THE SOLAR ORBITER MISSION

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ABSTRACT

Approved in October 2000 by ESA's Science Programme Committee as a flexi-mission, the Solar Orbiter will study the Sun and unexplored regions of the inner heliosphere from a unique orbit that brings the probe to within 45 solar radii (0.21 AU) of our star, and to solar latitudes as high as 38°. This orbit will allow the Solar Orbiter to make fundamental contributions to our understanding of the acceleration and propagation of energetic particles in the extended solar atmosphere. During quasi-heliosynchronous phases of the orbit, Solar Orbiter will track a given region of the solar surface for several days, making possible unprecedented studies of the sources of impulsive and CME-related particle events. The scientific payload to be carried by the probe will include a sophisticated remote-sensing package, as well as state-of-the-art *in-situ* instruments. The multi-wavelength, multi-disciplinary approach of Solar Orbiter, combined with its novel location, represents a powerful tool for studies of energetic particle phenomena.

INTRODUCTION

Ideas for an ESA *Solar Orbiter* mission were first discussed at the workshop "A Crossroads for European Solar and Heliospheric Physics", held on Tenerife in March 1998 (Priest et al., 1998). Following a pre-assessment study carried out in ESTEC in 1999, the mission was proposed by Marsch et al. (2000) to ESA in the framework of the F2/F3 Call for Ideas in 2000. Based on the results of the pre-assessment, and a further "delta" assessment study conducted between April and June 2000 (ESA, 2000), the mission was approved in October 2000 by ESA's Science Programme Committee (SPC) for launch in the 2008-2013 time-frame. In May 2001, the First Solar Orbiter Workshop was held on Tenerife (Battrick, 2001).

Following the reassessment of the ESA Science Programme in the Spring of 2002, the Solar Orbiter was re-confirmed by ESA's Science Programme Committee (SPC) in May 2002 for implementation with the BepiColombo mission as a single project, with launches in the 2011–2012 timeframe. The SPC also encouraged further international collaborations, specifically involvement of NASA in the Solar Orbiter as part of the International Living with a Star (ILWS) programme, linked to European participation in other elements of the NASA LWS/Solar Terrestrial Probes (STP) programme.

In this paper, we begin with a brief overview of the scientific objectives of Solar Orbiter, focusing on expected contributions to studies of energetic particle phenomena. This is followed by a description of the mission profile. Finally, we report on the ongoing activities related to the scientific payload.

SCIENTIFIC RATIONALE AND MISSION OBJECTIVES

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 in detail and under conditions impossible to reproduce on Earth or to study from astronomical distances. The results from missions such as Helios, Ulysses, Yohkoh, SOHO, and TRACE have advanced enormously our understanding of the solar corona, the associated solar wind and the three-dimensional heliosphere. However, we have reached the point where further in-situ measurements, now much closer to the Sun, together with high-resolution imaging and spectroscopy from a near-Sun

