GEOPHYSICAL RESEARCH LETTERS, VOL. 30, NO. 21, 2107, doi:10.1029/2003GL018332, 2003

Filament eruption without coronal mass ejection

Debi Prasad Choudhary
NASA/Marshall Space Flight Center, SD50/Space Science Department, Huntsville, Alabama, USA

Ronald L. Moore
NASA/Marshall Space Flight Center, SD50/Space Science Department, Huntsville, Alabama, USA

Received 4 August 2003; revised 23 September 2003; accepted 15 October 2003; published 8 November 2003.

[1] We report characteristics of quiescent filament eruptions that were not associated with coronal mass ejections (CMEs). We examined 12 quiescent filament eruptions, each of which was located far from disk center ($\geq$0.7 R_{Sun}) in diffuse remnant magnetic fields of decayed active regions, was well observed in full-disk movies in Hα and Fe XII, and had good coronagraph coverage. Of the 12 events, 9 were associated with CMEs and 3 were not. Even though the two kinds of eruption were indistinguishable in their magnetic setting and in the eruptive motion of the filament in the Hα movies, each of the CME-producing eruptions produced a two-ribbon flare in Hα and a coronal arcade and/or two-ribbon flare in Fe XII, and each of the non-CME-producing eruptions did not. From this result, and the appearance of the eruptive motion in the Fe XII movies, we conclude that the non-CME-associated filament eruptions are confined eruptions like the confined filament eruptions in active regions. *INDEX TERMS:* 7513 Solar Physics, Astrophysics, and Astronomy: Coronal mass ejections; 7536 Solar Physics, Astrophysics, and Astronomy: Solar activity cycle (2162); 7524 Solar Physics, Astrophysics, and Astronomy: Magnetic fields; 7519 Solar Physics, Astrophysics, and Astronomy: Flares; 7835 Space Plasma Physics: Magnetic reconnection. **Citation:** Choudhary, D. P., and R. L. Moore, Filament eruption without coronal mass ejection, *Geophys. Res. Lett.*, *30*(21), 2107, doi:10.1029/2003GL018332, 2003.

1. Introduction

[2] The filaments and filament eruptions considered in this paper are located in quiet regions that are occupied by large-scale, diffuse, remnant magnetic fields from decayed active regions. The filaments in these regions are called quiescent filaments [*Tandberg-Hanssen*, 1994]. They are observed as elongated dark features in chromospheric images on the solar disk. At the limb, they are bright against the sky and are known as quiescent prominences. These features are sheet-like structures of condensed chromospheric-temperature material suspended in the lower corona. This material has a temperature $\sim$100 times lower and a density $\sim$100 times higher than that of the surrounding corona. The filament traces a magnetic polarity dividing line below it in the photosphere, because it is suspended in sheared magnetic field in the core of a magnetic arcade [*Martin*, 1989; *Schmieder et al.*, 1996].

[3] After persisting for days to weeks, a quiescent filament can abruptly disappear in less than an hour. Such an event is known as a disparition brusque (DB). There are two categories of DB events, namely dynamic (DDB) and thermal (TDB) [*Mouradian and Soru-Escaut*, 1989]. In a DDB, the magnetic field undergoes a dynamic drastic change in configuration, an eruption that in many cases ejects the filament from the Sun, and also produces a coronal mass ejection (CME) that has the ejected filament in its core [e.g., *Moore*, 2001]. A new filament does not form in the disrupted field configuration for at least a few days. Apparently, a new filament cannot form until gradual evolution restores the appropriate configuration to the sheared core field. In a TDB, the field configuration is not disrupted. Instead, a temporary increase in heating of perhaps an hour in duration ionizes the neutral hydrogen in the filament material so that the filament becomes invisible in Hα. When the heating subsides, the plasma cools, the neutral hydrogen reforms, and the filament reappears.

