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Using PIC and PIC-MHD to investigate the occurrence of Fermi-1 acceleration in astrophysical shocks

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When charged particles cross an astrophysical shock, they can be accelerated through diffusive shock acceleration (DSA) aka Fermi-1 acceleration. This process involves repeated shock crossings, which occur if the particles are reflected toward the shock by the magnetic field. If the particles reach relativistic speeds, they become known as cosmic rays (CRs).

This process is difficult to simulate, because it involves both large scales (the size of the astrophysical shock, which is typically measured in pc) and microphysics (the interaction between individual particles and the magnetic field).

We investigate these interactions by combining both particle-in-cell (PIC) and combined PIC-MHD simulations. Using a PIC cell code, we simulate the formation of the shock, which allows us to determine which fraction of the total mass crossing the shock is reflected back upstream. Then, using the combined PIC-MHD method, we continue the simulation on a larger scale in order to follow the interaction between the reflected particles and the thermal gas. To determine whether they can trigger the magnetic instabilities that will allow for the particles to be reflected back toward the shock.

We find that this process depends on both the angle between the magnetic field and the flow and the Alfvenic Mach number. For large angles (quasi-perpendicular) the reflected particle fraction tends to be too small to trigger the required instabilities. However, this changes at high Alfvenic Mach numbers, where we find that even a low non-thermal particle fraction is enough to destabilize the magnetic field and initiate DSA.

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