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DOCUMENT

Solar Orbiter
Science Management Plan

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Updated length of rotating membership of SPICE representative to SWT from 1 year to 2 years	02/02/2012	P14	
Updated following comments from SPC Delegations	16/02/2012	All	

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1 SUMMARY AND SCOPE

Solar Orbiter is the first M-class mission of the European Space Agency's Cosmic Vision 2015-2025 programme. The mission is devoted to solar and heliospheric physics and will provide unprecedented close-up and high-latitude observations of the Sun and inner heliosphere. The mission will be carried out as an ESA mission open to the worldwide science community.

The Solar Orbiter baseline configuration consists of a 3-axis stabilized spacecraft that will be launched from Cape Canaveral on a NASA–provided Evolved Expendable Launch Vehicle (EELV), with an Ariane 5 from Centre Spatial Guyanais, Kourou (CSG) as possible back-up. The launch date is January 2017.

The Solar Orbiter Science Management Plan (SMP) describes the implementation of those aspects of the project, up to and including the post operational phase, that are required to ensure the fulfilment of the mission's scientific objectives, and to optimize its scientific return, with special emphasis on science operations and data management.

Based on the science management principles presented in this document, a Multi-Lateral Agreement (MLA) was established between ESA and the Lead Funding Agencies (LFA) to formalise the commitments and deliverables of all parties. Where and when relevant, the MLA will take precedence over the Science Management Plan.

The present document first summarizes the main aspects of the mission. The plan then outlines the role of the Solar Orbiter science advisory structure, and the ESA science management tasks from instrument selection to data distribution and archiving. The SMP also addresses the duties and rights of the Solar Orbiter investigators, as well as their interaction with the Solar Orbiter Science Working Team.

2 MISSION OVERVIEW

Solar Orbiter Mission Summary	
Top-level Science Questions	• How and where do the solar wind plasma and magnetic field originate in the corona? • How do solar transients drive heliospheric variability? • How do solar eruptions produce energetic particle radiation that fills the heliosphere? • How does the solar dynamo work and drive connections between the Sun and the heliosphere?
Payload	Heliospheric In-Situ Instruments: • Solar Wind Analyser (SWA) • Energetic Particle Detector (EPD) • Magnetometer (MAG) • Radio & Plasma Wave experiment (RPW) Remote-sensing Instruments: • Polarimetric and Helioseismic Imager (PHI) • EUV Imager (EUI) • Spectrometer/Telescope for Imaging X-rays (STIX) • Multi-Element Telescope for Imaging and Spectroscopy (METIS) • Spectral Imaging of the Coronal Environment (SPICE) • Solar Orbiter Heliospheric Imager (SoloHI)
Mission Profile	• Launch on NASA-provided EELV (Ariane 5 as back-up) • Interplanetary cruise with chemical propulsion and gravity assists at Earth and Venus • Venus resonance orbits with multiple gravity assists to increase inclination
Spacecraft	3-axis stabilized, Sun-pointing (with heat shield), rotatable solar arrays
TM band	X-band
Launch Date	Jan 2017
Nominal Mission Duration	7.0 yr (including Cruise Phase)
Ground TM Station	Malarguë (Argentina), 4 -8 hrs/day (effective)
Programmatic	• ESA is responsible for the Solar Orbiter spacecraft, transfer to nominal science orbit, mission operations • NASA is responsible for launch vehicle provision and launch operations • Scientific payload provided by ESA Member States, ESA and NASA

2.1 Introduction

The Sun's atmosphere and the heliosphere represent uniquely accessible domains of space, where fundamental physical processes common to solar, astrophysical and laboratory plasmas can be studied under conditions impossible to reproduce on Earth or to study from astronomical distances. The results from missions such as Helios, Ulysses, Yohkoh, SOHO, RHESSI, Hinode and STEREO, as well as the recently launched Solar Dynamics Observatory (SDO) mission, have advanced significantly our understanding of the solar corona, the associated solar wind and the three-dimensional heliosphere.

Each of these missions has a specific focus, being part of an overall strategy of coordinated solar and heliospheric research. An important element of this strategy, however, has yet to be implemented. We have reached the point where further *in-situ* measurements, now closer to the Sun, together with remote-sensing observations from a near-Sun and out-of-ecliptic perspective, promise to bring about major breakthroughs in solar and heliospheric physics. ESA's Solar Orbiter will, as part of a joint ESA-NASA programme that includes NASA's Solar Probe Plus (SPP) mission, provide many of the required observations.

2.2 Historical Background

The Solar Orbiter mission has its origins in a proposal called "Messenger" that was submitted by Richter et al. in 1982 in response to an ESA call for mission ideas. At the meeting "Crossroads for European Solar and Heliospheric Physics" held on Tenerife in March 1998, the heliophysics community recommended to "Launch an ESA Solar Orbiter as ESA's [next flexible] mission, with possible international participation, [for launch] around 2007." The kick-off meeting for a pre-assessment study of the "ESA Solar Orbiter" concept was held at ESTEC on 25 March 1999.

Solar Orbiter was subsequently proposed in 2000 by E. Marsch et al., and was selected by the Science Programme Committee in October 2000 as a Flexi-mission for launch after BepiColombo (in the 2008-2013 timeframe). A number of internal and industrial studies were then carried out, including parallel system-level Assessment Studies performed in industry between April and December 2004. At its 107th meeting in June 2004, the SPC confirmed the place of Solar Orbiter in the Cosmic Vision programme, with the goal of a launch in October 2013 and no later than May 2015.

Work continued on the mission and payload definition throughout 2005 and 2006, and at its meeting in February 2007, SPC asked the Executive to find ways to implement Solar Orbiter within a financial envelope of 300 M€ (at 2006 EC), while keeping a realistic contingency margin. In response to this request, a joint Science and Technology Definition Team (JSTDT) comprising scientists and engineers appointed by ESA and NASA, studied the benefits to be gained by combining ESA's Solar Orbiter mission and NASA's Solar Sentinels into a joint programme. This led to the release of an ESA Announcement of Opportunity for the Solar Orbiter Payload on 18 September 2007 and a NASA Small Explorer Focused Opportunity for Solar Orbiter (SMEX/FOSO) AO that was issued on 22 October 2007.

