ESA ESOC
Robert-Bosch-Strasse 5
64293 Darmstadt
Germany

VIGIL MISSION OBJECTIVES AND PAYLOAD DESCRIPTION

Prepared by	OPS-SW
	European Space Agency
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CHANGE LOG

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Mission name change, update of payload baseline	2	0	09/03/2022

Table of Contents

1. INTRODUCTION

This document summarises the Mission Objectives of the Vigil space weather monitoring mission and describes the main characteristics of the baseline payload instruments. The purpose of this document is to give an overview of the instruments, their key characteristics, observation objectives, and why they have been selected for the mission. This document does not contain detailed technical information about the instruments or their interfaces to the spacecraft and it cannot be used as an applicable document for any technical activities for the baseline payload instruments or the spacecraft.

2. VIGIL MISSION OBJECTIVES

The Vigil Mission shall position a satellite at the 5th Lagrangian point (L5) with the objective to perform continuous observations of the Sun and the space between the Earth and the Sun to provide measurement data for space weather nowcasting and forecasting and for event-based warnings and alerts when solar events take place. The observations from L5 will complement space weather monitoring from Sun-Earth line and enable more accurate space weather impact predictions and early warnings of potentially hazardous solar weather conditions emerging. ESA is cooperating in space weather monitoring with the US (NOAA and NASA) who are planning to continue maintaining operational space weather monitoring on the Sun-Earth line by missions to the 1st Lagrangian point (L1) and by instruments onboard satellites orbiting the Earth.

The field of view from L5 allows monitoring of the onset of Coronal Mass Ejections (CMEs) with a coronagraph from a different angle than coronagraphy from the Sun-Earth line. Combination of the observations from two directions is foreseen to provide better estimates of the CME direction and speed, and to allow detection of faint “stealth” CMEs and CMEs that are ejected rapidly one after another. Vigil mission will also be able to monitor the entire space between Sun and Earth with a heliospheric imager allowing mid-course tracking of solar wind features including CMEs as they travel towards Earth.

The Vigil mission will enable observation of the solar disc several days before it becomes visible from the Earth. Longer monitoring of the active regions and their flaring is expected to make statistical flare forecasting more accurate. Vigil observations also prevent situations where strong flaring can be detected behind the solar horizon but without means to investigate the seriousness of the threat further.

In-situ measurements in L5 will allow monitoring of high-speed solar wind streams several days in advance before they rotate towards the Earth. Magnetograph observations from L5 will provide fresh solar magnetic field data for numerical solar wind models used in CME propagation estimation and enable more precise predictions of the CME arrival times on Earth. Magnetograph data is also expected to improve the solar flare and CME onset forecasting accuracy.

As the baseline payload the Vigil spacecraft will carry 5 instruments, with 3 instruments dedicated to remote sensing of the Sun and the interplanetary space between the Sun and the Earth, and 2 instruments in-situ measuring the interplanetary magnetic field (IMF) and the solar wind characteristics at the L5 position.

The mission objectives are described in the Mission Requirements Document (**Error! Reference source not found.**) and summarised in Table 1 below.

Table 1. Vigil mission objectives.

	OBJECTIVE
Primary objectives	To provide improved assessment of CME motion and density, in the corona and heliosphere.
	To provide observations necessary to improve solar activity onset detection.
	Enable assessment of developing solar activity through the monitoring of active region development.
Secondary objectives	To determine the speed, density and temperature in solar wind features (e.g. SIRs) rotating towards Earth from an in-situ perspective.
	To monitor vector components of the Interplanetary Magnetic Field (IMF).

The aim of the Vigil mission is to demonstrate the benefits from space weather observations away from the Sun-Earth line for operational applications. For that purpose, the mission is designed to carry out observations at all times including severe space weather events and to provide data about the current space weather conditions in a 24/7 operational mode. The data for operational space weather applications shall be delivered to the users with low latency.

Benefits of using space weather measurements from L5 have been addressed in many scientific studies and presented in many peer review publications. The necessary tools and applications to utilise the data produced by the Vigil mission in ESA's Space Weather Service

Network will be developed in specific activities that will be carried out in the framework of the Space Safety Programme.

In addition to the baseline measurements for operational space weather applications, Vigil mission will support “bonus science” by making all measurement data available for research purposes through the data archive in the ESA Space Weather Data System.

