons at SNR shocks. This problem is called the electron injection problem and remains yet to be resolved. One of important acceleration processes related to this problem is the Shock Drift Acceleration (SDA) (Wu 1984, Leroy and Mangeney 1984). In this process, electrons are accelerated anti-parallel to the motional electric field via the gradient-B drift due to a magnetic field gradient in the shock transition region. However, it is well known that the process cannot reproduce a power-law spectrum observed at the Earth bow shock. Meanwhile, a statistical analysis of in-situ satellite observations (Oka et al. 2006) shows that the whistler critical Mach number of the shock regulates the nature of electron accelerations. This suggests that whistler waves play a important role for the acceleration of sub-relativistic electrons.

We here propose a new acceleration mechanism that takes into account the effect of stochastic pitch-angle scatterings by whistler waves during the course of the SDA. To simplify the analysis, we focus only on spatially integrated spectra and employ a box model in which only the dependence on the energy and pitch-angle of the distribution function is considered. We theoretically analyzed the energy spectrum of electrons in the limit of strong scatterings. In this case, the pitch-angle distribution is isotropic and the energy spectrum becomes a power-law roughly consistent with those measured in the bow shock. We also discuss Monte-Carlo simulation results for the proposed model to take into account the effect of an anisotropy in the pitch-angle distribution which should appear in general. We demonstrate that the simulation result agrees quite well with the theoretical prediction in the strong scattering limit. We find that there exists a maximum energy attainable through the proposed mechanism, which scales linearly with the pitch-angle diffusion coefficient. We will show these results, and discuss the application of the proposed model to the Earth bow shock.

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