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REMOTE SENSING OPTICAL INSTRUMENTATION FOR ENHANCED SPACE WEATHER MONITORING FROM THE L1 AND L5 LAGRANGE POINTS

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Abstract
As part of the Space Situational Awareness Programme (SSA), ESA has initiated the assessment of two missions currently foreseen to be implemented to enable enhanced space weather monitoring. These missions utilize the positioning of satellites at the Lagrangian L1 and L5 points. These Phase 0 or Pre-Phase A mission studies are about to be completed and will thereby have soon passed the Mission Definition Review. Phase A studies are planned to start in 2017. The space weather monitoring system currently considers four remote sensing optical instruments and several in-situ instruments to analyse the Sun and the solar wind conditions, in order to provide early warnings of increased solar activity and to identify and mitigate potential threats to society and ground, airborne and space based infrastructure. The suggested optical instruments take heritage from ESA and NASA science missions like SOHO, STEREO and Solar Orbiter, but the instruments are foreseen to be optimized for operational space weather monitoring purposes with high reliability and robustness demands. The instruments are required to provide high quality measurements particularly during severe space weather events. The program intends to utilize the results of the on-going ESA instrument prototyping and technology development activities, and to initiate pre-developments of the operational space weather instruments to ensure the required maturity before the mission implementation.

Keywords: Optical instruments, remote sensing, imaging, imaging spectropolarimetry, coronagraphy, heliospheric imaging, EUV imaging, space weather monitoring, space weather now- and forecast, solar observation.

I. INTRODUCTION

Observation of the Sun's activity and its interaction with the Earth underpins space weather monitoring and is of vital interest to mankind since it enables awareness of space weather conditions. This permits assessment and forecasting of potential impacts on ground based, airborne and space borne sensitive infrastructure. In general, space weather monitoring relies on two major observational techniques: (i) in-situ measurements targeting mainly the near-Earth magnetic and solar wind conditions and highly energetic particle streams from interplanetary shocks and the Sun, and (ii) remote sensing observations of the Sun and the heliospheric region between Sun and Earth. The latter observations are dedicated to identifying and possibly forecasting solar eruptions, or subsequently tracking coronal mass ejections (CMEs) and Stream Interaction Regions (SIRs) to observe and predict their evolution, propagation and arrival at Earth. Due to the nature of the two different observational techniques, we will focus here, in line with the topic of the conference, on the optical instrumentation needed to perform the remote sensing observations.

As part of the Space Weather monitoring system of ESA, within the SSA Programme, several Expert Service Centres have been established (http://swe.ssa.esa.int/web/guest/service-centre), which heavily rely on data generated by remote sensing systems. PROBA-2, originally launched in 2009 as a technology demonstrator, is providing EUV data from the SWAP instrument. Coronal observations from SOHO and also STEREO in particular are essential for the tracking of Coronal Mass Ejections (CMEs), albeit near to the Sun. It is worth noting that SOHO, which was planned to be operational for two years, is now almost 20 years beyond its nominal lifetime. In order to maintain and enhance the observational capabilities for operational space weather applications, ESA is working to develop a European space weather monitoring system. Collaboration with international partners and data exchange are foreseen as ways to enhance the system and improve the measurement coverage. Previous scientific missions such as SOHO and STEREO have paved the way for the development of both the observational techniques and necessary instrumentation. STEREO in particular has demonstrated the advanced capabilities afforded by remote observations from two vantage points. The Lagrangian L1 and L5 points turn out to be excellent positions from which to make such observations, as they provide relatively stable positions, so that in-situ monitoring and un-obscured observation of the Sun can be performed without restrictions. The combination of observations from L1 and L5 will provide a much more coherent and complete picture of solar activity, not least because the distant side view proffered by L5, with an angular difference of 60^{o} from the Sun-Earth line, will allow the observation of a significant part of the Sun that cannot yet be seen from Earth. Furthermore, the system will be able to monitor the entire space between Sun and Earth from L5. Together with the enhanced viewing capabilities and techniques, such an observational system, if well-coordinated, inter-calibrated and operated, can provide an excellent and powerful monitoring system that allows the establishment of almost real-time space weather situational awareness.

