The Relationship of Coronal Mass Ejections to Streamers

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Abstract
We have examined images from the Large Angle Spectroscopic Coronagraph (LASCO) to study the relationship of Coronal Mass Ejections (CMEs) to coronal streamers. We wish to test the suggestion (Low 1996) that CMEs arise from flux ropes embedded in a streamer erupting, thus disrupting the streamer. The data span a period of two years near sunspot minimum through a period of increased activity as sunspot numbers increased. We have used LASCO data from the C2 coronagraph which records Thomson scattered white light from coronal electrons at heights between 1.5 and 6R⊙. Maps of the coronal streamers have been constructed from LASCO C2 observations at a height of 2.5R⊙ at the east and west limbs. We have superposed the corresponding positions of CMEs observed with the C2 coronagraph onto the synoptic maps. We identified the different kinds of signatures CMEs leave on the streamer structure at this height (2.5R⊙). We find four types of CMEs with respect to their effect on streamers

1. CMEs that disrupt the streamer
2. CMEs that have no effect on the streamer, even though they are related to it.
3. CMEs that create streamer-like structures
4. CMEs that are latitudinally displaced from the streamer.

This is the most extensive observational study of the relation between CMEs and streamers to date. Previous studies using SMM data have made the general statement that CMEs are mostly
associated with streamers, and that they frequently disrupt it. However, we find that approximately 35% of the observed CMEs bear no relation to the pre-existing streamer, while 46% have no effect on the observed streamer, even though they appear to be related to it. Our conclusions thus differ considerably from those of previous studies.
1. Introduction

Streamers are the most prominent observable features of the large-scale magnetic field of the sun. CMEs, in turn, are thought to arise from the destabilization of large scale, closed magnetic structures/arcades associated with streamers. The effect of CMEs on streamers is therefore crucial to building a complete picture of CME initiation and subsequent propagation. The data from LASCO observations comprises the most detailed set of white light observations of CMEs to date. We use synoptic white light maps obtained from images taken by the C2 coronagraph of the LASCO instrument to map the streamers. We then superimpose CME locations inferred from C2 images on these synoptic maps. This dataset reveals several new aspects of the association between CMEs and streamers that have not been appreciated in previous studies such as those by Hundhausen (1993). In particular, it reveals that a substantial fraction of CMEs have very little effect on the existing streamer structure, and that many of them do not seem to bear any relation to a streamer. A relatively smaller percentage of CMEs also seem to create coronal structures that can be referred to as stalks or legs. We seek to elaborate on such aspects in this paper, and place them in the context of the current state of knowledge about the overall issue of CME initiation and propagation.

We start by examining previous observational work on the relationship between CMEs and streamers, and on the magnetic topology of the post-CME corona in §2. We next examine the theoretical motivations for investigating the effect of Coronal Mass ejections on streamers in §3. We move on to discussing the details of the method we use to construct white light synoptic maps, and the manner in which we mark the locations of CMEs on them in §4. §5 presents the salient results that can be drawn from our analysis of the data. A discussion of the significance of these results in the context of our current state of understanding about CMEs is contained in §6.

2. Observational Motivations

Howard et al. [1985] published a comprehensive catalog of CMEs observed with the Solwind instrument. They coined the phrase “streamer blowout” to denote events where the streamer that existed prior to the CME would start swelling and brightening, and eventually disappear as a result of the CME. They found that such events were typically slow in comparison to other kinds of CMEs. Illing & Hundhausen [1986] subsequently discussed a filament eruption and CME observed by the SMM coronagraph that resulted in a streamer blowout. Hundhausen [1993] published a comprehensive review of CMEs observed by the SMM spacecraft. He concluded that an appreciable fraction of CMEs observed during 1984 were “bugle” CMEs, which were so named because the pre-CME streamers looked like bugles facing to the left on a conventional white light synoptic map. The bugle-like structures on the synoptic maps are a consequence of the fact that the streamer widens prior to being blown out by the CME. He also concluded that CMEs are often associated with disruptions of the streamer structure. This, together with the idea that streamers are manifestations of the large-scale coronal magnetic field, is used to support the thesis that CMEs are associated with the destabilization of large-scale magnetic structures. The generally accepted notion that CMEs are associated with the streamer belt is also attributed to Hundhausen [1993]. The theme of CMEs being associated with large-scale, closed magnetic structures in the corona has also been emphasized by Bravo et al. [1998]. McAllister and Hundhausen [1996] conclude that 73% of coronal arcade events observed with the YOHKOH Soft X-Ray telescope are associated with streamer belts. This, together with the generally accepted notion that X-ray arcade events are proxies for CMEs, reinforces the notion that CMEs are very often associated with streamer belts. The present study however sketches a more complex picture of the association of CMEs with streamers.

