The Dynamic Behavior of Erupting Solar Prominences

Beryl A. C. Hovis-Afflerbach (California Institute of Technology) | Barbara J. Thompson (NASA GSFC Code 671)

Introduction

- **Solar prominences** are dynamic plasma structures suspended above the Sun's surface by its magnetic field. Prominences can remain quiescent for weeks in filament channels (regions of stressed magnetic field) then suddenly erupt, accelerating to 100s of kilometers per second.
- Approximately 72% (Gopalswamy et al. 2003b) of prominence eruptions are associated with **coronal mass ejections (CMEs)**, large magnetic field structures that are ejected from the Sun.

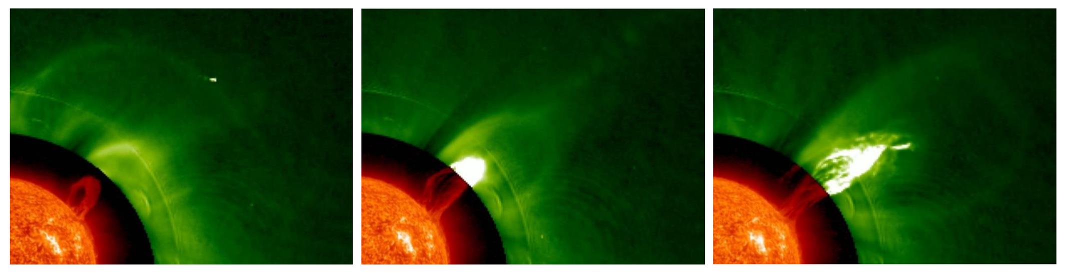


__Figure 1.__ Sequence of images taken by STEREO B over 90 minutes on 2010-08-01 of the Sun, a prominence, and its connected CME.

- CMEs are known to erupt due to instabilities in the magnetic field. However, the magnetic topologies involved in a CME can be extremely complex, and extend far beyond the site of the apparent instability. **We investigate the possibility that falling prominence material can serve as a proxy of the extended magnetic field topology, connecting to the source region but tracing out the surrounding global structure.**

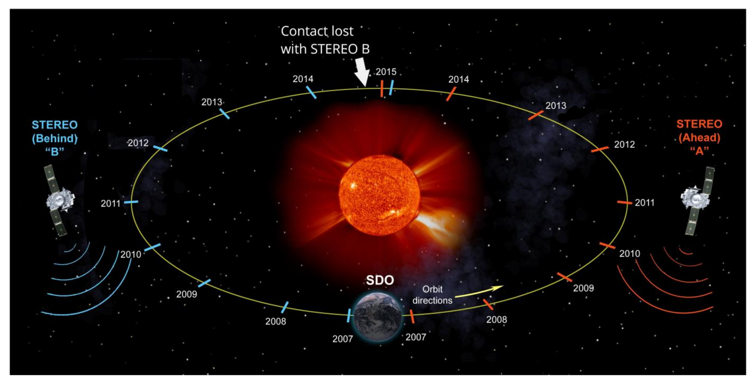


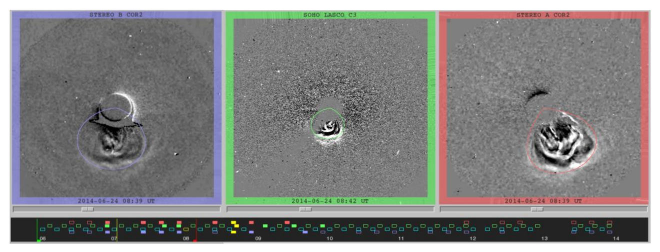
__Figure 2.__ Diagram showing the positions of spacecraft STEREO A and B relative to Earth in their orbits around the Sun, along with the position at which contact was lost with STEREO B.
Image credit: NASA/GSFC

How can we use observations of prominence behavior to improve our understanding and forecasting of CMEs?

Purpose

- In this project, we compare:
  - Eruption source location on the Sun,
  - Direction and behavior of prominence eruption, and
  - Direction and speed of CME.
- We seek to find connections that will allow us to more accurately forecast CMEs and to understand how the rest of the corona is involved, not just the source region.

Methods



We use SWPC_CAT, a tool which allows us to triangulate the CME, to measure CME trajectory, speed, and size.

