On the Role of Magnetic Fields in an Erupting Solar Filament

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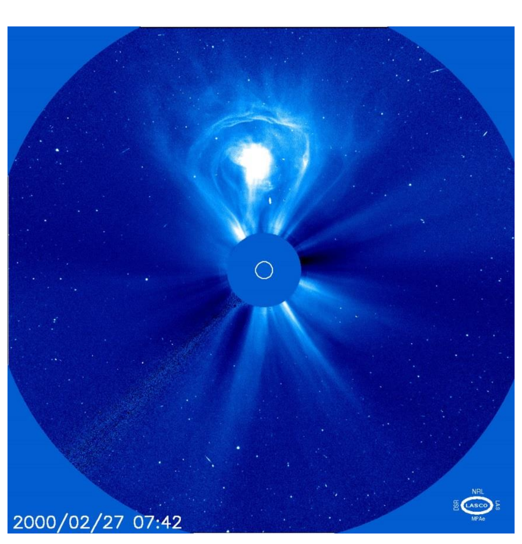
Abstract

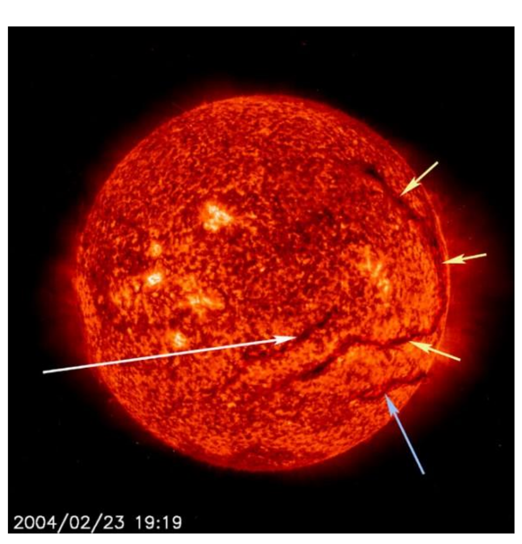
At present, the 24th solar cycle is coming to its closing stage. The numbers of sunspots and flares have significantly decreased, but the solar quiescent filaments/prominences still erupt from time to time. A filament eruption may lead to a coronal mass ejection (CME), which is one of the main driving mechanisms of space weather events. It is believed that magnetic flux ropes play an important role for the erupting filaments and CMEs. This work analyses a slow and flareless CME event associated with an erupting quiescent filament. By using the extreme ultraviolet (EUV) images of the Atmospheric Imaging Assembly onboard the Solar Dynamics Observatory, we trace the evolution of the filament, and present the details of the eruption and the manifestations of the magnetic fields in the low corona. Coronal cavity, horn-like structure, downflows and other fine structures are observed during the evolution. Some plasma blobs are moving upward along the filament and rotational motions occur at the foot of the filament. These results suggest the existence of a magnetic flux rope in the pre-eruption structures. A hot and long linear structure is also observed in EUV images during the eruption of the filament, which may indicate a current sheet. The eruption is without obvious X-ray enhancement but has growing post-eruption arcades. The magnetic energy of the eruption may be released via the ideal flux-rope instability and magnetic reconnection. Our study of this complex system may lead to a better understanding of the quiet Sun CME and its effect on the space weather forecast.

CMEs and Filaments

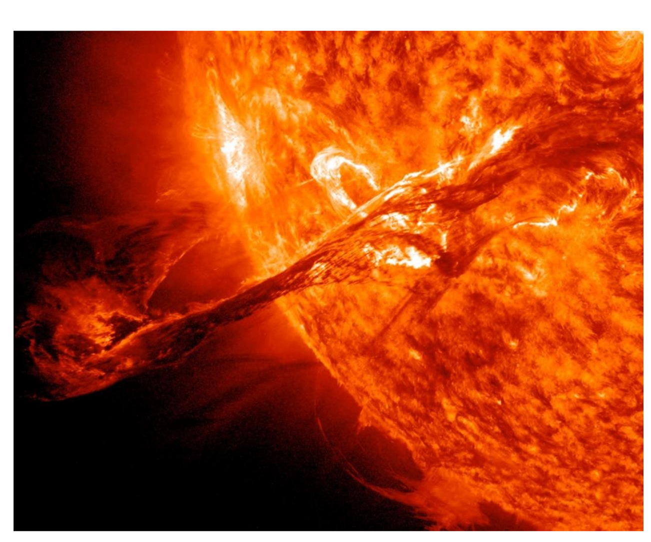
A **coronal mass ejection (CME)** is a significant release of magnetized plasma from the solar corona into the interplanetary space. It is one of the main driving mechanisms of space weather events that may lead to geomagnetic storms. At present, solar activity turns into its minimum, and the CMEs associated with the eruption of solar quiescent filaments/prominences are becoming more prominent. **Solar quiescent filaments** are dark curves-like structures that sometimes appear in the quiet Sun. They are large regions of very dense, cool gas, held in place by solar magnetic fields. Some long filaments are even larger than the radius of the Sun. When the dark filaments are above the limb of the Sun, they will turn to bright and significant, so they are also called solar prominences[1].



