THE COMING RENAISSANCE OF INNER HELIOSPHERE OBSERVATIONS FROM SOLAR ORBITER AND SOLAR PROBE

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HISTORIC MISSIONS TO UNDERSTAND THE SUN

- Early missions began observing the Solar Wind at the dawn of the Space Age
  - Russian Luna missions (1959) – first detected the solar wind
  - Mariner 2 (1962) - confirmed presence of solar wind as continuous stream
  - Pioneer 6+ (1965-1969) – measured the solar wind
  - Skylab (1973-1979) - Observed the Sun and confirmed the existence of coronal holes
- More recent missions continue…..
  - ACE, Ulysses, WIND, SOHO, Yohkoh, RHESSI, STEREO, TRACE, SDO….
HELIOS SPACECRAFT—THE FIRST VIEW OF THE INNER HELIOSPHERE

- Launched in 1974, 1976 on orbit that took them in to 0.29 AU.
  - Plasma Experiment (protons, electrons, helium)
  - Flux-gate Magnetometer
  - Plasma Wave Experiment
  - Cosmic Ray Experiment
  - Low-Energy Electron and Ion Spectrometer
  - Dust Experiments
- The original “solar probe” with a goal of investigating the matter between the Sun and Earth.
- Had no solar imaging capabilities
PAVING THE WAY TO SOLAR ORBITER AND SOLAR PROBE

- Prior missions gave us a foundation for understanding:
  - The solar wind is a continuous stream of charged particles, with varying speeds, densities, etc. and carries the solar magnetic field.
  - The heliosphere has radial and latitudinal variations, related to structure on the Sun.
  - Coronal holes produce high speed winds
  - Coronal mass ejections drives interplanetary shocks
  - The corona is >1MK
- These missions were not able to explore the regions where the solar wind is formed/accelerated or where heliospheric structures form.
WHY SOLAR ORBITER?

We need to be able to link observed structures and wind streams back to their sources on the Sun. Solar Orbiter seeks to answer the question "How does the Sun create and control the heliosphere?"

- 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?
Figure 2.13. Coordinated remote and in-situ observations of a flare source (lower left) producing a jet seen in UV and X-rays which outline the loops and interactions at loop footpoints (blue). Escaping electrons produce a radio burst (upper right) whose frequency depends on coronal height of the emitting particles. At the Solar Orbiter spacecraft, prompt arrival of energetic electrons time the arrival of escaping particles, and energetic ions provide signatures of extreme fractionation produced by the acceleration mechanism. The prompt arrival of the particles establishes that Solar Orbiter is magnetically connected to the X-ray source, allowing comparison with coronal magnetic field models in the region of the active region. (Figure adapted from A. Benz, 3rd Solar Orbiter Workshop, Sorrento)
McComas et al. 2008
### SOLAR ORBITER INSTRUMENTS AS PROPOSED

**Table 3.7 Solar Orbiter selected payload resource summary.**

<table>
<thead>
<tr>
<th>Investigation</th>
<th>Total Mass (kg)</th>
<th>Margin (%)</th>
<th>Power (W)</th>
<th>Margin (%)</th>
<th>Dimensions</th>
<th>Telemetry (kbps)</th>
<th>FOV</th>
<th>Heritage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>In-Situ</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Wind Analyzer (SWA)</td>
<td>15.9</td>
<td>15.0</td>
<td>14.2</td>
<td>~15</td>
<td>EAS: 11.5 cm x dia. 13.6 cm PAS: 30 x 20 x 20 cm HIS: 31 x 28 x 25 cm</td>
<td>14</td>
<td>EAS: 360° x ±45° PAS: -17.5° to +47.5° Azimuth-22.5° to +22.5° Elevation</td>
<td>Ulysses, ACE, STEREO</td>
</tr>
<tr>
<td>Energetic Particle Detector (EPD)</td>
<td>13.8</td>
<td>15.0</td>
<td>16.1</td>
<td>20.0</td>
<td>EPT1,2: 11 x 7 x 12 cm SIS1,2: 35 x 13 x 11 cm LET1,2: 22 x 15 x 11 cm HET: 13.8 x 17 x 16.2 cm STEIN: 10 x 13 x 13 cm</td>
<td>3.1</td>
<td>EPT 1.2: 30° cones SIS: 22° core (2x) LET1,2: 40° cone (3x) HET: 50° cone (2x) STEIN: 60° x 70° (2x)</td>
<td>STEREO, SOHO, ACE</td>
</tr>
<tr>
<td>Magnetometer (MAG)</td>
<td>2.1</td>
<td>10.0</td>
<td>1.9</td>
<td>25.0</td>
<td>Fluxgate sensor (2x): 9.75 x 4.9 x 6.7 cm Electronics: 15.9 x 16.2 x 9.8 cm</td>
<td>0.9 (normal) 6.8 (burst mode)</td>
<td>N/A</td>
<td>VEX, Themis, Rosette Lander, Double Star</td>
</tr>
<tr>
<td>Radio &amp; Plasma Waves (RPW)</td>
<td>13.6</td>
<td>15.0</td>
<td>11.5</td>
<td>20.0</td>
<td>Antenna (3x): 650 cm long SCM: 13.6 x dia. 10.4 cm Electronics: 24 x 21 x 15 cm</td>
<td>5</td>
<td>N/A</td>
<td>STEREO</td>
</tr>
<tr>
<td><strong>Remote</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polinmetric and Helioseismic Imager (PHI)</td>
<td>29.1</td>
<td>25.0</td>
<td>31.0</td>
<td>25.0</td>
<td>Optical unit: 79.5 x 40 x 29 cm Electronics: 20 x 40 x 29 cm</td>
<td>20</td>
<td>HRT: 16.8 x 16.8 arcmin FDT: 2.6° cone</td>
<td>SUNRISE/IMaX</td>
</tr>
<tr>
<td>EUV Imager (EUI)</td>
<td>18.1</td>
<td>20.0</td>
<td>24</td>
<td>25.0</td>
<td>Optical bench: 83 x 54.5 x 22.8 cm Electronics: 120 x 300 x 250 mm</td>
<td>20</td>
<td>FST: 5.2 x 5.2 arcdeg HRI: 1000 x 1000 arcsec</td>
<td>SOHO, STEREO, TRACE, PROBA2</td>
</tr>
<tr>
<td>Spectral Imaging of Coronal Environment (SPICE)</td>
<td>18.4</td>
<td>18.0</td>
<td>28.8</td>
<td>25.0</td>
<td>Optical bench: 91.1 x 34.9 x 17.7 cm Electronics: 20 x 18.6 x 12.4 cm</td>
<td>17</td>
<td>1 arcsec x 17 arcmin slit</td>
<td>SOHO, SUMER, CDS, HinODE</td>
</tr>
<tr>
<td>X-ray Spectrometer Telescope (STIX)</td>
<td>4.4</td>
<td>10.0</td>
<td>4.4</td>
<td>10.0</td>
<td>Imager Module: 55 x dia. 18 cm Spectrometer: 18 x 20 x 22 cm Electronics: 16 x 20 x 22 cm</td>
<td>0.2</td>
<td>2.5° for spectroscopy 1.5° for imaging</td>
<td>RHESSI</td>
</tr>
<tr>
<td>Coronagraph (METIS/CR)</td>
<td>20.6</td>
<td>25.0</td>
<td>25.0</td>
<td>25.0</td>
<td>Optical Bench: 90 x 44 x 25 cm Electronics: 22 x 25 x 10 cm</td>
<td>10</td>
<td>1.3°-3° annular, off-limb corona</td>
<td>SCORE/HERSHEYEL</td>
</tr>
<tr>
<td>Heliospheric Imager (SolOHi)</td>
<td>11.2</td>
<td>20.0</td>
<td>10.0</td>
<td>10.0</td>
<td>Optical unit: 425 x 140 x 180 mm Electronics: 100 x 100 x 50 mm</td>
<td>20</td>
<td>40° x 40°, offset 5° from Sun centre</td>
<td>STEREO</td>
</tr>
</tbody>
</table>
Solar Orbiter Orbit
SOLAR ORBITER ORBIT

