# PROSPECTS OF FUTURE SOLAR SPACE MISSIONS

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ABSTRACT

Recent results from solar space missions like Yohkoh, SOHO, TRACE, ACE, and Ulysses have produced stunning results that are invigorating solar research and challenging existing models of the Sun. Future space missions and new ground-based instruments promise to continue this "solar renaissance" in all areas of solar physics. This paper provides an overview of the next generation of solar space missions. The scientific objectives, mission profiles and payload capabilities of Solar-B, STEREO, Picard, SST, SDO, ASCE, Solar Probe, Solar Orbiter, Sentinels, and RAM are summarized.

## 1. INTRODUCTION

We have come a long way since the pioneering series of OSO missions and Skylab in the sixties and seventies. Recent solar space missions, in particular Yohkoh, SOHO, and TRACE have provided an unprecedented, thorough view of our star and have truly revolutionized solar physics. The next generation of solar space missions that includes Solar-B, STEREO, SDO, Solar Orbiter, Solar Sentinels, and hopefully others such as Solar Probe, ASCE, and RAM, promises to continue this "solar renaissance" by providing the ability to investigate solar processes on their fundamental scales, whether subarcsecond or global in nature, and by adding new viewing angles — high latitude, far-side, and out of Sun-Earth line viewing as well as close encounters.

Table 1 gives an overview over past, ongoing and planned space missions. In the following sections, the missions listed under "In development and under study" are discussed in more detail. Suborbital rocket and balloon flights are discussed elsewhere in this volume.

## 2. SOLAR-B

Solar-B[1] is an ISAS mission with US and UK participation as follow-on to the highly successful *Yohkoh* mission (Antiochos et al., 1997). Launch is planned for August 2005. The key scientific objectives of Solar-B are to study the generation and transport of magnetic fields and their role in heating and structuring the chromosphere and corona, and in eruptive events and flares. The 3-axis stabilized satellite (total mass ≈ 900 kg) will be launched into a polar sun-synchronous orbit with inclination 97.9°, altitude approximately 600 km and a nominal lifetime in orbit of three years. It points continuously to the Sun and is only occasionally occulted by the Earth for short periods of about two weeks duration.

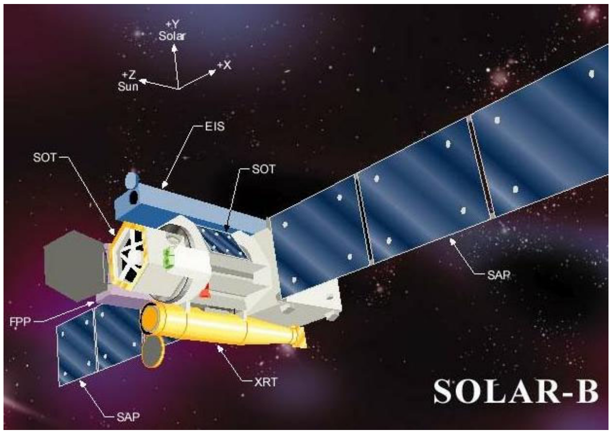


*Figure 1. Schematic view of the Solar-B spacecraft. The scientific instruments described in the text (SOT, FPP, XRT, EIS) are indicated.*

Its scientific payload comprises three instruments (Fig. 1). At the heart of Solar-B is a diffraction limited 50-cm aperture Solar Optical Telescope (SOT), with its Focal Plane Package (FPP) designed for high resolution photospheric and chromospheric imaging and spectro-polarimetry (Fig. 2). In addition there are two coronal instruments, the X-Ray Telescope (XRT) and the Extreme-ultraviolet Imaging Spectrometer (EIS).

The SOT will preserve image quality and ≈ 150 km diffraction limited resolution from 3880 – 6600 Å. It will feed the FPP which consists of the following three main components:

(i) a broad-band interference filter imager (BFI),

(ii) a narrow-band tunable birefringent filter imager (NFI),

[1] http://science.msfc.nasa.gov/ssl/pad/solar/solar-b.stm

| Mission | Launch | Scientific Objectives | Measurements |
|---|---|---|---|
| **Past Missions** | | | |
| OSO 1–8 | 1962-1978 | solar activity, flares | X-ray, UV |
| Skylab | 1973-1974 | solar atmosphere, corona | X-ray, EUV, UV, H$\alpha$, coronagr. |
| IMP-8 | 1973-2001 | solar wind plasma | *in situ* particles and fields |
| HELIOS 1 | 1974-1984 | heliosphere, plasma, particles | *in situ* particles and fields |
| HELIOS 2 | 1976-1980 | heliosphere, plasma, particles | *in situ* particles and fields |
| ISEE-3 | 1978-1983 | solar wind plasma | *in situ* particles and fields |
| SMM | 1980-1989 | solar activity, flares | X- + $\gamma$-ray, UV, total irradiance |
| Hinotori | 1981-1991 | solar activity, flares | X-ray imaging + spectroscopy |
| CORONAS-I | 1994-1995 | solar interior and activity | X- + $\gamma$-ray, UV, total irradiance |
| Yohkoh | 1991-2002 | solar flares | X- and $\gamma$-ray imaging + spectrosc. |
| **In Operation** | | | |
| Ulysses | 6 Oct 1990 | 3-D structure of heliosphere | *in situ* particles and fields |
| SAMPEX | 3 Jul 1992 | energ. particles, cosmic rays | *in situ* particles |
| Wind | 1 Nov 1994 | solar wind plasma | *in situ* particles and fields |
| SOHO | 2 Dec 1995 | solar interior, coronal heating, solar wind acceleration | helioseismology, irradiance, UV/EUV imaging & spectrosc. coronagraphy, *in situ* particles |
| ACE | 25 Aug 1997 | elemental & isotopic comp. of solar wind & energetic part. | *in situ* particles and fields |
| TRACE | 2 Apr 1998 | structure & dynamics of TR and corona | high res UV/EUV imaging |
| GOES-12/SXI | 23 Jul 2001 | solar flares | soft X-ray images |
| GENESIS | 30 Jul 2001 | isotopic & elemental abundances of solar wind | collection of SW sample and return for ground analysis |
| CORONAS-F | 31 Jul 2001 | dynamical processes of solar activity; flares | X-ray imaging + spectroscopy UV, coronagraphy, solar irrad. |
| HESSI | 5 Feb 2002 | flares / particle acceleration | X- & $\gamma$-ray imaging + spectrosc. |
| **In Development and Under Study** | | | |
| Solar-B | Aug 2005 | generation and transport of mag. fields; coronal heating | high res. vis. light magnetometry, EUV spectrosc., X-ray imaging |
| STEREO | Nov 2005 | CME origin and propagation | coronagraphy, UV imaging, *in situ* particles |
| PICARD | 2005 | solar diameter & shape | full Sun UV & visible imaging |
| Space Solar Telescope | 2005+ | magnetic fields, heating & expansion of corona | 1 m optical telescope EUV imaging, coronagraphy X-,$\gamma$-ray spectr. |
| SDO | Aug 2007 | nature of solar variability that affect life and society | helioseismology, magnetometry, UV imaging + spectroscopy EUV irradiance, photometry, coronagaphy |
| ASCE | 2007+ | coronal heating & solar wind acc. | UV spectrosc. coronagraphy |
| Solar Probe | 2009+ | cornal heating and solar wind acceleration | *in situ* particles and fields, imaging in EUV and vis. light magnetography, coronagraphy |
| Solar Sentinels | 2009+ | CMEs and geo-eff. SW | *in situ* & remote sensing |
| Solar Orbiter | 2011/12 | near-Sun heliosphere, dynamics of mag. atmosphere, out-of-ecliptic imaging of polar regions | *in situ* particles and fields, UV/EUV imaging & spectrosc., visible light magnetometry, coronagraphy, radio |
| RAM | 2014 | magnetic reconnection & microscale | ultra-high resolution X-ray, EUV/UV imaging + spectr. |

