Solar Orbiter

T.Appourchaux, L.Gizon and the SO / PHI team
derived from M.Velli's and P.Kletzkine's presentations

2nd Solar-C definition meeting, Tokyo, Japan
Content

- Science Objectives of Solar Orbiter
- Solar Orbiter mission and status
- Helioseismology, magnetic fields and PHI
- Solar Orbiter complementarity with other missions
- Conclusion
To answer How does the solar system work? ESA’s Cosmic Vision Q2.

Sun’s magnetized atmosphere and wind define planetary space environments (CV Q1)

It is the site of universal phenomena which can be studied and understood in detail (CV Q3):

magnetic reconnection, collisionless shocks, turbulence and collective nonlinear effects and energetic particle acceleration
Solar Orbiter in short

- Faster spacecraft rotation rate
- Dynamical reprocessing
- 1 AU
- 0.2-0.3 AU
- 10^5 km

Science objectives
Solar Orbiter is the logical and timely next step after Ulysses and SOHO, combining remote sensing and in-situ experiments.

Solar Orbiter carries a dedicated payload of **10 selected remote-sensing and in-situ instruments** measuring from the photosphere into the solar wind.
How does the Sun create and control the Heliosphere?

Q1) How and where do the solar wind plasma and magnetic field originate in the corona?

Q2) How do solar transients drive heliospheric variability?

Q3) How do solar eruptions produce energetic particle radiation that fills the heliosphere?

Q4) How does the solar dynamo work and drive connections between the Sun and the heliosphere?
**Mission Summary**

- **Launch date:** January 2017
- **Nominal Mission:** 7.5 years
- **Extended Mission:** 2.4 years
- **Orbit:** Elliptical orbit
  - Perihelion: 0.23 – 0.29 AU
  - Aphelion: 0.75 - 1.2 AU
- **Out of Ecliptic View:** multiple gravity assists with Venus to increase inclination out of the ecliptic to >25 deg (nominal mission) >34 deg during the extended mission
- **Co-rotation:** 2 periods of near-synchronization with the Sun’s rotation per orbit, allowing observations of evolving structures on the solar surface & heliosphere for almost a complete solar rotation

**Solar Orbiter Mission Overview**
Payload selected back in 2008
Preliminary Payload review held in end 2009-beg. 2010
Solar Orbiter down selected in February 2010, together with EUCLID and Plato (SPICA having a special status) for Phase A/B1
Two missions to be selected in mid-2011
Start of Phase B1: early 2011
Likely start of Phase B2/C/D: mid-2011
# Solar Orbiter Payload

<table>
<thead>
<tr>
<th>Investigation</th>
<th>Collaboration</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Wind Analyzer (SWA) PI C. Owen, UK</td>
<td>UK, I, F, Japan, D, CH, USA</td>
<td>SW ion &amp; electron bulk properties, ion composition (1eV- 5 keV electrons; 0.2 - 100 keV/q ions)</td>
</tr>
<tr>
<td>Energetic Particle Detector (EPD) J. Rodríguez-Pacheco, Spain</td>
<td>Spain, D, Fi, GR, CH, F, Slovakia, USA</td>
<td>Composition, timing, distribution functions of suprathermal - energetic particles</td>
</tr>
<tr>
<td>Magnetometer (MAG) T. Horbury, UK</td>
<td>UK, A, I, H, D, F, E, DK, USA</td>
<td>DC vector magnetic fields (0 – 64 Hz)</td>
</tr>
<tr>
<td>Radio &amp; Plasma Waves (RPW) M. Maksimovic, France</td>
<td>France, SE, CZ, NO, UK, A, D, GR, AU, I, H, FI, Russia</td>
<td>AC electric and magnetic fields (~DC – 20 MHz)</td>
</tr>
<tr>
<td>Polarimetric and Helioseismic Imager (PHI) S. Solanki, Germany</td>
<td>Germany, E, F, SE, NO, CH, AU, USA</td>
<td>Vector magnetic field and line-of-sight velocity in the photosphere</td>
</tr>
<tr>
<td>EUV Imager (EUI) P. Rochus, Belgium</td>
<td>Belgium, UK, F, D, USA</td>
<td>Full-disk EUV and high-resolution EUV and Lyman-α imaging of the solar atmosphere</td>
</tr>
<tr>
<td>Spectral Imaging of the Coronal Environment (SPICE) D. Hassler, USA</td>
<td>USA, UK, D, F, N</td>
<td>EUV spectroscopy of the solar disk and corona</td>
</tr>
<tr>
<td>X-ray Spectrometer Telescope (STIX) A. Benz, Switzerland</td>
<td>Switzerland, PL, D, CZ, IRE, A, UK, F, USA</td>
<td>Solar thermal and non-thermal x-ray emission (4 – 150 keV)</td>
</tr>
<tr>
<td>Coronagraph (METIS/COR) E. Antonucci, Italy</td>
<td>Italy, CK,F, D, GR, USA</td>
<td>Visible, UV and EUV imaging of the solar corona</td>
</tr>
<tr>
<td>Heliospheric Imager (SolOHI) R. Howard, USA</td>
<td>USA, Belgium, UK, Germany</td>
<td>White-light imaging of the extended corona</td>
</tr>
</tbody>
</table>

Mission and status
Q4) How does the solar dynamo work and drive the connections between the Sun and the heliosphere?