II. MISSION SCENARIO AND ARCHITECTURE

An investigation of such a system has been initiated by ESA in form of a parallel Phase 0 study by two industrial-led consortia (see acknowledgement). Both teams have analysed the architecture and mission designs of the L1 and the L5 Lagrangian monitoring systems. Although, as described above, the missions would benefit from a combined implementation, an independent assessment was assumed in first instance. The potential enhancements of a combined implementation were analysed in addition. As a starting point, before establishing the system architecture, the space weather system requirements and the existing product specifications were rigorously analysed, updated and refined, and the mission objectives and requirements were formulated. ESA is studying both L1 and L5 missions also in order to get a holistic view on the potential combination of the two missions, and in order to prepare ourselves for the potential configuration, which is expected to evolve in the future as part of the intended international collaborations, but for which the collaboration details have not yet been defined.

The Phase 0 studies have confirmed that the suggested instrumentation can be accommodated and that sufficient margin exists with respect to the available resources. The L1 mission could be launched with VEGA C, which is currently being developed by ESA with expected enhanced performance, and which should be available after 2018 or 2019. It is assumed in the baseline scenario that a propulsion module based on the LISA Pathfinder Transfer Module would be used to bring the spacecraft (S/C) to L1 within about one year. This is possible for the L1 mission because the S/C mass is similar to the LISA Pathfinder satellite. Such a mission concept would strongly benefit from the heritage of Lisa Pathfinder. Sending the other S/C to L5 needs more propulsion and therefore it is recommended to make use of direct injection. An Ariane 6.2 class launcher is considered as a potential option for this. In this scenario there would be additional space for a shared launch with a second spacecraft because the L5 S/C would be relatively small.

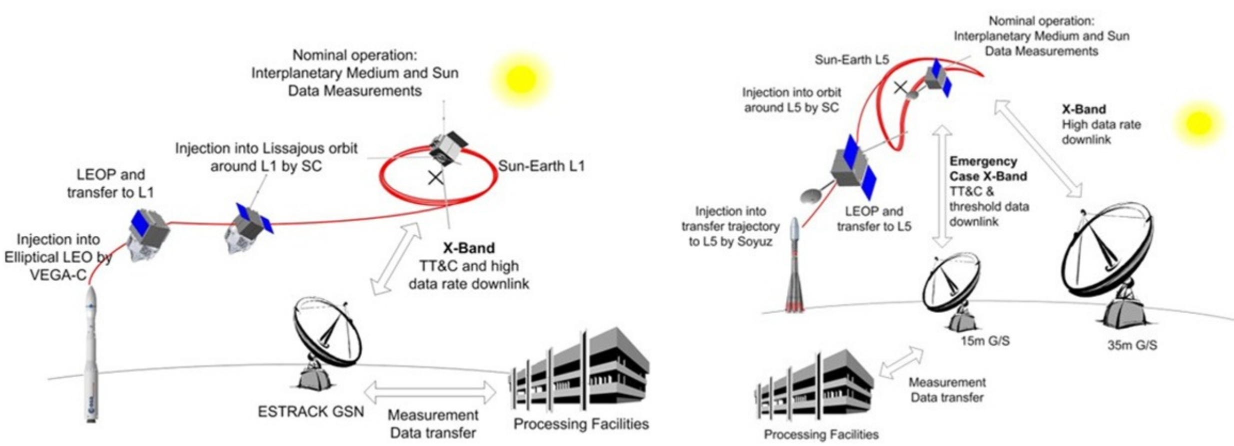


Fig.1: The schematic representation of the mission scenarios for the L1 (left) and the L5 mission (right).

It was found that the payload needed to fulfil the objectives of the L1 and the L5 missions is very similar as far as the remote sensing instruments are concerned, which means that an exchange of instruments and data at agency level would be beneficial to reduce the overall cost. The next chapter describes the optical payload currently foreseen for the two missions and is followed by a brief description of options for additional instruments on the spacecraft.

III. OPTICAL PAYLOAD

The current section describes the remote sensing optical payload, which is considered as mandatory for the Lagrangian missions. During the Phase 0 studies, two levels of instrument measurement requirements were defined: the minimum threshold requirements (T values in Table 1) considered necessary for current operational space weather applications as well as the goal requirements (G values in Table 1) that could enable new applications in the future. Although the specified performance is targeted to space weather purposes, enhanced observational capabilities would of course also serve the scientific community to improve the underlying understanding of the Sun and the Solar Wind and its interaction with the Earth. The specification of the goal values has also the purpose of investigating if technical advancements can be used to improve the mission performance over that afforded by the existing instrumentation. The detailed analysis of the system impact, the affordability and the related trade-offs for the system optimisations will be carried out in the subsequent Phase A studies.