↑ A CME is releasing from the Sun, Credit: NASA/ESA



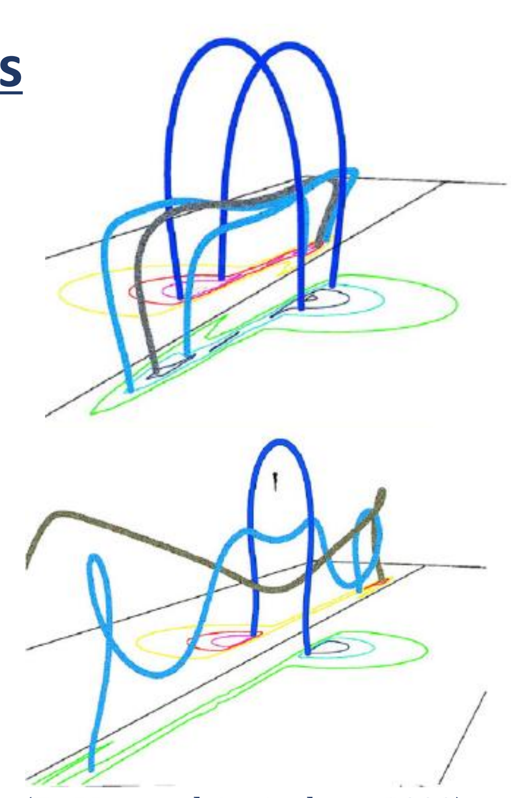
↑ Some long filaments on the quiet Sun, Credit: NASA/ESA



↑ A prominence above the limb of the Sun, Credit: NASA

Magnetic Structure of Filaments

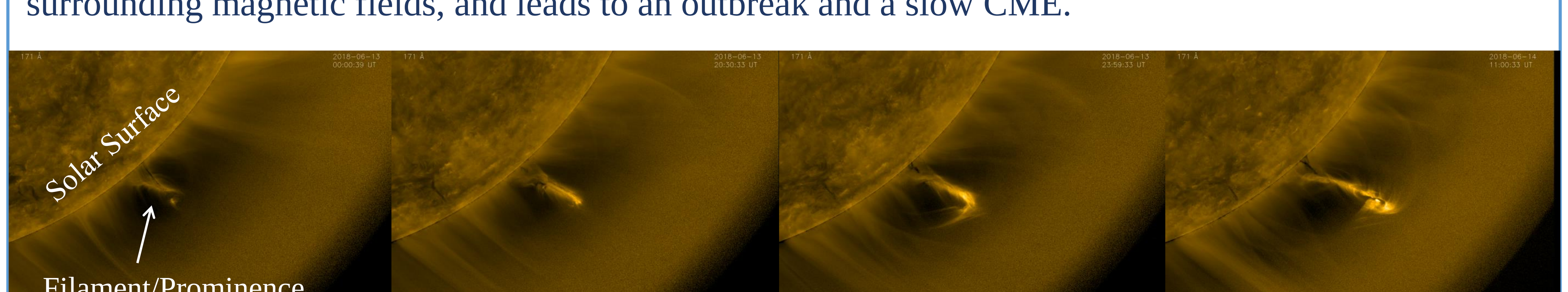
The magnetic field is the controlling force in the solar corona and it dominates the formation, evolution and eruption of filaments. The sustained gravitational support and thermal isolation of filaments are provided by their magnetic structures. The sheared-arcade (upper panel) and the magnetic flux rope (lower panel) models are two different magnetic structural models of filaments[1,2]. The sheared-arcade model contains the underlying sheared arcade and the overlying arcade of magnetic fields. The magnetic flux rope model is meaning that magnetic fluxes wrap around a central axis (or axes). The sheared-arcade and flux rope are relatively simple models, therefore dynamics and thermodynamics of filaments challenge many of the assumptions of the models[1]. However, these models provide a framework for understanding filaments and help us to forecast their eruptions in the solar corona.



