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Efficient Nonthermal Ion and Electron Acceleration Enabled by the Flux-Rope Kink Instability in 3D Magnetic Reconnection

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Solar flare and magnetotail observations show simultaneous acceleration of ions and electrons into power-law energy distributions extending to high energy. This suggests a common reconnection acceleration process but the underlying physics is not well understood. During magnetic reconnection, energetic particles undergo a universal Fermi acceleration process involving the curvature drift of particles. However, the efficiency of this mechanism is limited by the trapping of energetic particles within flux ropes. Using 3D fully kinetic simulations, we demonstrate that the flux-rope kink instability leads to field-line chaos in weak-guide-field regimes where the Fermi mechanism is most efficient, thus allowing particles to transport out of flux ropes and undergo further acceleration. As a consequence, both ions and electrons form clear power-laws which contain a significant fraction of the released energy. The low-energy bounds, which control the nonthermal energy contents, are determined by the injection physics, while the high-energy cutoffs are limited only by the system size. These results have strong relevance to observations of nonthermal particle acceleration in both the solar corona and magnetotail.

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