A. Overview of optical instrumentation

The optical instrumentation is used to monitor the Sun and the heliospheric region between Sun and Earth. For this purpose, four instruments are required. The composite FOV covered by the four instruments is different for the two vantage points L1 and L5 as illustrated in Fig.2 and 3, respectively.

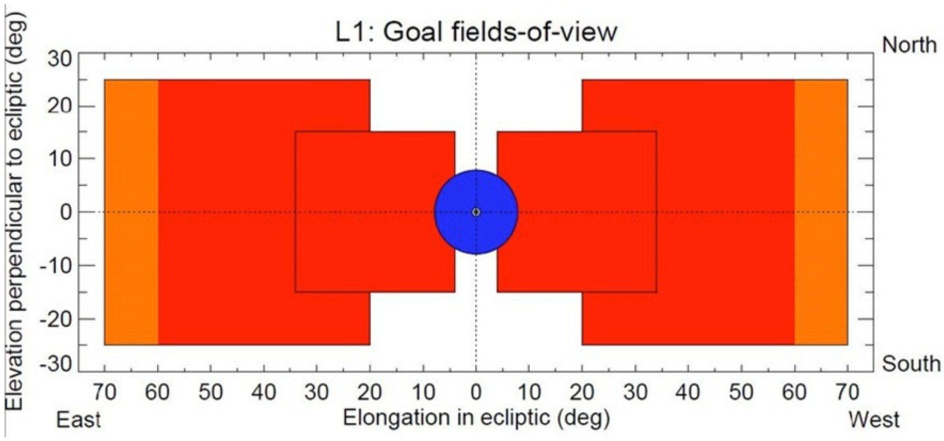


Fig. 2: Remote-Sensing FoVs in L1 (goal). Red: Heliospheric Imager; blue: Coronagraph; black (centre): Magnetograph and EUV Imager, slightly exceeding the solar disk, which is not explicitly indicated. Note the FoV-gap between ~1.2 and 2.5 Rs (white colour), which is not covered by the current remote sensing payload baselined for the L1 mission.

North, south, east, and west in Fig.1 refer to the angular offset from the Sun-spacecraft line. In terms of the Heliospheric Imager (HI), the goal FoV (which is depicted) will most likely require a twin-camera solution, as is the case for STEREO/HI. The current HI L1 goal and L5 FoVs extend out to 60^o (red colour), enabling imaging of Earth-directed events most of the way to Earth from the L1 vantage point and all of the way to Earth from L5. The HI inner camera covers 30^o x 30^o, centred in the ecliptic plane at 19^o elongation. The HI outer camera covers 50^o x 50^o degrees, centred in ecliptic plane at 35^o elongation.

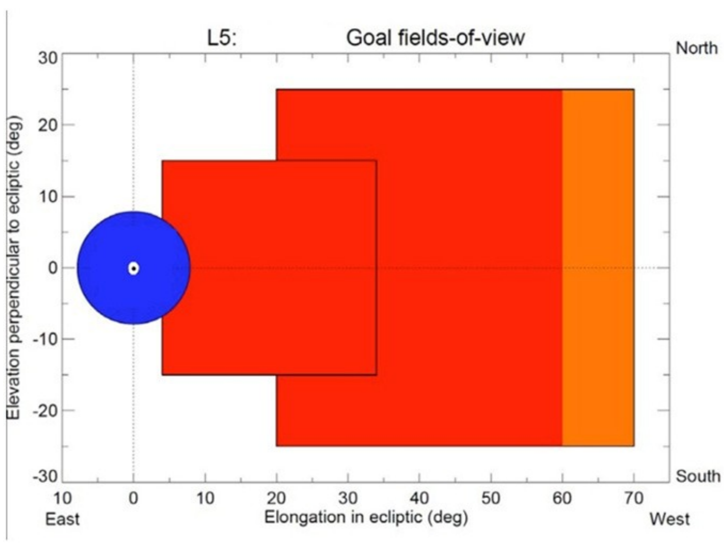
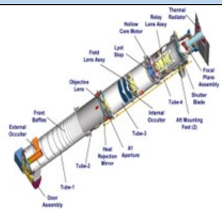
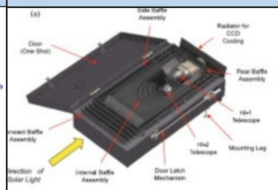
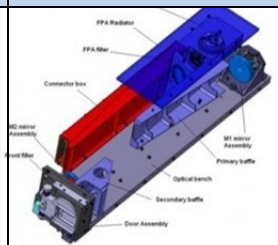
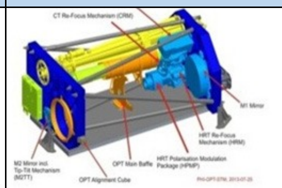


