8th Asia-Pacific Conference on Plasma Physics, 3-8 Nov, 2024 at Malacca

Unveiling the Mechanism for the Rapid Acceleration Phase in a Solar Eruption

Ze Zhong[1,2,3] , Yang Guo[2] , Thomas Wiegelmann[3], M. D. Ding[2] , and Yao Chen[1]
[1] Institute of Frontier and Interdisciplinary Science, Shandong University
[2] School of Astronomy and Space Science, Nanjing University
[3] Max Planck Institute for Solar System Research
e-mail (speaker): zezhong@sdu.edu.cn

Coronal mass ejections (CMEs) are explosive releases of magnetic energy. Their early kinematics usually consist of two distinct phases, a slow rise phase followed by a rapid acceleration phase[1].

For the rapid acceleration phase of solar eruptions, there may exist two underlying mechanisms, i.e., the ideal MHD instability, such as torus instability, and magnetic reconnection. The torus instability occurs if the overlying magnetic field decays fast enough. The resistive magnetic reconnection occurs in the current sheet between the flare and CME.

It is difficult to clarify which mechanism plays a leading role in the rapid acceleration phase due to coupling between the two processes[2]. One way to distinguish the two processes is to study whether one of them can drive the solar eruption alone. Previous studies demonstrate that either of the two processes could drive an eruption alone in the theoretical framework. Nevertheless, their respective contribution remains elusive in real observations.

Benefiting from the developed data-driven MHD technology[3], it is possible to disentangle their coupling by quantifying specific contributions, such as reconnection outflows and the work done by the large-scale Lorentz force. Our purpose is to clarify which mechanism dominates the rapid acceleration phase.

We focus on stereoscopic observations involving a single M-class flare associated with a CME. Major simulation results of the eruption, such as the macroscopic morphology, early kinematics of the flux rope and flare ribbons, match well with the observations as shown in Figure 1.

To quantify the role of reconnection outflows, we calculate three quantities in the defined 3D current sheet including upward kinetic energy, magnetic energy before and after reconnection. The evolution of the three quantities displays a similar tendency (Figure 2(g)). Note that the total injected magnetic energy is nearly 2 orders of magnitude higher than the magnetic energy after reconnection (Figure 2(h)). It suggests that most of the magnetic energy injected into the current sheet is released.

We also estimate the energy converted from the magnetic slingshot above the current sheet and the large-scale Lorentz force exerting on the flux rope during the rapid acceleration phase, and find that the work done by the large-scale Lorentz force is about 4.6 times higher than the former. It indicates that the large-scale Lorentz force plays a dominant role in the rapid acceleration phase for this eruption.

This work is supported by the National Key R&D Program of China (2022YFF0503004), National Natural Science Foundation of China (11973031 and 11790303).

References
[1] Schrijver, C. J., et al. 2008, ApJ, 674, 586
[2] Vršnak, B. 2016, AN, 337, 1002
[3] Jiang, C., et al. 2022, The Innovation, 3, 100236

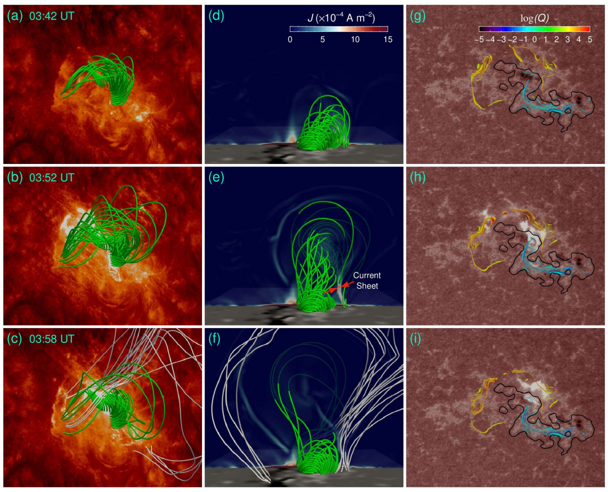

Figure 1. Three typical snapshots display the morphology of the flare at 03:42, 03:52, and 03:58 UT corresponding to the flare onset, impulse and peak times. (a)–(c) Magnetic field lines overlaid on the AIA 304 image. (d)–(f) A side view along the x-axis of the magnetic field. (g)–(i) Comparison between the QSLs on the bottom and the AIA 1700 Å emission, overlaid by the contour of Bz.

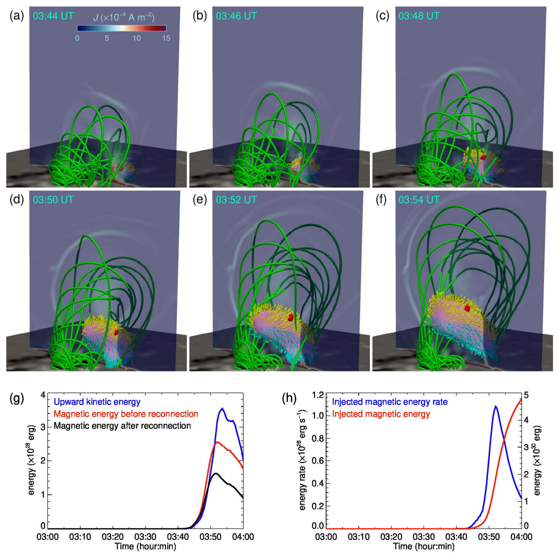

Figure 2. (a)–(f) Six snapshots depict the evolution of the flux rope, 3D current sheet (pink isosurface) and reconnection point (red sphere). (g) The blue, red, and black lines show the temporal evolution of the upward kinematic energy, magnetic energy before and after the reconnection in the defined 3D current sheet, respectively. (h) Total magnetic energy (red) injected into the 3D current sheet with time and its derivative (blue).