(DeVore and Antiochos , 2000)

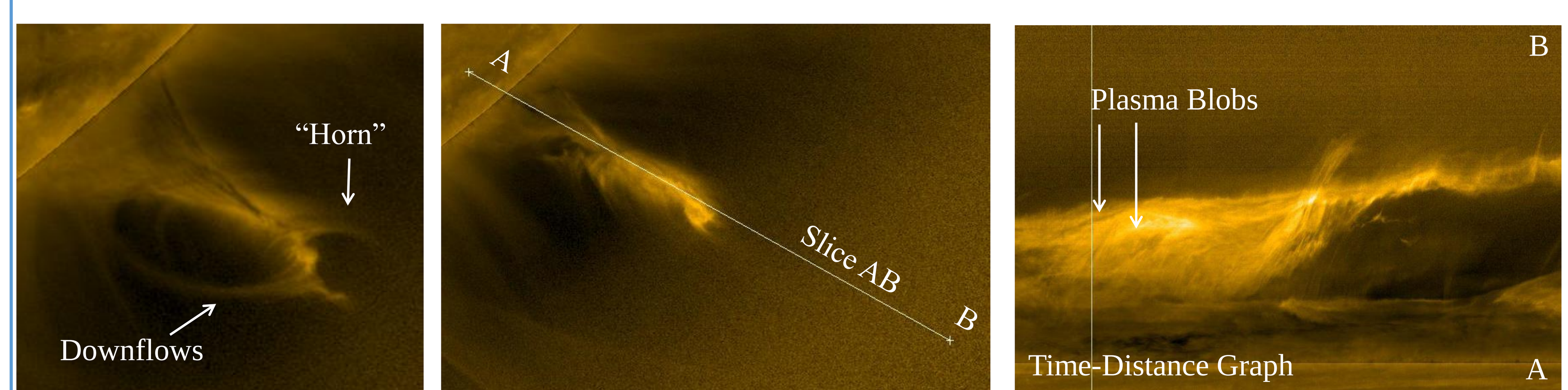
Slow Evolution of a Solar Quiescent Filament

A solar quiescent filament appeared on the western limb of the Sun in the middle part of June, 2018. As shown in the figures below, inside a coronal cavity, the filament slowly extends outward, and becomes bright on its top in the extreme ultraviolet images of the Atmospheric Imaging Assembly (AIA)[3] onboard the Solar Dynamics Observatory (SDO). A radial filter method is used to enhance the fine features of the filaments[4]. Comparing to flares and other rapid solar activities, the evolution of the solar quiescent filament is very slow and takes a number of days. Finally, it reconnects with the surrounding magnetic fields, and leads to an outbreak and a slow CME.

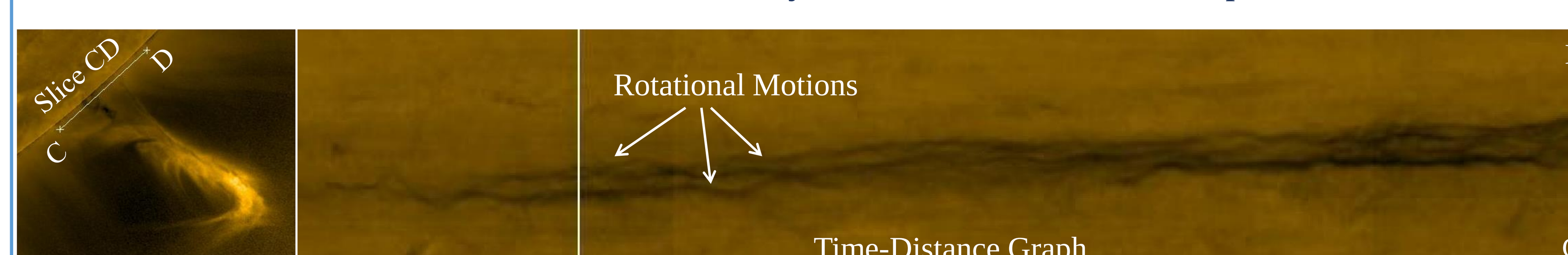


Fine Structures and Rotational Motions of the Filament

Although the overall evolution of the filament is slow, it actually is full of highly dynamic features in the small scale. As can be seen in figures below, there is a horn-like structure on the top of the filament, and it may related to a magnetic flux rope. Magnetic flux ropes are believed to have a close relationship with erupting filaments and CMEs. The horn-like structure appears bifurcation and brightening which may suggest that it had a magnetic reconnection and lead to downflows back to the solar surface. As we can see from the time-distance graph, some magnetized plasma blobs are moving upward and they may accumulate magnetic fields for the final eruption of the filament.