Fig. 3: Remote-Sensing FoVs for L5. Red: Heliospheric Imager, blue: Coronagraph, black (centre): Magnetograph and EUV Imager slightly exceeding the solar disk, which is not explicitly indicated. Note the FoV-gap between ~1.2 and 2.5 Rs (white colour), which is not covered by the current remote sensing payload baselined for the L5 mission.

Before discussing the individual aspects of the instruments, the related technologies and expected developments, we give an overview of the main features relevant for understanding the configuration and measurement objectives, and the differences and commonalities. It must be noted that although most of the parameters are relatively mature due to the existing heritage and experience, it is expected that the configurations will evolve in the next development phases.

Table 1: Overview of the main instrument parameters of the four optical instruments currently foreseen on the L1 and L5 Lagrangian missions. Goal (G) and threshold (T) values are indicated where relevant.

Instrument parameter	CORONAGRAPH	HELIOSPHERIC IMAGER	EUV IMAGER	MAGNETOGRAPH
Images	 Credits: R.A. Howard et al., Space Sci. Rev. 136, 67–115 (2008)	 Credits: C.J. Eyles et al., Sol. Phys. 254, 387–445 (2009)	 Credits: ROB http://proba2.sidc.be/about/SWAP	 Credits: MPS http://www.mps.mpg.de/solar-physics/solar-orbiter-phi
Measurement objective	CME characteristics derived from coronagraph imagery are a crucial input to model-derived CME arrival time prediction.	Imaging and tracking of the solar wind and CMEs well beyond the coronagraph field-of-view in order to permit mid-course assessment and correction of arrival time predictions.	Imaging of the complex low solar corona for monitoring magnetic complexity and activity in the corona.	Photospheric magnetic field mapping by exploiting the Zeeman effect; Continuum imaging. Optional: Hα and Ca II IR line core imaging.
European Heritage	SOHO / LASCO C2 & C3, SCOPE (ESA development)	STEREO/HI, Coriolis/SMEI	SOHO/EIT, PROBA-2/SWAP, SolO/EUI, ESIO (ESA development)	SolO PHI
Field of View (FoV)	Azimuthal: 360° Radial: 2.5 - 30 Solar radii (Rs).	L1: 4°-40° (T), 4°-60° (G) at both sides of the Sun-spacecraft line (two instruments with common DPU). L5: 4°-60°	Full disk with margin: 42.6´ x 42.6´.	Full disk with margin: 42.6´ x 42.6´. High-resolution telescope not yet considered.
Instrument technical baseline description	The baseline SCOPE design comprises an external occulter, composed of a series of 5 tapered disks, in front of an objective lens that images directly onto a CCD detector.	Visible-light camera systems, immersed within a comprehensive system of baffles, such that light entering the system falls on an objective lens that images directly onto a CCD detector.	Full-disk Cassegrainian telescope or an off-axis Newtonian, incorporating mirror coatings and filters to select one or more required EUV bands centred on key emission lines in which to image.	Comprises a refracting full-disk telescope, a pre-filter for wavelength selection, two tune-able etalons, a polarization modulator and analyser, two image detectors, an image stabilization system.
Measurement product(s)	An image of broad-band, visible-light radiance at coronal altitudes.	An image of broad-band, visible-light radiance at heliospheric altitudes.	Intensity image(s) for selected wavelength band(s).	Goal: Vector magnetograms (Stokes I, Q, U V); Magnetic field strength, azimuth and inclination from spectral line inversion; Continuum image. Optional: Hα and Ca II IR line core images.
Dynamic range	~ $4\text{x}10^{-9}$ to ~$2\text{x}10^{-11}$ of B_0 (G- FoV); with B_0 = solar back-ground (F- and K-corona).	~$1\text{x}10^{-11}$ to ~$3\text{x}10^{-13}$ of B_0 (G-FoV).	Nominal range dependent on line selection.	-4 kG to +4 kG
Relative measurement sensitivity / accuracy	~ $2\text{x}10^{-13}$ of B_0 (G-FoV) Accuracy: 20% 16 bit	~ $3\text{x}10^{-15}$ of B_0 (G-FoV) Accuracy: 20% 24 bit due to off-chip binning and summing of exposures.	10^{-3} W m^{-2} nm^{-1} 14 bit	10^{-3} of continuum intensity 12 bit
Optical resolution	<2´	<4´	T: 5´´; G: 2´´	T: 5´´; G: 2´´
Wavelength	500 – 900 nm	500 – 900 nm	T/G: Fe XII 19.3 n; G: He II 30.4 nm, Fe IX 17.1 nm and Fe XIV 21.1 nm.	Fe I 520, 630.2 or 617.3 nm; Optional: 656 and 854 nm.
Spectral resolution	n/a	n/a	Filter band width, several nm.	Adequate to properly resolve absorption line (~15 pm).

