Formation and Eruption of Complex Magnetic System with Multiple Flux Rope Proxies in Solar Active Region 12673

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Introduction

A magnetic flux rope is a set of magnetic field lines winding around a central axis in classical eruptive flare models and many CME observations. It is widely accepted that magnetic flux ropes play key roles in triggering solar eruptive events. With the high-resolution observations, the existences of flux ropes in the solar atmosphere have been evidenced recently. Moreover, some works imply that flux ropes (FRs) may be ubiquitous on the Sun.

Observations

From 2017 September 04 to September 10, active region (AR) 12673 produced a total of 4 X-class flares, 27 M-class flares, and a multitude of smaller ones. The X9.3 flare on September 06 is the largest flare in Solar Cycle 24. In preset work, we first detected successive eruptions of multiple flux rope proxies (FRPs) within 5 minutes before the peak of this super flare. The similar phenomenon was also observed during the X8.2 flare on September 10. Employing the multiwavelength images and the magnetograms from the Solar Dynamics Observatory (SDO), we investigate the eruption of complex magnetic system with multiple flux rope proxies in the two super flares and the evolution of magnetic fields underlying such complex structures.

Results

➢ *Overview of AR 12673*

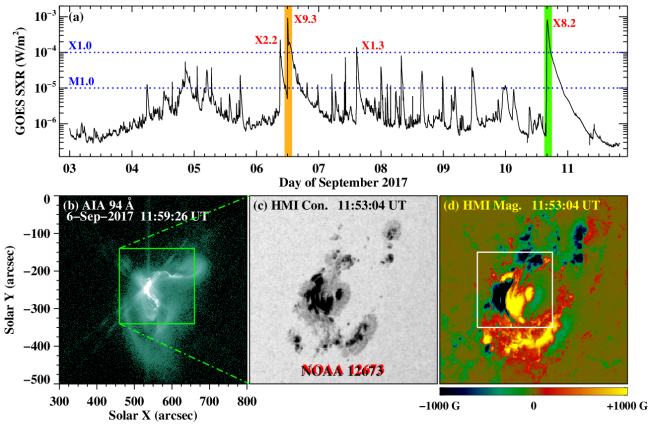

Fig.1 Flares during the evolution of AR 12673. (a): GOES SXR 1-8 Å flux variation from 2017 September 03 to September 11. Four X-class flares took place during this period, and the two largest ones reached up to X9.3 (orange region) and X8.2 (green region), respectively; (b)-(d): overview of the X9.3 flare in AR 12673 on September 06.

➢ *The X9.3 flare on September 06*

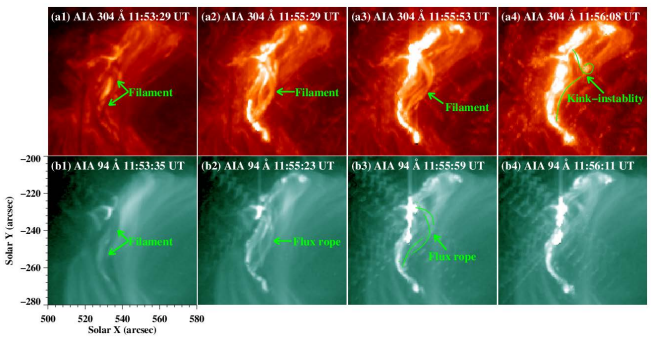

Fig.2 Eruption of the first flux rope. (a1)-(a4): sequence of extended AIA 304 Å images showing the eruption process of the kink-unstable filament. Their FOV is outlined by the white square in Figure 1(d); (b1)-(b4): corresponding 94 Å images exhibiting the flux rope in a hot channel.

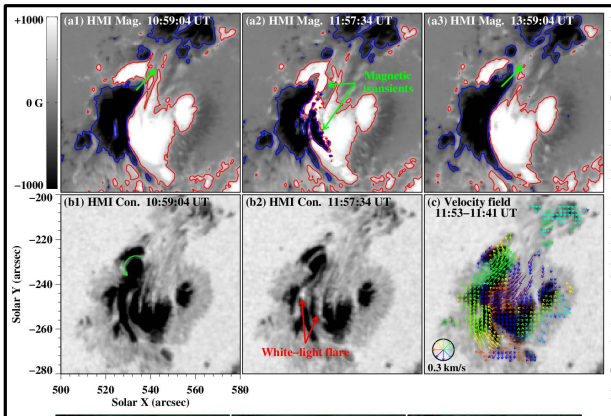

Fig.3 (a1)-(a3): HMI LOS magnetograms with contours of ±400 G displaying the magnetic fields under the flux rope around the flare peak at 12:02 UT; (b1)-(b2):corresponding HMI continuum intensity maps; (c): the horizontal photospheric velocity field (colored arrows) derived from the HMI intensitygrams computed by DAVE method.