*Table 1. Past, present, and future space missions.*

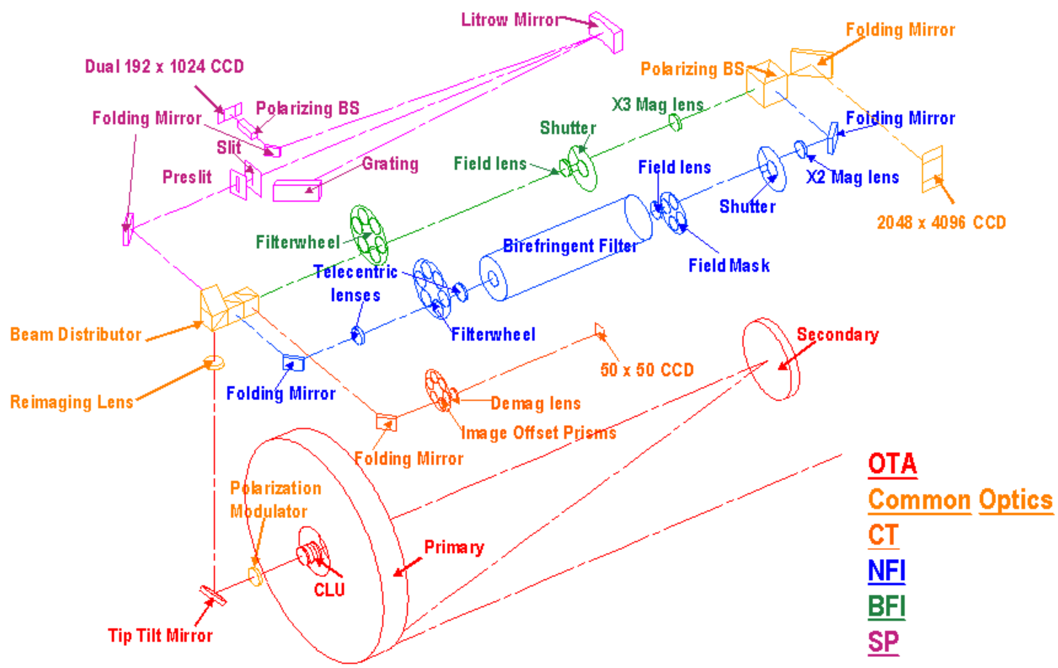


*Figure 2. Schematic view of the Solar-B Solar Optical Telescope (SOT) and its associated Focal Plane Package (FPP).*

(iii) a spectro-polarimeter (SP; Lites et al. 2001), essentially a space version of the HAO Advanced Stokes Polarimeter.

The image will be stabilized to better than 0.02 arcsec over a range from 0.02 to 20 Hz by a correlation tracker and active tilt mirror. The broad-band filter system will make diffraction-limited images with 0.05 arcsec pixels in the Ca II H line, CN and G bandheads, and continuum bands. Its maximum field-of-view (FOV) is 216 $\times$ 108 arcsec$^2$. It has a common focal plane with the narrow-band filter system, which will make filtergrams, (vector) magnetograms, Dopplergrams, and Stokes images in several photospheric lines, Mg b, and H$\alpha$. It has 0.08 arcsec pixels and a FOV up to 165 $\times$ 328 arcsec$^2$. The spectro-polarimeter will make vector magnetic measurements from Stokes spectra of the Fe I lines 6301 and 6302 Å, with 0.16 arcsec pixels and a FOV same as that of the narrow-band filter. The SP and filter imagers will usually observe simultaneously on the same target region.

XRT is an enhanced version of the SXT instrument on *Yohkoh*, providing atmospheric images at wavelengths from 2 to 60 Å. The image scale is 1 arcsec/pixel which is a factor 2.5 better than that of SXT, and it will respond to a broader range of plasma temperatures. XRT is a grazing-incidence (GI) modified Wolter I X-ray telescope, of 35 cm inner diameter and 2.7 m focal length. The 2048x2048 back-illuminated CCD has 13.5 $\mu$m pixels, corresponding to 1.0 arcsec and giving full Sun field of view. A small optical telescope using the same CCD will provide visible light images for coalignment with the SOT.

EIS[2] consists of a multilayer-coated off-axis telescope mirror (150 mm aperture) and a multilayer-coated toroidal grating spectrometer. It uses two back-thinned CCDs with 13.5 $\mu$m pixels as detectors. The instrument includes thin-film aluminum filters to reject longer wavelength radiation, a slit mechanism and two back-thinned CCD detectors at the focal plane. Monochromatic images are formed either by rastering the solar image across a narrow entrance slit or by using a very wide slit. The mirror and spectrometer combined will have a spatial resolution capability of 2 arcsec while the plate scale is 1”/pixel. The spectral resolution is good enough to allow the measurement of velocity to $\pm 3$ km/s. Half of each optic is coated to optimize reflectance at 170 – 210 Å, and the other half to optimize reflectance at 250 – 290 Å. Each wavelength range is imaged onto a separate back-thinned CCD detector of high quantum efficieny ($\approx$ 80%) for the chosen wavelenghts. The two wavelength bands include emission lines formed over a temperature range from roughly 0.1 to 20 MK. There are several pairs of density-sensitive lines.