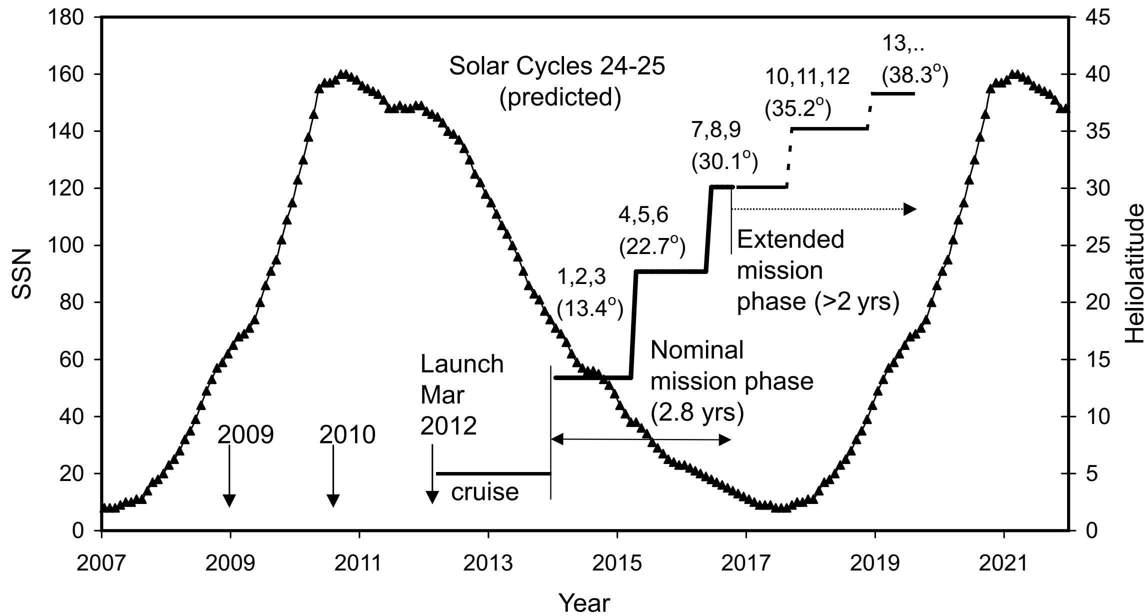

Fig. 1. Solar Orbiter mission phases for a launch in 2012 superimposed on a plot of the (projected) sunspot number for Solar Cycles 24-25. Launch opportunities in 2009 and 2010 are also marked (vertical arrows). Horizontal steps show the maximum heliographic latitude reached during each of the 13 orbits comprising the nominal and extended mission phases.

and out-of-ecliptic perspective, promise to bring about major breakthroughs in solar and heliospheric physics.

ESA's Solar Orbiter will view the Sun from both near-Sun and out-of-ecliptic perspectives, and perform

- Spectroscopy and imaging at high resolution
- Quasi-heliosynchronous *in-situ* sampling of particles and fields
- Remote sensing of the polar regions of the Sun

During the course of the mission the 3-axis stabilised spacecraft will make multiple near-Sun passes at distances down to 0.21 AU (45 $R_\odot$) and at heliographic latitudes reaching 38° in both hemispheres. This unique trajectory will be achieved using interleaved Earth/Venus gravity assists and Solar Electric Propulsion thrusting. As noted above, launch is presently foreseen in the period 2011-2012. This means that Solar Orbiter will carry out the near-Sun phase of its mission during the declining phase of solar cycle 24 (2013-2014), with high-inclination orbits occurring at solar minimum and the rising phase of cycle 25 (Figure 1).

The Solar Orbiter will address four major scientific themes, each at a specific phase of the mission: The Sun's magnetised plasma (close-up observations of the solar atmosphere); Linking the photosphere and corona to the heliosphere (quasi-heliosynchronous observations); Particles and fields (*in-situ* measurements in the unexplored inner heliosphere); The Sun's polar regions and equatorial corona (excursion out of the ecliptic).

Acceleration and Transport of Solar Energetic Particles

The processes which accelerate particles to very high energies are of great interest in astrophysics. Observations of energetic particles close to their sources on the Sun will allow us to study our nearest star, the Sun, as a particle accelerator.

A permanent source of difficulty has been our inability to predict the intensity of solar energetic particles at the Earth from observed transient activity on the Sun. An important part of the problem is that we do not know the suprathermal population that feeds the acceleration processes near the Sun. The efficiency for transferring energy from flares to energetic particles cannot be inferred from remote observations, because an unknown fraction of the accelerated ions remain trapped by strong magnetic fields near the Sun for a significant time after acceleration. Subsequent γ-ray and neutron emissions resulting from their eventual loss to the atmosphere are often too weak to be observable. Present

