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Injection Problems in Diffusive Shock Acceleration Theory

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Abstract

Injection of electrons into the Fermi 1st-order process has been one of long-standing problems in the Diffusive Shock Acceleration (DSA) theory for astrophysical shocks, because it involves complex plasma kinetic processes that can be studied only through full Particle-in-Cell (PIC) simulations. It is thought that electrons must be pre-accelerated from their thermal momentum to several times the postshock thermal proton momentum to take part in the DSA process, and electron injection is much less efficient than proton injection due to smaller rigidity of electrons.

Several recent studies using PIC simulations have shown that some of incoming protons and electrons gain energies via shock drift acceleration (SDA) while drifting along the shock surface, and then the particles are reflected toward the upstream region. Those reflected particles can be scattered back to the shock by plasma waves excited in the foreshock region, and then undergo multiple cycles of SDA, resulting in power-law suprathermal populations. In these PIC simulations, however, subsequent acceleration of suprathermal electrons into full DSA regime has not been explored yet, because extreme computational resources are required to follow the simulations for a large dynamic range of particle energy.

Non-Maxwellian tails of high energy particles have been widely observed in space and laboratory plasmas. Such particle distributions can be described by the combination of a Maxwellian-like core and a suprathermal tail of power-law form, which is known as the kappa-distribution. The existence of kappa-like suprathermal tails in the electron distribution would alleviate the problem of extremely low injection fractions for weak quasi-perpendicular shocks such as those widely thought to power radio relics found in the outskirts of galaxy clusters.