In total, 14 proposals were received by ESA in response to the Payload AO. The final report of the Payload Review Committee, giving a recommended payload for selection, was issued on 24 May 2008. Meanwhile, at its meeting in November 2007, SPC gave approval to start an 18-month industrial Phase B1 study lead by Astrium UK and this was kicked off in March 2008.

A major change in the progress of Solar Orbiter occurred in November 2008, when SPC decided to integrate Solar Orbiter into the first planning cycle of Cosmic Vision 2015-25 as an M-mission candidate for the first launch opportunity in 2017. In addition, in view of NASA's high prioritization of Solar Probe Plus (SPP) in its Living With a Star programme (compared with Sentinels), and the strong science synergies between Solar Orbiter and SPP, ESA called for an independent review of the PRC's recommended payload, now in the context of a joint Solar Orbiter-SPP scientific programme. The joint ESA-NASA review panel confirmed the validity of the recommended payload in its report of March 2009. As a result, the instrument selections recommended by the PRC in 2008 were formally announced on 20 March 2009. In parallel, NASA announced the results of the FOSO selection, and selected 2 instruments and portions of 2 instruments to be included in the Solar Orbiter payload.

At its 128th meeting on 17th & 18th February 2010, ESA's Science Programme Committee decided that Solar Orbiter be one of the three M-class candidates to proceed into definition phase and made a further programmatic change by endorsing a "fast track" approach outlined in ESA/SPC(2010)3, rev. 1. This approach was based on the scientific acceptability of increasing the minimum perihelion to ~0.28 AU and making maximum re-use of Bepi-Colombo technologies. Furthermore, it called for the start of the spacecraft implementation programme (Phase B2) in early 2011, with a view, if selected, to mission approval and adoption by the SPC in October 2011, leading to a launch in 2017. In line with this approach, the industrial Phase B2 activities were kicked-off in February 2011.

In March 2011, NASA informed ESA that it had decided to reduce its contribution to the payload to 1 full instrument and 1 sensor. Specifically, the Spectral Imaging of the Coronal Environment and Suprathermal Ion Spectrograph investigations would not be funded. Given the scientific importance of these investigations, the SPC decided that, should Solar Orbiter be selected, the SPICE and SIS measurement capabilities should be recovered through the inclusion of European-led instruments in the payload, procured under ESA's responsibility.

Solar Orbiter was ultimately selected and adopted as the first M-class mission of ESA's Cosmic Vision programme by the SPC on 4 October 2011.

2.3 Scientific Objectives

Solar Orbiter's mission is to address the central question of heliophysics: ***How does the Sun create and control the heliosphere?*** This, in turn, is a fundamental part of the second science question of ESA's Cosmic Vision programme: ***"How does the solar system work?"*** Solar Orbiter is specifically designed to identify the origins and causes of the solar wind, the heliospheric magnetic field, solar energetic particles, transient interplanetary disturbances, and the Sun's magnetic field itself.

Solar Orbiter's scientific mission can be broken down into four top-level science objectives:

1. How and where do the solar wind plasma and magnetic field originate in the corona?
The solar corona continuously expands and develops into a supersonic wind that extends outward, interacting with itself and with the Earth and other planets, to the heliopause boundary with interstellar space, far beyond Pluto's orbit. The solar wind has profound effects on planetary environments and on the planets themselves – for example, it is responsible for many of the phenomena in Earth's magnetosphere and is thought to have played a role in the evolution of Venus and Mars through the erosion of their upper atmospheres. Two classes of solar wind – 'fast' and 'slow' – fill the heliosphere, and the balance between them is modulated by the 11-year solar cycle. The fast solar wind (~700 km/s and comparatively steady) is known to arise from coronal holes. The slow solar wind (~400 km/s) permeates the plane of the ecliptic during most of the solar cycle so it is important to Earth's space environment. The slow solar wind differs from the fast wind in mass flux and composition, which is consistent with confined plasma in the solar corona. The specific escape mechanism through the largely closed magnetic field is not known since candidate sites and mechanisms cannot be resolved from 1 AU. Fast and slow wind carry embedded turbulent fluctuations, and these also display different properties compatible with different solar origins. It is thought that such fluctuations may be responsible for the difference in heating and acceleration between different solar wind streams. Understanding the physics relating the plasma at the solar surface and the heating and acceleration of the escaping solar wind is crucial to understanding both the effects of the Sun on the heliosphere and how stars in general lose mass and angular momentum to stellar winds.

2. How do solar transients drive heliospheric variability?
The largest transient events from the Sun are coronal mass ejections (CMEs), large structures of magnetic field and material that are ejected from the Sun at speeds up to 3000 km/s. CMEs are also of astrophysical interest since they are the dominant way that stars shed both magnetic flux and magnetic helicity that build up as a result of the stellar dynamo. Interplanetary CMEs (ICMEs) are the major cause of interplanetary shocks, but the locations and mechanisms by which shocks form around them are not known since they occur in the inner solar system. Similarly, the longitudinal structure of ICMEs is not directly observable from the ecliptic, while their extent has a large impact on the acceleration of energetic particles. ICMEs are a major

cause of geomagnetic storms but their effectiveness at disrupting the magnetosphere is only loosely related to the parent CME, because the evolution of the propagating cloud with the surrounding heliosphere is complex and has not been well studied. These unknowns have direct impact on our ability to predict transient ("space weather") events that affect Earth.