__Figure 3.__ CME fit for 2014-06-24 event using SWPC_CAT tool.

Persistence Mapping

- Persistence Mapping is a tool that allows us to track an erupting prominence's motion, which traces out the CME's connections to the lower corona.
- When a pixel reaches a maximum value, it retains that value. This technique is called "Persistence Mapping," (Thompson & Young 2016) because **extreme values persist into subsequent image frames until those values are exceeded**.
- The brightness of the pixel indicates the degree of change. Darker pixels did not exhibit much change, while bright pixels exhibited a great deal of change. This helps us to distinguish noise and ambient variations from major changes associated with the prominence evolution.

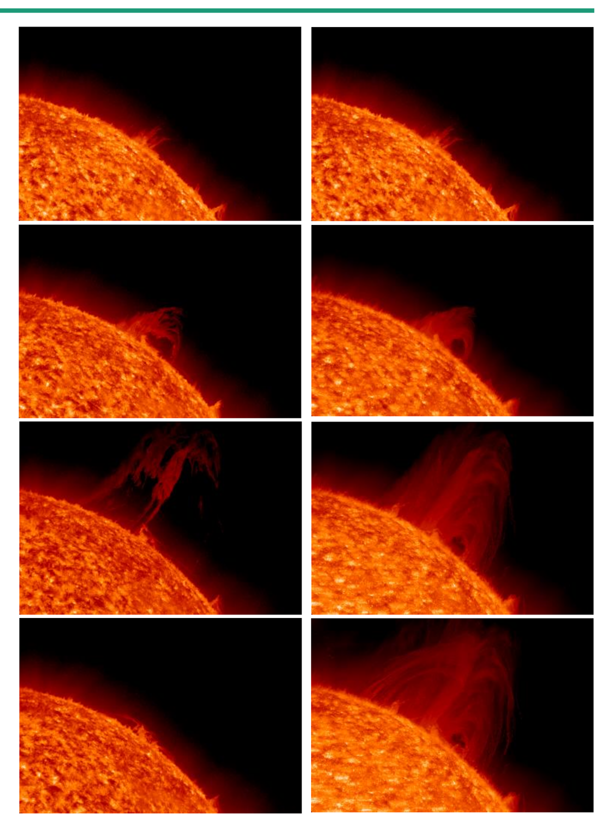


__Figure 4.__ Original images (left) and persistence maps (right) of prominence eruption in 304Å on 2010-09-30. The paths traced out by the prominence are visible in the persistence images.

Data Analysis

Danger of using only the source location

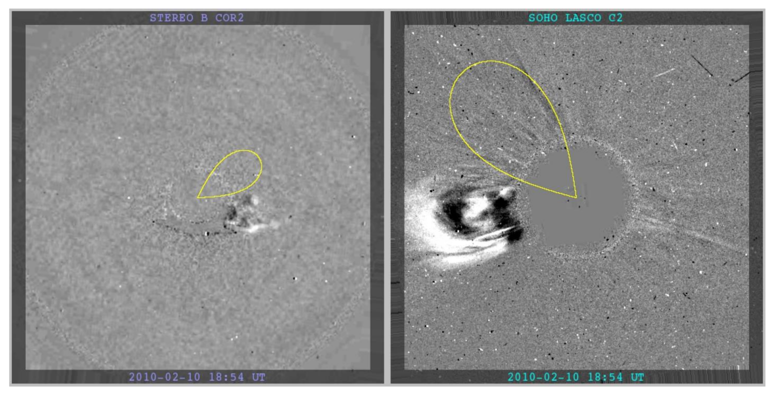


__Figure 5a.__ A measurement of the CME on 2010-02-10 with latitude and longitude set to those of the observed source location. The projection does not match the CME visible in the coronagraphs.

