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The Inner Coronagraph on Board ADITYA-L1 and Automatic Detection of CMEs

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Abstract. Visible Emission Line Coronagraph (VELC) on board ADITYA-L1 is an internally occulted coronagraph with mirror as its primary objective element. It has a field of view (FOV) starting from 1.05 $R_\odot$ – 3 $R_\odot$. It will observe the corona in continuum centered at 5000 Å and will perform spectroscopic observations of inner corona in two visible (5303 Å and 7892 Å) and one infrared (10747 Å) wavelengths. VELC will be capable of observing **the** corona with high spatial and temporal resolutions. We present an overview of the inner coronagraph (VELC) design and introduce the concept of an on-board automated coronal mass ejections (CMEs) detection logic proposed for this payload.

Keywords. Sun, Coronal Mass Ejections, Coronagraph

1. Introduction

The outer atmosphere of the Sun, corona, has brightness million times fainter than that of the solar disk. Hence it is too faint to be seen unless solar disk is occulted by moon during a total solar eclipse. However, total solar eclipses are rare events and last only for few minutes giving observers/researchers very little time to perform experiments. This problem was resolved when Lyot invented coronagraph (Lyot 1930) to observe corona by creating an artificial solar eclipse. Since ground-based coronagraphs suffer from atmospheric scattered intensity, coronagraphs were sent to space to overcome atmospheric effects. A white light coronagraph having FOV from 3 $R_\odot$ – 10 $R_\odot$ on board OSO-7 (Koomen *et al.* 1975) observed large scale coronal transients for the first time from space in 1971 (Hansen *et al.* 1971). White light coronagraphs on board Skylab (MacQueen *et al.* 1974) and Solwind (Michels *et al.* 1980) having FOV from 1.5 $R_\odot$ – 6 $R_\odot$ and 2.6 $R_\odot$ – 10 $R_\odot$, respectively, have added to our understanding of CMEs. Solar Maximum Mission (SMM) (MacQueen *et al.* 1980) had a white light coronagraph with FOV from 1.5 $R_\odot$ – 6 $R_\odot$ and spatial resolution better than 10 arcsec. Coronagraph onboard SPARTAN 201 (Guhathakurta *et al.* 1993) with FOV of 1.25 $R_\odot$ – 6 $R_\odot$ flew five times between April 1993 and November 1998 and provided valuable data. Among the existing space based coronagraphs, Large Angle Spectroscopic COronagraph (LASCO) (Brueckner *et al.* 1995) on board Solar and Heliospheric Observatory (SOHO) has FOV starting from 2.5 $R_\odot$ whereas Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) (Howard *et al.* 2008) on board Solar Terrestrial Relations Observatory (STEREO) has FOV starting from 1.2 $R_\odot$. The only coronagraph which observed corona closest to the Sun is LASCO C1 with FOV starting from 1.1 $R_\odot$ up to 3 $R_\odot$. However, it stopped observations in 1998 two years after its launch. MkIII (Fisher *et al.* 1981) in Mauna Loa Solar Observatory (MLSO) observed the inner solar corona from 1.2 $R_\odot$ to 2.2 $R_\odot$. Later Mk4 (Elmore *et al.* 2003) recorded the polarization brightness (pB) images of corona from 1.12 $R_\odot$ to 2.8 $R_\odot$. It was succeeded by K-COR coronagraph (de Wijn *et al.* 2012) in 2013 having FOV same as that of Visible Emission Line Coronagraph (VELC). However, ground-based coronagraphs suffer from atmospheric conditions and limited observing time. Though our understanding and knowledge of solar outer corona has increased over the years, the observations of inner corona is not yet fully explored with high spatial and temporal resolutions. VELC ([Prasad *et al.* 2017, Singh *et al.* 2013, Singh *et al.* 2011) which is expected to launch in 2020, will provide an opportunity to study the inner corona and dynamics of CMEs in this region with unprecedented details having field of view starting from 1.05 $R_\odot$.

With the rise in the volume of data generated, automated CME detection techniques are also planned to be implemented on board so that the telemetry load is reduced and only images containing CMEs are downloaded. A number of on-ground automated CME detection techniques have been developed (Hess & Colaninno 2017). However, on ground automated CME detection algorithms are memory intensive and hard to be implemented on-board for CME detection. Therefore, a simple algorithm is designed to detect CMEs in the coronagraph images onboard VELC. Among the upcoming solar missions, Multi Element Telescope for Imaging and Spectroscopy (METIS) for Solar Orbiter mission scheduled to be launched in 2018 is also planning to have an on-board automated CME detection algorithm (Bemporad *et al.* 2014). This algorithm is primarily based on intensity threshold only.

In this proceedings we discuss the capabilities and uniqueness of VELC in section 2. The performance of the proposed algorithm on the synthetic images is briefly discussed in section 3.

2. Visible Emission Line Coronagraph

Visible Emission Line Coronagraph (VELC) is one of the seven payloads on-board ADITYA-L1 which will observe solar corona from Lagrangian 1 (L1) point. L1 point is located at 1.5×10^6 km from Earth at sun-earth line which provides continuous observations of Sun throughout the year. In addition to this, L1 point is devoid of Earth's magnetic field, thus accurate magnetic field measurements are possible at this location.

VELC has four channels which include one continuum channel that will have field of view from 1.05 - 3 $R_\odot$ and will take images of corona at 5000 Å with passband of 10 Å, while the other channels will perform spectroscopic observations from 1.05 $R_\odot$ to 1.5 $R_\odot$ using multi-slit spectrograph to study the solar corona at emission wavelengths of 5303 Å, 7892 Å, 10747 Å. While combining imaging and spectroscopic observations, we will be able to study the origin of coronal transients and their dynamics in the inner corona.