- Launch scheduled for October 2018
- Cruise phase
  - Lasts ~3 years
  - Up to 7 degrees inclination
- Nominal Mission Phase
  - Lasts ~5 years (before first pass inside of 0.35 AU)
  - Up to 25 degrees inclination
- Extended Mission Phase
  - Lasts ~2 years
  - Up to 33 degrees inclination
WHY SOLAR PROBE

“To determine the structure and dynamics of the Sun’s coronal magnetic field, understand how the solar corona and wind are heated and accelerated, and determine what mechanisms accelerate and transport energetic particles.”

This goal is divided into three objectives

1. Trace the flow of energy that heats and accelerates the solar corona and solar wind.
2. Determine the structure and dynamics of the plasma and magnetic fields at the sources of the solar wind.
3. Explore mechanisms that accelerate and transport energetic particles.

To observe as close as 9Rs gives us a chance to observe the generation of the solar wind at its source.
HOW? SAMPLE CORONAL PARTICLES AND FIELDS IN SITU

= Wave speed

Image courtesy M. Velli
THE SCIENCE INVESTIGATIONS

- Coronal and solar wind plasmas
  - Solar Wind Electrons Alphas and Protons (SWEAP) Investigation
- Electric and magnetic fields
- Energetic particle radiation
- Wide field white light imager
TRADING ANGULAR MOMENTUM WITH VENUS

Launch
July 30, 2018

1st Min Perihelion at 9.5 $R_S$
12/19/2024

1st Perihelion at 35 $R_S$
10/31/2018

Venus Flyby1
9/27/2018
Venus flyby2
12/21/2019

Venus Flyby5
10/10/2021
Venus Flyby6
8/15/2023

Venus Flyby7
10/31/2024

Venus Flyby3
7/5/2020
Venus Flyby4
2/15/2021

Sun
Mercury
Venus
Earth
TIMELINE

- Launch: July 2018 on Delta-IV Heavy
- First perihelion @ 34 Rs October 2018
- First perihelion with @ 10 Rs December 2024
Collector Assembly at 700C

Courtesy J. Kasper
SOLAR PROBE + SOLAR ORBITER

- Connecting in-situ observations ~10Rs with in-situ and remote observations ~60Rs give unique opportunities for observing the evolution of solar plasma from the corona into the inner heliosphere.

- Multipoint observations in the inner heliosphere will provide a new detailed view of structures and phenomena.

- Out of the ecliptic view of the inner heliosphere gives 3D view of the inner heliosphere.

- Coordinated campaigns with ground based and L1 based observatories offer opportunities to maximize science.
SOLAR ORBITER + SOLAR PROBE

SO & SPP observe the same energetic particles along a magnetic field line. SO observes the acceleration site remotely.

SO observes remotely the plasma low in the corona (UV spectra) and at 9.5 Rs (SoloHI); SPP measures plasma in situ at 9.5 Rs and with SPP/HI out to >50 Rs.

Coronal plasma ~10 hours of transit time at ~150 km/s

Marsch et al. 2006
SUMMARY

Together Solar Probe and Solar Orbiter Will

• Reveal the sources and mechanisms for the origin of the magnetic field and the solar wind
• Explore mechanisms for energetic particle acceleration and transport
• Examine how dynamics of the heliosphere is driven by transient and recurrent features on the Sun
THE END