Our study differs from that of Hundhausen [1993] in the following aspects:

- Our conclusions are based on examination of data from observations spanning two years, whereas Hundhausen’s conclusions about the relationship of CMEs to streamers are based on data spanning one year (see Figure 1).

- The superior sensitivity of the LASCO instrument allows us to arrive at more quantitative and definite conclusions regarding the effect of CMEs on streamers as compared to the study of Hundhausen [1993].

3. Theoretical Motivations

We first proceed to undertake a brief review of streamer models. Early streamer models were mo-
tivated primarily by eclipse observations. A comprehensive review of such models is given in Koutchmy and Livshits [1992]. In particular, the early model of Pacuman and Kopp [1971] modeled the streamer as a magnetostatic structure containing an axisymmetric current sheet. Subsequent treatments have attempted to include the effects of the solar wind on the streamer structure in a self-consistent manner. Wang et al. [1997] published a streamer model that was motivated by LASCO observations. They interpreted the observed streamers as arising from Thomson-scattering electrons that are concentrated around a warped current sheet encircling the sun. Their model employs a potential extrapolation of the photospheric magnetic field up to a source surface of approximately 2-3 \( R_\odot \). While it reproduces the gross features of the streamer belt near solar minimum rather well, it does not include free currents in the corona, and consequently does not address any dynamical phenomena like the effect of CMEs on the streamer.

We next briefly review models of CME initiation and propagation. Our intent in doing so will be to identify model predictions that address the issue of the effect of CMEs on streamers.

Some models of CME initiation rely on the picture of a flux rope breaking through/disrupting an overlying magnetic field arcade, resulting in the observable CME in the field of view of a coronagraph. These are based on models published by Low [1996] which suggest that the cavity underlying helmet streamers is a flux rope containing prominence material. There exist equilibrium solutions where the magnetic flux rope is attached to the Sun, and also in the case where it is detached from the Sun. The concept of a detached flux rope embedded in a helmet streamer has been taken as a starting point for a number of numerical simulations. Guo et al. [1996] simulate the dynamic response of the streamer to the emergence of a current-carrying magnetic bubble. If the magnetic field carried by the bubble is oppositely directed to that of the overlying streamer, they find that reconnection occurs at the flanks of the emerged structure where the current density is maximum. Depending upon the initial energy in the current-carrying magnetic bubble, they find that the overall streamer structure either remains quasi-static, or disrupts. Wu and Guo [1997] also address the role of magnetic buoyancy in disrupting the streamer. They find that low-density flux ropes disrupt the streamer faster than high-density ones. The overall conclusion seems to be that all models of flux rope-streamer systems disrupt the streamer during a CME; the differences in the speeds at which the streamer is disrupted.

Some other groups (see, for instance, Mikic and Linker [1997], Steinolfson [1994]) model CMEs by considering reconnection processes at the bottom of the magnetic arcade that results in the formation of a pinched-off plasmoid. The formation and subsequent propagation of the plasmoid can be interpreted as a disruption of the streamer. Antiochos [1998], on the other hand, argues that reconnection occurs above the arcade that actually erupts, so as to allow the erupting structure to rise.

4. Procedure

4.1. The data

The data used in this study was obtained by the Large Angle Spectroscopic Coronagraph (LASCO) instrument aboard the Solar and Heliospheric Observatory (SOHO). A detailed description of LASCO is given in Brueckner et al. [1995]. Briefly, LASCO consists of 3 coronagraphs, C1, C2 and C3. Here, we have used images from the C2 coronagraph which cover the corona from a distance of 1.5 out to 6 \( R_\odot \), and are obtained with a typical cadence of 30 to 60s between images. The LASCO images record all of the CMEs that occur during periods of operation, as well as the evolution of the coronal streamers. The CME times and locations with respect to the coronal streamers are the basis for this study. The procedure is described in the following sections. We have used the data from the start of LASCO operations in January 1996 until the period in June 1998 when SOHO was lost for 2.5 months. This covers times of very low solar activity near solar minimum through a period of increasing activity as the sun enters the new activity cycle. Figure 1 displays the monthly and smoothed sunspot number index (obtained from the Sunspot Index Data Center at http://www.oma.be/KSB-ORB/SDIC). We have indicated the period covered by the LASCO observations and contrasted it with that covered by the SMM observations (Handhausen [1993]) on the figure.

