Heating at Slow Shocks

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One of the lasting legacies of Harry Petschek is the realization of the existence and importance of slow-mode shocks in the overall reconnection process. According to the model originated by Harry, and explained in retrospection [1], standing slow shocks extend out from the reconnection site, where the incoming flow is diverted, accelerated and heated at the expense of the magnetic field energy. Slow shocks are observed, but only occasionally, in the magnetotail [2]. They can also be modeled in hybrid (particle ion, massless fluid electron) simulations [3]. At modest incident angles (θ_{Bn} =60° - 75°) in the simulations, the shock forms from the coupling of two ion streams through kinetic Alfven waves, which leads to ion heating at the shock, a population back-streaming ions and ion cyclotron waves propagating at angles highly oblique to the magnetic field, consistent with observations [2]. Electron heating is also observed at slow shocks, with stronger heating parallel to the magnetic field. Because the electrons are modeled in the simulations as an abiabatic fluid, we study electron heating using particle-in-cell simulations of slow-mode shocks (θ_{Bn} =75° and β_e = 0.01). We show that the kinetic Alfven waves principally heat the electrons along the field direction, so that the downstream electron temperature becomes anisotropic ($T_{e||} > T_{e\perp}$), as observed at slow shocks in space. Consistent with theory [4], the electron heating is stronger than in previous simulations performed at this same θ_{Bn} but at higher β_e = 0.1 [5]. The waves also give rise to spiky structures in the density in the shock ramp, which can resolve the disagreement in the observations concerning the width of slow shocks [2].

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