3. VIGIL BASELINE PAYLOAD

3.1. Photospheric Magnetic Field Imager (PMI)

PMI is a vector magnetograph based on the heritage of the PHI instrument of Solar Orbiter. Development of PMI is led by Max Planck Institute for Solar System Research (MPS). Photospheric Magnetic Field Imager (PMI) will 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 enhanced space weather applications. The instrument will also generate solar white light images as by-products of magnetograph measurements and produced as continuum images observed at an additional wavelength point in the vicinity of the magnetically sensitive spectral line.

The magnetograph measurements are used as the basis on which to model the background solar wind, including Stream Interaction Regions (SIRs) and Co-rotating Interaction Regions (CIRs), for arrival time prediction of CMEs at Earth. Inspection of longitudinal magnetic fields can also provide a warning of developing solar activity in the form of Active Regions (AR). From L5, such data would allow ARs that may present a threat to Earth to be identified up to 6 or 7 days in advance (compared to 3 or 4 days feasible using terrestrial or L1 observations).

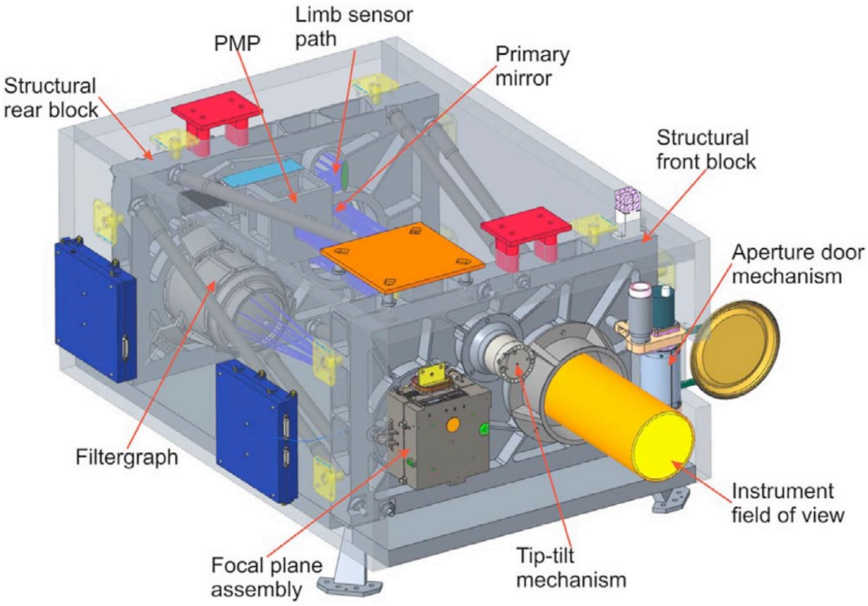

Figure 1. PMI instrument design.

3.2. Compact Coronagraph (CCOR)

The coronagraph is the key instrument for detection of the onsets of the Coronal Mass Ejections (CMEs). CMEs are the most destructive space weather effects at Earth through direct CME impact and via the Solar Energetic Particles (SEPs) generated at accompanying CME shock fronts. The geo-impact potential of CMEs is magnified when consecutive CMEs interact or when CMEs interact with high-speed solar wind in Stream Interaction Regions (SIRs). Onset of a CME can be seen in the coronagraph image as transient increase in the light scattering from the plasma cloud of the CME. Coronagraph is the most definitive method to detect CME onsets and provide the associated warnings.

Coronagraph measurements on Sun-Earth line, however, may not detect very faint CMEs ejected to the general direction of the instrument and they may miss onsets of consecutive CMEs because the instrument image is still covered by the first CME in the series. Combination of coronagraphic measurements from the Sun-Earth line and from L5 will overcome many of the limitations noted above. A faint “stealth” CME could be detected by the coronagraph in L5, and its propagation may also be captured by the HI instrument onboard the Vigil mission. Vigil coronagraph would also detect consecutive, Earth oriented CMEs that would be difficult or impossible to detect from Sun-Earth-line. Combination of the measurements from Sun-Earth-line and L5 would also allow elimination of the ambiguity between front- and backside CMEs, i.e., CMEs propagating away from the Earth direction. L5 coronagraph measurements could be used on their own for space weather services and thus having instruments both on Sun-Earth-line and in L5 provides additional redundancy in the case that one of the measurement systems is not available for a short period of time.

