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Multi-scale dynamics of magnetic flux tubes and inverse magnetic energy transfer[1]

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The physical picture of interacting magnetic flux tubes provides a useful paradigm for certain plasma dynamics in a variety of astrophysical environments, such as the solar corona, the heliosheath, and Weibel-generated magnetic fields in supernova shocks. We investigate a system of parallel flux tubes as well as more generic magnetically dominated turbulent systems, of which the long-term evolution is dictated by the mergers of magnetic structures. We propose that the mergers are dynamically constrained by the conservation of ideal invariants (the magnetic potential and axial fluxes of each tube), and the flux tubes evolve in a critically-balanced fashion (along the direction perpendicular to the merging plane). An analytical model for the time evolution of quantities such as the magnetic energy and the energy-containing scale is constructed in the reduced-magnetohydrodynamic description, as borne out by our direct numerical simulations. An important conclusion is that such systems exhibit an inverse transfer of magnetic energy that terminates only at the system scale. Magnetic reconnection is identified as its underlying key mechanism and sets the time scale of the system evolution. This quantitative description of inverse energy transfer could improve our understanding of longstanding problems such as coronal heating, galactic magnetogenesis, and high-energy emission in gamma-ray bursts. As an example, we estimate the scale and strength of the initial seed field for the Galactic dynamo problem by considering the interaction between inverse magnetic transfer and ambient galactic turbulence.

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