3. How do solar eruptions produce energetic particle radiation that fills the heliosphere?
Like many astrophysical systems, the Sun is an effective particle accelerator. Large solar energetic particle (SEP) events produce highly energetic particles that fill the solar system with ionizing radiation. CME-driven shocks can produce relativistic particles on time scales of minutes, and many CMEs convert ~10% of their kinetic energy into energetic particles. Other processes produce high-energy particles on magnetic loops without involving shocks. The multiple processes operating in SEP events are not well understood or distinguishable from observations at 1 AU. In particular, particles accelerated in the corona and inner heliosphere are scattered by inhomogeneities in the interplanetary magnetic field (IMF) before they arrive at Earth, destroying much of the information they carry about the processes that accelerated them. Particle transport and scattering in the inner solar system are poorly understood since the turbulence properties cannot be determined from 1 AU. The actual seed population of particles energized by CME-driven shocks in the inner solar system is unexplored, and needs to be understood to construct a complete picture of particle acceleration in shock-related events.

4. How does the solar dynamo work and drive connections between the Sun and the heliosphere?
The Sun's magnetic field connects the interior of the star to interplanetary space and is dominated by a quasi-periodic 11-year sunspot cycle that modulates the form of the heliosphere and strongly affects the space environment throughout the solar system. The large-scale solar field is generated in the Sun's interior, within the convection zone, by a dynamo driven by complex three-dimensional mass flows that transport and process magnetic flux. Despite notable advances in our knowledge and understanding of solar magnetism made possible by Ulysses, SOHO, and Hinode observations as well as by recent theoretical models and numerical simulations, fundamental questions remain about the operation of the solar dynamo and the cyclic nature of solar magnetic activity. Of paramount importance to answering these questions is detailed knowledge of the transport of flux at high latitudes and the properties of the polar magnetic field. To date, however, the solar high latitudes remain poorly known owing to our dependence on observations made from the ecliptic. In addition to questions about the global dynamo and the generation of the large-scale field, there are unanswered questions about the origin of the small-scale internetwork field observed in the quiet photosphere. Is this weak field produced by turbulent local dynamo action near the solar surface?

Detailed information on these core objectives is given in the Solar Orbiter Definition Study Report (ESA/SRE(2011)14), and the flow-down to the science requirements is presented in the Solar Orbiter Science Requirements Document (SOL-EST-RS-1858)

2.4 Mission Description

The baseline mission is planned to start in January 2017 with a launch aboard a NASA-provided EELV from Cape Canaveral, leading to a ballistic trajectory combined with planetary Gravity Assist manoeuvres (GAM). About 4.5 months after launch, a Venus GAM will put the spacecraft in a trajectory towards the Earth. 10.4 months later, an Earth GAM with a pericentre height of 300 km inserts the spacecraft in a heliocentric orbit in 3:2 resonance with the Earth, such that there is another Earth GAM at the same position 2 years later. About 2 months after the last Earth swing-by, a Venus GAM will insert the spacecraft into the initial heliocentric operational orbit in a 4:3 resonance with Venus and with perihelion radius at 0.28 AU. This initial operational orbit has an orbital period of 168.5 days, corresponding to a semi-major axis of 0.6 AU, and a solar inclination of 16.6°. A series of Venus GAM following the sequence of resonances 4:3-4:3-3:2-

5:3 will increase the solar inclination to the final value of 34.0° while providing a series of close approaches for the science observations of the Sun.

Science operations will be conducted predominantly in an encounter-like mode, whereby the full payload will operate only during certain key portions of each science orbit. As a baseline, these will comprise three 10-day periods centered on perihelion, and highest northern and southern solar latitude. A subset of the payload (nominally the *in-situ* instruments) will operate throughout the entire orbit, within the constraints imposed by spacecraft operations (e.g. telemetry downlink sessions). In addition, it is envisaged to acquire limited remote-sensing observations if the available telemetry downlink and other operational constraints allow.

2.5 International Cooperation

Solar Orbiter is a collaborative ESA-NASA mission, with the provision of launch services and parts of the payload for Solar Orbiter by NASA, and the provision of remote sensing support from Solar Orbiter to the SPP in-situ observations during the simultaneous part of the two missions. SPP is currently scheduled to be launched in 2018, thereby coinciding with Solar Orbiter during parts of both the ecliptic and out-of-ecliptic phases of the mission.

2.6 Payload Selection Process

ESA issued an Announcement of Opportunity (AO) to the Scientific Community for the Solar Orbiter payload in September 2007. In parallel, NASA issued a call for instrument proposals within the framework of a Small Explorer Focused Opportunity for Solar Orbiter (SMEX/FOSO). In total, 14 proposals were received by ESA in response to the Payload AO. The final report of the Payload Review Committee, giving a recommended payload for selection, was issued on 24 May 2008. The instrument selections recommended by the PRC in 2008 were formally announced on 20 March 2009.

The investigations as selected are:

- **Energetic Particle Detector (EPD)**

EPD will measure the composition, timing, and distribution functions of suprathermal and energetic particles. Scientific topics to be addressed include the sources, acceleration mechanisms, and transport processes of solar energetic particles; magnetic connectivity through the use of suprathermal particles as field-line tracers; the radial dependence of CME-driven shocks and associated particle populations. EPD covers the energy range from just above the solar wind (a few keV/n) to relativistic electrons and high-energy ions (100 MeV/n protons, 200 MeV/n heavy ions). The instrument comprises multiple sensors to cover this wide range of energies and species.

- **Extreme Ultraviolet Imager (EUI)**

EUI will provide image sequences of the solar atmospheric layers above the photosphere, thereby providing an indispensable link between the solar surface and outer corona that ultimately shapes the characteristics of the interplanetary medium. Scientific topics to be addressed include monitoring the low atmosphere counterparts of large-scale solar eruptive events such as coronal mass ejections (CMEs) and the study of fine-scale processes in the solar atmosphere. EUI will also provide the first-ever images of the Sun from an out-of-ecliptic viewpoint (up to 34° of solar latitude during the extended mission phase). The EUI instrument consists of separate high-resolution imagers (HRI) and a single dual-band full Sun imager (FSI).