[4] It has long been known that the collision of a CME with the Earth's magnetosphere often produces a geomagnetic storm [*Gosling et al.*, 1991], and that an erupting quiescent filament (a DDB) is often involved in the birth of a CME and becomes part of the CME [*Webb et al.*, 1976; *Webb and Hundhausen*, 1987; *Munro et al.*, 1979]. It has also long been known that the disappearance of a large quiescent filament tends to be followed a few days later by increased geomagnetic activity [*McNamara and Wright*, 1982]. Detailed study of individual DDB-CME events shows that the erupting quiescent filament is a tracer of the core of the magnetic explosion that becomes the CME [e.g., *Choudhary et al.*, 2002]. However, many DDBs have no associated CME. Statistical studies of DDBs identified from Hα or microwave images taken during times covered by coronagraph observations show that about 30% of quiescent filament eruptions have no associated CME [*Pojoga and Huang*, 2003; *Gopalswami et al.*, 2003]. Because the DDBs are identified by comparing images from one day to the next, these statistical studies do not reveal the nature of the eruption in non-CME-associated DDBs or how it differs from that in CME-associated DDBs. In this letter, we report observed characteristics of quiescent filament eruptions not associated with CMEs and consider the implications for the nature of these eruptions.

2. Data and Event Selection

[5] The filament eruption events reported here were found in full-disk line-center Hα movies. We found many of our events in the full-disk movies from the Improved Solar Observing Network (ISOON) instrument at Sacramento Peak. These images have 1.1-arcsecond pixels, and

0094-8276/03/2003GL018332

Table 1. Summary of Eruptive Filament Events

Date	Disk Position	Post-Eruption loops	Time[a]	CME
26 February 2000	E50N40	Yes	23:26	Yes
04 March 2000	E50S30	Yes	16:24	Yes
12 September 2000	W40S40	Yes	11:21	Yes
24 November 2002	E50N20	Yes	19:43	Yes
03 January 2003	W90N30	Yes	16:25	Yes
14 January 2003	E90S25	No[b]	17:25	Yes[c]
13 March 2003	E50N55	No[b]	22:19	Yes[c]
14 March 2003	W50S30	Yes	17:15	Yes
01 May 2003	E40N30	No	15:14	No
02 May 2003	W40S20	No	18:40	No
09 Jun 2003	E50N10	No	21:00	No
23 Jun 2003	W60S20	Yes	20:33	Yes

[a]Time of disappearance of the filament in Hα.
[b]These events appeared to have Fe XII flare ribbons but no arcades of coronal loops.
[c]These CMEs were much less obvious than the one in Figure 1.

are recorded at a cadence of once per minute. The rest of our events were found in the Hα movies from the full-disk synoptic telescope at Big Bear Solar Observatory [*Denker et al.*, 1999]. These movies are practically the same as the ISOON movies in cadence, spatial resolution, and visibility of quiescent filaments.

[6] We have found 12 DDB filament events (listed in Table 1) that were well observed in the full-disk Hα movies and that also met the following five criteria. First, each filament was a large (length >100,000 km) quiescent filament, seated in the remnant magnetic field of one or more decayed active regions. The magnetic setting of each filament was found from a full-disk magnetogram from the Michelson Doppler Imager on the Solar and Heliospheric Observatory [*Scherrer et al.*, 1995]. Second, each filament displayed eruptive motion as it disappeared and did not reappear for at least a day. This behavior ensures that the filament disappearance was a DDB event rather than a TDB event. Third, we required that the time span from eruption onset to a few hours later be covered by observations from the C2 white light coronagraph of the Large Angle Spectroscopic Coronagraph (LASCO) on the Solar and Heliospheric Observatory (SOHO) [*Brueckner et al.*, 1995]. The LASCO C2 coronagraph images the corona around the entire Sun from 2 to 6 solar radii and detects practically any CME that originates well away from disk center. Fourth, we required that the filament eruption be located at least 45° (at least 0.7 R_{Sun}) from disk center, in order that we can be confident that the LASCO images show whether or not the eruption produced a CME. Fifth, we required the filament eruption to be covered in the 195 Å Fe XII coronal images from the Extreme-Ultraviolet Imaging Telescope (EIT) on SOHO [*Delaboudiniere et al.*, 1995]. These images show the coronal plasma at temperatures around 1.5 MK, have 2.6 arcsecond pixels, and usually have a cadence of 12 minutes. These movies show coronal-temperature aspects of the magnetic eruption in which the erupting Hα filament is entrained. They also show whether an arcade of coronal loops, straddling the magnetic neutral line previously occupied by the filament, was produced in the aftermath of the eruption.