4.2. Construction of White Light Synoptic Maps of the Corona

The white light synoptic maps are constructed from intensities measured at a height of 2.5 solar radii over the east and west limbs of images from the C2 coronagraph (Figures 2 and 3). Following the convention for such synoptic maps, time increases from
the right to the left. The start date corresponds to the time when the central meridian is on the east (west) limb; hence, the start date of a west limb map is the same date as the middle of the east limb map (half a rotation as the sun rotates east to west). A more complete set of synoptic maps for the whole SOHO/LASCO mission are available at [http://lasco-www.nrl.navy.mil/carr_maps](http://lasco-www.nrl.navy.mil/carr_maps). All the maps display the ratio of the observed signal to a background model to account for scattered light and the dust (F) corona. Vertical black lines are missing data blocks. Synoptic maps for Carrington rotation 1919 (February 1997) onward have a longitudinal resolution of 0.5 degrees (0.91 hours) per pixel; the prior rotations have a longitudinal resolution of 1 degree (1.82 hours) per pixel. All the maps have a latitudinal resolution of 1 degree per pixel.

4.3. Synoptic Locations of CMEs

We mark the footpoints of the CME when it emerges into the field of view of the C2 coronagraph at 2.2 R⊙. The latitudinal extent of the CME is measured in the plane of the sky. The longitude of the CME is taken to be the longitude of the east/west limb at the time of observation. No attempt is made to account for the possible longitudinal displacement of the CME out of the plane of the sky. The coordinates of the footpoints of the CME are converted into heliographic coordinates and superimposed on the white light synoptic maps. The ‘X’s in Figures 2 and 3 are the counterparts of CME footpoints as observed in individual images, and represent the latitudinal extrema of the CME. In Figures 2 and 3, a pair of ‘X’s connected by a vertical dashed line appearing against the background of a white light synoptic map thus represents a CME. Halo CMEs, which were first reported by Howard et al. [1982], are interpreted as CMEs moving towards (or away from) the earth. Halo events usually originate around 90 degrees from the limb. They are typically wide, sometimes spanning an entire solar diameter, so that their footpoint locations do not fit the general scheme used here. We mark the halo events with a vertical string of ‘H’s, and don’t join them with a dashed line, as we do with the other CMEs. We include the halo events in our catalog for the sake of completeness.

5. Results

Our observations span a period between January 1996 and June 1998, which ranges from near minimum solar activity to progressively increasing activity, as shown in Figure 1. An examination of the data (examples of which are shown in Figures 2 and 3) reveals that the CMEs can be placed into four categories, based on their relationship to the streamer. We describe below the classifications, and the percentage of CMEs that fall into each of the categories. We have recorded a total of 375 CMEs during our observation period, of which 30 are halo CMEs. The percentage figures mentioned in each category are based upon an examination of the entire dataset covering the period of observations mentioned above. Owing to space constraints, we do not show the entire dataset in this paper. We display the datasets corresponding to Carrington rotations 1925 and 1932 in Figures 2 and 3 respectively. These two figures contain examples of all the four categories of events described below.

1. Creates streamer: This category includes events where considerably more coronal material is present at the location of the CME after its eruption compared to that prior to the eruption. It includes the creation of post-CME structures that can be variously described as stalks, streaks, legs and so on. Figures 4 a-c show a representative example of an event where a ‘leg’ is created following a CME. The leg is created towards the northern boundary of the CME, and persists for approximately 1.5 days following the CME. This event, which occurs on 1997/07/24, can be discerned on the east limb synoptic map of Figure 2. This class of events relates most closely to those discussed by Kahler and Hundhausen [1992]. We have placed 29 events in this category, which corresponds to 8.4% of the total number of non-halo CMEs recorded.

2. Displaced from streamer: This category includes events that are displaced from whatever streamer structure is present. Figure 5 shows an example of such an event. This event occurs on 1997/07/24, and appears on the west limb synoptic map of Figure 2. 93 events fall into this category, which corresponds to 27% of the total number of non-Halo events recorded. Events in this category do not have any effect on the streamer.

