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A fundamental mechanism of solar eruption initiation

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Solar eruptions, such as solar flares and coronal mass ejections, are spectacular magnetic explosions in the Sun's corona, and how they are initiated remains unclear. Prevailing theories often rely on special magnetic topologies that may not generally exist in the pre-eruption source region of corona. Here, using fully three-dimensional magnetohydrodynamic simulations with high accuracy, we show that solar eruptions can be initiated in a single bipolar configuration with no additional special topology[1]. Through photospheric shearing motion alone, an electric current sheet forms in the highly sheared core field of the magnetic arcade during its quasi-static evolution. Once magnetic reconnection sets in, the whole arcade is expelled impulsively, forming a fast-expanding twisted flux rope with a highly turbulent reconnecting region underneath. The simplicity and efficacy of this scenario argue strongly for its fundamental importance in the initiation of solar eruptions.

We have further investigated the behavior of the fundamental mechanism with different photospheric magnetic flux distributions, namely, magnetograms, by combining a theoretical analysis and a numerical simulation[2]. Our study shows that the bipolar fields of different magnetograms, sheared continuously, all exhibit similar evolutions – from slow storage to the fast release of magnetic energy – that are in accordance with the fundamental mechanism and demonstrate the robustness of the proposed mechanism. Furthermore, we found that the magnetograms with a stronger polarity inversion line (PIL) produce larger eruptions and the key reason is that the sheared bipolar fields with a stronger PIL can achieve more non-potentiality and their internal current sheet can form at a lower height and with a higher current density, by which the reconnection can be more efficient. This also provides a viable trigger mechanism for the observed eruptions in active regions with a strong PIL.

The fundamental mechanism also explained homologous eruptions, i.e., coronal mass ejections with similar structure repeatedly from the same source region. With magnetohydrodynamic simulation, we show that homologous solar eruptions can be efficiently produced by recurring formation and disruption of a coronal current sheet as driven by the continuous shearing of the same polarity inversion line within a single bipolar configuration[3]. These eruptions are initiated by the same mechanism, in which an internal current sheet forms slowly in a gradually sheared bipolar field and reconnection of the current sheet triggers and drives the eruption. Each of the eruptions does not release all the free energy, leaving a large amount in the post-flare arcade below the erupting flux rope. Thus, a new current sheet can be more easily formed by further shearing of the post-flare arcade than by shearing a potential field arcade, and this is favorable for producing the next eruption. Furthermore, it is found that the new eruption is stronger since the newly formed current sheet has a larger current density and a lower height. In addition, our results also indicate the existence of a magnetic energy threshold for a given flux distribution, and eruption occurs once this threshold is approached.

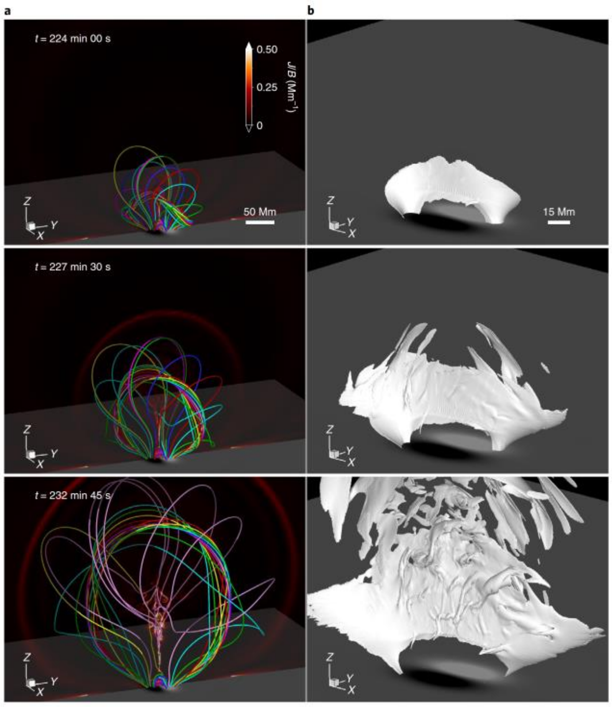

Figure 1. Evolution of magnetic field lines (a) and current sheet (b) in 3D during the simulated eruption.

References
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3. Bian, X., Jiang, C., Feng, X., Zuo, P. & Wang, Y. Homologous Coronal Mass Ejections Caused by Recurring Formation and Disruption of Current Sheet within a Sheared Magnetic Arcade. *ApJL* **925**, L7 (2022).