Duration of single measurement	10 s to 20 s	20 min	TBD	Line scan duration 30-60 sec (TBC) - several exposures for all polarization states and wavelength positions.
Latency	L1: 5 min; L5: 15 min	L1: 10 min; L5: 15 min	L1: 10 min; L5: 30 min	L1: 10 min, L5: 30 min
Cadence	5 min	30 min	L1: 5 min; L5: 10 min	10 min
Detector	2048 x 2048 CCD or CMOS, 1 detector, down-linked image binned to 1024x 1024	2048 x 2048 CCD or CMOS, 2 detectors, down-linked image binned to 1024x 1024	2048 x 2048 CCD or CMOS, 1 detector	2048 x 2048 CCD or CMOS, 2 detectors
Data rate	24 kbps (G)	L1 (G): 42 kbps L5 (G): 60 kbps	L1: 1 band - 24 kbps (T); 4 bands - 78 kbps (G) L5: 1 band - 6 kbps (T); 4 bands - 39 kbps (G).	7 kbps (T, longitudinal magnetograph, without Hα and Ca II IR line core images) 33 kbps (G, vector magnetograph, without Hα and Ca II IR line core images)
Dimension	Sensor unit incl. FEE: 600x250x250 [mm]; DHU: 230x200x80 [mm]	Sensor units, 2 units for L1 (T) (760x500 x230 [mm]) and 1 unit for L5 (840 x 550 x 260 [mm]) DHU: 1 unit L1 and L5 (250 x 150 x 60 [mm])	Sensor box: 260x120x120 [mm]; Electronics box: 150x 80 x 80 [mm]	Sensor unit: 800 x 200 x 200 [mm]; Electronics box: 150 x 80 x 80 [mm]
Mass	11.8 kg (includes 4 kg DHU)	L1 (T): 32 kg; L5: 20 kg	7.5 kg	22 kg (includes 4 kg DHU)
Power	25 W	L1 (T): 38 W; L5: 22 W	5 W	20 W

B. Coronagraph

The most destructive space weather effects at Earth are associated with CMEs, both through direct CME impact and via the Solar Energetic Particles (SEPs) generated at any accompanying CME shock front. As is becoming increasingly clear, the space weather potential of CMEs is magnified when consecutive CMEs interact or when CMEs interact with Stream Interaction Regions (SIRs). Moreover, if a CME propagates through a rarefied high-speed stream region, it is likely to dissipate less energy (as drag on it will be reduced) and will hence impact Earth at higher speed. Through Thomson scattering of photospheric light off free electrons, coronagraphs image the near-Sun solar wind (the solar corona) and the CMEs therein with, in general, full 360° azimuthal position angle coverage around the Sun in broad-band, visible light. Coronagraphs provide definitive, and clear, evidence that a CME has been launched and are hence fundamental to any space weather monitoring solution.

