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Understanding the Genesis of Eruptive Solar Magnetic Flux Ropes

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Magnetic flux ropes that consist of helical magnetic field lines winding around a common axis are ubiquitous in plasmas in the universe with different scales. In the study of solar plasmas, magnetic flux rope is widely accepted as a fundamental structure to form magnificent and disastrous eruptions, known as coronal mass ejections. Although it has been detected in situ in the interplanetary space since 1970s, flux rope's origin on the Sun is a long-standing mystery and has been under intense debate for decades. With the aid of recent high-resolution and multi-wavelength observations, we are able to further understand the genesis and evolutionary process of eruptive flux ropes in the solar corona.

For an eruption occurring at the solar limb, we found a coherent erupting flux rope initiates from a small-scale seed at the upper tip of a pre-existing current sheet, beneath a sheared magnetic arcade [1]. For a sigmoid eruption occurring near the solar disk center, we observe a coherent sigmoidal flux rope builds upon a hot, S-shaped thread embedded in a sigmoidal region [2]. The buildup process is featured not only by the lengthening and thickening of the S-shaped thread, but also by the slipping and expanding of its footpoint in the low atmosphere. In contrast to two competing, well-known pre-eruption magnetic field configuration of CMEs, i.e., sheared arcade vs. flux rope, our observation that a large-scale flux rope initiates from a seed in both limb and on-disk events suggests a hybrid state with a tiny twisted core embedded in a shear arcade. The seed flux rope is a key structure in the transition from a sheared arcade to a large-scale CME flux rope, with the hybrid state lying in the middle of a spectrum of pre-eruption magnetic configuration. In addition, we propose from the observations a different formation scenario of sigmoidal flux rope than the traditional one that a continuous S-shaped structure is formed by tether-cutting reconnection between two opposite bundles of J-shaped loops.

During the eruption of a pre-existing flux rope, the flare ribbon, especially the ribbon hook mapping QSL footprints of the flux rope boundary that separated the twisted field lines from ambient less-twisted field lines, exhibits complex patterns and evolves dynamically [2]. Combing the evolution of the low-atmosphere ribbon and the coronal dimming, we found that the footpoints of the pre-eruption flux rope are distinct from those of the post-eruption CME. Our observations suggest that the magnetic fluxes in the pre-eruption flux rope are replaced by those with completely different magnetic connectivities during the eruption, which would lead to significant differences between the ICME and its solar source, adding another layer of difficulty for forecasting space weather effects of ICMEs. The observations shed new light on the 3D magnetic reconnection between the flux rope and the surrounding magnetic fields, which poses a challenge to the standard picture.

References

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[2] Gou T. *et al.*, A Flux Rope's Birth in a Sigmoidal Region and Rebirth During Eruption, 2021, to be published.