3. Results

[7] Even though in each of the 12 events listed in Table 1 the filament disappeared by erupting, only 9 of these eruptions produced a CME. In the aftermath of each of the CME-associated eruptions, either a two-ribbon flare or both a two-ribbon flare and a coronal arcade formed straddling the magnetic neutral line. These usually persisted for several hours, in the normal manner of long-duration flares that are produced together with a filament eruption and CME [*Kahler*, 1992; *Webb*, 2000; *Sterling et al.*, 2000; *Moore et al.*, 2001]. None of the 3 non-CME eruptions were followed by a long-lasting two-ribbon flare and/or coronal arcade. In these eruptions the pattern of Hα and Fe XII emission was more complex than in the CME-producing eruptions, and was of shorter duration, fading away within an hour or so after the filament disappeared. In the CME eruptions, the filament in the Hα movie usually appeared to be ejected, appeared to lift off and erupt upward. In two of the non-CME-producing eruptions (01 May 2003 and 02 May 2003), the filament motion in the Hα movie also appeared to be ejective in this same manner. However, in the other non-CME-producing eruption (09 Jun 2003), the filament motion in the Hα movie was qualitatively different, more of an unwinding or a turning-over than an upward ejection. In the Fe XII movies, the motion of the filament appeared to be ejective in all of the CME-producing eruptions and each of the non-CME-producing eruptions appeared to be a turning-over or an unwinding. We will now illustrate the above characteristics by presenting a representative example of each of the two kinds of eruption.

[8] One of our eruptions that produced a CME is shown in Figure 1. Panel (a) shows the Hα filament a few minutes before the start of the eruption. The eruption in Hα lasted about 45 minutes, from the start of the first motions until the filament had completely disappeared. Panel (b) shows the two Hα flare ribbons about an hour after the filament eruption. The magnetogram in panel (c) shows that the filament was on the neutral line between two large areas of opposite-polarity diffuse magnetic flux. The images in panels (d) and (e) are running-difference images from the EIT Fe XII movie. Panel (d) shows the filament eruption in progress, and panel (e) shows the coronal arcade about three quarters of an hour later. In both the Fe XII movie and the Hα movie, the filament motion definitely appeared to be ejective. The images in panels (f) and (g) are running-differences of images from the LASCO C2 coronagraph. An obvious large CME from the filament eruption is seen in panel (g), at roughly 2 hours after the filament eruption on the Sun.

[9] One of our eruptions that did not produce a CME is shown in Figure 2. The Hα image in panel (a) shows the filament about an hour before it erupted. The heliographic location of this filament (on the northwestern disk at about 0.7 R_{Sun} from disk center) and the filament's length and orientation all are similar to those of the filament in Figure 1. The duration of the eruption viewed in Hα was also about the same as for the eruption in Figure 1, about three quarters of an hour from the initial motion of the filament to its final disappearance. The Hα image in panel (b) shows the region a few minutes after the filament had completely disappeared. As in this image, no flare ribbons or other brightenings were discernible in the Hα images during or after the eruption. The magnetogram in panel (c) shows that the magnetic setting of this non-CME-associated event was similar to that of the CME-related eruption in Figure 1:

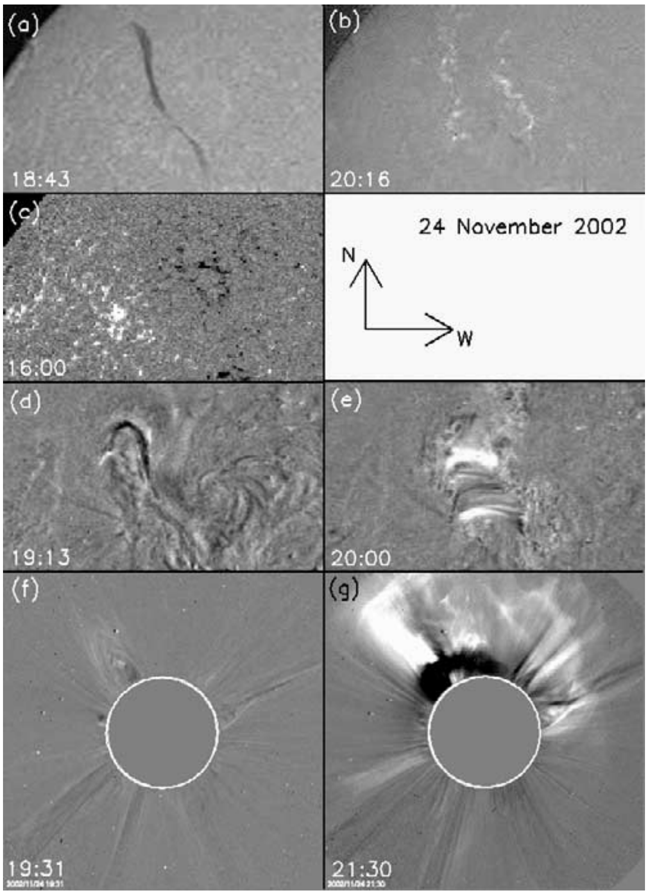

Figure 1. The CME-producing eruption of 24 November 2002. (a–b): Hα filtergrams (a) before and (b) after the eruption. (c): MDI magnetogram. (d–e): EIT Fe XII running-difference images during and after the eruption. (f–g): LASCO C2 running difference images (f) before and (g) after the CME emerged from behind the occulting disk. The edge of the occulting disk, at 2 R_{Sun}, is marked by the white circle.

the filament neutral line was between diffuse remnant negative flux to the west and diffuse remnant positive flux to the east. In the Hα movie, the filament motion was mainly upward, giving the impression that this filament eruption was an ejective eruption like the one in Figure 1. However, in the Fe XII movie, the motion of both the dark filament and brighter coronal structure around it definitely appeared not to eject, but the filament seemed to turn over as it disappeared. The Fe XII running-difference image in panel (d) illustrates the complex character of the rapidly changing coronal brightening that occurred in this eruption. The rate of change and the brightness decreased over the next hour. The faint bright features seen in the Fe XII running-difference image in panel (e) are the last traces of this complex brightening in the magnetic field rooted near the neutral line. In agreement with the absence of a pair of flare ribbons in the Hα movie, the coronal image in panel (e) shows that there was no coronal arcade in the aftermath of this filament eruption. Finally, the LASCO C2 running-difference images in panels (f) and (g) show that the corona above the eruption was about as undisturbed about two hours after the eruption (panel (f)) as is was before the eruption (panel (g)), clearly showing that this eruption produced no CME.

4. Discussion

[10] It is well known that many quiescent filament eruptions occur at the onset of CMEs. Statistical studies of the concurrence of CMEs with filament disappearances imply that a significant fraction (~30%) of quiescent filament eruptions are not associated with CMEs. We have corroborated this conclusion and have found characteristic differences between the two kinds of filament eruptions by examining, in Hα movies, Fe XII movies, and white-light coronagraph images, the dynamics and consequences of the eruption in a random sample of 12 quiescent filament eruptions. Our sample of 12 events is not large enough to establish the fraction of quiescent filament eruptions that do not give rise to CMEs. That 3 of our 12 events had no CME is consistent with the 30% finding of the statistical studies. We are presently expanding our sample to improve our statistics.

[11] It is known that a filament eruption in an active region is either ejective or confined [*Machado et al.*, 1988;

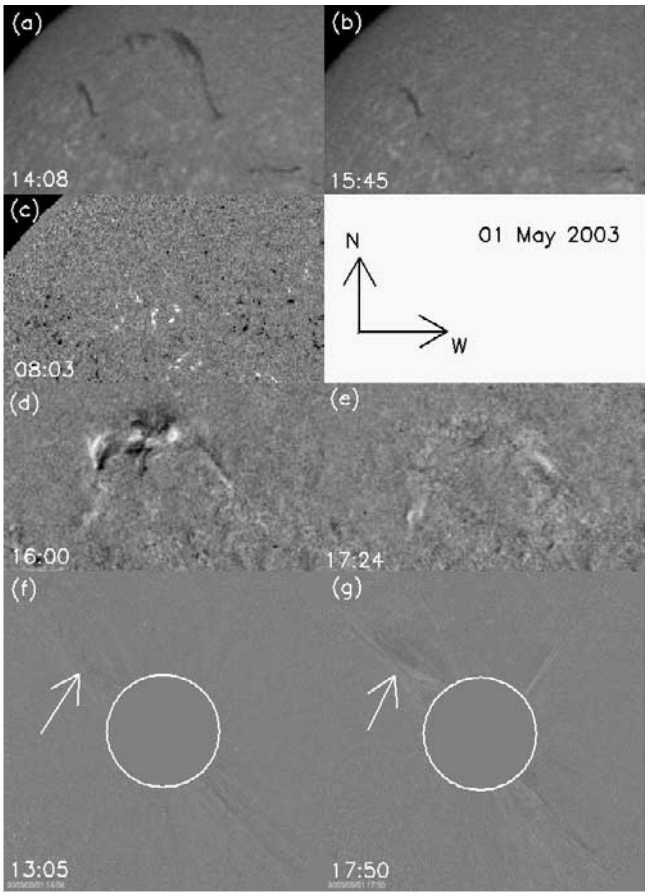

Figure 2. The non-CME-producing eruption of 1 May 2003. The image in each panel is of the same type as in the corresponding panel of Figure 1. The running-difference image in (f) is before the eruption and the image in (g) is about two hours after the eruption when the CME would be expected to have reached somewhere around the location pointed to by the arrow, had the eruption produced a CME.

