Investigating the ‘double-expansion’ of the 2011-03-08 eruption

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ABSTRACT

Methods of multiscale image analysis were employed and their efficacy on the SWAP data tested for revealing CME structure while suppressing other features. The methods employed are described in detail in Young & Gallagher (2008), whereby successive filtering of an image via a Gaussian and derivative-of-Gaussian produces a number of scales of detail to be inspected. This also produces an image with intensities that represent the relative edge strengths in the original image, which can be used to characterize the structure of interest – specifically for this case the erupting material involved in the CME. In order to overlap the observations from SWAP and MK4, the core material of the CME in its early eruption phase was chosen for its higher signal to noise ratio than the CME front, for example, that was not discernible in the early stages of the observations. In the LASCO field-of-view, the core material was determined to be moving at the same speed as the CME front, at $\sim 500\ km\ s^{-1}$. The front portion of the core material in the MK4 images was characterized via point-&-click methodology on the multiscale images of enhanced edges, and an ellipse was fit to the curved front. The same was done for the erupting loop structure observed in SWAP, with the expectation that it might directly correlate to the CME core. However, it was found that the erupting material that starts at the same time and location in both the MK4 and SWAP images, did not proceed to erupt at the same rate. Rather the core material observed in MK4 moves at greater speeds than the loop structures observed in SWAP; rising from an initial speed of $\sim 100\ km\ s^{-1}$ (at $\sim 1.5\ R_{\odot}$) to a final speed of $\sim 400\ km\ s^{-1}$ (at $\sim 2\ R_{\odot}$), while the loops continue to steadily rise at $\sim 100\ km\ s^{-1}$. The reason for this is unclear, and requires further investigation.

Subject headings: Sun: activity; Sun: corona; Sun: coronal mass ejections (CMEs); Techniques: image processing

1. Introduction

An important aspect of studying CMEs, is the ability to resolve their low-corona propagation and associated source regions on the disk; be it a flaring or non-flaring active region, a prominence/filament eruption or other rising loop system, or else a ‘stealth CME’ without any specifically detectable source. Prominence lift-offs often become the core material of a CME, and rising loops often form some part of the CME morphology. Their low-corona kinematics and morphology provide insight into the early forces at play, and so a rigorous study of such phenomena is key to understanding the physics involved in the initiation phase of CMEs.

In order to connect CMEs to their source regions, data from disk imagers, such as *PROBA2*/SWAP and *SDO*/AIA, may be used in tandem with the coronagraph observations. However, difficulties in the interpretation of the observed features arise due to the varying instrument specifications, e.g., image passbands, fields-of-view (FOVs), cadences, etc. Therefore, to bridge the gap between the white-light images of the extended corona and the EUV observations of the solar disk and low corona, the SWAP imager was used in conjunction with the MLSO/MK4 coronagraph to directly compare the observations of CMEs as they erupt through