- **Magnetometer (MAG)**

MAG will provide in-situ measurements of the heliospheric magnetic field. Scientific topics to be addressed by MAG include the way the Sun's magnetic field links into space and evolves over the solar cycle; how particles are accelerated and propagate around the solar system, including to the Earth; how the corona and solar wind are heated and accelerated. The magnetometer instrument will comprise two sensors, both in shadow and mounted on a boom behind the spacecraft body.

- **Multi Element Telescope for Imaging and Spectroscopy (METIS)**

METIS/COR will simultaneously image the visible and ultraviolet emission of the solar corona and diagnose, with unprecedented temporal coverage and spatial resolution the structure and dynamics of the full corona in the range from 1.2 to 3.0 (from 1.6 to 4.1) solar radii from Sun centre, at minimum (maximum) perihelion during the nominal mission. This is a region that is crucial in linking the solar atmospheric phenomena to their evolution in the inner heliosphere.

- **Polarimetric and Helioseismic Imager (PHI)**

PHI will provide high-resolution and full-disk measurements of the photospheric vector magnetic field and line-of-sight (LOS) velocity as well as the continuum intensity in the visible wavelength range at a cadence of one set of observables per minute. The LOS velocity maps will have the accuracy and stability to allow detailed helioseismic investigations of the solar interior, in particular of the solar convection zone. The PHI instrument consists of two telescopes, a High Resolution Telescope (HRT) that will image a fraction of the solar disk at a resolution reaching 150 km at perihelion, and a Full Disk Telescope (FDT) to image the full solar disk at all phases of the orbit.

- **Radio and Plasma Waves (RPW)**

The RPW experiment is unique amongst the Solar Orbiter instruments in that it makes both in situ and remote-sensing measurements. RPW will measure magnetic and electric fields at high time resolution using a number of sensors/antennas, to determine the characteristics of electromagnetic and electrostatic waves in the solar wind.

- **Solar Orbiter Heliospheric Imager (SoloHI)**

SoloHI will image both the quasi-steady flow and transient disturbances in the solar wind over a wide field of view by observing visible sunlight scattered by electrons in the solar wind. The SoloHI field of view is centred on the ecliptic plane but is offset from the Sun and covers a range of elongation angles, thereby providing continuous synoptic images of the inner heliosphere with good spatial resolution.

- **Spectral Imaging of the Coronal Environment (SPICE)**

SPICE is an EUV imaging spectrograph. Scientific topics to be addressed by SPICE include studies of solar wind origin by matching in-situ composition signatures in solar wind streams to surface feature composition; studies of the physical processes that inject material from closed structures into solar wind streams; studies of the source regions of solar energetic particles (SEP) by imaging remotely the suprathermal ions thought to be seed populations of SEP events as they are accelerated and depleted.

- **Spectrometer/Telescope for Imaging X-rays (STIX)**

STIX provides imaging spectroscopy of solar thermal and non-thermal X-ray emission from ~4 to 150 keV. STIX will provide quantitative information on the timing, location, intensity, and spectra of accelerated electrons as well as of high temperature thermal plasmas, mostly associated with flares and/or microflares.

- **Solar Wind Analyzer (SWA)**

SWA consists of a suite of sensors that will measure the density, velocity, and temperature of solar wind ions and electrons, thereby characterising the solar wind between 0.28 and 1.4 AU from the Sun. In addition to determining the bulk properties of the wind, SWA will provide measurements of solar wind ion composition for key elements (e.g. the C, N, O group and Fe, Si or Mg).

As noted above, in March 2011, NASA informed ESA that, as a consequence of budgetary pressures, it had become necessary to reduce its contribution to the payload to 1 full instrument and 1 sensor. Subsequently, ESA received two unsolicited proposals from European-led consortia for the provision of SIS **(part of the EPD suite)** and SPICE replacement instruments, respectively. These proposals were based on the selected instrument designs and included the previously envisaged contributions from ESA member states, but required additional ESA funding. Following an internal review, these instruments were designated as "facility instruments", with the additional cost to be borne by the Solar Orbiter project.

2.7 Modes of Participation

The possible modes of participation to the Solar Orbiter programme are:

(1) Principal Investigator (PI), heading an instrument consortium providing an instrument;

(2) Co-Principal Investigator (Co-PI) may be appointed if a major development is carried out in a country/institution different from the one of the PI; A Co-PI will have similar rights as a PI, but the PI will remain the formal interface to the Project Office;

(3) Co-Investigator (Co-I), a member of an instrument consortium providing an instrument;

(4) SPICE Consortium Lead, heading the instrument consortia providing the SPICE facility instrument, with responsibilities up to and including the in-orbit commissioning phase;

(5) SIS Consortium Lead, as above for the SIS facility instrument;

(6) SPICE/SIS Science Steering Committee member;

(7) Guest Investigator (GI), a scientist participating in the data analysis of one or more instruments;

(8) Interdisciplinary Scientist (IDS), an expert in specific overarching science themes connected with solar and heliospheric physics.

It is anticipated that Announcements of Opportunity for participation of Guest Investigators and Interdisciplinary Scientists will be issued after launch.

2.7.1 *Principal Investigator*

Within the remit of the MLA, t~~T~~he PI **or,** ~~, within the remit of the MLA~~**when applicable, an LFA representative**~~-~~, will have the following responsibilities:

(1) Management

(i) Establish an efficient and effective managerial scheme, which will be used for all aspects and through all phases of her/his instrument programme.

(ii) Organise the efforts, assign tasks and guide other members of the instrument consortium.

(iii) Ensure that plans are established, implemented and analysed such that the status reporting complies with the requirements of the ESA Project Office.

(iv) Provide the ~~sole~~ formal managerial and technical interface of the instrument to the industrial prime via the ESA Project Office.

(v) Support ESA management requirements (e.g. investigation progress reviews, programme reviews, change procedures, product assurance, etc.) outlined in the Experiment Interface Document (EID).
(vi) Where applicable, be responsible for ensuring compliance with all ITAR regulations in a timely manner. Surveillance requirements arising from ITAR regulations shall be reported to ESA and any costs associated with such requirements shall be borne by the PI.