Moore, 1988]. Ejective active-region eruptions produce CMEs; confined active-region eruptions do not produce CMEs [*Canfield et al.*, 1999; *Falconer et al.*, 2002]. In these eruptions, confined or ejective, the filament is held in the sheared core field of a closed bipolar magnetic arcade (as in quiescent filament eruptions), and the eruption is apparently driven by an explosion of the sheared core field [*Moore*, 1988, 2001; *Moore et al.*, 2001]. We believe that the results presented in the present paper show that the dichotomy of confined and ejective sheared-core-field eruptions found in active regions extends to the larger-scale, weaker-field similar magnetic configurations in which quiescent filaments reside and erupt. That is, it appears that quiescent filament eruptions are similar to active-region filament eruptions not only in their basic pre-eruption field configuration being a closed arcade with sheared core field, but also in their having a similar dichotomy of confined and ejective eruptions. This similarity suggests that quiescent filament eruptions, confined or ejective, are unleashed in the same way as active-region filament eruptions.

[12] From line-of-sight photospheric magnetograms it is not possible to detect the shear in the core magnetic field that presumably holds the filament or to examine whether the sheared field configuration is significantly different for the two kinds of eruptions. This is illustrated by the two examples presented in this paper: the line-of-sight magnetograms show a similar photospheric flux distribution for both the eruptive event and the confined event. Also, the source region of the CME studied by *Choudhary et al.* [2002] had a flux distribution similar to that in our examples. Moreover, the energy for the eruption, in the form of shear in the core field, may be stored mostly above the photosphere. Therefore, to detect whether and how the sheared pre-eruption field configuration differs between confined and ejective eruptions, it may be useful to observe the vector magnetic field in the core field at higher altitudes, by using infrared or ultraviolet lines formed at chromospheric or transition-region temperatures in the filaments.

[13] **Acknowledgments.** This work was supported by NASA's Office of Space Science through its Solar and Heliospheric Supporting Research and Technology Program. The work was performed while D. P. C. held a National Research Council NASA/MSFC Resident Research Associateship. The Improved Solar Optical Observing Network (ISOON) project is a collaboration between the Air Force Research Laboratory Space Vehicles Directorate and the National Solar Observatory. SOHO is a project of international collaboration between ESA and NASA.

References

Brueckner, G. E., R. A. Howard, M. J. Koomen, C. M. Korendyke, D. J. Michels, J. D. Moses, D. G. Socker, K. P. Dere, P. L. Lamy, A. Llebaria, et al., The Large Angle Spectroscopic Coronagraph (LASCO), *Solar Phys.*, *162*, 357–402, 1995.

Canfield, R. C., H. S. Hudson, and D. E. McKenzie, Sigmoidal morphology and eruptive solar activity, *Geophys. Res. Lett.*, *26*, 627–730, 1999.

Choudhary, D. P., S. Gosain, and N. Srivastava, The source of a coronal mass ejections in a decayed active region, *Astron. Astrophys.*, *395*, 257–262, 2002.

Delaboudiniere, J.-P., G. E. Artzner, J. Brunaud, A. H. Gabriel, J. F. Hochedez, F. Millier, X. Y. Song, B. Au, K. P. Dere, R. A. Howard, et al., EIT: Extreme-Ultraviolet Imaging Telescope for the SOHO Mission, *Solar Phys.*, *162*, 291–312, 1995.

Denker, C., A. Johannesson, W. Marquette, P. R. Goode, H. Wang, and H. Zirin, Synoptic Hα full-disk observations of the Sun from Big Bear Solar Observatory: I. Instrumentation, image processing, data products, and first results, *Solar Phys.*, *184*, 87–102, 1999.

Falconer, D. A., R. L. Moore, and G. A. Gary, Correlation of the coronal mass ejection productivity of solar active regions with measures of their global nonpotentiality from vector magnetograms: Baseline results, *Astrophys. J.*, *569*, 1016–1025, 2002.

