The Living With a Star (LWS) Sentinels Mission

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<tr>
<th>Name</th>
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<tr>
<td>Robert P. Lin (Chair)</td>
<td>UCB</td>
<td>Spiro K. Antiochos</td>
<td>NRL</td>
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<td>Antoinette B. Galvin</td>
<td>UNH</td>
<td>Dennis K. Haggerty</td>
<td>APL</td>
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<td>Stephen W. Kahler</td>
<td>AFRL</td>
<td>Joseph E. Mazur</td>
<td>Aerospace</td>
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<td>Richard A. Mewaldt</td>
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<td>Neil Murphy</td>
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<td>James M. Ryan</td>
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<td>Rainer Schwenn</td>
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<td>Thomas Zurbuchen</td>
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<td>Robert F. Wimmer-Schweingruber</td>
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Ex-Officio and other non-members:

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<tbody>
<tr>
<td>Adam Szabo</td>
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<td>Sentinels Study Scientist</td>
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<td>Michael Wargo</td>
<td>NASA/HQ</td>
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<td>Lika Guhathakurta</td>
<td>NASA/HQ</td>
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<td>Chris StCyr</td>
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<td>Haydeee M. Maldonado</td>
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<td>Hermann Opgenoorth</td>
<td>ESA</td>
<td>ILWS Chair</td>
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<tr>
<td>Ronald D Zwickl</td>
<td>NOAA/SEC</td>
<td>User Community Representative</td>
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## STDT Meetings:

<table>
<thead>
<tr>
<th>Meeting Type</th>
<th>Date Range</th>
<th>Location</th>
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<tr>
<td>Full Meeting #1</td>
<td>Sept 8-10, 2004</td>
<td>Berkeley</td>
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<td>Full Meeting #2</td>
<td>Feb 2-4, 2005</td>
<td>Berkeley</td>
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<td>Full Meeting #3</td>
<td>Apr 11-13, 2005</td>
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<td>Full Meeting #4</td>
<td>Jun 29 - Jul 1, 2005</td>
<td>Berkeley</td>
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<td>Full Meeting #5</td>
<td>Sept 7-9, 2005</td>
<td>U. Michigan</td>
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<td>Writers’ Meeting</td>
<td>Oct 16-20, 2005</td>
<td>Wintergreen</td>
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<tr>
<td>Writers’ Meeting</td>
<td>Mar 2-3, 2006</td>
<td>Greenbelt</td>
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<td>Report Release</td>
<td>May 24, 2006</td>
<td>Spring AGU</td>
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Discover, understand and model the heliospheric initiation, propagation and solar connection of those energetic phenomena that adversely affect space exploration and life and society here on Earth.
Sentinels Science Objectives

- Determine where, when and how are solar energetic particles accelerated and their transport.

- Determine the origin, evolution and interaction of CMEs, shocks and other transient solar wind structures.

- Characterize the interplanetary environment (worse case scenarios)

- Develop forecasting capabilities for Earth, Mars and for spacecraft in transit.
SEP Focused Science Questions

- Determine the roles of CME-driven shocks, flares and other processes in accelerating energetic particles.
  - When and where are energetic particles accelerated by the Sun?
  - How are the energetic particles observed at the Sun related to those observed in the interplanetary medium?
  - What conditions lead to the jets associated with impulsive SEP events?
  - What physical processes accelerate SEPs?

- Identify the conditions that determine when CME-driven shocks accelerate particles to high energy.
  - What are the seed populations for shock-accelerated SEPs and how do they affect SEP properties?
  - How do CME/shock structure and geometry as well as ambient conditions affect SEP acceleration?

- Determine how energetic particles are transported from their acceleration site and distributed in radius, longitude and time.
  - What processes scatter and diffuse SEPs both parallel and perpendicular to the magnetic field?
  - What are the relative roles of scattering, solar wind convection and adiabatic cooling in SEP event decay?
CME Focused Science Questions

• Determine the physical mechanisms of eruptive events that produce SEPs.
  _ What solar conditions lead to the initiation of a fast CME?
  _ How does the pre-eruption corona determine the SEP-effectiveness of a CME?
  _ How close to the Sun and under what conditions do shocks form?

• Determine the multiscale plasma and magnetic properties of ICMEs and shocks.
  _ How does the global 3D shape of ICMEs/shocks evolve in the inner heliosphere?
  _ How does CME structure observed at the Sun map into the properties of interplanetary CMEs?

