Investigating 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.

2. Techniques

New CORIMP techniques for detecting and characterising 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). In order to connect CMEs to their source regions, data from disk imagers, such as *PROBA2*/SWAP and *SDO*/AIA, should be used in tandem with the coronagraph observations. However, difficulties arise due to the varying instrument specifications, e.g., image passbands, fields-of-view (FOVs), cadences, etc.
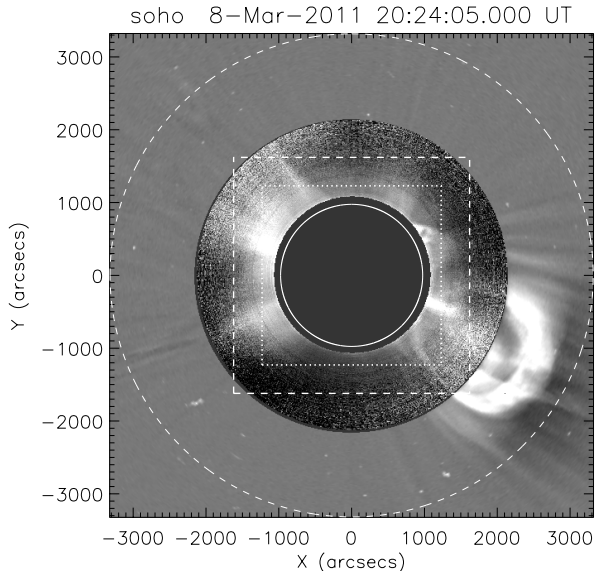
Fig. 1.— A LASCO/C2 image with an MLSO/MK4 image overlaid in the range 1.1–2.2 R$_\odot$, dated 2011 March 8 at 20:24 and 20:22 UT respectively. The C2 image has been processed via the CORIMP techniques of normalising radial graded filter (NRGF) and quiescent background subtraction. It has been trimmed to a half-width of 3.4 R$_\odot$, which is the upper limit of the PROBA2/SWAP FOV as indicated by the dashed circle. The SWAP FOV during nominal operations is indicated by the dashed box. The SDO/AIA FOV is indicated by the inner dotted box. The limb of the Sun behind the occulter is indicated by the solid white circle. A CME is observed off the south-west limb as a bright loop structure with some inner core material, as seen here in the Thomson-scattered white-light coronagraph images. It is clear how the SWAP and AIA images can be used to bridge CME observations to the low corona and solar disk, for studying the physics of their initiation phase.

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, as shown in Figure 1. This allows a direct correspondence of features in the
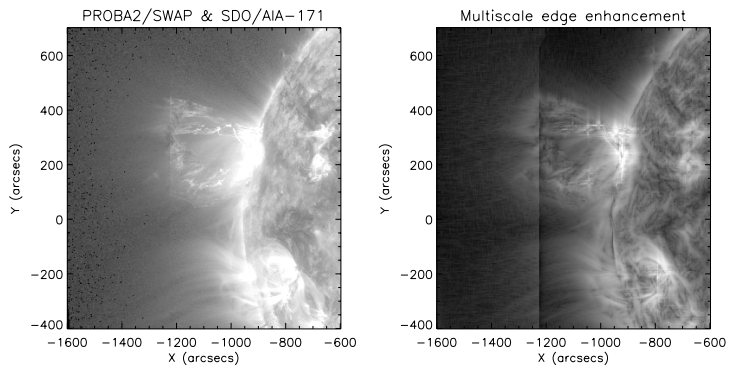

Fig. 2.— Combined PROBA2/SWAP and SDO/AIA-171 image of an erupting prominence observed on 2012 April 16 at 17:43 UT. *Left:* The level-1 data, with the AIA image extending to approximately 1.3 R$_\odot$ and SWAP continuing out to ∼ 1.7 R$_\odot$. *Right:* The result of a multiscale edge enhancement technique: the intensity showing the relative strengths of the detected edges along the structures in the image. A substantial amount of detail is revealed within the erupting prominence material and across the solar disk and corona.

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.