## 3. STEREO

The principal scientific objective of NASA’s Solar-TErrestrial RElations Observatory[3] (STEREO; Rust et al., 1998) is to understand the origin and consequences of coronal mass ejections (CMEs). By using two identically instrumented spacecraft, one drifting ahead of Earth and one behind, it will provide new perspectives on the structure of the solar corona and CMEs. It will obtain simultaneous images of the Sun from the two spacecraft and build a 3-D picture of CMEs and the complex structures around them. It will also study the propagation of disturbances through the heliosphere and their effects at

[2] http://www.mssl.ucl.ac.uk/solar-b/

[3] http://sd-www.jhuapl.edu/STEREO/

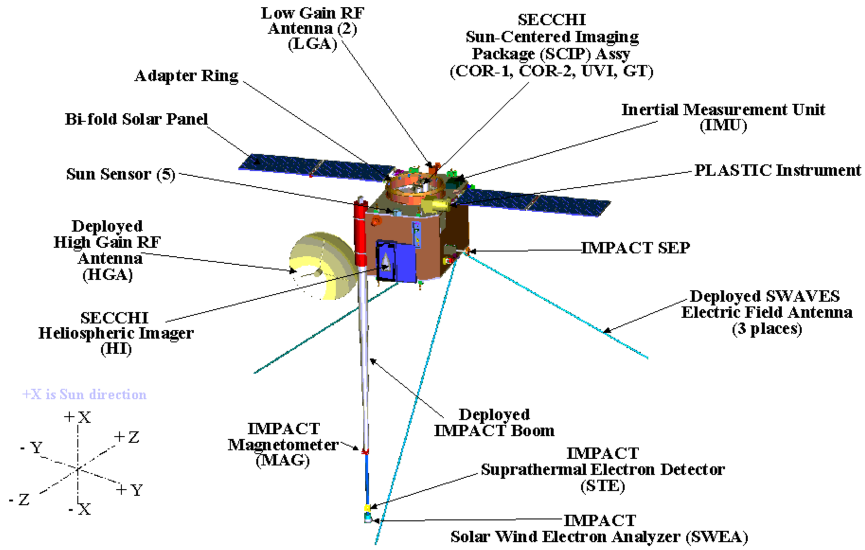


*Figure 3. Schematic view of a STEREO spacecraft.*

Earth orbit. STEREO is a multilateral international collaboration involving participants from France, Germany, the United States, and the United Kingdom. The two spacecraft carry four identical instrument suites (Fig. 2):

(i) SECCHI[4], the Sun Earth Connection Coronal and Heliospheric Investigation, which includes four instruments: two white-light coronagraphs (covering the range 1.25–4 $R_\odot$, and 2–15 $R_\odot$), an EUV imager (full-disk, 1” pixels) and a heliospheric imager (an externally occulted coronagraph that can image the heliosphere from 12 $R_\odot$ to beyond Earth’s orbit)

(ii) STEREO/WAVES (SWAVES), an interplanetary radio burst tracker that will trace the generation and evolution of traveling radio disturbances from the Sun to the orbit of Earth.

(iii) IMPACT, the In situ Measurements of Particles and CME Transients investigation, which will measure the 3-D distribution and plasma characteristics of solar energetic particles and the local vector magnetic field.

(iv) PLASTIC, the PLAsma and SupraThermal Ion and Composition experiment, which will provide plasma characteristics of protons, alpha particles and heavy ions.

STEREO is scheduled for launch on a Delta 2925-10L in November 2005. Each of the two spacecraft weights approximately 556 kg (dry mass) and provides 540 W power. They will slowly drift apart in ecliptic longitude with a total separation of 45° after the first year and 90° after the second year. The mission is expected to last two years at minimum, hopefully five years.

[4] `http://projects.nrl.navy.mil/secchi/index.html`

## 4. PICARD

PICARD (Damé et al, 2001) is a CNES microsatellite mission to measure the solar diameter, solar shape, solar differential rotation, and the solar constant over three years to investigate the nature of their relations and their variabilities. A key objective is to provide a reliable measurement of the ratio $W = \frac{d\ln(R)}{d\ln(L)}$. The main instrument on PICARD is a 110 mm telescope that will provide full disk images of the Sun on a 2k × 2k CCD detector in 4 wavelengths bands: 230 nm, 548 nm, 160 nm, and Ly $\alpha$. Now in Phase B, PICARD is expected to be launched in 2005.

## 5. SPACE SOLAR TELESCOPE - SST

The Space Solar Telescope (SST) was proposed in 1992 by Guoxiang Ai in China, and has subsequently been considered for a bilateral collaborative project between China and Germany (Schmidt and Ai, 1998). Its key scientific objectives are to measure magnetic fields in the photosphere and chromosphere at very high spatial resolution, to determine their 3-D topology, and to understand the heating, cooling and expansion of the corona in the context of the underlying magnetic field structure. The principal instrument of SST will be a 1-m diffraction limited optical telescope for high resolution magnetometry. It will be complemented by a full disk H$\alpha$ and white light telescope, a bundle of high resolution EUV imagers, a coronagraph, a wide band X-ray and Gamma-ray spectrometer, and a solar and interplanetary radio spectrometer. Total spacecraft mass is estimated to be 2000 kg. Target orbit is a sun-synchronous, nearly polar orbit of 730 km altitude and 98.3° inclination.

