Visible Emission Line Coronagraph on Aditya-L1

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Solar coronagraph mimics total solar eclipse by blocking the solar disk and enabling the observation of extended coronal atmosphere of the Sun. Visible Emission Line Coronagraph (VELC), on-board Aditya-L1 space mission, is an internally occulted solar coronagraph capable of simultaneous imaging, spectroscopy and spectro-polarimetry close to the solar limb. This payload is designed to study the coronal plasma and heating of the solar corona. Studying development, dynamics and origin of coronal mass ejections and measurement of coronal magnetic fields over active regions are other important science goals. VELC is designed to image the solar corona at 500 nm with an angular resolution of 5″ over a field of view (FOV) of 1.05–3 R_o. It also facilitates simultaneous multi-slit spectroscopy at three emission lines, viz. Fe XIV (530.3 nm), Fe XI (789.2 nm) and Fe XIII (1074.7 nm) with a spectral resolution of 28 , 31 and 202 mÅ/pixel respectively, over an FOV of 1.05–1.5 R_o. The payload has a dual-beam spectro-polarimetry channel for magnetic field measurements at 1074.7 nm.

Keywords: Coronagraph, coronal mass ejection, payload, solar corona.

Introduction

VISIBLE Emission Line Coronagraph (VELC) payload on-board Aditya-L1 is an internally occulted solar coronagraph with simultaneous imaging, spectroscopy and spectro-polarimetry channels close to the solar limb[1]. The primary science goals of this mission are: (i) diagnostics of the corona and coronal loops plasma (temperature, velocity and density); (ii) heating of the corona; (iii) development, dynamics and origin of coronal mass ejections (CMEs); (iv) studies on the drivers for space weather and (v) measurement of coronal magnetic fields (not planned by any space mission so far). The imaging of the solar corona provides information about the intensity and its variation with space and time only. Whereas spectroscopy gives information about velocity, line-width and its variation with space and time which are essential for the complete understanding of the physics and dynamics of the solar corona and its heating mechanisms. In addition, the polarimetric capabilities will address the space weather-driving mechanisms which in turn can potentially lead to its prediction. The proposed payload will provide the first comprehensive measurements of the strength and topology of the magnetic field in the upper solar atmosphere over active regions. The current VELC design is an enhanced version of the earlier proposed coronagraph on Aditya-1 mission which had only imaging channels[2–4].

VELC is designed to image solar corona from 1.05 R_o *to* 3 R_o (R_o: solar radius) with a plate scale of 2.5″/pixel. Figure 1 shows the optical layout of VELC. It has an entrance aperture of 148 mm and an off-axis parabola of about 200 mm as primary mirror (M1). To meet the stringent scatter light requirements[5] and thus the signal-to-noise ratio (SNR) over field of view (FOV), the surface micro-roughness of the primary mirror has to be in the range 1.5–1.7 Å. A spherical mirror M2 acts as an internal occultor which reflects the coronal light and allows the disc light to pass through the central hole[6]. The disc light passing through M2 is reflected out of the instrument by M3. A dichroic beam splitter (DBS1) reflects the coronal light into an imaging channel at about 500 nm (continuum) and transmits light >500 nm to spectroscopy

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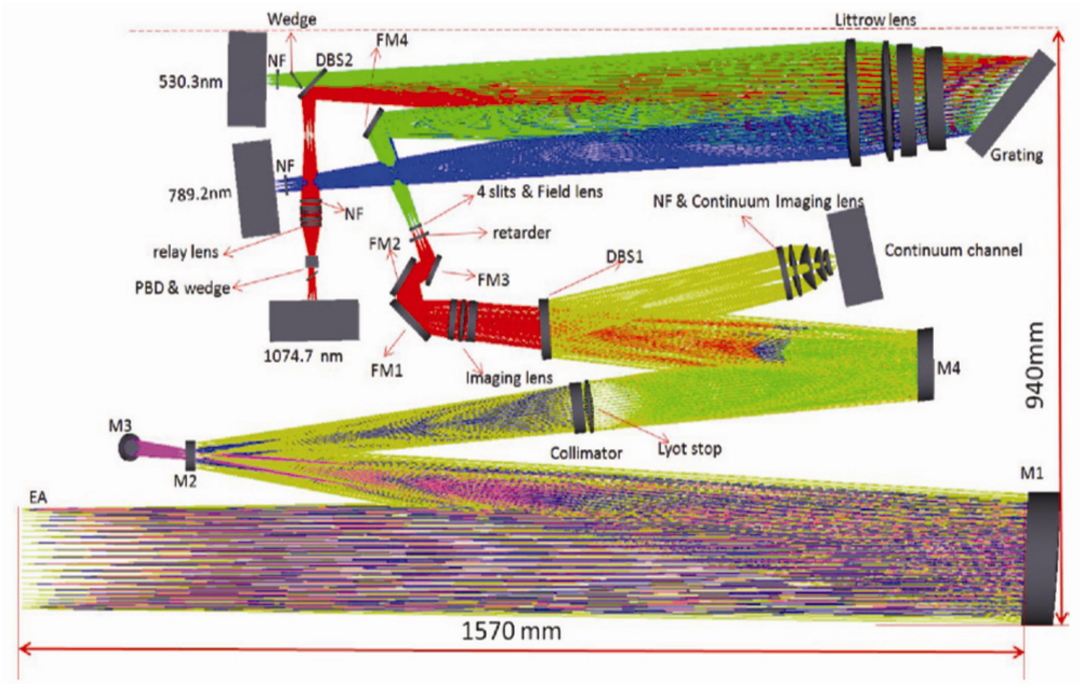

