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Electron-ion temperature ratio in mildly relativistic shocks

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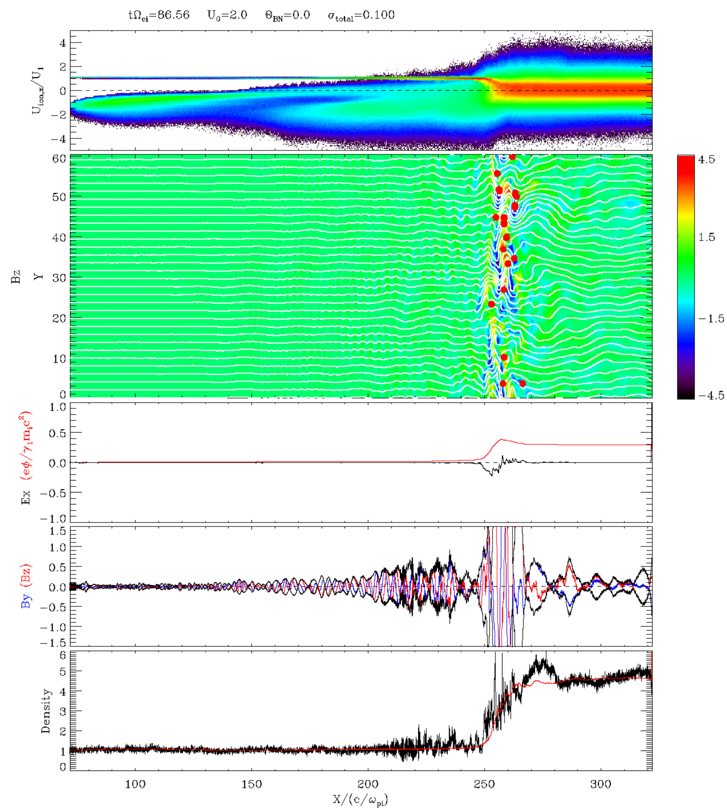
In astrophysical collisionless shocks, both ions and electrons are efficiently heated, and furthermore the thermal energy of the electrons downstream becomes much higher than the energy of the incident electron bulk flow energy due to the energy conversion from ions to electrons. While the temperature of the shock-heated electrons is a critical parameter in shock dynamics, the energy partitioning between ions and electrons remains an unsolved problem. In this presentation, we will examine the plasma processes of ion and electron heating, as well as particle acceleration, by focusing on a shock front/transition region for mildly relativistic shocks. We perform a two-dimensional particle-in-cell (PIC) simulation, which will allow us to explore the dynamics of collisionless shock waves. The mildly relativistic shock waves play a significant role in active galactic nuclei and microquasars, which are known for their intense X-ray and gamma-ray emission, is a subject of active research in astrophysics.

Figure below illustrates the transition from upstream to downstream in a mildly relativistic parallel shock with an upstream flow four-velocity of 2.0, which corresponds to a bulk Lorentz factor of 2.24. From the top to the bottom panel, the ion phase space, the two-dimensional structure of magnetic fields, the longitudinal electric field (black) and the shock potential (red), the transverse magnetic fields (B_y with blue and B_z with red), and the plasma density (cross section with black and the average in y with red) are presented. The shock front is situated around $x(c/\omega_{pi})=250$, measured in terms of ion inertia length. A proportion of the incoming ions undergo reflection at the shock front, with the resultant Alfvenic waves (i.e., whistler waves) being generated upstream. Due to the high Mach number shock, these waves are convected downstream and undergo compression with the larger amplitude. The electron cyclotron damping and/or the parametric instabilities of these excited Alfvén waves represent a pivotal concern in the context of plasma heating.



In addition to the wave heating, the magnetic reconnection process occurring around the shock front, induced by the presence of the large-amplitude Alfven waves can contribute to the ion and electron heating. The while lines depicted in the second panel from the top correspond to the magnetic field lines, while the red dots represent the saddle points of the vector potential derived from the magnetic fields Bx and By. These saddle points correspond to the positions of X-points of reconnection.

Additionally, the cross-shock potential contributes to partial electron heating. As illustrated in the third panel, the longitudinal electric field E_x (black) and the electrostatic potential (red) are depicted, and the negative electric field is capable of accelerating electrons at the shock front.

In this presentation, we will provide a comparative analysis of plasma heating by Alfvenic waves, reconnection, and the total cross-shock potential. We will discuss the plasma kinetic mechanisms responsible for electron-ion energy partitioning.

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