## 6. SOLAR DYNAMICS OBSERVATORY (SDO)

The Solar Dynamics Observatory[5] (SDO, Hathaway et al., 2001) is the first cornerstone mission in NASA's Living With a Star (LWS) programme, which is an initiative "to develop the scientific understanding necessary to effectively address those aspects of the coupled Sun-Earth system that directly affect life and society". Since the 2002 IACG meeting in Padua, LWS is part of the "International Living with a Star" (ILWS) programme. SDO's objective in this programme is to understand the nature and source of solar variability that affects life and society. Key questions to be addressed by SDO are: What mechanisms drive the quasi-periodic 11-year cycle of solar activity? How is active region magnetic flux synthesized, concentrated, and dispersed across the solar surface? Where do the observed variations in the Sun's total and spectral irradiance arise, and how do they relate to the magnetic activity cycle? Is it possible to make accurate and reliable forecasts of space weather and climate?

To address these questions, the NASA Announcement of Opportunity (released on 18 January 2002; AO 02-OSS-01) invited proposals for the following instruments, from which NASA expects to select a complementary subset, depending on costs and available resources:

- a Helioseismic and Magnetic Imager (HMI — an advanced version of the MDI instrument on SOHO), that will provide continuously full disk, 1-arcsec resolution oscillations images and magnetograms at a cadence of less than 50 sec for near-surface diagnostics of the dynamics of the solar interior for understanding solar variability (both global and local helioseismology techniques).
- an Atmospheric Imaging Array (AIA — a vastly advanced version of the EIT/SOHO and TRACE instruments), that will provide simultaneous high resolution images (0.5 arcsec pixels) of the full disk over a wide range of temperatures (0.02–4 MK) with high time resolution (10 s cadence) to characterize the rapid evolution of plasma in the chromosphere and lower corona.
- a Spectrometer for Irradiance in the EUV (SIE), that provides continuous observations of the full-disk solar EUV irradiance that causes variations in composition, density, and temperature of the Earth's ionosphere and thermosphere. It will operate in the range from 10 to 1200 Å, with 1 Å spectral resolution and 10 s temporal resolution.
- a White-light Coronagraphic Imager (WCI — an advanced version of the LASCO instrument on SOHO), that measures polarized intensity in white light to characterize variations in coronal structure and to detect CMEs.
- a UV/EUV Imaging Spectrometer (UIS — an advanced version of the SUMER/CDS spectrometers on SOHO), to measure line profiles that reveal dynamic properties of the magnetic solar atmosphere from the photosphere into the corona, with comparable time cadence, spatial resolution and field-of-view as AIA.
- a Photometric Imaging Telescope (PIT), that provides measures of photometric intensity over the full solar disk every minute in order to determine the origins of solar luminosity and irradiance variability and to reveal and deep-seated thermal structures that may be associated with the solar cycle and/or active regions.
- a Helioseismic and Vector Magnetic Imager (HVMI), that provides vector photospheric magnetic field observations over the whole disk with 1-arcsec resolution every 10 minutes. This instrument could be an inexpensive optional modification of HMI.

SDO launch is planned for August 2007 for a prime mission of five years. It will fly in an inclined geosynchrononous orbit, which satisfies the requirements for a high scientific data rate well in excess of 100 Mbps and nearly continuous observations with a single dedicated ground station.

## 7. ADVANCED SPECTROSCOPIC AND CORONAGRAPHIC EXPLORER (ASCE)

The Advanced Spectroscopic and Coronagraphic Explorer[6] (ASCE) is one of four mission proposals selected by NASA in April 2002 for a detailed concept study. NASA intends to select two of the four proposals by early 2003 for full development and Medium-class Explorer flights in 2007 and 2008.

ASCE addresses the following three fundamental questions:

- What are the physical processes responsible for heating and accelerating the primary and secondary plasma components of the solar wind?
- How is subphotospheric magnetic energy transported into the corona to be dissipated as heat and to drive mass flows?
- How are CMEs heated and accelerated, and what role do they play in the evolution of the solar magnetic field?

The ASCE payload includes three co-aligned instruments:

(i) Advanced UltraViolet Coronagraph Spectrometer (AUVCS): a large-aperture, externally occulted coronagraph spectrometer designed for spectroscopic diagnostics of the solar corona over a broad UV wavelength range, including H I Ly $\alpha$, H I Ly $\beta$, tthe O VI doublet at 1030 Å, and — for the first time — He II 304 Å.

