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Kinetic simulations of high Mach shocks: PIC simulations vs in-situ measurements

Artem Bohdan[1], Martin Pohl[1,2], Jacek Niemiec[3], Paul J. Morris[1], Yosuke Matsumoto[4], Takanobu Amano[5], Masahiro Hoshino[5], and Ali Sulaiman[6]

[1]Deutsches Elektronen-Synchrotron (DESY), Astroparticle physics, Germany (artem.bohdan@desy.de)
[2]Institute of Physics and Astronomy, University of Potsdam, Potsdam, Germany
[3]Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland
[4]Department of Physics, Chiba University, Chiba, Japan
[5]Department of Earth and Planetary Science, the University of Tokyo, Tokyo, Japan
[6]Department of Physics and Astronomy, University of Iowa, Iowa, USA

High-Mach-number collisionless shocks are found in planetary systems and supernova remnants (SNRs). Electrons are heated at these shocks to temperatures well above the Rankine–Hugoniot prediction. However, the processes responsible for causing the electron heating are still not well understood. We use a set of large-scale particle-in-cell simulations of nonrelativistic shocks in the high-Mach-number regime to clarify the electron heating processes. The physical behavior of these shocks is defined by ion reflection at the shock ramp. Further interactions between the reflected ions and the upstream plasma excites electrostatic Buneman and two-stream ion–ion Weibel instabilities. Electrons are heated via shock surfing acceleration, the shock potential, magnetic reconnection, stochastic Fermi scattering, and shock compression. The main contributor is the shock potential. The magnetic field lines become tangled due to the Weibel instability, which allows for parallel electron heating by the shock potential. The constrained model of electron heating predicts an ion-to-electron temperature ratio within observed values at SNR shocks and in Saturn’s bow shock. We also present evidence for field amplification by the Weibel instability. The normalized magnetic field strength strongly correlates with the Alfvenic Mach number, as is in-situ observed at Saturn's bow shock.