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Electron pre-acceleration in shock transition regions of weakly magnetized perpendicular shocks

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One of the long-standing issues regarding cosmic ray acceleration by the Fermi process at astrophysical shocks is the electron injection problem. Some population of the electrons must be pre-accelerated before the Fermi process because low-energy electrons cannot resonate with MHD-scale waves in the shock downstream. It is believed that this acceleration takes place in the shock transition region (a thin layer with a thickness of ion gyro-radius).

We investigate the electron pre-acceleration by Weibel instability, which is known to be the dominant instability for non-relativistic, high-Mach number shocks. We use 2D and 3D particle-in-cell simulations to show that Weibel instability can amplify the magnetic field efficiently when there is a strong enough background magnetic field to magnetize the electrons but not the ions.

The 2D simulation shows clear evidence of magnetic reconnection and associated electron acceleration. This result is consistent with previous shock simulations, which indicate that the Weibel instability determines the dynamics of shocks with these parameters.

In the 3D simulation, we find the same efficient magnetic field amplification. However, the structure in the nonlinear stages is much more turbulent than in 2D.

This scenario applies to nonrelativistic shocks with Alfven Mach-numbers of 100s, which is a typical value for young supernova remnants believed to accelerate a significant portion of galactic cosmic rays.