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Radiative Magnetohydrodynamic Simulation of the Confined Eruption of a Magnetic Flux Rope: Unveiling the Driving and Constraining Forces

Flares and CMEs are different manifestations of the same energy release process, during which flux ropes act as the key magnetic structure. However, due to the lack of in-situ observation, it is still difficult to capture the dynamic evolution of flux rope in detail. Here, we analyze the forces that control the dynamic evolution of a flux rope in a 3D RMHD simulation conducted with the MURaM code, whose eruption gives rise to a C8.5 confined flare. The flux rope rises slowly with an almost constant velocity of a few km/s in the early stage when the gravity and Lorentz force are nearly counterbalanced. After it rises to the height where the decay index of the external poloidal field satisfies the torus instability criterion, the significantly enhanced Lorentz force breaks the force balance and drives the rapid acceleration of the flux rope. Fast magnetic reconnection is immediately induced within the current sheet under the erupting flux rope, which provides strong positive feedback to the eruption. The eruption is eventually confined due to the tension force from the strong external toroidal field. Our result provides a detailed and comprehensive analysis on the dynamic evolution of flux rope eruption, which suggests that the gravity of plasma plays an important role in sustaining the quasi-static stage of the preeruptive flux rope, while the Lorentz force, which is contributed from both the ideal MHD instability and magnetic reconnection, dominates the evolution of flux rope during the eruption process.

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