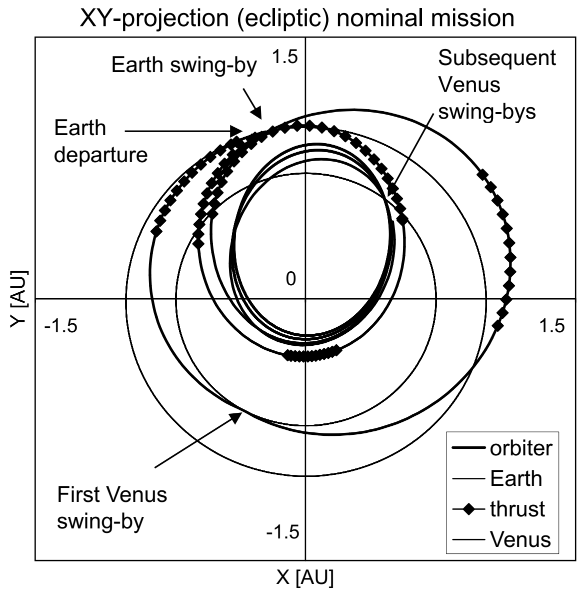

Fig. 2. Ecliptic projection of the Solar Orbiter trajectory (cruise and nominal mission phases).

observations indicate that small transients occur sufficiently often to allow a determination of the efficiency, e.g. by neutrons as proxies for the magnetically bound component. Our ability to solve this issue will be greatly enhanced by the Solar Orbiter, because during its multiple perihelion passages we will (a) gain a better knowledge of the source spectrum, (b) obtain new observations on particle motion in the hypothetical storage region, and (c) measure changes in the spectrum as the ions and electrons propagate from the Sun to the spacecraft after escape from the trapping region.

The Solar Orbiter will for the first time investigate the particle environment in close proximity to the different source regions on the Sun, such as coronal holes, streamers, coronal mass ejections (CMEs) and associated shocks, active regions, and flare locations. In particular, with Solar Orbiter we will be better able to

- determine the solar source conditions for different particle species (e.g. e^-, p, ^{3}He, heavy ions, p/He ratios) from composition measurements, energy spectra and time evolution;
- distinguish clearly between gradual (shock-associated) CME events and impulsive flare-type events related to magnetic reconnection;
- study the effects of particle acceleration and turbulence-moderated propagation at different locations with respect to the CME centre;
- find the differences between the particle signatures associated with parallel and perpendicular shocks at the east and west flanks of CMEs;
- probe the effects of magnetic reconfigurations in the aftermath of CME launches, at times when the acceleration processes still occur in the corona;
- detect, perhaps for the first time, energetic particle populations from microflares, a measurement which is not possible further away from Sun due to background problems.

In addition, with Solar Orbiter, we will be able to study important global aspects of the Sun and heliosphere by utilising the energetic particles as probes for the coronal and heliospheric magnetic field, and by analysing the propagation of solar particles and modulation of galactic cosmic rays.

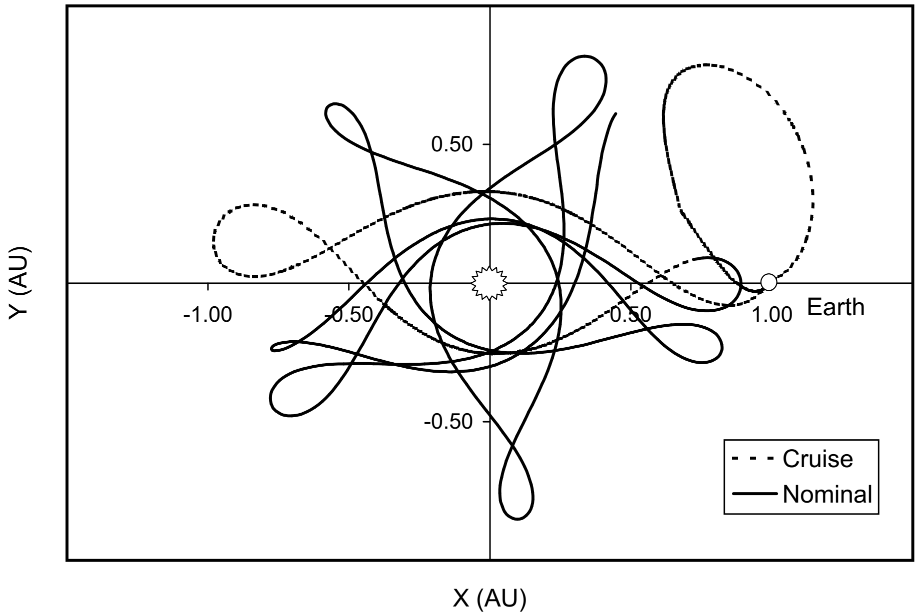

Fig. 3. Solar Orbiter trajectory in a co-ordinate system that is fixed with respect to the Sun-Earth line.