(2) Science
(i) Monitor the compliance of the instrument design to the scientific requirements outlined in the Sci-RD.
(ii) Attend meetings of the Science Working Team and Groups, as appropriate; report on instrument development, and take a full and active part in their work.
(iii) Provide the formal scientific interface of the instrument consortium with the ESA Project Office.
(iv) Ensure adequate calibration of all parts of the instrument, both on the ground and in space. This includes the provision of all required calibration data and software to the ESA SOC along with a full instrument technical and science user manual for use by the general science user community.
(v) Participate in the definition of the science operations and data handling, and support the Science Operation Centre.
(vi) Exploit the scientific results of the mission and assure their diffusion as widely as possible.
(vii) Provide the scientific data (raw data, calibrated data, and higher level data), including relevant calibration software and/or products, and associated documentation, to the Solar Orbiter archive (in a format that will be agreed with the ESA SOC for application by the general science community) upon delivery to, and verification by, the PI team.

(3) Hardware
(i) Define the functional requirements of the instrument and auxiliary test equipment (e.g. MGSE, EGSE, CGSE, etc.)
(ii) Ensure the development, construction, testing and delivery of the instrument. This shall be performed in accordance with the technical and programmatic requirements outlined in the AO including its annexes such as the EID-A, and subsequently reflected in the PI response, EID-B.
(iii) Ensure that the instrument is to a standard that is appropriate to the objectives and lifetime of the mission, and to the environmental and interface constraints under which it must operate.
(iv) Deliver adequate verification models (EQMs, STMs, etc.) of the instrument to the prime contractor, as required to verify system interfaces. The envelope of this delivery is ruled by the EID-A, in accordance with technical programme needs.
(v) Deliver a Flight Model and Flight Spare (kit) in accordance with the technical requirements defined in the EID-A, together with the relevant Ground Support Equipment.
(vi) Support the system level integration and test activities related to and involving the instrument.
(vii) The PIs shall provide the necessary equipment to process their data as agreed with ESA and specified in the EID-A.
(viii) Ensure that all procured hardware is compliant with ESA requirements, through participation in technical working groups and control (e.g. cleanliness) boards, as requested, and that the hardware allows system level performance compatibility to be maintained.
(ix) Provide the overall documentation during the project, as defined in the EID-A.

(4) Software
(i) Ensure the development, testing and documenting of all software necessary for the control, monitoring and testing of the instrument, in accordance with the rules and guidelines established in the EID-A.
(ii) Specify and then support the development, testing and documenting of all software necessary for the testing, operation and data reduction/analysis of any parts of the instrument provided under ESA responsibility, in accordance with the rules and guidelines established in the EID-A.

(iii) Ensure the timely delivery to ESA of any instrument-specific software that is required for testing or operations and its documentation to ESA, or elsewhere, in accordance with approved ESA guidelines, procedures and schedules. This includes the provision of software required in the ESA SOC as agreed in the Science Implementation Requirements Document.

(iv) Maintain and update all PI-provided instrument software and its documentation until the end of the mission, at which point it is to be delivered to the SOC as part of the final archive.

(5) Product Assurance

Provide product assurance functions in compliance with EID-A requirements.

(6) Operations

Provide support for preparation and implementation of the mission and science operation up to the end of the mission including delivery of a user manual and data base inputs in accordance to the EID-A requirements.

(7) Financial

The financial status of the PI teams**, within the remit of the MLA,** will have to be guaranteed by the Lead Funding Agency. ~~The Lead Funding Agency will be considered responsible vis-à-vis ESA for all financial matters related to the selected investigations.~~ Co-I teams are required via their national funding agencies to seek agreement with the Lead Funding Agency on financial matters related to the selected investigations.

(8) Communications and Public Relations

Support science communications and public relations activities of ESA (and where applicable, the Lead Funding Agency), and provide suitable information and data in a timely manner, as outlined in the Science Communication Plan (see section 4.5.2).

2.7.2 Co-Principal Investigators

Although not a preferred arrangement, in some exceptional circumstances, a Co-PI may be appointed. The single point interface to the Project Office will remain the PI.

Co-PIs are responsible for their own funding which is guaranteed via their national funding agencies and must be underwritten by formal interagency agreements with the Lead Funding Agency, representing the PI and which holds overall fiscal responsibility with respect to instrument development and delivery to ESA.

2.7.3 Co-Investigators

Members of each PI-led consortium may be proposed as Co-Investigators. Each Co-I should have a well-defined role either with regard to hardware/software delivery or with regard to scientific support of the investigations within the instrument consortium. The PI-led consortium may review the status of its members regularly and implement changes if required. The Lead Funding Agency will however not change during the development of a given instrument.

Co-Is are responsible for their own funding which is guaranteed via their national funding agencies and must be underwritten by formal interagency agreements with the Lead Funding Agency representing the PI and which holds overall fiscal responsibility with respect to instrument development and delivery to ESA.

2.7.4 SPICE (SIS) Consortium Lead

The SPICE (SIS) Consortium Lead, within the remit of the MLA, will have the following responsibilities:

(1) Management

(i) Establish an efficient and effective managerial scheme, which will be used for all aspects and through all phases of the SPICE (SIS) instrument programme up to and including in-orbit commissioning.
(ii) Organise the efforts, assign tasks and guide other members of the instrument consortium.
(iii) Ensure that plans are established, implemented and analysed such that the status reporting complies with the requirements of the ESA Project Office.
(iv) Provide the sole formal managerial and technical interface of the instrument to the industrial prime via the ESA Project Office.
(v) Support ESA management requirements (e.g. investigation progress reviews, programme reviews, change procedures, product assurance, etc.) outlined in the Experiment Interface Document (EID).
(vi) Where applicable, be responsible for ensuring compliance with all ITAR regulations in a timely manner. Surveillance requirements arising from ITAR regulations shall be reported to ESA.