2.1. *Optical Design of VELC*

The optical layout of VELC can be referred to Figure 1 of Prasad *et al.* (2017). VELC has an entrance aperture of 147 mm. The primary mirror is an off-axis parabolic mirror located at a distance of 1570 mm from entrance aperture which reflects light to a spherical concave mirror having a hole at its center. The surface roughness of this mirror has to be in the range of 1.5-1.7 Å to keep the scattered light minimum and achieve the required signal to noise. It rejects the light up to 1.05 $R_\odot$ from center of solar disk through a hole perpendicular to entrance aperture. This serves as an internal occulter by rejecting the disk light and allowing only coronal light into the instrument. The reflected coronal light is collimated using a doublet lens and passed through a dichoric beam splitter which reflects the light with wavelength less than 5100 Å to the imaging channel and passes the rest of the light to the spectroscopic channels.

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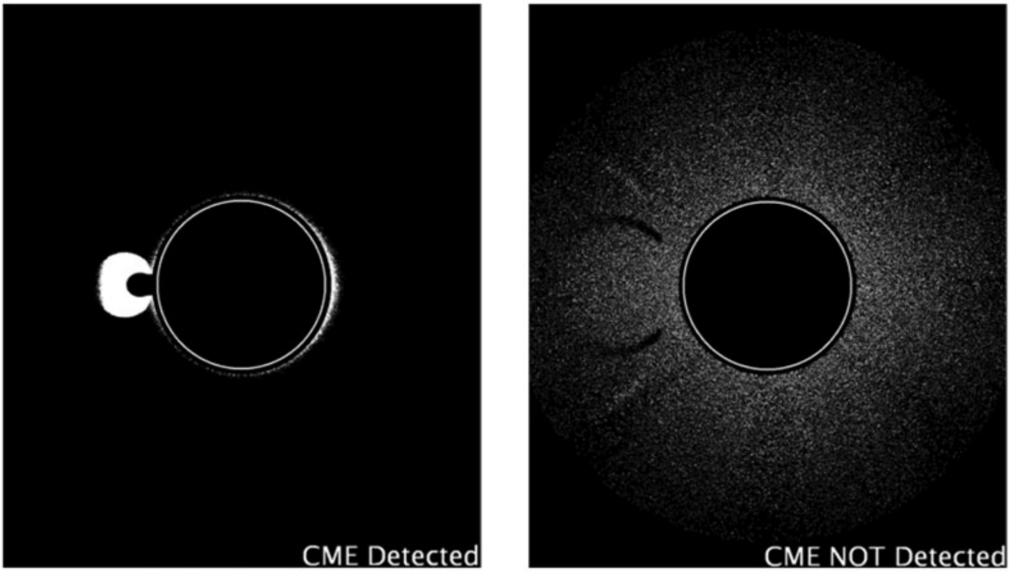

(a) (b)

Figure 1. (a) CME detected in synthetic coronal image when the intensity and size of the CME is more than chosen intensity and area threshold, (b) CME not detected in synthetic coronal image when CME merges with the background

In the imaging channel a narrow filter of pass band 10 Å centered at 5000 Å images the solar corona through a four element imaging lens on a 2560×2160 CMOS detector with pixel size of 6.5 μm.

VELC is unique amongst the existing space-based coronagraphs. It will take images of corona to height as low as 1.05 $R_\odot$ with cadence as high as 1 s. It should be noted that the existing space-based coronagraphs have cadences no faster than 5 min. VELC will perform simultaneous spectroscopic and imaging observations. The complete description of other channels of VELC can be found in Prasad *et al.* (2017).

3. On-board Detection of CMEs in VELC

The capability of VELC to image the corona at high cadence will generate more than 200 Gbits of data per day for VELC continuum channel alone. To identify and store the most useful data and download them using the available telemetry a simple algorithm has been designed which can be easily implemented in the on-board electronics. This algorithm will be the first of its kind.

The algorithm is implemented by first building the signal in coronagraph images. In order to increase the signal, 10 images of 100 ms exposure are added to make a 1 s equivalent exposure image. 10 images of 1 s exposure are further averaged to build the signal. These images are re-binned to lower resolution and difference is taken at an interval of 120 s. Intensity threshold is applied on the difference images with threshold value proportional to the mean of each image. It is accompanied by area threshold i.e. convolving the binary image with a kernel of appropriate size depending on the science requirements. The maximum value of convolved image is compared with an area threshold. The use of area threshold separates the CMEs structures from the noise which can be otherwise detected. The aim of this algorithm is to detect the CMEs in the images and not to track

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them. Once the CME is detected the observations will continue at a higher cadence. The images containing CMEs will then be downloaded and rest will be discarded.

In order to test the performance of this algorithm, synthetic coronal images with pixel resolution of 2.51 arcsec were prepared for VELC field of view, details of which will be presented in the forthcoming paper (Patel *et al.* 2018). The synthetic images contain contribution from scattered intensity (Venkata *et al.* 2017) and photon noise. CMEs of different sizes and intensities were launched on these images.

Figure 1a demonstrates that the algorithm has detected a CME in a simulated image while Figure 1b shows that the detection has failed when the intensity of the CME became faint and almost merged with the background. The value of convolution threshold for this case is chosen as 0.8 with kernel of size 10×10.

4. Conclusion

VELC will provide an unique opportunity to understand the dynamics of large scale coronal transients in inner corona by combining observations from imaging and spectroscopic channels. We have demonstrated that the detection algorithm based on intensity and area thresholding can detect CMEs in synthetic coronagraph images on-board VELC/ADITYA-L1. A thorough analysis has been planned for studying the detection efficiency of the CME detection algorithm for various cases of CMEs and modifying values of free parameters suitable for our requirements. The detailed analysis will be presented in Patel *et al.* (under preparation).

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