Figure 1. Optical layout of Visible Emission Line Coronagraph (VELC).

channels. The multi-slit spectroscopic channels at three emission lines, namely 530.3, 789.2 and 1074.7 nm have a spectral resolution of 28, 31 and 202 mÅ/pixel respectively, over the FOV of 1.05–1.5 R_0. The dual-beam spectro-polarimetry at 1074.7 nm is used for magnetic field measurements. The spectrograph in VELC operates in near littrow configuration and uses a plane reflective grating with 600 grooves/mm blazed at 42° as a dispersive element. A four-element littrow lens acts as the collimator and camera of the spectrograph. Tolerance analysis, thermal analysis and ghost image analysis are carried out on the final design to ensure that the instrument meets the performance requirements over the operating temperature range 22°C ± 3°C. Intensity of ghost images is found to be 10^{-7} times that of the source intensity. VELC has 18 sub-assemblies consisting of optical systems, detector systems, mechanisms, etc. and these are accommodated on an optical bench made of titanium. The first global resonating frequency of VELC is close to 100 Hz. The thermo-structure and thermo-optical analysis shows that the thermal distortions are within the acceptable limits. The dynamic parameters of the VELC system are established and are in acceptable limits of the space mission. VELC has three multi-operational mechanisms such as entrance aperture door, retarder rotation mechanism and linear scan mechanism.

VELC includes three sCMOS (visible channels) and one InGaAs (IR channel) detector systems. Each of the detectors has four packages consisting of Detector Head Assembly (DHA), Control and Data Processing Electronics (CDPE), Power Supply Electronics (PSE) and Interface to BMU (CERT). The sensor, Detector Proximity Electronics (DPE) and interface with payload thermal control system constitute the DHA. Considerable efforts are made in the selection of sensors (to meet the proposed science goals), configuring electronics design and interface, mechanical interface, thermal interface, optimizing camera electronics, on-board data processing protocols, etc.

VELC integration and calibration

The payload consists of 18 optical assemblies (40 optical elements), four mechanisms (three multi-operational and one single operation), four detector systems, etc. All of these systems have to be integrated, tested and calibrated to achieve the designed system performance. Sub-system level tests and calibrations are being developed. Stringent contamination control protocols have been evolved and implemented to minimize the scatter due to particulate and molecular contaminants. Sub-system level tests and payload integration will be carried out in class-10 clean facility. Vacuum calibration of VELC is critical and hence its final performance test will be carried out in vacuum environment. Several system-level calibration protocols such as PSF/MTF measurements, spectroscopic, radiometric/photometric, polarization calibrations, etc. are planned and also being implemented.

Control of instrument background to achieve the proposed science goals of VELC is critical. The disk light scattered from the surface micro-roughness of the primary mirror is the major contributor for instrument scatter. The payload team has adopted the following methods for estimation of scatter and measurement of scattered light from the primary mirror[5]. These include: (i) theoretical estimation of scatter light using existing theoretical models and optimizing the surface roughness requirements of the primary mirror; (ii) development of Near Specular Scatterometer (NSS) for validating the surface topography and scatter distribution, and also for continuous monitoring of surface micro roughness of witness coupons; (iii) development of Coronagraph Scatter Measurement Facility (CSMF) for testing the integrated payload-level scatter measurements for the flight model; (iv) design of baffles to further minimize the instrument scatter and (v) contamination control protocols to minimize mirror degradation during the integration and calibration process.

Data volume and on-board logic

VELC is designed for continuous observation of the Sun. The estimated data volume from all the four channels and in particular, the continuum channel is about a couple of terra bits per day. However, keeping in view the challenges of L1 orbit for data downlinks and the requirements of large on-board storage requirements, development of on-board intelligence is essential. A CME detection logic is developed and being implemented on-board. This is to select the required data, especially for the standard mode operation of the detector (CME mode). CMEs generally do not occur always and hence, selection of data with the occurrences of CME would help in reducing the data volume considerably. VELC will primarily have two modes of operation, i.e. synoptic mode (default mode for CME observations) and proposal-based mode. With all possible optimizations in exposure times, cadence and observation periods, required by the proposed science goals, VELC data volume per day is around ~120 Gbits. The requirements of on-board calibration of VELC are critical and methodologies for realizing the same are being finalized. On-board calibrations such as dark, flat-field and photometric/radiometric calibrations are planned. The design of VELC and the proposed science goals define the stability requirements of the satellite. The satellite is planned to have a pointing accuracy of better than 20 arcsec (3-σ level), jitter of 0.5 arcsec and stability of 0.2 arcsec/s.

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