ESA is working in cooperation with NOAA to fly the Compact Coronagraph (CCOR) developed by the U.S. Naval Research Laboratory (NRL) onboard the Vigil mission. CCOR is planned to fly onboard the GOES-U satellite in GEO and the SWFO-L1 mission to L1 point to ensure reliable and redundant coronagraphy on the Sun-Earth line. Having the same coronagraph in L5 is foreseen to make combination of the observations simpler and to enhance the utilisation of data. A layout of the CCOR instrument is presented in Figure 2. ESA has been working together with NOAA to confirm that the CCOR measurements will meet the Vigil coronagraphy requirements.

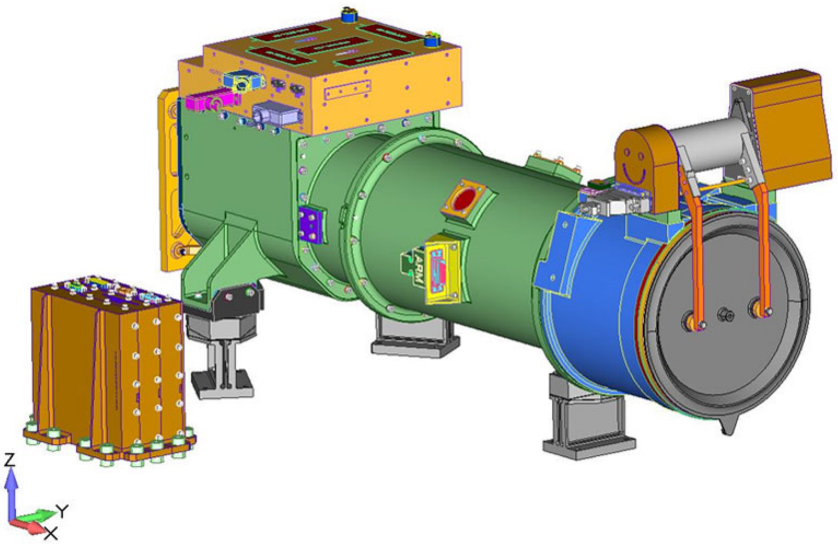

Figure 2. CCOR instrument design (courtesy of NRL).

3.3. Heliospheric Imager (HI)

The Heliospheric Imager shall provide wide-angle, white-light images of the region of space between the Sun and the Earth. These images are required to enable tracking of Earth-directed CMEs over their propagation path once they have left the field-of-view of the coronagraph instrument. Continuous monitoring of the CME propagation and particularly detection of the changes in the propagation speed will allow more accurate CME arrival time and impact predictions. CME morphology and propagation evolve throughout its propagation due to the interaction with the background solar wind and with other CMEs propagating to the same direction. The HI instrument is expected to help identifying situations where consecutive CMEs merge on the way towards the Earth creating a faster CME with higher impact on Earth. Heliospheric imagery can also provide information on the background solar wind itself (enabling, for example, prediction of SIR arrival at Earth).

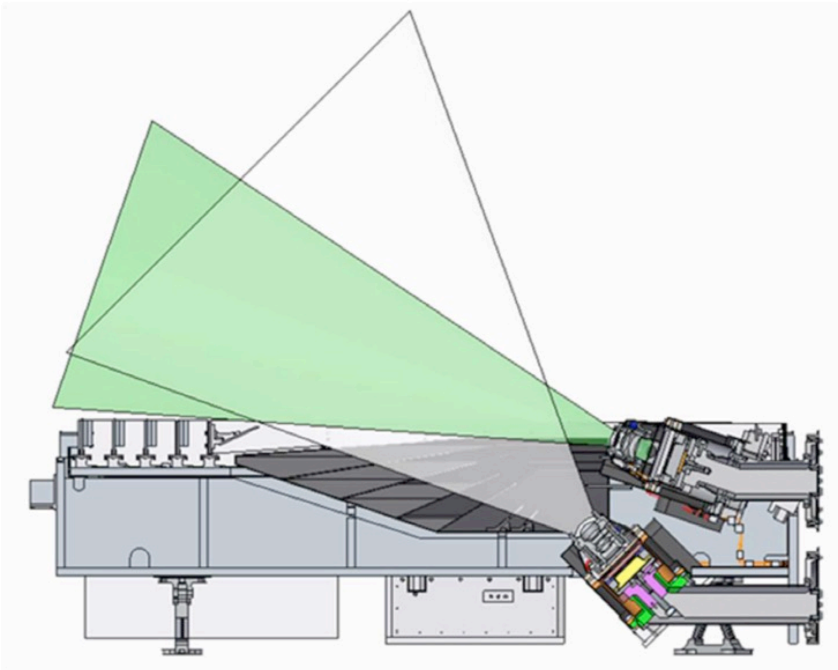

Figure 3. Layout of the Vigil HI instrument.

