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Non-relativistic Perpendicular Shocks in Young Supernova Remnants

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For parameters that are applicable to the conditions at young supernova remnants, we present results of 2D3V particle-in-cell simulations of a non-relativistic plasma shock with a large-scale perpendicular magnetic field. We developed a new clean setup that uses the collision of two plasma slabs with different density and velocity, leading to the development of two distinctive shocks and a contact discontinuity without artificial transients that may limit the veracity of the simulation. The Alfvenic Mach number of both shocks is $M_{\mathrm{A}} \simeq 30$, whereas the sonic Mach numbers differ with values $M_{\mathrm{s}} \simeq 250$ and $M_{\mathrm{s}} \simeq 750$.
Both the forward and the reverse shocks are mediated by a Weibel-like filamentation instability that produces mainly magnetic turbulence.
We observe significant shock rippling and strong fluctuations in the turbulent shock structure, and also features of the shock self-reformation. Proton reflection at the shocks leads to shock-surfing acceleration that generates a moderate non-thermal tail in the particle spectra measured downstream, suggesting that few ions undergo more than one reflection cycle. Electrons are pre-accelerated in a layer of Buneman waves at the shock foot, but are very efficiently isotropized upon passage through the shock ramp, and hence their downstream spectrum is quasi-thermal with high temperature. We note that electrons and ions show the same transverse drift in the ramp region, which is commensurate with $\mathbf{E}x\mathbf{B}$ drift, but not the gradient drift that is usually invoked for shock drift acceleration. Thus, electrons loose energy by drifting.
We discuss the impact of our findings on pre-acceleration of electrons at high-Mach-number perpendicular shocks and their injection into diffusive shock acceleration. First results of the studies of oblique quasi-perpendicular shocks will also be presented.

Collaboration

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