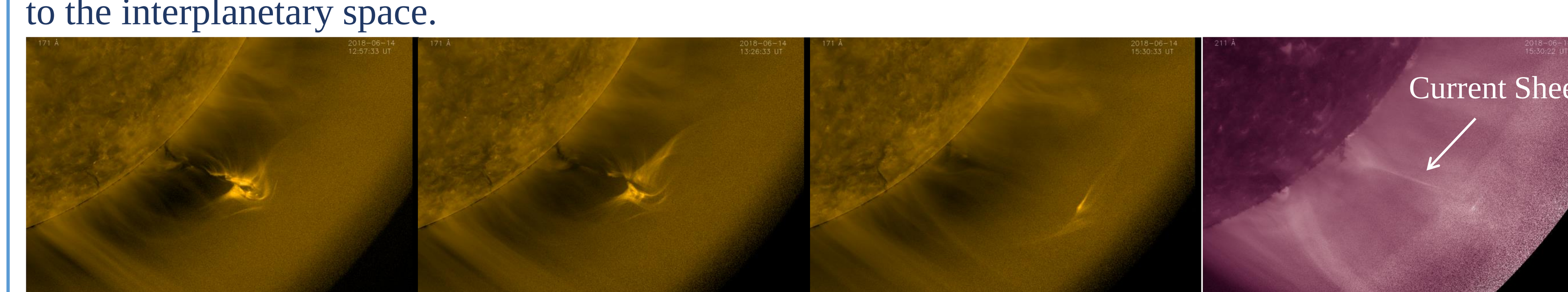


By using the time-distance graph, we also analyses rotational motions in the filament. As shown in figures below, a slice (CD) is made at the location near the feet of the filament, and the dark materials in the middle of the slice appear a wave-like pattern in the time-distance graph. It may indicate that these materials have rotational motions which may be involved in the final eruption.



Magnetic Reconnection and Final Eruption

After a long period of evolution, the filament finally erupted and caused a slow CME. As shown in the figures below, the erupting structure moves to the sides and outward. In the SDO/AIA 211 waveband image, we can see a long bright line that are nearly perpendicular to the solar surface, while there is no such bright line in the AIA 171 waveband images. The different observations in these different wavebands may indicate that this long line structure has a high temperature and it may be a current sheet produced by the magnetic reconnection of the eruption. The eruption is without obvious X-ray enhancement, but has growing post-eruption arcades which can be explained by the standard flare model. A CME can be observed from the image of SOHO/LASCO and it may cause disturbance to the interplanetary space.



Space Weather Forecast of NCSW

As human exploration is across the planet Earth and has gone into the space, **space weather** has became an indispensable part of our modern society. Similar to the climate and the weather, solar activities are complicated, resulting in the long-term and short-term influences on the Earth. In the long-term, the Sun has an approximate 11-year sunspot cycle. In the short-term, it produces solar flares, CMEs and other eruptive activities. Although the eruptive processes on the Sun usually last for only few minutes to several hours, they may seriously harm satellites, spacecrafts, aircrafts, power grids, oil pipelines, and even the health of astronauts, flight crews and passengers.

The **National Center for Space Weather (NCSW)** is one of the operational units of China Meteorological Administration (CMA). NCSW was founded in 2002, and it acts as the national center authorized by the National Council, to carry out the space weather operation and provide space weather services. NCSW has space-based and ground-based observations for space weather.

NCSW provides monitoring, early warning, three-day forecast, weekly report, monthly report, annual report and other space weather services, for solar flares, the sunspot number, the F107 index, geomagnetic storms, and ionospheric disturbance etc. The space weather operational products are released on its homepage[5] everyday. NCSW also issues those information to general public, special users and decision makers though hard-copy bulletins, mobile phone messages, e-mails, special column of the China Meteorological Newspaper, and the weather report of China Central Television.

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Reference:

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