3.4. Plasma Analyser (PLA)

PLA will measure the basic parameters of the Solar Wind and Coronal Mass Ejections (CMEs) at L5 with performance that will allow the measurements also in severe space weather conditions. The obtained measurement of Solar wind bulk velocity, solar wind bulk density and solar wind temperature, are required for monitoring of the solar wind that is turning towards the Earth and particularly for detection of high-speed solar wind streams that produce SIRs and CIRs. More accurate forecasting of the times when these streams hit the Earth will benefit

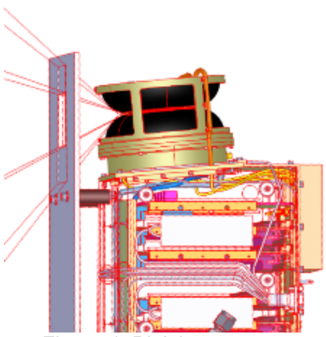

Figure 4. PLA instrument.

satellite operators to avoid damage and service interruptions caused by satellite surface charging. The characteristics of the solar wind determine the state of the magnetosphere (radiation belt energisation, penetrating electric field, cross-polar cap potential, and strength of a storm sudden commencement) and the solar wind measurements at L5 will help to make long term forecasts of the solar wind induced disturbances within the Earth's magnetosphere. PLA measurements can also be used in refining CME models and improving arrival time and geoimpact estimates by using global heliospheric models for which observations at L5 would provide an additional sampling point.

The PLA optics is based on MSSL's Improved Plasma Analyser (IPA). The optics has been incorporated into the Electron Analyser System (EAS) sensor for the Solar Orbiter mission. The FoV is adapted to the observational configuration of the Vigil mission and PLA will measure ions instead of electrons.

3.5. Magnetometer (MAG)

Measurement of the Interplanetary Magnetic Field (IMF) at L5 can be used to monitor the CIRs and SIRs up to 4-5 days in advance before their arrival at Earth. These measurements are important for forecasting magnetic storms and disturbances caused by SIR with extended lead-times. Measurements at L5 can be also used to predict the magnetic field structure of the column of solar wind along the Sun-Earth line. IMF measurements are critical for the interpretation of the solar particle measurements by the radiation monitor onboard Vigil.

The fields to be measured can have strengths ranging from a few nT to hundreds of nT, considering as a worst-case scenario the 23 July 2012 CME, with a peak magnetic field strength (e.g. as measured by STEREO-A) of ~109 nT. Since the magnetic field can assume any orientation, and a safety factor is desirable, a capability to measure a maximum of at least 200 nT is required from the instrument.

Magnetic field measurements are a very well-established technique in space science with well-known heritage. The MAG instrument has a strong heritage from instruments using the dual- or triaxial fluxgate sensor for measuring the ambient magnetic field, based on the saturation effect of the highly permeable ring core. The main challenge for magnetometer measurements is that of eliminating magnetic disturbers from other items on the spacecraft, e.g. electrical systems and structures with changing magnetic properties. Two sensors are therefore foreseen which will measure the magnetic field with an accuracy of about 1 nT. The sensors will be placed on a boom of about 7 m length. MAG has a strong heritage from J-MAG instrument flying on JUICE mission.

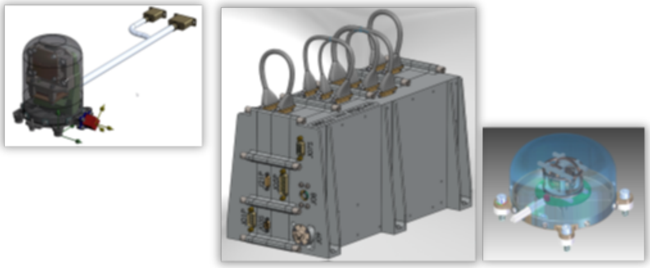

Figure 5. Elements of the Vigil MAG instrument.