We shall extend the CORIMP techniques, first developed for coronagraphs, to enhance and characterise 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 2 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 3, 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$_\odot$
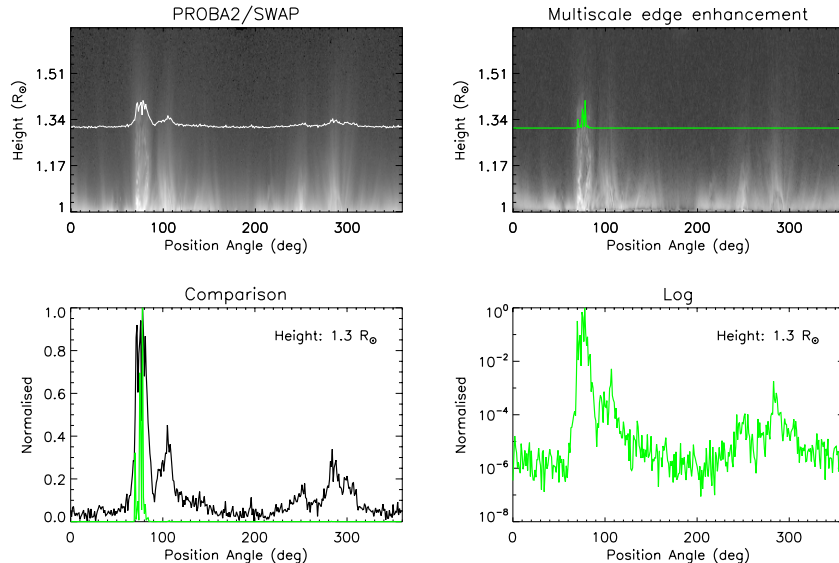
Fig. 3.— The top two panels show polar-unwrapped images of the solar corona across the PROBA2/SWAP FOV on 2012 April 16 at 17:43 UT; left being the level-1 data, right being the enhanced data. Across each image, at a constant height of 1.3 $R_\odot$, an intensity slice is plotted (of arbitrary normalised units) to demonstrate how the background coronal structure is suppressed by the multiscale techniques, to highlight only the complex structure of the prominence. The bottom left plot shows a direct comparison of the two intensity slices, where the prominence is located between $70 - 90°$. The bottom right plot shows a log scale of the normalised intensity slice across the enhanced image to demonstrate that the rest of the coronal structure is still present, just strongly suppressed relative to the prominence material.

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 knowl-

edge 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. 4). 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 de-
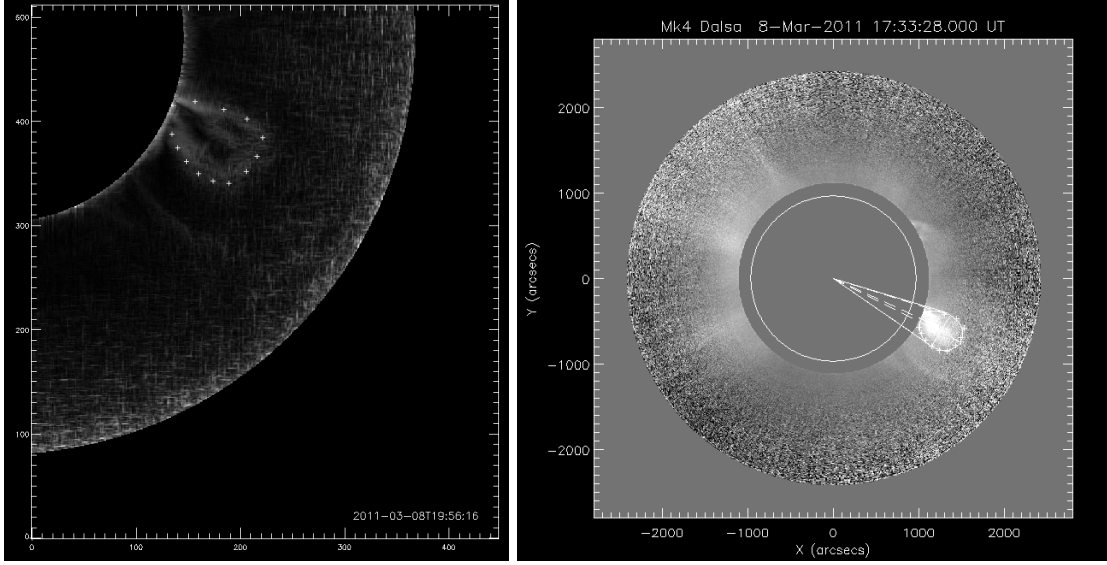
(a) The magnitude of the edge strengths from the multiscale filtering procedure, for an section of the MK4 observation of the erupting CME at 19:56 UT on 8 March 2011. A point-&-click characterization of the front edge of the CME core material is shown by the plus symbols.

(b) An MK4 observation of the erupting CME, with the ellipse fit to the points shown in the left figure, in order to characterize the core material of the erupting CME.
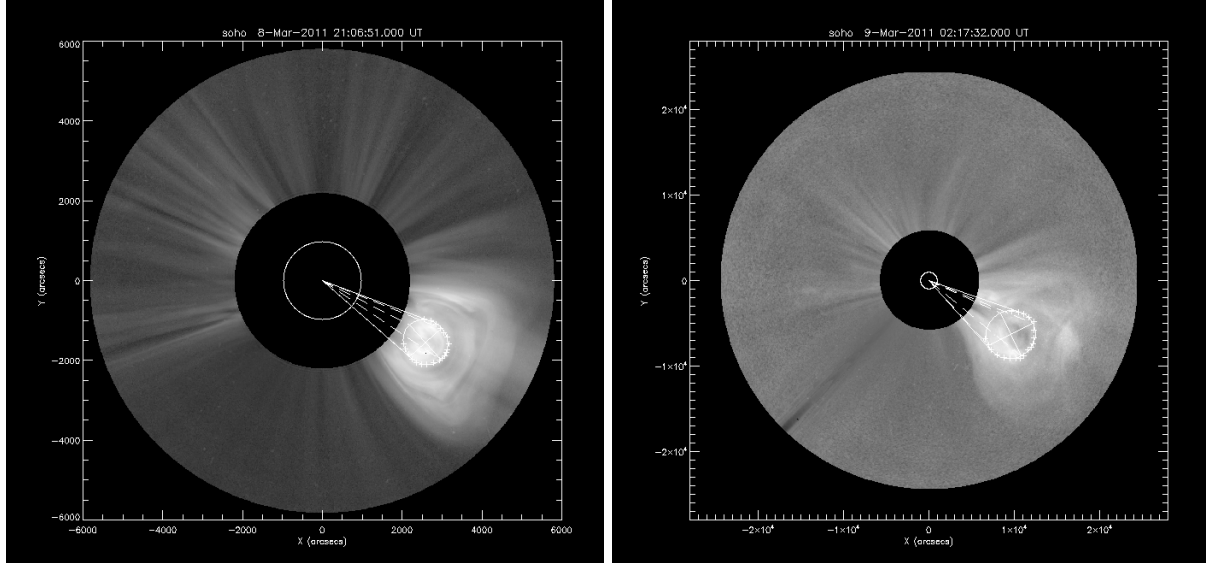
(c) LASCO/C2 observation of the CME at 21:06 UT on 8 March 2011.

