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Fast turbulent magnetic reconnection and its implications for particle acceleration and high energy emission in compact objects

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Magnetic reconnection is ubiquitous in Astrophysics, from the Earth's magnetotail to the solar and black hole coronae, and becomes an effective mechanism for converting magnetic to kinetic and thermal energy in turbulent environments. We study turbulence's effect on magnetic reconnection rate via high-resolution 3D MHD simulations across an extensive parametric space. With an initial multi-mode perturbation in the system, turbulence is self-generated and sustained in the current sheet - the magnetic reconnection site, resulting in fast rates of $V_{\rm rec}/V_A \sim 0.03 - 0.08$, where $V_A = B/\sqrt{4\pi\rho}$ is the Alfvén velocity. These rates surpass those driven solely by resistive tearing modes/plasmoid instabilities. Our results show that the reconnection rates remain independent of Lundquist and magnetic Prandtl numbers, aligning with the theory of turbulent reconnection proposed by Lazarian and Vishniac (1999) and with solar observations and prior simulations of accretion flows and relativistic jets. Plasma-β shows mild influence, decreasing $V_{\rm rec}$ from 0.036 to 0.028 as β increases from 2.0 to 64.0, for simulations with Lundquist number of $S = 10^5$, being an important consequence for small β plasmas (e.g., sun, accretion disks, and relativistic jets). By injecting thousands of test particles into our turbulent current sheet, we demonstrate that magnetic reconnection is an effective mechanism to accelerate particles to very high energies as a first-order Fermi process.

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