3. No effect: This category includes events which, unlike those included in the previous category, do not have any effect on the streamer.
seem to have no effect on the streamer. There are several examples of such events on the synoptic maps in Figures 2 and 3. These CMEs are typically dim, and are evident only in running difference images. This implies that the CMEs are probably displaced from the plane of the sky. We record 160 events in this category, which corresponds to 46% of all the non-Halo events.

4. **Streamer blowout**: In this category, we include all events where part, or all of the streamer structure that exists prior to the CME disappears (or becomes significantly reduced in intensity) following the CME. Insofar as the effect of CMEs on streamers is concerned, this category of events is the most dramatic, and has been most widely discussed in the literature (Howard et al. [1985], Hundhausen [1993]). Furthermore, as noted in §3, most theoretical models of CME initiation and propagation seem to predict a disruption of the streamer of some kind. Figures 6 a-b show an example of a streamer blowout event. This event occurs on 1998/02/04, and appears on the west limb synoptic map of Figure 3. We have recorded 56 events in this category, which corresponds to 16% of the total number of non-Halo events recorded.

The creation of streamer-like structures following a CME bears no relation to the streamer structure that existed prior to the CME. We may therefore add the numbers for categories 1 (Creates Streamer) and 2 (Displaced from Streamer), and conclude that 35% of the non-Halo CMEs observed bear no relation to the pre-existing streamer. Similarly, events in categories 3 (No effect on Streamer) and 4 (Streamer Blowout) are associated with the streamer. We therefore add the numbers ascribed to these two categories and conclude that 63% of all the non-halo CMEs we observe are related to the streamer. Figure 7 summarizes the statistics presented in this section.

6. **Discussion**

The relationship of CMEs to streamers is an area which has been examined only by Hundhausen [1993] and McAllister and Hundhausen [1996] so far. The results obtained from our study, which surveys the relationship between CMEs and streamers for the period Jan 1996 - Jun 1998, modify some of the prevalent perceptions on this subject. Some statements in the literature (e.g., Hundhausen, 1993) suggest that CMEs originate from the streamer belt, and that they often disrupt the streamer. McAllister and Hundhausen [1996] find that 73% of X-ray arcade events are associated with streamers. Since X-ray arcade events observed by YOHKOH are generally considered to be proxies for CMEs, this tends to suggest that a large fraction of CMEs are associated with streamers. We find that about 63% of the observed CMEs are associated with streamers. Thus, our conclusions are fairly consistent with those of McAllister and Hundhausen [1996]. Hundhausen [1993] concludes that approximately 50% of the CMEs observed in 1984 result in streamer disruptions. However, we find that only a small percentage (16%) of CMEs result in disruption of the streamer.

The most surprising result of our analysis, in our view, is the large number of CMEs in category 3 of the preceding section. We observe that a significant fraction (46%) of the observed CMEs do not have any effect on the streamer, although they seem to be associated with it. We now discuss how such events pose a paradox in the context of the flux rope model for CMEs. In the flux rope model of Low [1996], for instance, the flux rope is located at the base of the streamer. If ejected, this should disrupt the streamer. There have been a number of papers in the recent literature that report ejections of helical magnetic flux ropes (Dere et al. [1998], Chen et al. [1997]), as suggested by Low [1996]. There have also been a number of theoretical treatments that envisage a CME as a magnetic flux rope, as outlined in §3. One possible explanation for events which overlap the streamer, but do not seem to affect it in any way is as follows: the CME could be longitudinally displaced from the limb, and its two-dimensional projection in the plane of the sky could therefore be rather faint. The observed streamer, on the other hand, is in the plane of the sky, and is therefore bright. However, the longitudinal extent of a typical flux rope is expected to be comparable to, if not larger than that of undulations in the warped current sheet that are manifested as the streamer. Therefore, even if an ejected flux rope is longitudinally displaced from the observed streamer structure, it is difficult to reconcile it with the fact that it has no effect whatsoever on the streamer.

Another view of the CMEs classified in category 3 is as follows. Figure 8 shows the relative contributions of matter at different angles out of the plane of the sky to the total integrated brightness. It is evident from Figure 8 that a structure situated 45 degrees...
away from the plane of the sky would seem 20% as bright as one situated in the plane of the sky. The CMEs in category 3 are typically dim, which implies that they are displaced from the plane of the sky. If we assume that these CMEs are about 20% as bright as the brightest ones observed, we can roughly estimate from Figure 8 that they are displaced by at least 45 degrees from the plane of the sky, and perhaps not spatially related to the streamers observed in the synoptic maps. Such projection effects could therefore be one possible explanation for the paradox posed by events in category 3, which overlap the streamer, but do not disrupt it.