4.1) How is magnetic flux transported to and reprocessed at high solar latitude?

4.2) What are the properties of the magnetic field at high solar latitudes?

4.3) How does the solar dynamo work?
4.1) How is magnetic flux transported to and reprocessed at high solar latitude?

- Detect flows at and below the solar surface, in particular at high latitudes
- Most important flows are:
  - Differential rotation
  - Meridional circulation

Helioseismology and magnetic field
4.2) What are the properties of magnetic fields at high solar latitudes?

At $27^\circ$ magnetic measurement is far improved. Granulation tracking can now follow large-scale flows.
4.3) How does the solar dynamo work?

- SO can probe the tachocline at low / medium latitudes
- Solar-cycle variations at high latitudes
- Joint observations with SDO, GONG (long time series) : probe deep interior; very high potential with Plan-A !
SO/PHI: Polarimetry and helioseismology

- Provide B to EUV imagers and spectrometer (linkage science)
- First proper view of magnetic and velocity field at the poles
- Stereoscopic helioseismology to probe the deep interior
- Stereoscopy of the photosphere
- Provide magnetic context for Solar Probe plus
- S/C resources: 30 kg, 31 W, 20 kbps
SO/PHI instrument concept

- Solar radial velocity and vector magnetic field (absorption line)

- High Resolution Telescope (HRT):
  - FOV: 16.8 arcmin, 1" arcsec resolution (0.5" pixel, 95 kms at 0.28 AU)

- Full Disk Telescope (FDT):
  - FOV: 2.6 deg, 9.3" arcsec resolution (4.6" pixel, 930 kms at 0.28 AU)

- FDT and HRT used in sequence on different part of the orbit
SO/PHI sub-systems

- Entrance window (14-cm diameter)
- HRT / FDT
- Off-pointing mechanisms
- Image Stabilization System (to 0.02 arcsec rms)
- Polarization Modulation Package
- Feed select (HRT or FDT)
- Filtergraph (Fabry-Perot)
- Focal Plane Assembly
- E-box
Potential Synergy with Other Missions: Solar Probe Plus

Joint NASA-ESA Solar Orbiter - Solar Probe Assessment ‘09

Enhanced science from mutual context / alignments
<table>
<thead>
<tr>
<th>Mission</th>
<th>Instruments</th>
<th>Velocity</th>
<th>Magnetic field</th>
<th>Resolution (kms)</th>
<th>Inclination (deg)</th>
<th>Minimum distance (AU)</th>
<th>Duration above 30 deg per orbit (days)</th>
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<tbody>
<tr>
<td>SOHO</td>
<td>SOI</td>
<td>Yes</td>
<td>Longitudinal</td>
<td>3000</td>
<td>7</td>
<td>0.92</td>
<td>0</td>
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<tr>
<td>GOLF</td>
<td>Yes</td>
<td>Longitudinal</td>
<td>None</td>
<td>7</td>
<td>0.92</td>
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<tr>
<td>Hinode</td>
<td>BFI</td>
<td>Yes</td>
<td>Vector</td>
<td>140</td>
<td>7</td>
<td>0.97</td>
<td>0</td>
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<tr>
<td>NFI</td>
<td>Yes</td>
<td>Vector</td>
<td>210</td>
<td>7</td>
<td>0.97</td>
<td>0</td>
<td></td>
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<tr>
<td>SDO</td>
<td>HMI</td>
<td>Yes</td>
<td>Vector</td>
<td>750</td>
<td>7</td>
<td>0.97</td>
<td>0</td>
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<tr>
<td>SOLO</td>
<td>PHI (HRT)</td>
<td>Yes</td>
<td>Vector</td>
<td>190</td>
<td>35</td>
<td>0.28</td>
<td>~15 (perihelie)</td>
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<td></td>
<td>PHI (FDT)</td>
<td>Yes</td>
<td>Vector</td>
<td>1800</td>
<td>35</td>
<td>0.28</td>
<td>~40</td>
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<td></td>
<td>MAG</td>
<td>N/A</td>
<td>Yes</td>
<td>N/A</td>
<td>35</td>
<td>0.28</td>
<td>~40</td>
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<tr>
<td>Plan-A</td>
<td>DSI</td>
<td>Yes</td>
<td>Vector</td>
<td>750</td>
<td>&gt; 40</td>
<td>1</td>
<td>150</td>
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<td>Solar probe +</td>
<td>In-situ</td>
<td>N/A</td>
<td>Yes</td>
<td>N/A</td>
<td>3.4</td>
<td>0.04</td>
<td>0</td>
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</table>

- **High resolution velocity and magnetic field of the poles with SO / PHI**
- **Solar Orbiter has both in-situ and remote sensing instruments**
- **Ideal for linking with any in-situ only mission or remote-sensing only mission**
Conclusion

Solar Orbiter answers the Cosmic Vision question "How does the solar system work?":

- **Exemplified by the theme of Sun-Heliosphere Connection:** Solar Orbiter will reveal how the Sun creates and drives the heliosphere.
- **The selected payload is optimized to answer the most fundamental science questions of solar and heliospheric physics**
- **Solar Orbiter will be launched in 2017, in synergy with Solar Probe Plus, and hopefully Plan-A**
- **Plan-A ideal for 3-D stereoscopic helioseismology!**