

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

J. P. Byrne<sup>1</sup> et al.

<sup>1</sup>*Institute for Astronomy, University of Hawai‘i, 2680 Woodlawn Drive, Honolulu, HI 96822, USA.  
jbyrne@ifa.hawaii.edu*

## 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  $\sim 500 \text{ km s}^{-1}$ . 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  $\sim 100 \text{ km s}^{-1}$  (at  $\sim 1.5 R_\odot$ ) to a final speed of  $\sim 400 \text{ km s}^{-1}$  (at  $\sim 2 R_\odot$ ), while the loops continue to steadily rise at  $\sim 100 \text{ km s}^{-1}$ . 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.

## 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) ( $17.4 \text{ nm}$ ) imager.

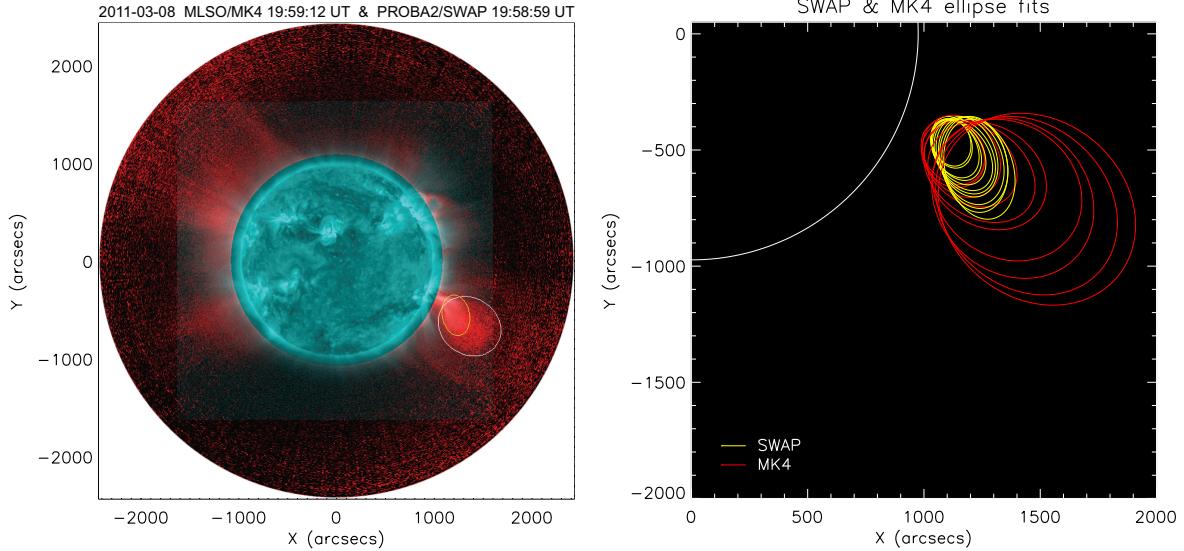


Fig. 1.— *Left:* A merged SWAP (blue) and MK4 (red) image with the ellipse fits to the characterized CME core material as observed by each instrument. *Right:* The SWAP and MK4 ellipse fits to the characterized CME core material over the course of the eruption.

The CME is observed in MLSO/MK4 (ref) coronagraph data, providing scattered white-light images of the corona from  $\sim 1.14\text{--}2.86 R_{\odot}$ .

New CORIMP techniques for detecting and characterizing CMEs in coronagraph data have been developed and applied to the *SOHO/LASCO* and *STEREO/SECCHI* datasets (Morgan et al. 2012; Byrne et al. 2012), based in part on multiscale methods of image noise suppression and edge enhancement (Byrne et al. 2009; Young & Gallagher 2008). 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 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 con-

nnection of CMEs to the Sun during their initial phases of eruption and acceleration away from their source regions on the disk.

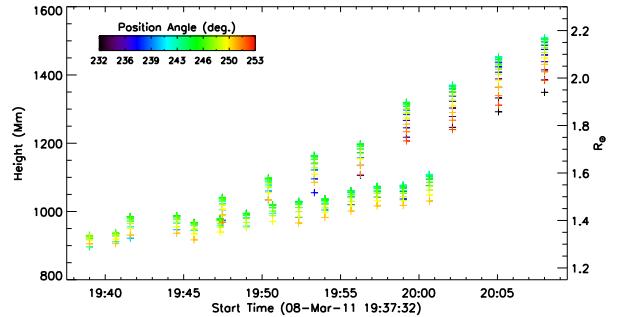


Fig. 2.— SWAP (left) and MK4 (right) observations of the erupting loop system that forms the inner core of the CME on 2011 March 8, at times 19:52 and 19:53 UT respectively. The images have been processed via the multiscale decomposition of Young & Gallagher (2008), showing here intensities that represent the magnitude of the detected edges, at a particular scale with high signal-to-noise ratio.

We shall extend the CORIMP techniques, first developed for coronagraphs, to enhance and char-

acterize 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  $1 - 1.7 R_{\odot}$  are displayed. The comparison of an intensity slice at a height of  $1.3 R_{\odot}$  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.

### 3. The 8 March 2011 Event

A CME was observed on 2011 March 8 off the west limb, from active region N?? that underwent numerous flares in the preceding hours (Fig. ??). The CME was observed as a series of rising loops, that attained an initial height in the low corona (of approximately half a solar radii) before destabilizing and forming a typical three-part CME structure that propagates out through the corona.

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. 1a for a frame at 19:56 UT. 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. An ellipse was fit to the detections in order to characterize the dynamical evolution of the CME core throughout the MK4 and LASCO observations.

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

### 4. Conclusions

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