Combining Diffusive Shock Acceleration and Stochastic Shock Drift Acceleration Theory

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The acceleration of charged particles to energies orders of magnitude higher than the thermal energy occurs commonly in space and astrophysical plasma environments. One of the leading candidate mechanisms for non-thermal particle acceleration is the shock acceleration. The diffusive shock acceleration (DSA) or the first-order Fermi acceleration at a collisionless shock has been thought of as the mechanism producing high-energy cosmic rays. Remote-sensing observations of young supernova remnant (SNR) shocks demonstrate the presence of relativistic electrons with power-law energy spectra, which are radiating synchrotron photons in a broad frequency range. In contrast, in-situ spacecraft observations of shock waves in the heliosphere indicate that the acceleration of electrons at shocks is inefficient. The discrepancy between the two regimes may reasonably be understood by using a newly developed theory called the stochastic shock drift acceleration (SSDA). SSDA is able to explain acceleration of sub-relativistic electrons diffusively confined within the transition layer of the shock. Since the maximum energy by SSDA is proportional to the shock speed squared, it may produce mildly relativistic electrons only at high-speed shocks. The pre-accelerated electrons may be accelerated even further by DSA to ultra-relativistic energies.

We here present a theory that gives a unified understanding of the two important acceleration mechanisms. Indeed, we show that both of them can be derived from the same transport equation. Under the diffusion approximation, SSDA is nothing more than the particle acceleration of particles in an oblique shock of finite thickness, while DSA considers an infinitesimally thin shock. The acceleration rate of SSDA is much faster than DSA because of the small spatial scale involved. On the other hand, the spectral index is typically softer than the standard DSA prediction. Combining them together, we will be able to predict an energy spectrum of electrons from non-relativistic (but suprathermal) to ultra-relativistic energies by a single theoretical model.

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