MISSION PROFILE

Using solar electric propulsion (SEP) in conjunction with multiple planetary swing-by manoeuvres, it will take the Solar Orbiter only two years to reach a perihelion of 45 solar radii at an orbital period of 149 days. Within the nominal 5 year mission phase, the Solar Orbiter will perform several swing-by manoeuvres at Venus, in order to increase the inclination of the orbital plane to 30° with respect to the solar equator. During an extended mission phase of about two years the inclination will be further increased to 38° (Figures 1 and 2). Figure 3 shows the trajectory plotted with respect to a fixed Sun-Earth line, demonstrating the excellent coverage in solar longitude. The Solar Orbiter spacecraft will be 3-axis stabilised and always Sun-pointed. Telemetry will be handled via X-band low-gain antennae, and by a 2-axis steerable Ka-band high-gain antenna. The total spacecraft mass is $\sim$1600 kg, which is compatible with a Soyuz-Fregat launch from Kourou. Figure 4 shows a schematic view of the spacecraft configuration during the cruise phase.

SCIENTIFIC INSTRUMENTS

Strawman Payload

The strawman payload currently consists of two sets of instruments: a remote-sensing package focusing on solar observations (Table 1), and an *in-situ* package focusing on heliospheric studies (Table 2). Resources presently foreseen for the scientific instruments include a total mass allocation of $\sim$145 kg and an average data acquisition rate of 75 kbps. In the current baseline, remote-sensing data acquisition is limited to a period of 30 days around perihelion. The final flight payload will be selected by an open competitive process via an ESA AO.

In addition to the instruments listed in Tables 1 and 2, the Payload Working Group is also studying: 1) a hard X-ray telescope that will establish the timing, location and spectra of energetic electrons near the Sun, and so provide a high-energy link between in-situ and imaging observations; 2) a heliospheric imager; and 3) a γ-ray detector.

Payload Working Groups and Future Activities

This mission will take a scientific space probe much closer to the Sun than has ever been reached before by a man-made object. In particular, the thermal load of almost 25 solar constants presents an unprecedented technical challenge, and the scientific instruments have to be designed accordingly. These must be low-mass, compact and intelligent, making use of efficient on-board data compression/storage techniques. Although developments from past space missions may form the starting point, the extreme environment close to the Sun – both thermal and radiation – will, with high probability, necessitate innovative new designs.