• Determine how the dynamic inner heliosphere influences the evolution of ICMEs.
  _ How is the inner heliospheric solar wind determined by coronal and photospheric structure?
  _ How do ICMEs interact with the preexisting heliosphere?
  _ How do ICMEs interact with each other?
Sentinels Modeling Requirements

• Global Heliospheric Models
  Inputs: $2\pi$ photospheric magnetic maps
coronal plasma conditions
  Validation: dispersed inner heliospheric in-situ observations
  Enhancements: data assimilation

• Transient Dynamics Models (e.g., CME onset and evolution)
  Inputs: high resolution photospheric vector magnetic fields
coronal plasma conditions
         $2\pi$ photospheric magnetic maps
  Validation: multi-point in-situ measurements of CMEs in inner heliosphere
coronal plasma diagnostics
         white-light coronagraph images of structures
  Enhancements: data assimilation

• SEP Acceleration and Transport Models
  Inputs: turbulence close to the Sun
         source population and SEP properties near acceleration site
         plasma and magnetic configuration at CME-driven shocks
  Verification: in-situ SEP observations at different longitudes
  Enhancements: combining global, initiation and particle codes
Sentinels Measurement Requirements

- Multi-point, in-situ observations in the inner-most heliosphere
- 2π remote observation of the Sun.
- Detailed coronal spectroscopy and wide FOV coronal imaging
Sentinels Observational Strategy

• Inner Heliospheric in-situ Observations
  - Close to the Sun: 1-2 SEP mean-free-paths (<0.3 AU)
  - Sufficient duration: 10s of SEP events (> 30% duty cycle below 0.3 AU)
  - # of points: Minimum of 4 s/c for CME geometry and SEP field line connection

• In-situ and Imaging Observation Overlap
  - Duration: > 1 year
  - FOV: Coronagraph FOV ~0.3 AU (60 Rs)
Inner Heliospheric Sentinels

Instruments

- Dual Magnetometer
- AC Magnetic Fields Search Coil
- Radio Science
- Solar Wind Ions
- Solar Wind Electrons
- Solar Wind Composition
- Suprathermal Electrons and Ions
- Low Energy Ions and Electrons
- High Energy Ions and Electrons
- SEP Charge State
- Neutron Spectrometer
- X-Ray Imager
- Gamma-Ray Spectrometer
3 Venus gravity assists for each spacecraft

Final orbits:
0.25 x 0.76 AU

Orbital periods:
127-137 days

Cruise:
2 yr 3-11 months

Launch opportunities:
March 2012, Feb 2014, Sept 2015, March 2017
Inner Heliospheric Sentinels
Spacecraft Design

- 4 identical spin stabilized spacecraft
- Spin axis: Ecliptic North
- Launch vehicle: single Atlas V-541
- $C_3$: 23-27 km$^2$/s$^2$ depending on launch opportunity
- Delta V: 100 m/s per s/c

- Spacecraft dry mass: 504 kg per spacecraft
- Instrument mass: 70.5 kg per spacecraft
- Total launch mass with margins: 3192 kg

- Power generated at 1 AU: 220 W
- Power generated at 0.25 AU: > 500 W
- Radiation tolerance: 6 krad

- Telemetry rate: 6.5 kbps
- RF frequency: X-band
- RF transmit power: 100 W max
- Real time telemetry
Near-Earth Imaging Sentinel

- Sun-sync Earth orbit.

- Significant overlap with IHS and SDO.

- Instrumentation:
  - Inner Coronagraph (1.3 – 5 Rs)
  - Outer Coronagraph (4 – 55 Rs)
  - UV Spectroscopic

- Similar concept previously proposed under Midex.
Far Side Sentinel

• 1 AU orbit, 120° - 180° leading Earth.

• Taurus launch.

• Total launch mass: 250-350 kg

• Significant overlap with IHS and Solar Orbiter.

• Instrumentation:
  
  * Full Disk Magnetograph
  
  * Optional small in-situ package
Ballistic trajectory that minimizes time to 60 degrees and then drifts from 60 to 180 degrees in < 4 years

- $C_3 = 3.9-4.5\ km^2/s^2$
- Delta-V = 85 m/s
- Launch Vehicle: Taurus 2130
The Phases of Sentinels

Phase 1:
- Inner Heliospheric Sentinels
- Solar Orbiter
- SDO
- STEREO
- WIND, ACE

Phase 2:
- Imaging Sentinels
- ESA Solar Orbiter
- Inner Heliospheric Sentinels

Solar Cycle:
- 2010
- 2015
- 2020
- 2025
ESA Solar Orbiter and Sentinels

• Inner heliospheric (0.22 x 0.9 AU) mission in the same time frame as IHS.

• Both in-situ and remote sensing instrumentation.

• 2\textsuperscript{nd} half of mission to latitudes above 30°.