***(2)** Hardware*

~~*(2)*~~ **(i) Define the functional requirements of the instrument and auxiliary test equipment (e.g. MGSE, EGSE, CGSE, etc.)**
(i**i**) Ensure the development, construction, testing and delivery of the instrument. This shall be performed in accordance with the technical and programmatic requirements outlined in the EID-A and EID-B.
(ii**i**) Ensure that the instrument is to a standard that is appropriate to the objectives and lifetime of the mission, and to the environmental and interface constraints under which it must operate.
(~~ii~~i**v**) Deliver adequate verification models (EQMs, STMs, etc.) of the instrument to the prime contractor, as required to verify system interfaces. The envelope of this delivery is ruled by the EID-A, in accordance with technical programme needs.
(v) Deliver a Flight Model and Flight Spare (kit) in accordance with the technical requirements defined in the EID-A, together with the relevant Ground Support Equipment.
(~~i~~v**i**) Support the system level integration and test activities related to and involving the instrument.
(v**ii**) Ensure that all procured hardware is compliant with ESA requirements, through participation in technical working groups and control (e.g. cleanliness) boards, as requested, and that the hardware allows system level performance compatibility to be maintained.
(vi**ii**) Provide the overall documentation during the project, as defined in the EID-A.

(3) Software
(i) Ensure the development, testing and documenting of all software necessary for the control, monitoring and testing of the instrument, in accordance with the rules and guidelines established in the EID-A.

(4) Product Assurance
Provide product assurance functions in compliance with EID-A requirements.

(5) Operations
Provide support for preparation and implementation of the mission and science operation up to the end of the in-orbit commissioning phase, including delivery of a user manual and data base inputs in accordance to the EID-A requirements.

2.7.5 SPICE (SIS) Science Steering Committee

The SPICE (SIS) Science Steering Committee, under the chairmanship of the Solar Orbiter Project Scientist (or his delegated representative), will have overall responsibility for the scientific aspects of the SPICE (SIS) facility instruments. Membership of the Committee will comprise one representative each of the nationally-funded groups participating in the SPICE (SIS) consortium, together with a number (maximum 4) of external scientists appointed through an Announcement of Opportunity. In the case of SPICE, the Committee will appoint one of its members (for a fixed term of 2 years, in rotation) to act as the formal representative on the

Solar Orbiter Science Working Team **and report on instrument development and take a full and active part in the SWT work**. In the case of SIS, this responsibility will be carried by the EPD Principal Investigator. The Science Steering Committee will have the following specific responsibilities.

(i) Monitor the compliance of the instrument design to the scientific requirements outlined in the Sci-RD.
(ii) Ensure adequate calibration of all parts of the instrument on the ground.
(iii) Participate in the definition of the science operations and data handling, and support the Science Operation Centre up to and including in-orbit commissioning.
(iv) Establish a mechanism for the provision of scientific data (raw data, calibrated data, and higher level data), including relevant calibration software and/or products, to the Solar Orbiter archive for dissemination to the general science community.

2.7.6 Guest Investigators

Guest Investigators (GIs) are individual scientists who wish to make use of the data collected by one or more instruments. Their proposals shall be submitted to ESA following an open AO process. Their tasks, which will be time limited, shall be agreed with the PIs, with concurrence of the ESA Project Scientist.

Guest Investigators will be selected after launch and will be expected to participate in the activities of the Science Working Team, including science communications.

2.7.7 Interdisciplinary Scientists

To ensure a top-level oversight of mission science, a number of Interdisciplinary Scientists (IDS) will be selected through an open AO process. In general, these IDSs should not reflect instrument specific domains, but rather cover specific science themes and take part in the analysis of data from different onboard instruments, and have the same data rights as members of PI-led instrument consortia. Proposals submitted by IDSs must describe clearly their scientific case, the relevance of their contribution to the mission and the instrument data sets needed to carry out their research programme. Financial endorsement by the national funding agencies, should they require funds for their activity, is also required. The IDSs, like the PIs, are expected to provide adequate support to the communications activities of ESA. The IDSs will be appointed for a first period of three years (TBC), renewable but not exceeding the nominal duration of the mission.

3 SCIENCE AND PROJECT MANAGEMENT

3.1 The ESA Project Scientist

ESA nominates the ESA Solar Orbiter Project Scientist (PS). The PS is the Agency's interface with the Principal Investigators for scientific matters. The PS, together with the NASA-nominated NASA Solar Orbiter Collaboration Project Scientist, will chair the Science Working Team (SWT) and coordinate its activities.

During all phases of the mission, i.e. implementation phase until the end of the exploitation phase, the Solar Orbiter Project Scientist will be responsible for all science-related issues within the Project. During the development phase, the PS will advise the ESA Project Manager on technical matters affecting scientific performance. The PS will monitor the state of implementation and readiness of the instrument operations and data processing infrastructure. A small team will support the PS in the above-mentioned tasks.

After the in-flight commissioning phase, a Mission Manager will take over the responsibility for the mission throughout the exploitation phase. The Mission Manager will have overall responsibility for the delivery of the scientific output of the mission as approved within assigned constraints. The PS will continue his/her activity as the main interface with the scientific community and the main scientific interface with the MOC and SOC. The PS will coordinate the creation of the scientific products, their archiving and distribution to the scientific community.

3.2 Science Working Team

The executive membership of the Solar Orbiter Science Working Team will consist of the Principal Investigators, the SPICE and SIS Science Steering Committee representatives, and the ESA and NASA Solar Orbiter Project Scientists. Co-Investigators, Guest Investigators, Interdisciplinary Scientists and other interested scientists will be invited to participate in SWT meetings. The Project Scientists will co-chair the SWT.

The SWT will monitor and advise ESA on all aspects of the Solar Orbiter mission that will affect its scientific performance. It will assist the PS in maximizing the overall scientific return of the mission within the established boundary conditions. It will act as a focus for the interests of the scientific community in Solar Orbiter.