[5] http://lws.gsfc.nasa.gov/lws_missions_sdo.htm

[6] http://cfa-www.harvard.edu/asce/mission.html

(ii) Advanced Large Aperture Solar Coronagraph (ALASCO): visible light polarimetry over a circular field-of-view from 1.1 to 10.3 $R_\odot$

(iii) Advanced Solar Disk Spectrometer (ASDS): high spatial, spectral, and temporal resolution spectroscopy of the solar disk, chromosphere, transition region, and corona to 1.5 $R_\odot$.

A key element of the ASCE payload is the Deployable External Occulter Module (DEOM), which deploys a linear (AUVCS) and circular (ALASCO) occulter to a distance of 13 meters forward of the respective telescope entrance aperatures. The use of a deployable boom and the resulting larger external occulter to telescope mirror distance significantly increases useful telescope mirror area, decreases scattered light, and allows observations lower in the corona.

A Taurus 2210 ELV delivers ASCE to a 600 km earth orbit at 28.5 degrees inclination.

## 8. SOLAR PROBE

The primary objective of the Solar Probe[7] mission (Gloeckler et al., 1999) is to understand the processes that heat the solar corona and produce the solar wind. The present mission profile foresees the Probe to arrive at the Sun along a polar trajectory perpendicular to the Sun-Earth line with a perihelion of 4 solar radii from the Sun's center. It will first travel to Jupiter for a gravity assist, leave the ecliptic plane, fly over the Sun's poles to within 8 solar radii, and reach perihelion over the equator at 4 solar radii. Two perihelion passages are planned, separated by about 5 years.

To achieve its scientific objective, it carries a complement of *in situ* and remote sensing instruments. The strawman payload includes for the *in situ* science package: vector magnetometer, solar wind ion composition and electron spectrometer, energetic particle composition spectrometer, plasma wave sensor, and a fast solar wind ion detector. The remote sensing package includes a magnetograph/helioseismograph, a high resolution XUV imager, and an all-sky, 3-D coronagraph imager. Mass and power allocations for the whole payload are 19 kg and 16 W, respectively.

An Announcement of Opportunity to propose instruments was issued by NASA in September 2000. Unfortunately, due to budgetary pressures the selection process for these packages is currently on hold and the prospects for the mission were unclear at the time of writing.

## 9. SOLAR SENTINELS

The Solar Sentinels, the next solar mission in NASA's LWS program after SDO, consists of a fleet of spacecraft distributed throughout the heliosphere. Their key objective is to provide global characterization of the heliosphere leading to improved accuracy of transient propagation models and to provide tomographic images of the Sun. While not yet well defined at the time of writing, a Sentinels fleet consisting of six spacecraft was under consideration: four Inner Heliospheric Sentinels in heliocentric orbits ranging between 0.5 and 0.95 AU, a FarSide Sentinel in a 1 AU orbit opposite Earth, on the far side of the Sun, and a single L1 Sentinel to provide solar wind input information to the geospace components. These elements will work together to track solar disturbances as they evolve and transit the inner heliosphere. The inner heliospheric sentinels are spinning satellites. The FarSide Sentinel is three-axis stabilized.

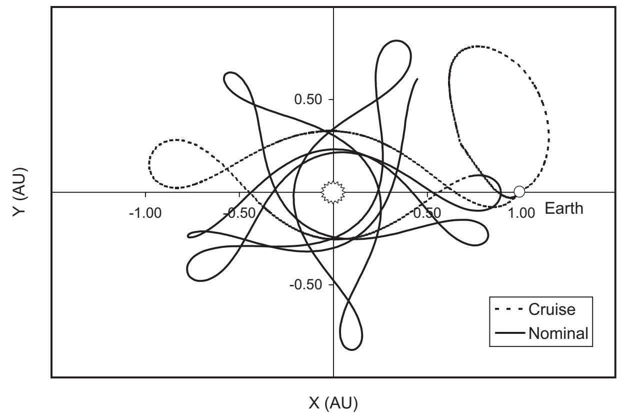


*Figure 5. Solar Orbiter trajectory in a co-ordinate system that is fixed with respect to the Sun-Earth line.*

## 10. SOLAR ORBITER

Solar Orbiter[8] (Marsch et al., 2000, 2001) was selected as a "Flexi"-mission by ESA's Science Programme Committee (SPC) in October 2000. It was re-confirmed by the SPC in May 2002 for implementation with the BepiColombo mission to Mercury as a single project in 2011/2012. An industriual pre-definition study is expected to start in the fall of 2002.