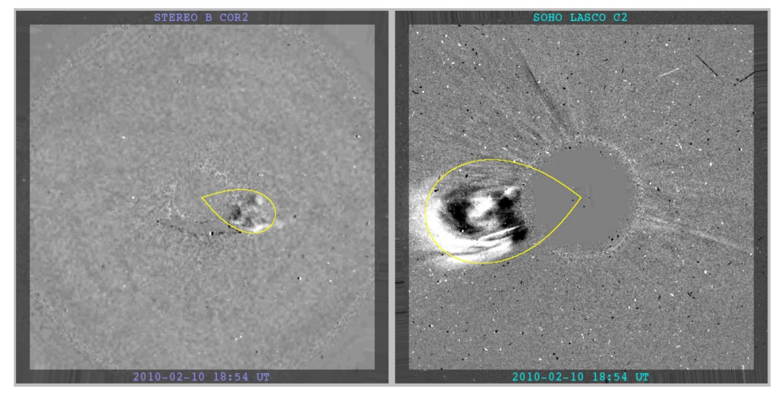


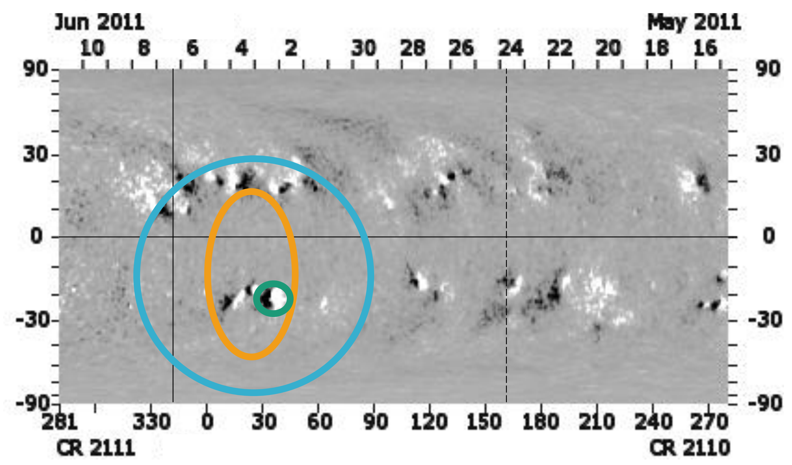
__Figure 5b.__ A measurement of the same CME with latitude and longitude set to match the CME as seen in the coronagraphs. This is a much better fit and demonstrates that using only the source location to forecast CMEs can lead to errors.

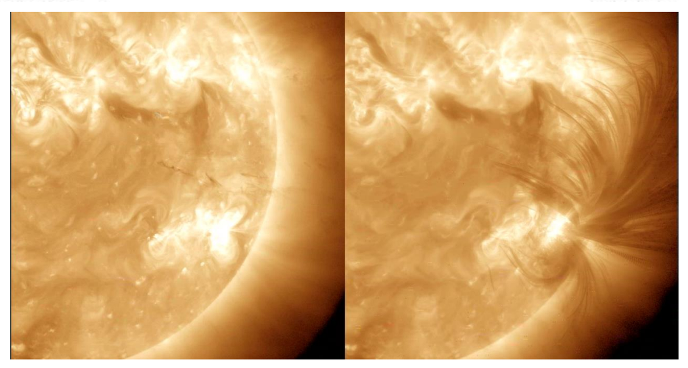
Results

- We plotted the three objects for comparison on the magnetogram (a map of solar magnetic field polarity and strength) over one Carrington Rotation (one solar rotation in a rigidly rotating coordinate system).
  - Source region
  - Falling prominence material
  - CME direction and half-width
- The solid black line designates the Sun's center at the time with as seen by Earth, and the dashed line designates the back side.

2011-06-07

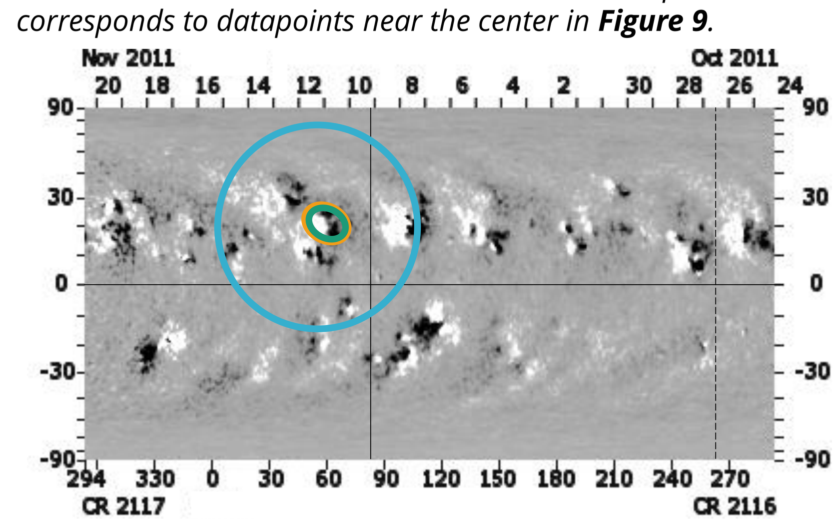
__Figure 6a.__ (above) In this event, the CME and prominence are both centered northeast of the source. The CME is centered over the prominence, not the source.
__Figure 6b.__ (below) The evolving field lines traced out by the prominence are visible in the persistence map (right), and the prominence's predominantly northward motion is clearly visible.