Gopalswamy, N., M. Shimojo, W. Lu, S. Yashiro, K. Shibasaki, and R. A. Howard, Prominence eruptions and coronal mass ejection: A statistical study using microwave observations, *Astrophys. J.*, *586*, 562–578, 2003.

Gosling, J. T., D. J. McComas, J. L. Phillips, and S. J. Bame, Geomagnetic activity associated with earth passage of interplanetary shock disturbances and coronal mass ejections, *J. Geophys. Res.*, *96*, 7831–7839, 1991.

Kahler, S. W., Solar flares and coronal mass ejections, *Ann. Rev. Astron. Astrophys.*, *30*, 113–141, 1992.

Machado, M. E., R. L. Moore, A. M. Hernandez, M. G. Rovira, M. J. Hagyard, and J. B. Smith Jr., The observed characteristics of flare energy release. I. Magnetic structure at the energy release site, *Astrophys. J.*, *326*, 425–450, 1988.

Martin, S. F., Conditions for the formation of the prominences as inferred from optical observations, in *Dynamics of Quiescent Prominences*, *IAU Colloq.*, edited by V. Ruzdjak and E. Tandberg-Hanssen, Berlin and New-York, Springer-Verlag, *177*, 1–48, 1989.

McNamara, L. F., and C. S. Wright, Disappearing solar filaments and geomagnetic activity, *Nature*, *299*, 537–538, 1982.

Moore, R. L., Evidence that magnetic energy shedding is the drive in accompanying flares and coronal mass ejections, *Astrophys. J.*, *324*, 1132–1137, 1988.

Moore, R., Solar prominence eruption, in *Encyclopedia of Astronomy and Astrophysics*, edited by P. Murdin, Institute of Physics Publishing, Bristol, 2691–2695, 2001.

Moore, R. L., A. C. Sterling, H. S. Hudson, and J. R. Lemen, Onset of the magnetic explosion in solar flares and coronal mass ejections, *Astrophys. J.*, *552*, 833–848, 2001.

Mouradian, Z., and I. Soru-Escaut, Quiescent filament "appearance and disappearance", in *Dynamics of Quiescent Prominences*, edited by V. Ruzdjak and E. Tandberg-Hanssen, *IAU Colloq. 177*, 379–391, 1989.

Munro, R. H., J. T. Gosling, E. Hildner, R. M. MacQueen, A. I. Poland, and C. L. Ross, The association of coronal mass ejections with other forms of solar activity, *Solar Phys.*, *61*, 201–215, 1979.

Pojoga, S., and T. S. Huang, Disappearing solar filaments and their relation with coronal mass ejections, *Bull. Am. Astron. Soc.*, *35*, 815, 2003.

Scherrer, P. H., R. S. Bogart, R. I. Bush, J. T. Hoeksema, A. G. Kosovichev, J. Schou, W. Rosenberg, L. Springer, T. D. Tarbell, A. Title, C. J. Wolfson, and I. Zayer, The Solar Oscillations Investigation — Michelson Doppler Imager, *Solar Phys.*, *162*, 129–188, 1995.

Schmieder, B., P. Demoulin, G. Aulanier, and L. Golub, Differential magnetic shear in an active region, *Astrophys. J.*, *457*, 881–886, 1996.

Sterling, A. C., H. S. Hudson, B. J. Thompson, and D. M. Zarro, Yohkoh SXT and SOHO EIT observations on "sigmoid-to-arcade" evolution of structures associated with halo CMEs, *Astrophys. J.*, *532*, 628–647, 2000.

Tandberg-Hanssen, E., The nature of solar prominences, Kluwer Academic Publishers, Dordrecht, Holland, 1994.

Webb, D. F., Understanding CMEs and their source regions, *J. Atmos. Sol. Terr. Phys.*, *62*, 1415–1426, 2000.

Webb, D. F., and A. J. Hundhausen, Activity associated with the solar origin of coronal, mass ejections, *Solar Phys.*, *108*, 383–410, 1987.

Webb, D. F., A. S. Krieger, and D. M. Rust, Coronal X-ray enhancements associated with H-alpha filament disappearances, *Solar Phys.*, *48*, 159–186, 1976.

D. P. Choudhary and R. L. Moore, NASA/Marshall Space Flight Center, SD50/Space Science Department, Huntsville, AL 35812, USA. (debi.choudhary@msfc.nasa.gov)