The key mission feature of the Solar Orbiter is to study the Sun from close-up (45 solar radii, or 0.21 AU) in an orbit tuned to solar rotation in order to examine the solar surface and the space above from a co-rotating vantage point at high spatial resolution, and to provide images of the Sun's polar regions from heliographic latitudes as high as 38°. To reach its novel orbit (Fig. 4 and 5), Solar Orbiter will make use of low-thrust solar electric propulsion (SEP) interleaved by Earth and Venus gravity assists.

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 (Fig. 6).

[7] http://www.jpl.nasa.gov/ice_fire/sprobe.htm

[8] http://sci.esa.int/home/solarorbiter/

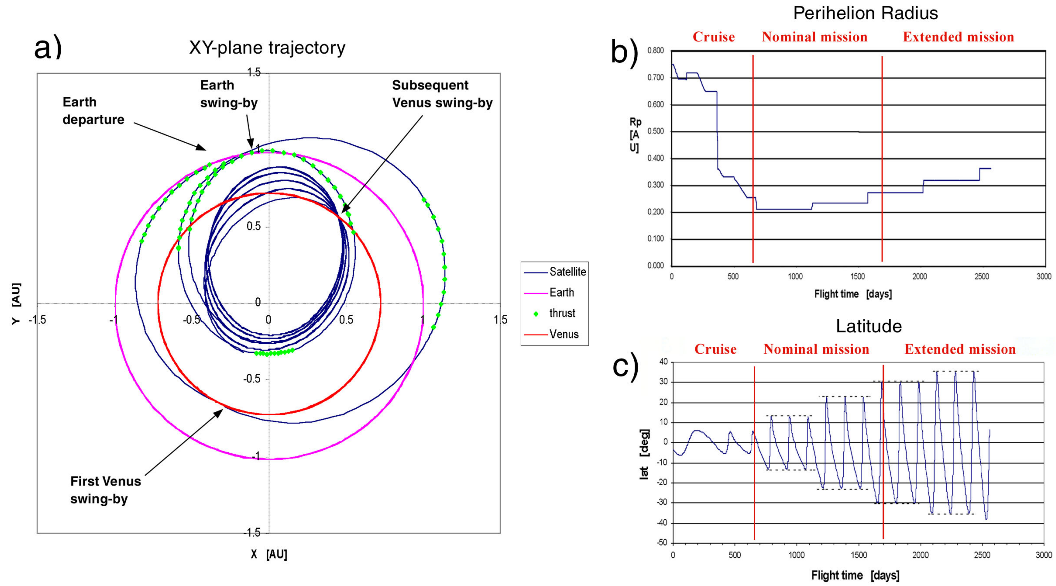


*Figure 4. Orbit design of Solar Orbiter: Ecliptic projection of the spacecraft trajectory (a); perihelion radius (b) and spacecraft heliographic latitude (c) versus mission flight time in days.*

The Solar Orbiter will address four major scientific themes, each at a specific phase of the mission:

(i) The Sun's magnetised plasma: close-up observations of the solar atmosphere;

(ii) Linking the photosphere and corona to the heliosphere: quasi-heliosynchronous observations;

(iii) Particles and fields: *in-situ* measurements in the unexplored inner heliosphere;

(iv) The Sun's polar regions and equatorial corona: excursion out of the ecliptic.

Resources presently foreseen for the scientific instruments include a total mass allocation of 130 kg and a data acquisition rate of 75 kbps. The final flight payload will be selected by an open competitive process via an ESA AO. The strawman payload considered in the Assessment Study (Marsch et al., 2000) encompasses two instrument packages: Solar remote-sensing instruments: EUV full-Sun and high resolution imager, high-resolution EUV spectrometer, high-resolution and full-sun visible light telescope and magnetograph, EUV and visible-light coronagraphs, radiometer. Heliospheric instruments: solar wind analyzer, radio and plasma wave analyser, magnetometer, energetic particle detectors, interplanetary dust detector, neutral particle detector, solar neutron detector.

In May 2002 ESA has established two Solar Orbiter Payload Working Groups (WG): (i) a "Remote-sensing Instrumentation WG" and (ii) an "In-situ Instrumentation WG". The WGs comprise members of the scientific community from both sides of the Atlantic with expertise in instrumentation of the kind envisaged for the Solar Orbiter. One of their tasks is to address potential problem areas arising as a result of the extreme thermal and radiation environment and to identify necessary technological developments.

