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On Fermi acceleration of charged particles in oblique shocks

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Astrophysical shocks are well known for their ability to accelerate charged particles through the process of diffusive shock acceleration (DSA), aka Fermi 1 acceleration. Diffusive shock acceleration involves repeated shock crossings with the particles picking up speed each time they are reflected by the local magnetic field. However, this process requires that the particles can trigger local instabilities in the magnetic field which will twist the magnetic field lines, enabling the field to reflect the particles.

In high-Mach, quasi-parallel shocks, this is done efficiently by the non-resonant streaming instabilities. For quasi-perpendicular shocks, where the magnetic field makes a steep angle with the flow, this process becomes more difficult, and models by e.g. Caprioli & Spitkovski (2014a,b, Haggerty & Caprioli) showed no acceleration for shocks with the magnetic field at angles of 60 degrees or more with the upstream flow. Van Marle et al. (2018), showed that particle acceleration at higher angles is theoretically possible, but these results were obtained using a prescribed injection rate for particles at the shock, which assumed that the injection rate would similar to that of a quasi-parallel shock.

Now, by combining multiple techniques, we investigate this process more closely. We use a particle-in-cell (PIC) code to model the details of the shock structure and derive the particle injection rate as a function of the shock conditions. Then using a combined PIC and magnetohydrodynamics (MHD) code we continue the simulation on a much larger scale to determine whether, for the given injection rate, the upstream magnetic field can be sufficiently disturbed that Fermi1 acceleration becomes possible.

Our results show that the energy of the upstream particle flow has to exceed the local magnetic field energy in order to distort the magnetic field. Therefore, the chance of triggering Fermi 1 acceleration increases for a weak magnetic field. We find that for a 60 degree obliquity, Fermi 1 acceleration can occur for shocks with an Alfvénic Mach number of 50 or more. However, this critical Alfvénic Mach number increases rapidly for higher obliquity angles, making Fermi 1 acceleration unlikely when the shock becomes quasi-perpendicular.

References:

Caprioli D. & Spitkovski, A., 2014, ApJ, 783, 91
Caprioli D. & Spitkovski, A., 2014, ApJ, 794, 46Haggerty S. & Caprioli D. 2019, ApJ, 887, 165
van Marle, A.J., Casse, F., & Marcowith, A., 2018, MNRAS, 473, 3394

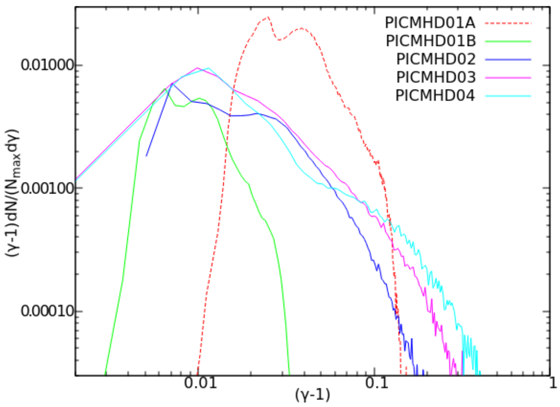

Figure 1: Spectral energy distributions (SEDs) for shocks with obliquity of 60 degrees with Alfvenic Mach numbers of 20 (PICMHD01A,B), 50 (PICMHD02), 100 (PICMHD03) and 300 (PICMHD04). As the Alfvenic Mach number increases, the SEDs start to show a high energy tail, indicative of Fermi 1 acceleration.