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Pre-acceleration in the Electron Foreshock by Electron Acoustic Waves

To undergo diffusive shock acceleration, electrons need to be pre-accelerated to increase their energies by several orders of magnitude, else their gyro-radii are smaller than the finite width of the shock. In oblique shocks, where the upstream magnetic field orientation is neither parallel or perpendicular to the shock normal, electrons can escape to the shock upstream, modifying the shock foot to a region called the electron foreshock. To determine the pre-acceleration in this region, we undertake PIC simulations of oblique shocks while varying the obliquity and in-plane angles. We show that while the proportion of reflected electrons is negligible for $\theta_{\rm Bn} = 74.3^{\circ}$, it increases to $R \sim 5\%$ for $\theta_{\rm Bn} = 30^{\circ}$, and that, via the electron acoustic instability, these electrons power electrostatic waves upstream with energy density proportional to $R^{0.6}$ and a wavelength $\approx 2\lambda_{\rm se}$, where $\lambda_{\rm se}$ is the electron skin length. While the initial reflection mechanism is typically a combination of shock surfing acceleration and magnetic mirroring, we show that once the electrostatic waves have been generated upstream they themselves can increase the momenta of upstream electrons parallel to the magnetic field. In $< 1\%$ of cases, upstream electrons are prematurely turned away from the shock and never injected downstream. In contrast, a similar fraction are re-scattered back towards the shock after reflection, re-interact with the shock with energies much greater than thermal, and cross into the downstream.

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