2011-11-09

__Figure 7.__ In this event, falling prominence material did not move far from the source region, and the source, prominence, and CME were more or less centered around the same point. This event corresponds to datapoints near the center in __Figure 9__.



2014-09-02

__Figure 8.__ In this event, the CME and prominence move in opposite directions relative to the source, differently than __Figures 6__ and __7__. Events such as this one tell us that Sun's magnetic field can change in complex and unexpected ways during an eruption, both locally and globally, and profoundly affect CMEs.

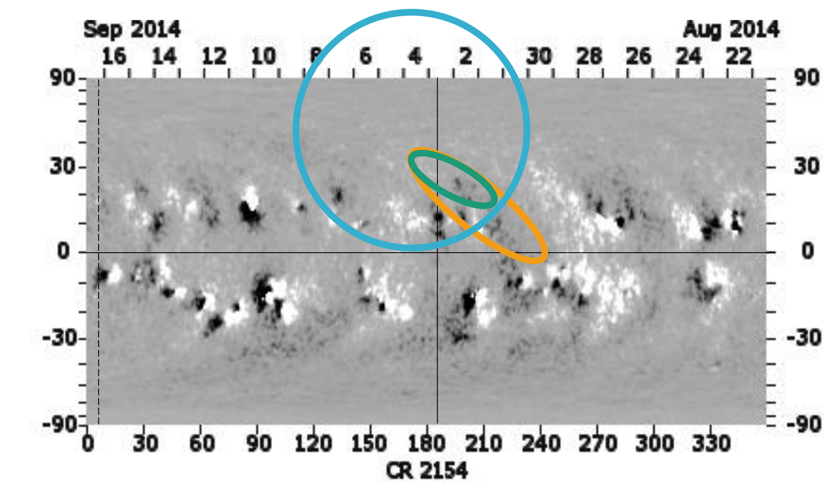
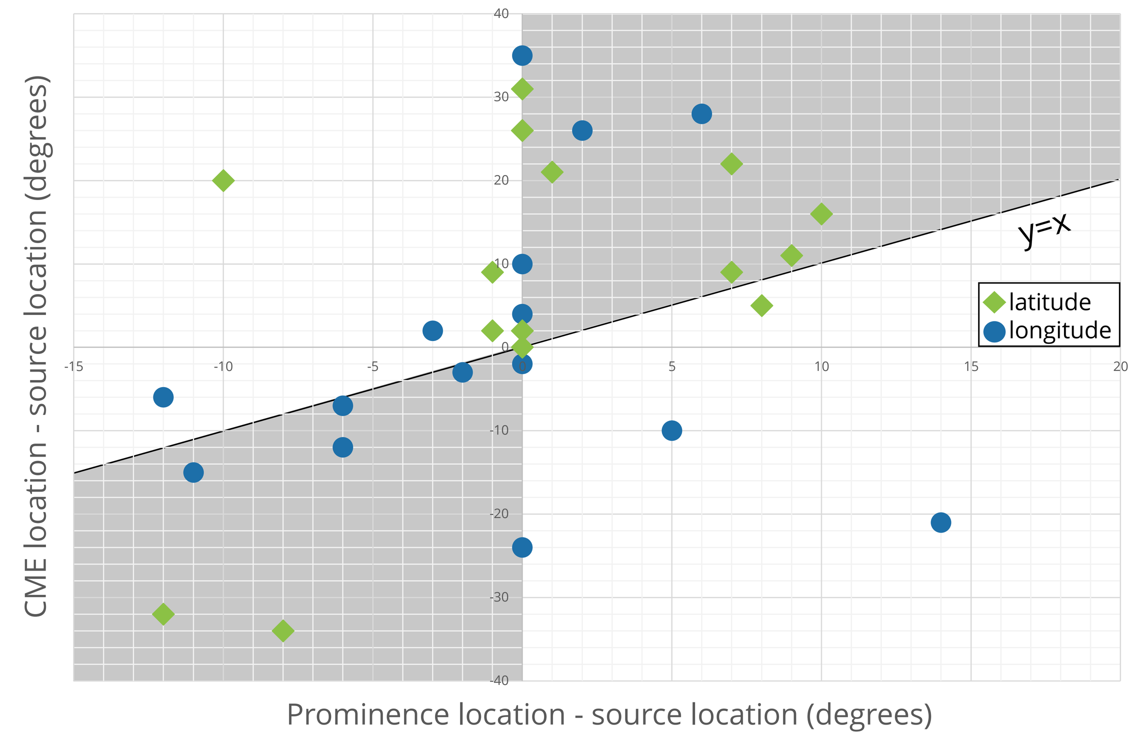


