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Insights into the Rotation and Eruption of Magnetic Flux Ropes Influenced by External Toroidal Magnetic Fields

We perform a data-constrained simulation with the zero-beta assumption to study the mechanisms of rotation and failed eruption of a filament in active region 11474 on 2012 May 5. Our simulation reproduces most observational features very well, e.g., the large-angle rotation, the confined eruption and flare ribbons. We discover two flux ropes in the sigmoid system, an upper flux rope (MFR1) and a lower flux rope (MFR2) grows by tether-cutting reconnection during the eruption, which correspond to the filament and hot channel in observations, respectively. Both flux ropes undergo confined eruptions. The rotation of MFR1 is related to the shear-field component along the axis. The toroidal field tension force and the non-axisymmetry forces confine the eruption of MFR1. We also suggest that the mutual interaction between MFR1 and MFR2 contributes to the large-angle rotation and the eruption failure.

Then, we perform three-dimensional magnetohrdronamic simulations to model the eruption of magnetic flux ropes in the magnetic configuration with and without external toroidal magnetic fields, to examine the mechanisms by which the toroidal magnetic field facilitates flux-rope rotation, and in exploring potential alternative rotation mechanisms beyond the effects of sheared fields and kink instability. The behavior of flux ropes in two simulations exhibits significant contrasts. We indicate that toroidal fields facilitate the flux-rope rotation by promoting the release of the initial twist and amplifying the lateral Lorentz force exerted on the flux rope. In addition, slipping magnetic reconnection between flux-rope field lines and sheared-arcade field lines can also contribute to the rotation.

Primary author: ZHANG, Xiaomeng

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