While coronagraphy in L5 provides a side-on view of Earth-directed CMEs, these CMEs exhibit a characteristic “halo” appearance in coronagraph imagery when viewed from a location close to the Sun-Earth line (e.g. L1), in that they appear to expand outwards from the Sun over the full 360° of azimuth. By providing images of such halo CMEs, a coronagraph situated near the Sun-Earth line can provide near-conclusive and timely proof of impending CME impact at Earth (ambiguity between front- and back sided CMEs can potentially be resolved through examination of complementary on-disk datasets). The C2 and C3 LASCO coronagraphs on the L1 SOHO spacecraft have underpinned space weather prediction services over much of the last two decades. For coronagraphic imaging, an L1 vantage point is preferable to Earth orbit ─ particularly for space weather monitoring ─ as the stray light and particle environments are much less challenging, and L1 is not subject to the Earth and lunar eclipses that beset many Earth orbits.

Advances in coronagraphy may in future prove more definitively the benefit of polarization measurements in the localization of CMEs [1], or the potential benefit of near-Sun coronal imaging (i.e. within 2.5 sun radii), for example for the provision of SEP predictions. Coronal imaging can also be performed within specific wavebands, in particular Lyman-alpha, which has the potential to yield unprecedented information on coronal magnetic fields [2]. However, these features are currently not considered in the baseline configurations. Currently initiated developments by ESA investigate the feasibility and target the demonstration of a new coronagraph design that should lead to a more compact instrument, which would be beneficial for the future mission implementations. The concept was first investigated by [3], and a first demonstration of the efficacy of this design has been carried out by NOAA [4]. The concept seems to be very promising and is currently considered as the baseline for the Lagrange missions. If the demonstration of the concept is not successful, then the traditional design used by LASCO C2 and C3 on SOHO will need to be revived resulting in larger resource demands, or alternatively other concepts with European heritage can be considered [5].

C. Heliospheric Imager

The Heliospheric Imager shall provide wide-angle, white-light images of the heliospheric region between Sun and Earth. These images are required to enable tracking of Earth-directed CMEs over much of their propagation path, in order to mitigate deficiencies in arrival times predictions based on near-Sun data. CME morphology and propagation can evolve all the way out to 1 AU, due to mutual interactions and the interaction with the background solar wind (e.g. SIRs and Co-rotating Interaction Regions [CIRs]); such interactions are often poorly modelled. Moreover, heliospheric imagery can also provide information on the background solar wind itself (enabling, for example, prediction of SIR arrival at Earth). Such imagery is virtually impossible from the ground.

Continued monitoring of Earth-directed CMEs requires observations from two vantage points to more accurately characterize CME morphology and kinematics. Heliospheric imaging from an L5 vantage point provides a clear, side-on view of Earth-directed CMEs which permits more accurate tracking of their propagation. A vantage point some 40° to 80° from the Sun-Earth line is considered optimal, L5 is preferred also due to other advantages. Together with observations from L1, this stereoscopic view of CMEs enables their properties to be reconstructed and hence the accurate determination of CME arrival time and speed at Earth. Note that an L1 vantage point is preferable to Earth orbit as the stray light and particle environments are much less challenging, and L1 is not subject to the Earth and lunar eclipses that beset many Earth orbits.

The technical challenge with this instrument lies in the very faint signal that is generated by the CMEs, which is much less than the background signal. Any additional stray-light generated by scattering off S/C structures or insufficient baffling could easily result in the inability of the instrument to observe CMEs. However, the concept of heliospheric imaging has proven heritage (STEREO HI). Due to the limited azimuthal coverage of the FoV, observations from L1 require two instruments to observe both east and west of the Sun-Earth line. Although the HI optical camera systems are relatively small, the instrument is dominated by the baffling arrangement and the cooling configuration of the detectors to enable low-noise detection. Further miniaturisation relies therefore on advances in detector technologies, baffle design and coating technologies, including the corresponding modelling capabilities. It is planned to investigate if such instrument can be further optimised to reduce the resource demands and to improve the performance.

It should be noted that future technologies might exploit also here the polarization properties of heliospheric visible-light, which is suggested to be able to greatly improve the localization of CMEs (more so than in the corona). Although proposed for several potential missions [6] a polarized heliospheric imager has not yet been flown, so this capability is unproven and also not considered in the baseline configuration. However, this, and other advancements in heliospheric imaging shall be borne in mind as the instrument and mission design processes progress, or for future next generation implementations.