3.3 The ESA Project Office

ESA has established a Solar Orbiter Project Office, headed by a Project Manager, which will fulfill its function until the completion of the spacecraft initial commissioning phases. ESA, via the Project Manager and later by the Mission Manager, will retain overall responsibility for the mission through all phases.

The Project Office will be responsible for the mission design and implementation.

Within the executive mandate of the project and with regards to the Solar Orbiter Investigator teams, the Project Office will be responsible for:

- Design and implementation of the overall Solar Orbiter mission;
- Definition of the overall technical, managerial and interface requirements for the Solar Orbiter mission;

- Design, development, integration and verification of the Solar Orbiter spacecraft;
- Coordination of the provision of the instruments EPD, MAG, METIS, PHI, RPW and SPICE, and through PRODEX, EUI and STIX;
- Provision of support to NASA activities relating to integration of the Solar Orbiter spacecraft to the NASA provided EELV, and to launch site operations;
- Performing the in-orbit commissioning;
- Controling and operating the Solar Orbiter spacecraft and provision of ground station network support during operations.

The ESA Project Manager will periodically call Project Reviews, which will include all aspects of the mission including the development status of the Solar Orbiter. In particular the Solar Orbiter Team will have to show compliance with schedule, resources, interfaces, safety and any other relevant aspect of the Solar Orbiter implementation.

The ESA Project Office will monitor the progress of the design, development and verification of all Solar Orbiter instruments. The instrument consortia will have to demonstrate to ESA (and where applicable, the Lead Funding Agency), in regular reports and during formal reviews, compliance with the scientific mission goals, the spacecraft system constraints, the spacecraft interfaces and the programme schedule as defined in the mutually agreed Experiment Interface Document (EID).

Following completion of the in-flight commissioning, the Mission Manager will assume responsibility for management of the Solar Orbiter project: organisation and overall management of teams and staff assigned to the Solar Orbiter project, of the science operations team and the mission operations teams.

Specifically this will include the overall responsibility for:

- Insertion of the Solar Orbiter into its initial science orbit;
- Check-out of Solar Orbiter prior to first perihelion passage;
- Science operations;
- Archiving of Solar Orbiter data products.

The Mission Manager will be supported by the Project Office with respect to spacecraft system engineering issues.

3.4 Steering Committee

A Multi-Lateral Agreement (MLA) is established between ESA and the Lead Funding Agencies to formalise the commitments and deliverables of all parties. A Solar Orbiter Steering Committee with representatives from the Lead Funding Agencies and ESA is then set up to oversee the timely fulfillment of the obligations of all parties to the MLA.

4 SCIENCE OPERATIONS AND DATA

4.1 Solar Orbiter Operations Concept

ESA will be responsible for the launch and operations/check-out of the spacecraft.

ESA will establish the Solar Orbiter Mission Operations Centre (MOC), located at the European Space Operations Centre (ESOC). ESA will also establish a Science Operation Centre (SOC), located at the European Space Astronomy Centre (ESAC).~~SA will establish the Solar Orbiter Mission Operations Centre (MOC) and the Science Operation Centre (SOC).~~

4.2 Mission Operations Centre

The Solar Orbiter Mission Operations Centre (MOC) will be responsible for the operation and control of the spacecraft.

The Solar Orbiter Project Office will define, in agreement with the MOC, the requirements and responsibilities for mission operations, on the basis of a Mission Implementation Requirement Document (MIRD) and a Mission Implementation Plan (MIP).

The MOC will, in particular, be responsible for the following tasks, relevant to science operations:

- Overall mission planning;
- Provision of instrument raw data, spacecraft housekeeping and auxiliary data to the SOC via the ESOC Ground System Data Dissemination System (EDDS) in a timely manner and in an agreed format;
- Performing anomaly (out of limit) checks on a set of payload parameters;
- Notifying payload anomalies to the SOC/PIs.

4.3 Science Operations Centre

Science operations will be conducted in close coordination between ESA and the PI teams.

Key science operations responsibilities and functions include:

- Optimisation of the science return from the Solar Orbiter mission by defining and implementing an efficient and cost-effective science ground system and operational scheme for all mission phases;
- Preparation of the long-term and short-term payload operations plan based on input from the SWT chaired by the PS, to be implemented by the Mission Operations Centre;
- Provision of instrument raw data, spacecraft housekeeping and auxiliary data to the PI teams in an agreed format and through a user interface that will be maintained during normal working hours;
- Preparation of the Solar Orbiter science data archive based on requirements defined by the Project Scientist.

The specific responsibilities of the Science Operations Centre are:

- Definition and implementation of efficient and cost-effective science operations planning, data handling and archiving concepts;

- Act as the sole interface seen from the MOC perspective on any matter related to routine instrument operations and mission planning;
- Provision of Operations/Liaison Scientists where applicable;
- Support of instrument operations during commissioning, nominal and extended mission phases ;
- Coordination of the science operations planning;
- Coordination of science-related inputs and updates for the Flight Operations Plan (FOP);
- Consolidation of the instrument operation timelines before their submission to the MOC;
- Distribution of instrument raw data and supporting information;
- Preparation, together with the Solar Orbiter SWT, of summaries of scientific results at regular intervals and for mission highlights;
- Preparation of guidelines for science data archiving and creation of the Solar Orbiter scientific data archive;
- Support to Public Relations activities;
- Ensure the Knowledge Management over the long mission duration;
- Provide software support to the PI teams for payload operations;
- Support the MOC in the preparation of the payload operations before the end of the commissioning phase;
- Follow up the development of the experiments and participate in tests;
- Archiving of non-scientific data needed for instrument calibration, e.g. from check-outs during cruise phase;

The science operations will be defined by the Solar Orbiter Project Scientist and the SWT. This process will include the production of a Science Implementation Requirements Document (SIRD) and Science Implementation Plan (SIP). The responsibilities of the PIs with regard to science operations are described in section 2.7.1.

