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Particle Acceleration in Turbulence and Stochastic Reconnection

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While particle acceleration in shocks has been extensively explored, an alternative less investigated mechanism involves particle acceleration in magnetic reconnection sites. Magnetic reconnection may occur when two magnetic fluxes of opposite polarity encounter each other. In the presence of finite magnetic diffusivity, the converging magnetic lines annihilate at the discontinuity surface where a current sheet forms. In [1], the authors first proposed that an efficient first-order Fermi process can occur within a current sheet, where trapped charged particles may bounce back and forth several times and gain energy due to head-on collisions with the two converging magnetic fluxes incoming with the reconnection speed V_{rec}. They found that the particle energy gain after each round trip is $\Delta E/E \propto V_{rec}/c$. Within the Lazarian-Vishniac model of fast magnetic reconnection [2] in the presence of turbulence, V_{rec} can be of the order of Alfvén speed V_A, resulting in even more efficient acceleration mechanism. A similar model was demonstrated within a collisionless reconnection scenario [3], in which the acceleration is controlled by the contraction of two-dimensional (2D) loops due to firehose instability.

We analyze the energy distribution evolution of test particles (protons) injected in three dimensional (3D) magnetohydrodynamic (MHD) simulations of different magnetic reconnection configurations. When considering a single Sweet-Parker topology, the particles accelerate predominantly through a first-order Fermi process. When turbulence is included within the current sheet, the acceleration rate is highly enhanced, as a result of two factors, (1) the converging flow driven by reconnection becomes fast and independent of resistivity, and (2) the formation of a thick volume filled with multiple simultaneously reconnecting magnetic fluxes allows the particles to multiply the energy gain as compared to a single current sheet situation (see Fig. 1). The results published in [4] indicate therefore, that charged particles trapped within the turbulent volume near current sheet suffer several head-on scatterings with the contracting magnetic fluctuations, which significantly increase the acceleration rate and qualifies for a first-order Fermi process. For comparison, we also tested acceleration in MHD turbulence, where particles suffer collisions with approaching and receding magnetic irregularities, resulting in a reduced acceleration rate. We argue that the dominant acceleration mechanism approaches a second order Fermi process in this case. In this work we consider turbulence imposed externally, and turbulence developed self-consistently by reconnection from the initial background noise.

References

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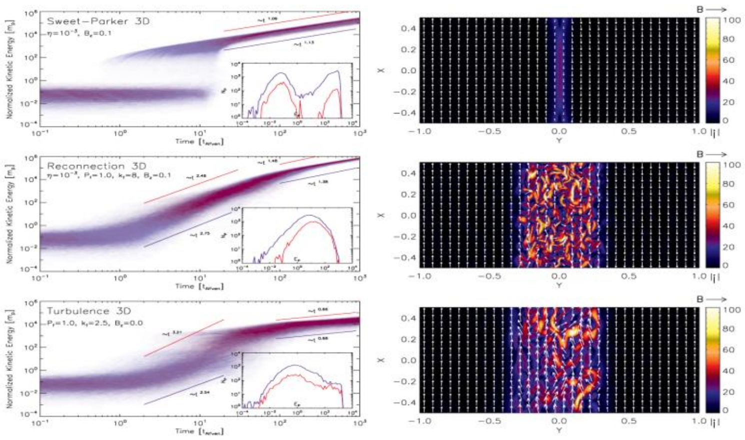

Figure 1. Left: Particle kinetic energy distributions for 10 000 protons injected in the Sweet-Parker reconnection (top), fast magnetic reconnection (middle), and purely turbulent (bottom) domains. The colors indicate which velocity component is accelerated (red or blue for parallel or perpendicular, respectively). The energy is normalized by the proton mass. Subplots show the particle energy distributions at t = 5.0. Right: The exemplary vertical cuts through the domain at Z = 0 of the absolute value of current density |J| overlapped with the magnetic vectors for the corresponding reconnection/turbulence configurations.