D. Magnetograph

Presently, low-resolution (angular resolution ≥5 arcsec) longitudinal magnetograms are, for the majority of observational endeavours, used as the basis on which to model the background solar wind (including SIRs and CIRs) for arrival time prediction of CMEs (and background structures themselves) at Earth. Here we propose a longitudinal magnetograph with 5 arcsec spatial (angular) resolution as the threshold solution. Inspection of low-resolution longitudinal magnetic fields can also provide some basic "watch" warning of developing solar activity, from a magnetic perspective. From L5, such data would allow active regions that may present a threat to Earth to be identified 6 or 7 days in advance (compared to 3 or 4 days feasible using terrestrial or L1 observations).

The high-resolution (≤2 arcsec) vector magnetograph proposed here as the goal solution, instead would provide the complete photospheric vector magnetic field information (field strength, azimuth, inclination) and most of the physical parameters (e.g. distribution of vertical and horizontal magnetic fields, distribution of inclination angles, twist, writhe, helicity, current density, share angles, photospheric magnetic excess energy etc.) for future enhanced space weather applications. Studies on how this data can be utilized and how much it would benefit sophisticated flare and CME forecast models shall be carried out in parallel to the on-going technical activities. The absence of a comparable ground based network perfectly justifies the consideration of the high-resolution vector magnetograph also for the L1 mission. Identical instrumental, observational and timing constraints at both Lagrange points shall allow the perfect merge of high-resolution vector magnetic field information for 67% of the solar surface, one of the important synergies to be expected from a combined L1/L5 mission.

Solar white light images are a low-cost by-product (in terms of telemetry, mass, power) of standard magnetographs and are realized in the form of continuum images, observed at an additional wavelength point in the vicinity of the magnetically sensitive spectral line under investigation. Hα and Ca II IR line core images could be considered as a further optional by-product of the magnetograph, delivering important chromospheric context information on the formation of solar eruptive events. Thus finally, the magnetograph could in principle sequentially scan the magnetically sensitive white-light photospheric line (at 4 wavelength points for magnetograms and at 1 wavelength point for the continuum image), and optionally the chromospheric Hα line (at 1 additional wavelength point at the Hα line core) and/or the chromospheric Ca II IR line (at one additional wavelength point at Ca II IR line core).

Due to the involvement of European institutes in previous developments of magnetographs in space [7], and in particular for the PHI instrument on Solar Orbiter [8], a high level of expertise and good heritage for the operational instrument development already exists in Europe. However, the PHI instrument is built for the requirements of the Solar Orbiter mission and therefore includes two telescopes, a Full Disk Telescope (FoV=2.1°) and a High Resolution Telescope (FoV= 16.8 arcmin). For the operational space weather monitoring a single telescope is currently presumed to be sufficient. Due to the much closer distance of Solar Orbiter to the Sun, the optical configuration of PHI is not directly suitable and must be redesigned or adapted for the Lagrangian missions (at 1 AU distance to the Sun) in any case. However, most of the technologies, subunits, electronics or instrument control- and data processing software should be reusable. At present it is unclear whether or not $LiNbO_3$ etalons will be still available or if a potential backup solution will be required. As far as the detector is concerned, it is expected that the detector from PHI, which is a 2048 x 2048 CMOS detector, can be reused. For the preparation of the Lagrangian missions it is foreseen to build an elegant breadboard, focussing on the consolidation of the required instrument performance and the optimisation of the optical design for space weather purposes. If necessary, the development or adaptation of the critical subunits has to be initiated. Identical instruments are foreseen for the L1 and the L5 mission.

E. EUV Imager

EUV imaging, exploiting a core set of wavelengths corresponding to different atomic transitions from highly ionized ions at a wide range of different temperatures, is used to monitor solar activity in the solar transition region and corona. This allows the imaging and monitoring of active regions, coronal holes and quiet Sun, as well as other solar activity such as flares and prominence eruptions. Thus, images in selected EUV emission lines are valuable for the monitoring of magnetic complexity and impending Earth-affecting solar activity, particularly from L5 on the region of the Sun that is yet to rotate to the longitude of Earth. The different EUV wavelengths provide information on different optical depth layers of the solar atmosphere; whilst one wavelength, utilizing a highly ionized ion of, say, iron, can provide valuable monitoring of coronal structure and activity (threshold scenario). Several lines across a range of temperatures (goal scenario) allow the investigation of a wider range of key phenomena and solar atmospheric heights. In this context, EUV imaging provides a basic measure of approaching complex active regions and the more immediate indicator of potentially Earth-impacting events such as flares and eruptions.