The SOC will be implemented using internet, electronic communications, video conferencing etc., and its functionality may be augmented by national data centres that act as local sites and, where appropriate, provide specialised data processing and other user services. In order to fulfil their responsibilities with respect to science operations during all phases of the mission (both pre- and post-launch), PIs will require adequate support from their funding agencies.

4.4 Data Rights

Solar Orbiter data will be made available according to the following procedure. Reduction of science data is under the responsibility of PI teams for PI-led instruments. In the case of SPICE and SIS, this task will be the subject of a separate ESA AO. Following in-orbit commissioning, the PIs of PI-led instruments retain exclusive data rights for the purpose of calibration and verification for a period of 3 months after the receipt of the original science telemetry and auxiliary orbit, attitude and spacecraft status information. Upon delivery of data to the ESA SOC it will be made available to the scientific community at large through the ESA science data archive. It must be stressed that PI teams must clearly indicate in their proposal the level of resources allocated to the task of ensuring science data enters the ESA science archive in a timely manner. These resources must be agreed by the funding agencies involved.

The PI teams will also be required to share data with the GIs and IDSs so as to enhance the scientific return from the mission, in accordance with procedures to be agreed and formalised within the SWT.

The PI teams will provide records of processed data with all relevant information on calibration and instrument properties to the ESA science data archive. The format for the spacecraft data shall be compatible with those defined for the ESA science data archive. The ESA science data archive will be the repository of all mission products.

Scientific results from the missions will be published, in a timely manner, in appropriate scientific and technical journals. Proper acknowledgement of the services supplied by ESA (and where applicable, the Lead Funding Agency) will be made.

The PI teams will provide ESA (and where applicable, the Lead Funding Agency) with processed and useable data for Science Communication purposes as soon as possible after their receipt.

4.5 Communication and Public Outreach

4.5.1 Public Outreach

The Solar Orbiter mission is expected to attract much public interest. Hence, the mission will be given proper importance and exposure within the framework of the communication activities of the Science Programme. Each Solar Orbiter Investigator must provide material and information for Public Relations to ESA (and where applicable, to the Lead Funding Agency).

During the development phase of the mission, ESA will set up web pages on the Solar Orbiter mission as an information tool for the general public and the media. With the progress of the mission the web pages will be enriched with more material and features related to the mission.

The active cooperation of all scientists involved in the Solar Orbiter mission in providing relevant information and results to ESA (and where applicable, to the Lead Funding Agency) is expected for the success of the related communication activities.

4.5.2 Science Communication

The Solar Orbiter Mission will be included in the overall ESA Communications Plan and a detailed Solar Orbiter Communication Plan will be drafted in due time with inputs from the Project Scientist.

The Project Scientist will initiate and publish project related progress reports and reviews of scientific results from the mission. Scientific articles suitable for public release will be provided by the members of the SWT, upon their own initiative or upon request from the Project Scientist, at any time during the development, operational and post-operational phases of the mission.

Acronyms

3-D	3-Dimensional
AO	Announcement of Opportunity
AU	Astronomical Unit
Co-I	Co-Investigator
Co-PI	Co-Principal Investigator
CGSE	Calibration Ground Support Equipment
CME	Coronal Mass Ejection
CSG	Centre Spatial Guyanais
EDDS	ESOC Ground System Data Dissemination System
EELV	Evolved Expendable Launch Vehicle
EGSE	Electrical Ground Support Equipment
EID	Experiment Interface Document
EID-A	EID-Part A
EID-B	EID-Part B
EPD	Energetic Particle Detector
EQM	Electrical Qualification Model
ESAC	European Space Astronomy Centre
ESA	European Space Agency
ESTEC	European Space Research and Technology Centre
EUI	EUV Imager
EUS	EUV Spectrometer
FM	Flight Model
FOP	Flight Operations Plan
FOSO	Focused Opportunity for Solar Orbiter
FSI	Full Sun Imager
GAM	Gravity Assist Manoeuvre
GI	Guest Investigator
GSE	Ground Support Equipment
HRI	High Resolution Imager
IDS	Interdisciplinary Scientist
IMF	Interplanetary Magnetic Field
ITAR	International Traffic in Arms Regulations
JSTDT	Joint Science and Technology Definition Team
MAG	Magnetometer
METIS	Multi-Element Telescope for Imaging and Spectroscopy
MGSE	Mechanical Ground Support Equipment
MIP	Mission Implementation Plan
MIRD	Mission Implementation Requirements Plan
MLA	Multi-lateral Agreement
MOC	Mission Operations Centre
MOU	Memorandum of Understanding
NASA	National Aeronautics and Space Administration
PI	Principal Investigator
P/L	Payload
PHI	Polarimetric and Helioseismic Imager
PRC	Payload Review Committee
PS	Project Scientist
RPW	Radio and Plasma Wave Analyser

RSSD	Research and Scientific Support Department of ESA
S/C	Spacecraft
Sci-RD	Science Requirements Document
SDO	Solar Dynamics Observatory
SEP	Solar Energetic Particle
SIP	Science Implementation Plan
SIRD	Science Implementation Requirements Document
SIS	Suprathermal Ion Spectrograph
SMEX	Small Explorer
SMP	Science Management Plan
SOC	Science Operations Centre
SoloHI	Solar Orbiter Heliospheric Imager
SOHO	Solar and Heliospheric Observatory
SPC	Science Programme Committee
SPICE	Spectral Imaging of the Coronal Environment
SPP	Solar Probe Plus
SRE-O	Science Operations Department
SRE-OD	Science Operations Development Division
SRE-P	Scientific Projects Department
SRE-S	Research & Scientific Support Department
SSAC	Space Science Advisory Committee
SSWG	Solar System Working Group
STEREO	Solar Terrestrial Relations Observatory
STIX	Spectrometer/Telescope for Imaging X-rays
STM	Structural Thermal Model
SWA	Solar Wind Analyser
SWT	Science Working Team
WWW	World Wide Web