Effects of impurities and electron trapping in collisionless electrostatic shocks

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Electrostatic collisionless shocks appear in various laboratory and space plasmas; and they are also used in laser-plasma based acceleration schemes to produce mono-energetic ion beams [1].

We investigate the existence and properties of low Mach-number electrostatic collisionless shocks, with particular emphasis on the effect of impurities and electron trapping. We use a semi-analytical approach similar to Ref. [2, 3] to describe the vicinity of the shock. These shock solutions show good correspondence to simulation results initialized with density discontinuities with the fully kinetic, Eulerian Vlasov-Maxwell solver of `Gkeyll`[4].

We find that even a small amount of impurities can influence the shock properties significantly, including the reflected light ion fraction, which can change several orders of magnitude. We provide accurate analytical expressions for the reflected fractions of main ions and impurities, which illuminate the different behavior of hydrogen, depending on its role as main ion or impurity. The reflection of heavy impurities by a shock in a hydrogen plasma is vanishingly small, while shocks in heavy ion plasmas – with relevance to laser-based ion acceleration experiments – reflect most of the hydrogen impurity ions. When the electron distribution is flat in the trapped phase space regions due to the downstream potential oscillations, bifurcation of shock-like solutions is observed for low Mach-numbers.

References

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