Recent examples of such imagers include the EIT instrument [9] aboard SOHO at L1, the SDO/AIA [10], the Proba-2/SWAP instrument [11] in Earth orbit, the EUI of Solar Orbiter [12] and the EUVI instrument [13] aboard the STEREO spacecraft in solar orbit. Due to identical instrumental, observational and timing constraints at both Lagrange points, the synergies gained from a combined L1/L5 mission will be without existing comparison, allowing the perfect merge of high-resolution high-cadence EUV images for 67% of the solar surface and off solar limb. This will lead to much improved coverage of the development of active regions on the east side of the Sun, yet to rotate to the longitude of Earth, where increasing magnetic activity can finally lead to energy release and the eruption of Earth-directed events. Therefore, the operational follow-up and investigation of chromospheric and low-coronal activity by means of EUV images shall be another cornerstone for enhanced flare and CME forecast in the frame of the combined L1/L5 mission.

The mentioned heritage instruments have various configurations. Whereas ESIO is geared towards a small instrument with a detector array of 512 x 512 pixels and a resolution of 12 arcsec, SWAP provides (as part of the SSA service fleet) 3.2 arcsec sampling with a 1k x 1k detector. EUI employs 'low' and high resolution channels with 2k x 2k and 3k x 3k detectors. The choice of the (EUV enhanced) detector appears therefore uncritical, and instead it needs to be decided which of the mentioned instruments are considered as the best baseline for the Lagrangian missions. Developments will depend on the choice of the final spatial resolution of the instrument and the number of wavelengths considered necessary. Wavelength selection is certainly a critical aspect for an operational mission with the expectation of high reliability for mechanisms, and the selected components of the used electronics, since none of the heritage instruments are ready to provide four different wavelengths. The selection of the number of wavelengths / filters needs therefore careful consideration.

F. Optional Remote Sensing Strawman Payload

Within the Phase 0 studies and to support the objectives of the SSA programme, we have investigated the usefulness of a NEO Imager to detect, monitor and characterize Near-Earth Objects (NEOs). Because of the background light from the Sun, optical observations from the Earth are very constrained if objects within 1 AU of the Sun are to be observed. Observations from the Lagrangian point could therefore make use of the shadow of the S/C and be able to scan the inner regions within the Earth orbit. It was confirmed that a scanning instrument would be very efficient and could potentially detect the majority of the otherwise invisible objects, and thereby prevent unexpected impacts on Earth such as the Chelyabinsk meteor or asteroid 2016QA2 that recent passed unexpectedly close to Earth. Some first ideas of the corresponding scanning strategies have been identified. Further investigations are necessary to maximize the overall NEO detection and orbit characterization efficiency, and to allow for early and effective mitigation strategies against objects with high impact probability on Earth. A scanning mechanism and optical configuration with low system impact would need to be developed. In the current configuration, the L1 and L5 mission architectures and preliminary designs show sufficient system margin. For the L5 mission, limitations are rather on the data transmission than on the power and mass. Other instruments could therefore in principle be included in the L5 payload if sufficient funding for the mission is provided and if such instruments can be developed within the current time frame, which foresees the launch in 2023.

IV: CONCLUSION AND OUTLOOK

Within this paper we have provided the context of the Lagrangian mission configurations as derived from the Phase 0 studies for an Enhanced Space Weather Monitoring System. The L1 and L5 Lagrangian points have been shown to provide excellent vantage points for observations of the Sun and monitoring of the Earth/Sun system, in particular if operated in concert. We have presented an overview of the observational objectives for the necessary optical instruments and their performance parameters. The targeted space weather monitoring system is expected to have an operational character, and data transmission will have to be performed almost in real time and with high reliability on a 24/7/365 basis. The mission development therefore needs to make use of existing heritage. However, it is also obvious that several modifications have to be made, or retired instruments need to be reconstructed for the presented purposes. This requires a streamlined assessment in Phase A to consolidate the mission objectives, the corresponding instrument designs, and the mitigation of potential technical risks by early demonstration of the performance and compliance to the performance specifications with the required technology readiness.

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