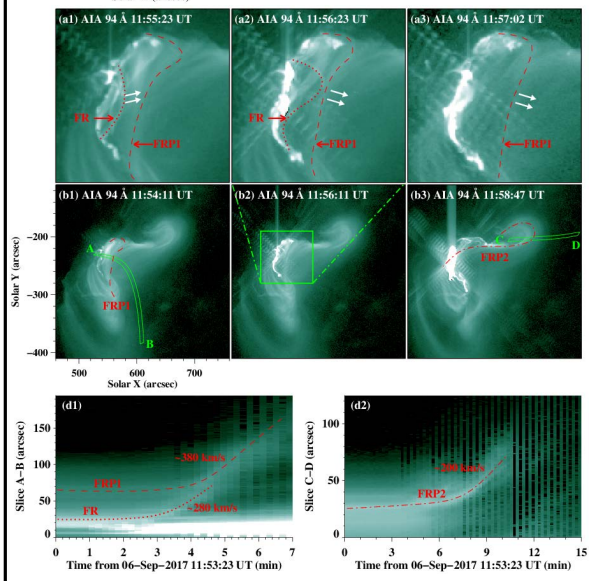

Fig.4 Dynamic evolutions of multiple flux rope proxies during the X9.3 flare. (a1)-(a3): sequence of AIA 94 Å images showing interaction between the FR and FRP1; (b1)-(b3): 94 Å images with a larger FOV exhibiting FRP1 and FRP2; (d1)-(d2): time–space plots along the arc-sector domains "A–B" and "C–D" of panels (b1) and (b3) in the 94 Å channel.

➢ *Evolution of the magnetic fields in AR core region*

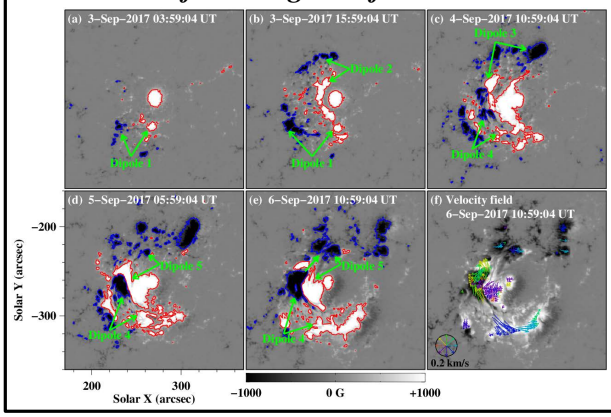

Fig.5 Sequence of HMI LOS magnetograms displaying the evolution of magnetic fields in AR 12673 from September 03 to September 06. Five newly emerging dipoles are marked by green arrows. Panel (f) shows the velocity field derived from the LOS magnetograms.

Conclusions and discussions

- Employing the SDO observations, we investigate the two largest flares of Solar Cycle 24 occurring in AR 12673 and the evolution of the AR magnetic fields. Before the onset of the X9.3 flare, the rapid shearing motion along the PIL and rotation of the sunspot in the AR core region resulted in the kink-instability of a flux rope. Then this kink-unstable flux rope erupted upward and led to the successive eruptions of another two flux rope proxies within 5 minutes before the peak of the X9.3 flare.

- The evolution of the AR magnetic fields shows that five dipoles emerged successively at the east of the main sunspot. We propose that in AR 12673, significant flux emergence and successive cross-separations between the patches of different newly-emerging dipoles resulted in the formation of the complex system with multiple flux rope proxies and the storage of dramatic magnetic energy.

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Poster

4. Eruptions in the solar atmosphere

Quasi-simultaneous eruptions of multiple flux ropes in active region 12673 leading to the two largest flares in Solar Cycle 24

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Solar active region (AR) 12673 in 2017 September produced two largest flares in Solar Cycle 24: the X9.3 flare on September 06 and the X8.2 flare on September 10. We attempt to investigate the detailed evolutions of the two super flares and the associated magnetic fields. Before the X9.3 flare on September 06, one negative magnetic patch began to move along the polarity inversion line in AR core region and kept shearing with adjacent positive fields. The strong shearing motion contributed to the kink-instability of a flux rope, which subsequently erupted upward with a projected velocity of $\sim$280 km s^{-1}. Another two flux ropes beside the kink-unstable flux rope then were disturbed and successively erupted within 5 minutes like a chain reaction. Similarly, three flux ropes were detected to consecutively erupt during the X8.2 flare occurring in the same AR on September 10. We examine the evolution of the AR magnetic fields from September 03 to 06 and find that four dipoles emerged successively at the east of the main sunspot. The interactions between these dipoles took place continuously, accompanied by magnetic flux cancellations and strong shearing motions. In AR 12673, significant flux emergence and successive interactions between the different emerging dipoles resulted in a complex magnetic system, accompanied by the formations of multiple flux ropes. We first propose that the quasi-simultaneous eruptions of multiple flux ropes within several minutes resulted in the two largest flares in Solar Cycle 24.