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Electron pre-acceleration at merger shocks of galaxy clusters

Particle pre-acceleration constitutes a central unresolved problem in the theory of diffusive shock acceleration (DSA). This process acting at merger shocks in galaxy clusters is thought to produce relativistic electrons forming the so-called radio relics through their radio and X-ray emissions. DSA may also be a source of high- and ultra-high-energy cosmic rays and associated gamma-rays and neutrinos. We report on our recent studies of electron pre-acceleration in cluster shocks with large-scale 2D kinetic particle-in-cell simulations that allow us to investigate the effects of the ion-scale rippling of the shock front and the multi-scale turbulence in the shock transition and downstream. We show that electron injection to DSA can be provided through the process of stochastic shock-drift acceleration (SSDA), in which electrons are confined in the shock transition by pitch-angle scattering off turbulence and gain energy from the motional electric field. Through analysis of multi-scale turbulence in the shock at different pre-shock conditions we demonstrate a crucial role of the shock rippling in electron acceleration via SSDA.

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