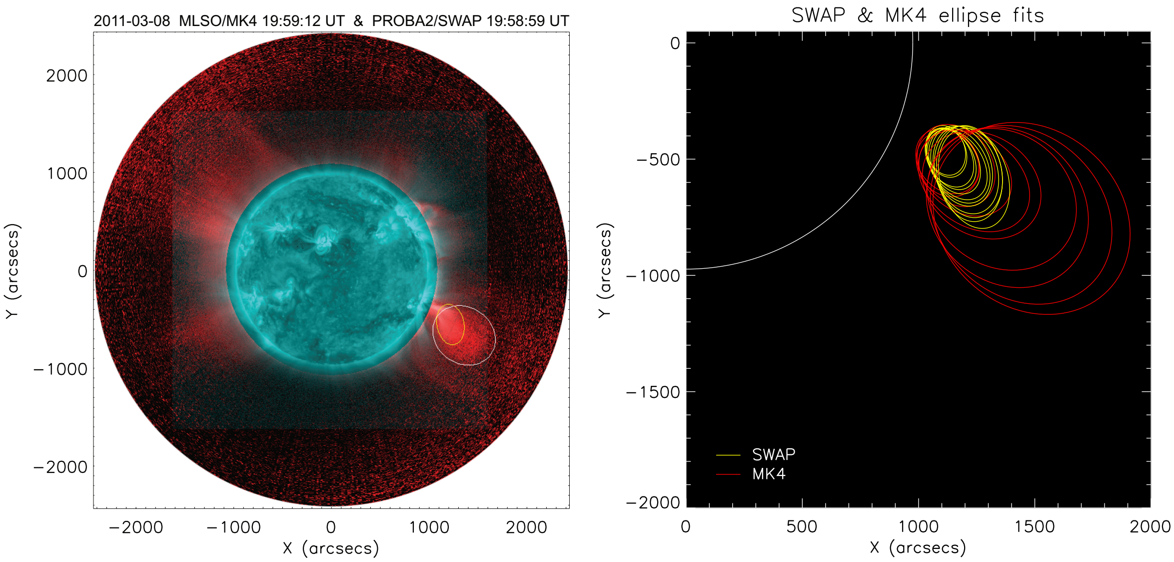

Fig. 1.— *Left:* A merged SWAP (blue) and MK4 (red) image with the ellipse fits to the characterized CME core material as observed by each instrument. *Right:* The SWAP and MK4 ellipse fits to the characterized CME core material over the course of the eruption.

the overlapping FOVs. This allows a direct correspondence of features in the EUV images with those in the white-light images, providing new insight into the connection of CMEs to the Sun during their initial phases of eruption and acceleration away from their source regions on the disk.

2. Observations & Techniques

A CME erupted from active region NOAA 11165 (S20W91) at approximately 19:30 UT on 8 March 2011. The active region caused numerous flares, notably an M1.5 flare at GOES start-time 19:35 UT associated with the rising loop system that erupted to form the core material of the CME. The loop system evolution is clearly visible up to $\sim 1.3\,R_\odot$ in *SDO*/AIA (ref) images, with the proceeding eruption observed to a height of $\sim 1.6\,R_\odot$ in the larger field-of-view of the *PROBA2*/SWAP (ref) (17.4 nm) imager.

The CME is observed in MLSO/MK4 (ref) coronagraph data, providing white-light polarization brightness images of the corona from ~ 1.14–$2.86\,R_\odot$. The data was prepared via an instrumental vignetting function that maximizes the image contrast by offsetting the radial brightness gradient in order to best reveal structures such as CMEs and streamers.

In order to best reveal the eruption material in the low signal-to-noise SWAP and MK4 images, multiscale methods of noise suppression and edge enhancement were employed, as developed by Young & Gallagher (2008) and repeatedly shown effective in the analysis of CME morphology (Byrne et al. 2012, 2009). This allowed a point-&-click characterization of the core material of the CME, which was the brightest structure to be tracked through the different imagers when the CME front was not yet fully formed. The rising loop system observed in the SWAP images, and the erupting CME core material that coincided both temporally and spatially with the rising loops, at least initially, were characterized by ellipse-fits to the detected front edges of the structures. Figure 1 (left) shows an overlay of a SWAP and MK4 image during the eruption at times 19:58:59 and 19:59:12 UT respectively, with the ellipses fit to the erupting fronts at those times (from point-&-click characterizations of the edge enhanced multiscale decompositions of the images). Figure 1 (right) shows the progression of the ellipse fits to the fronts over the course of the eruption, indicating how the white-light material observed in MK4 propagates away from the source quicker than the EUV material observed in SWAP. These methods were also applied to the *SOHO*/LASCO (ref) observations of the CME, in order to characterize both the dynamical evolution of the CME front and its bright core that was directly associated with the core material observed with MK4.