***Figure 9.** Comparison of Prominence and CME Motion*



- Each data point represents a comparison of the CME movement and prominence movement in latitude or longitude for a single event.
- Points in the 1st and 4th quadrants or close to the **y=x** line (drawn on the figure) represent events in which the CME moves in the same direction as the falling prominence.
- 73% of the data points fall in the shaded areas. These represent events in which the CME extends farther in the same direction from the source region as the falling prominence material. In these events, the prominence is still an indicator of the CME progression; however, the offset increases from the prominence altitude (1-1.5 solar radii) to the CME measurement altitude (3-4 solar radii).

Source Region Type Comparison

It is clear from **Figure 9** that some eruptions follow the source → falling prominence → CME pattern, while some do not. We hypothesized that active region prominences, confined initially to a very small source region (such as in **Figures 6** and **7**), may exhibit different behavior than "quiet sun" prominences (such as in **Figure 8**), which usually come from much larger, but weaker magnetic regions.

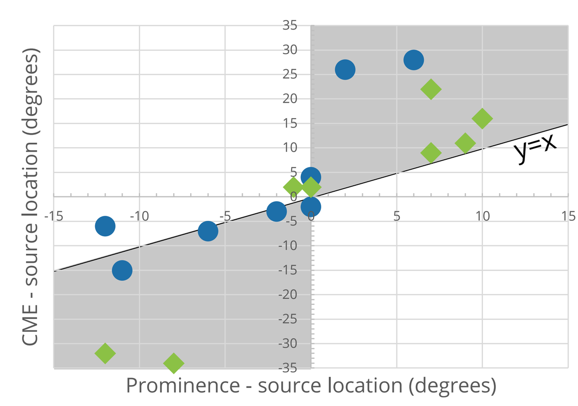


__Figure 10a.__ The subset of eruptions that correspond to active region sources follow the observed pattern more closely.

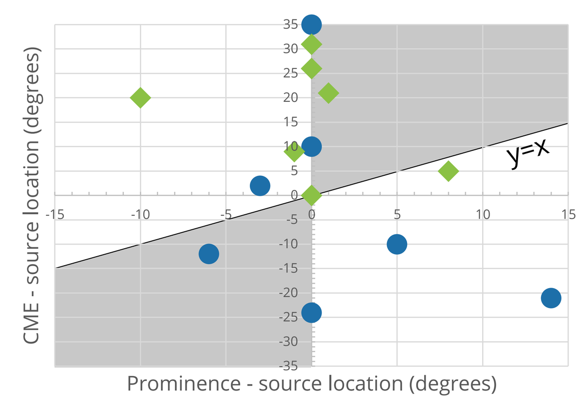


__Figure 10b.__ The subset of eruptions that correspond to "quiet sun" sources exhibit more variable behavior.

Conclusions

- The dynamics of the erupting prominence, not just the source location, tell us about the CME progression.
- The CME motion is typically farther from the source region than the falling prominence motion. The falling prominence material can serve as a "midpoint" between source and CME, connecting complex CME magnetic topology back to the entire lower coronal volume involved in the eruption.
- Eruptions from source regions with strong magnetic field follow this pattern more consistently.
- From our data, neither longitude nor latitude appears to be more affected. This may indicate that global polar fields do not have as much of an effect, but could also be because most of our events were from solar maximum, when the Sun exhibits less of a dipolar structure. We do not have enough events during solar minimum to determine which, if either, is more affected.

Future Work

- Continue mapping falling prominence material and measuring CMEs for more events, including ones during solar minimum, to better understand the relationship in a broader variety of cases.
- Measure the CME using the Graduated Cylindrical Shell (GCS) model to determine the CME magnetic field orientation and compare that with the prominence structure, rather than just SWPC_CAT, a tool which is adequate for measuring the CME direction but is less comprehensive (Bosman, et al. 2013).

References

Bosman E., et al. (2013). 3D CME Parametrization - Comparison of GCS and CAT techniques and ENLIL applications. *Tenth European Space Weather Week Workshop*, Antwerp, Belgium, 2013.
Gopalswamy, N., et al. (2003b). Prominence eruptions and coronal mass ejection: A statistical study using microwave observations. *Astrophysical Journal, 586*, 562–578.
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