(d) LASCO/C3 observation of the CME at 02:17 on 9 March 2011.

Fig. 5.— MK4 and LASCO observations of a CME as it erupts off the south-west limb on 8 March 2011, with an ellipse fit to the characterized core material.

termined for each image, as shown in Fig. 8a 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

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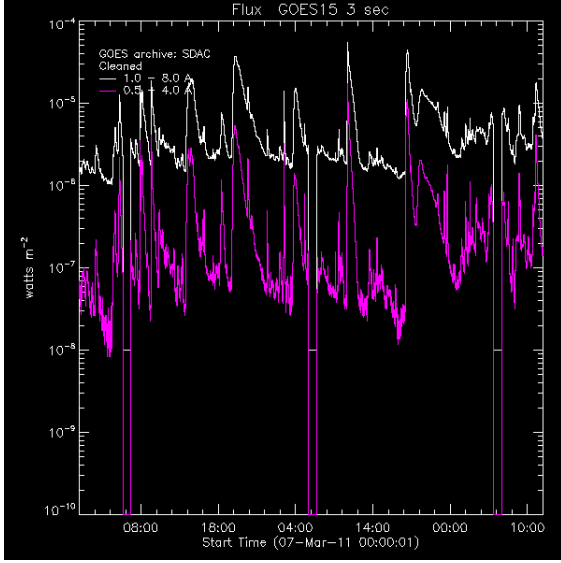
Fig. 4.— GOES x-ray flux.

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. 6.

4.   Conclusions
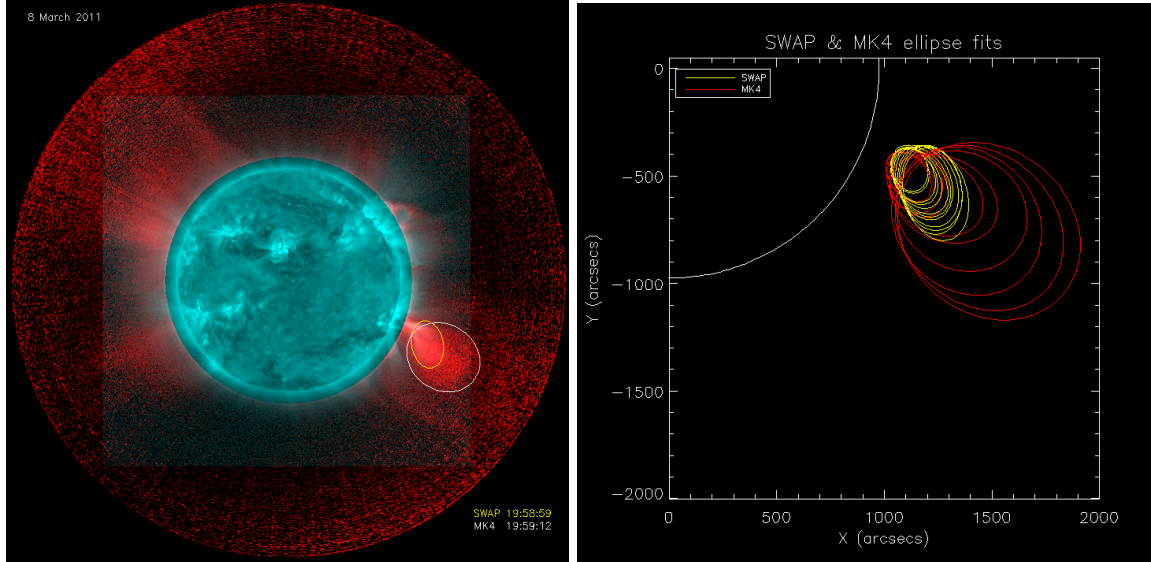
Fig. 6.— caption.

Fig. 7.— caption.

Fig. 8.— *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.

REFERENCES

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