7. Conclusions

We have drawn the following conclusions from our study of CMEs over the period spanning January 1996 – June 1998:

1. 8.5% of all the CMEs observed create streamer-like structures after they erupt.

2. 27% of all the CMEs are latitudinally displaced from the streamer. They thus seem to bear no relation to the streamer.

3. 46% of all the CMEs overlap the streamer, but seem to have no effect on it. This large fraction is especially puzzling if most CMEs are flux ropes embedded in the streamer, for they would be expected to disrupt the streamer when they erupt.

4. Only 16% of all the observed CMEs disrupt the streamer.

These conclusions considerably modify the prevalent perceptions that CMEs are usually associated with streamers, and that they frequently disrupt it. The large percentage of CMEs that do not affect the streamer despite being associated with it is especially intriguing. One possible explanation for such CMEs is that they are longitudinally displaced from the plane of the sky, as explained in §6. Even so, it casts doubt on the theme of CMEs being associated with disruptions of large scale, closed structures in the corona.

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**Figure 1.** This figure displays the monthly sunspot number and a smoothed fit to the data from 1980 to 2000. We have marked the period covered by the SMM observations reported by Hundhausen (1993) and that covered by the LASCO observations.

**Figure 2.** Figures 2 and 3 are examples from the dataset we have used in this work. Figure 2a shows the east limb white light synoptic map for Carrington rotation 1925, with CME footpoints superimposed on it. Figure 2b shows the corresponding map for the west limb. The streamer is the bright structure along the equator. The ‘X’s in Figures 2 and 3 are the counterparts of CME footpoints as observed in individual images, and represent the latitudinal extrema of the CME. In Figures 2 and 3, a pair of ‘X’s connected by a vertical dashed line appearing against the background of a white light synoptic map thus represents a CME. It is seen from the synoptic maps of Figures 2 and 3 that CMEs affect the streamer in different ways. Individual images for the specific CMEs marked on Figure 2 are shown in Figures 4 and 5.

**Figure 3.** Figure 3 shows the east and west limb white light synoptic maps for Carrington rotation 1932, with CME footpoints superimposed on it. Individual images for the specific CME marked on Figure 3b are shown in Figure 6.

**Figure 4.** Figures 4a, 4b and 4c show a sequence of images taken with the LASCO C2 coronagraph. They show a CME taking off on the north-eastern limb. It creates a bright stalk that was not present prior to the CME, and persists for approximately 1.8 days following the CME. This CME is an example of an event in category 1, §5, “Creates Streamer”. This CME occurred on 07/24/97, and is marked on the synoptic map of Figure 2a. It is clearly evident from Figure 2a that a bright, long-lived stalk is created after the passage of the CME.

**Figure 5.** This figure shows a CME occurring on the north-western limb. It is an example of a CME that is displaced from the main streamer structure, as described in category 2, §5, “Displaced from Streamer”. This event occurred on 07/24/97, and is marked on the synoptic map of Figure 2b. As is evident from Figure 2b, the CME is displaced northward from the streamer.

**Figure 6.** Figures 6a and 6b show a CME which disrupts and “blows out” the streamer. It is an example of the class of events described in category 4, §5, “Streamer Blowout”. This event occurred on 02/04/98, and is marked on the synoptic map of Figure 3b. It can be clearly seen from Figure 3b that this CME disrupts the streamer.

**Figure 7.** Figure 7a embodies the central result of our paper. It shows the relative number of events in each of the categories described in §5. The events in categories 1 and 2 bear no relation to the pre-existing streamer. We add the percentages assigned to these two categories and conclude that 35% of all the CMEs are unrelated to the pre-existing streamer, as shown in figure 7b. Similarly, adding the numbers assigned to categories 3 and 4 leads to the conclusion that 63% of CMEs are related to the pre-existing streamer, as shown in figure 7b.

**Figure 8.** Figure 8 gives the relative contribution of electrons along the line of sight to the total brightness. For example, electrons located more than 40 degrees from the plane of the sky, contribute only about 20% of the total signal.
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