3. 'Double Eruption' of the 8 March 2011 CME

The CME onset was observed as a series of rising loops, that attained an initial steady height in the low corona, of approximately half a solar radii, before destabilizing and becoming the inner core material of a typical three-part CME that propagated out through the corona at a bulk speed of $\sim 400\,km\,s^{-1}$, following an initial acceleration of $\sim 20\,m\,s^{-2}$ away from the sun. The characterized eruption of the CME core in the MK4 images shows this same kinematic profile, however the associated erupting loop structures in the SWAP images proceed at a slower rate, moving at a speed of only $\sim 100\,km\,s^{-1}$. The different height-time profiles of the SWAP and MK4 observations is shown in Fig. 2.

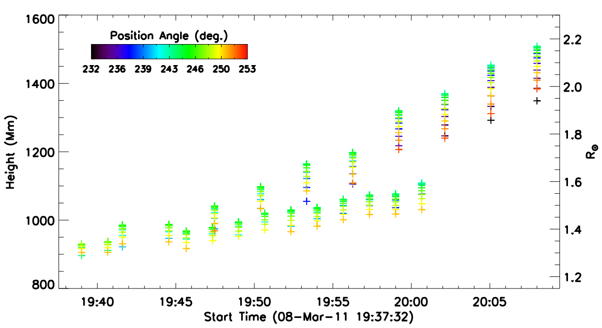

Fig. 2.— The 'double eruption' height-time profile of the characterized eruption observed simultaneously with the SWAP imager and MK4 coronagraph (see the ellipse-fits in Fig. 1 above). The erupting EUV loops move at a speed of $\sim 100\,km\,s^{-1}$ while the associated core of the resulting CME is observed to accelerate up to a speed of $\sim 400\,km\,s^{-1}$.

We shall extend the CORIMP techniques, first developed for coronagraphs, to enhance and characterize the detailed structure in the EUV images of SWAP and AIA. For example, an overlay of SWAP and AIA-171 images is shown in Figure **??** for an erupting prominence on 2012 April 16 at 17:43 UT. The left image shows the level-1 processed data. The right image shows the result of the multiscale filtering technique developed by Young & Gallagher 2008, applied in such a manner as to enhance the edges of the detected structure in the data. The complex nature of the erupting material is such that its signal may be multiplied across numerous scales, while the more linear background coronal features and small-scale noise fall away (as detailed in Byrne *et al.* 2012). This is demonstrated in Figure **??**, where the original and multiscale enhanced SWAP images are polar-unwrapped about Sun-centre and the coronal heights of $1-1.7\,\mathrm{R}_\odot$ are displayed. The comparison of an intensity slice at a height of $1.3\,\mathrm{R}_\odot$ in each, reveals how the multiscale techniques best characterise the complex structure of the erupting prominence material and suppress the more linear background features. Such methods of image processing will be further enhanced with the application of a radial filter (as per the NRGF technique of Morgan *et al.* 2006 to be extended for use on the EUV images).

The CORIMP methods, which have been used to detect and characterise CMEs in coronagraphs, thus show excellent promise for revealing the structure of the eruptions in EUV images that precede, or underlie, the CMEs. It is a goal of this proposal to develop such techniques for applying to the SWAP images in combination with the MK4 images, to bridge the gap between disk and corona observations. This will allow us to quantify their early acceleration, along with their expansion and possible deflection from their source region locations, in a more comprehensive manner than has been previously possible. These unique datasets will therefore help to advance our knowledge of the forces that act during the initiation phase of CMEs. It is intended that this work be published in a peer-reviewed journal, and the developed codes made publicly available through the CORIMP branch of the SSW tree.

The multiscale filtering technique of Young & Gallagher (2008), as developed for the automated CORIMP CME detection and tracking catalogue (Byrne et al. 2012), was employed in the analysis of MK4 and LASCO coronagraph data for the 2011 March 8 event. The filters were applied such that the magnitude of the edge strengths was determined for each image, as shown in Fig. ??a for a frame at 19:56 UT.

The kinematic profile of the characterized CME core material is shown in Fig. ??.

4. Conclusions

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