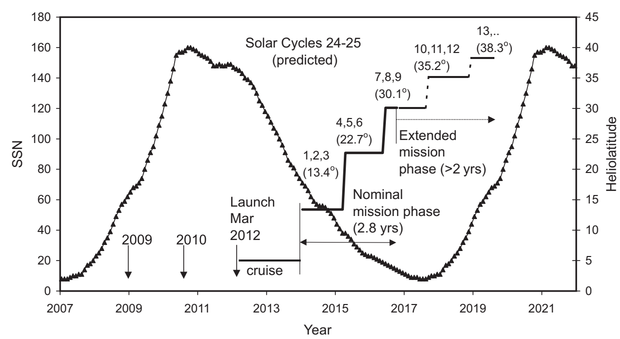


*Figure 6. Solar Orbiter mission phases for a launch in 2012 superimposed on a plot of the (projected) sunspot number for Solar Cycles 24-25. Launch opportunities in 2009 and 2010 are also marked (vertical arrows). Horizontal steps show the maximum heliographic latitude reached during each of the 13 orbits comprising the nominal and extended mission phases.*

## 11. RECONNECTION AND MICROSCALE (RAM) PROBE

The Reconnection and Microscale (RAM) Probe is one of the candidates for future missions currently considered in the ongoing NASA SEC Roadmap process. It will address the fundamental astrophysical processes of magnetic reconnection, micro-scale instabilities and particle acceleration with a set of of imaging and spectroscopic instruments with vastly improved spatial and temporal resolution. The measurement strategy includes:

- Ultra-high resolution (0.02 arcsec/pixel) EUV coronal imaging
- High resolution (0.1 arcsec/pixel) EUV/UV spectroscopy
- X-ray imaging spectroscopy (1 arcsec/pixel; $(\lambda/\Delta\lambda \sim 500\quad 1\,\mathrm{keV})$ from 0.2 to 10 keV, with millisecond time resolution
- Multi-wavelength EUV/UV intermedia scale imaging (0.1 arcsec/pixel)
- High time resolution in all instruments

## 12. CONCLUSIONS

The vast domain from the solar interior to the heliopause is a highly complex physical system, linked to the Sun by its magnetic field and expanding atmosphere, the solar wind. To understand the complex structure and dynamics of the Sun-Heliosphere system requires a multi-spacecraft approach that combines high resolution observations, both remote sensing and *in situ*, with observations from multiple viewing angles and from out-of-ecliptic vantage points. The missions described above represent an exciting fleet of solar space missions. The multiple technique, multiple vantage point approach will open up new areas of research, expanding considerably from our near-Earth/ecliptic view, and will provide crucial new information for solving some of the long-standing scientific questions about the nature of our daylight star and its influence on Earth.

## ACKNOWLEDGMENTS

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## REFERENCES

Antiochos, S., Acton, L., Canfield, R. et al. (1997). The SOLAR-B Mission. Final Report of the Science Definition Team. `http://science.msfc.nasa.gov/ssl/pad/solar/sdt-rpt.stm`

Damé, L., Appourchaux, T., Berthomieu, G., et al. (2001). PICARD: Solar Diameter Measure and g-Mode Search, in Proc. SOHO-10/GONG 2000 Workshop, ESA SP-493, 321-326.

Gloeckler, G. et al. (1999). Solar Probe: First Mission to the Nearest Star. Report of the NASA Science Definition Team for the Solar Probe Mission. `http://www.jpl.nasa.gov/ice_fire/SP_SDT_Report.htm`

Hathaway, D. et al. (2001). Solar Dynamics Observatory — Report of the Science Definition Team. `http://lws.gsfc.nasa.gov/lws_mission_sdo.htm`

Lites, B.W., Elmore, D.F., Streander, K.V. (2001). The Solar-B Spectro-Polarimeter. in Proc. 20th NSO/Sac Peak Summer Workshop, ed. M. Sigwarth, ASP Conf. Ser. 236, p. 33

Marsch, E., et al. (2000). Solar Orbiter - A High-Resolution Mission to the Sun and Inner Heliosphere. Assessment Study Report, ESA-SCI(2000)6.

Marsch, E., Harrison, R., Pace, O., et al. (2001). Solar Orbiter - A High-Resolution Mission to the Sun and Inner Heliosphere, in "Solar Encounter: The First Solar Orbiter Workshop", ESA SP-493, XI-XXVI.

Rust, D. et al. (1998). STEREO Science Definition Team Report, `http://sd-www.jhuapl.edu/STEREO/Sci/ team-Report.html`

Schmidt, W., Ai, G. (1998). Space Solar Telescope, a proposal to observe the Sun at very high resolution, in "A Crossroads for European Solar & Heliospheric Physics", ESA SP-417, 189–198.