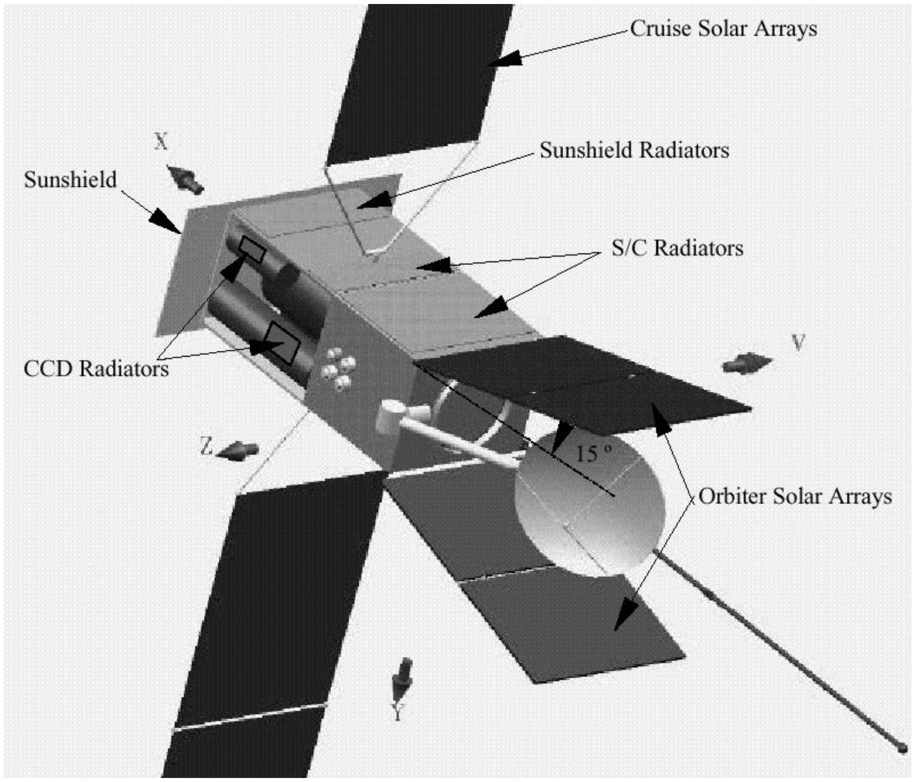

Fig. 4. Schematic design of the spacecraft configuration during the cruise phase. The high gain antenna and the Orbiter solar array are stowed.

Table 1. Solar Remote-Sensing Instrumentation (Strawman Payload)

Name	Measurement	Specifications
Visible-light Imager/Magnetograph (VIM)	Hi-res disk imaging and polarimetry	Fe 630 nm line
EUV Imager/Spectrometer (EUS)	Imaging and diagnostics of transition region and corona	EUV emission lines
EUV Imager (EXI)	Coronal imaging	He and Fe ion lines
UV/Visible Coronagraph (UVC)	Imaging and diagnostics of the corona	Coated mirror
Radiometer (RAD)	Solar constant	Visible light

Table 2. Heliospheric In-Situ Instrumentation (Strawman Payload)

Name	Measurement	Specifications
Solar Wind Plasma Analyser (SWA)	Thermal ions and electrons	0 – 30 keV/Q (ions); 0 – 10 keV (e^-)
Radio and Plasma Wave Analyser (RPW)	AC electric and magnetic fields	μV/m – V/m; 0.1 nT – μT
Radio Sounding (CRS)	SW density and velocity	X- and Ka-band
Magnetometer (MAG)	Magnetic fields (DC – 500 Hz)	4 – 65536 nT
Energetic Particle Detector (EPD)	Solar and Cosmic-ray particles (e^- and ions from H to Fe)	e^-: 0.02 – 0.4 MeV ions: 0.02 – 100 MeV/n
Dust Detector (DUD)	Interplanetary dust	10^{-16} – 10^{-6} g
Neutral Particle Detector (NPD)	Neutral atoms	0.6 – 100 keV
Neutron Detector (NED)	Solar neutrons	$>$1 MeV

Given the technical and financial constraints associated with this mission, it is essential that key technologies requiring significant development be identified as early as possible. ESA has therefore set up a Payload Working Group (PWG), comprising two subgroups - a “Remote-sensing Instrumentation PWG” and an “In-situ Instrumentation PWG” - made up of members of the scientific community with expertise in instrumentation of the kind envisaged for the Solar Orbiter. The tasks of the PWGs include: 1) a realistic assessment of the strawman payload, including definition of mass, size, power requirements; 2) identification of key problem areas arising as a result of the extreme thermal and radiation environments; 3) identification of necessary technological developments; and 4) provision of detailed input to a Solar Orbiter Payload Definition Document (PDD).

The schedule of activities as currently foreseen is as follows:

- Draft PDD by end 2002
- Refinement of PDD inputs Jan-Mar 2003
- Resource analysis, leading to an optimised payload complement by Jun 2003
- Kick-off Industrial Mission assessment Jul 2003 (6-9 months)
- AO release end 2004
- Phase B/C/D: 2005-2010

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