# The Living With a Star (LWS) Sentinels Mission


Robert P. Lin – STDT Chair
*University of California, Berkeley*

Haydee M. Maldonado – Study Manager
*NASA Goddard Space Flight Center*

Adam Szabo – Study Scientist
*NASA Goddard Space Flight Center*

# Sentinels STDT

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|---|---|---|---|
| Robert P. Lin (Chair) | UCB | Spiro K. Antiochos | NRL |
| Stuart D. Bale | UCB | Joseph M Davila | GSFC |
| Antoinette B. Galvin | UNH | Dennis K. Haggerty | APL |
| Stephen W. Kahler | AFRL | Joseph E. Mazur | Aerospace |
| Richard A. Mewaldt | Caltech | Neil Murphy | JPL |
| Geoff D. Reeves | LANL | Pete Riley | SAIC |
| James M. Ryan | UNH | Karel Schrijver | Lockheed |
| Rainer Schwenn | MPI Lindau | Allan J. Tylka | NRL |
| Thomas Zurbuchen | U Mich | | |

Robert F. Wimmer-Schweingruber University of Kiel

**Ex-Officio and other non-members:**

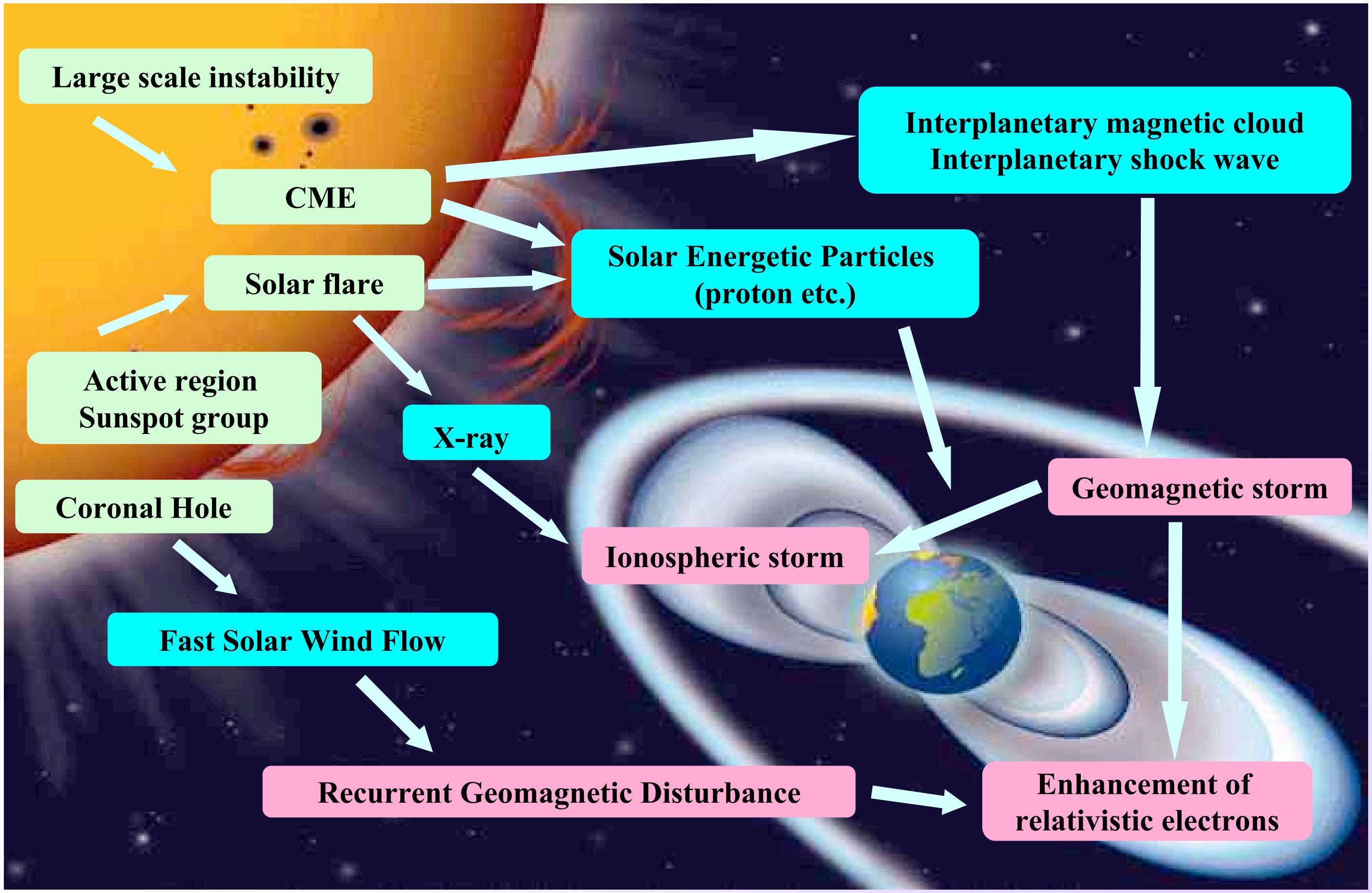
| | | |
|---|---|---|
| Adam Szabo | GSFC | Sentinels Study Scientist |
| Michael Wargo | NASA/HQ | Exploration Representative |
| Lika Guhathakurta | NASA/HQ | Program Scientist |
| Chris StCyr | GSFC | LWS Sr. Project Scientist |
| Haydee M. Maldonado | GSFC | Project Manager |
| Hermann Opgenoorth | ESA | ILWS Chair |
| Ronald D Zwickl | NOAA/SEC | User Community Representative |

# Sentinels STDT

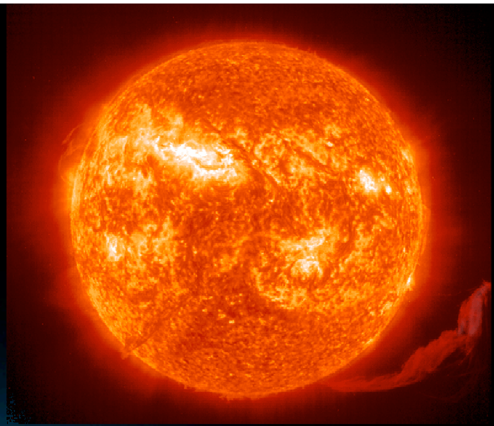
STDT Meetings:

| | | |
|---|---|---|
| Full Meeting #1 | Sept 8-10, 2004 | Berkeley |
| Full Meeting #2 | Feb 2-4, 2005 | Berkeley |
| Full Meeting #3 | Apr 11-13, 2005 | APL |
| Full Meeting #4 | Jun 29 - Jul 1, 2005 | Berkeley |
| Full Meeting #5 | Sept 7-9, 2005 | U. Michigan |
| Writers’ Meeting | Oct 16-20, 2005 | Wintergreen |
| Writers’ Meeting | Mar 2-3, 2006 | Greenbelt |
| Report Release | May 24, 2006 | Spring AGU |

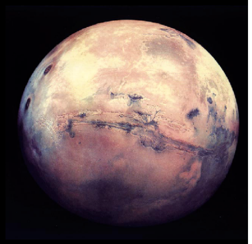
# Sentinels Primary Objective




**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<br>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<br>coronal plasma conditions<br>$2\pi$ photospheric magnetic maps

  Validation: multi-point in-situ measurements of CMEs in inner heliosphere<br>coronal plasma diagnostics<br>white-light coronagraph images of structures

  Enhancements: data assimilation

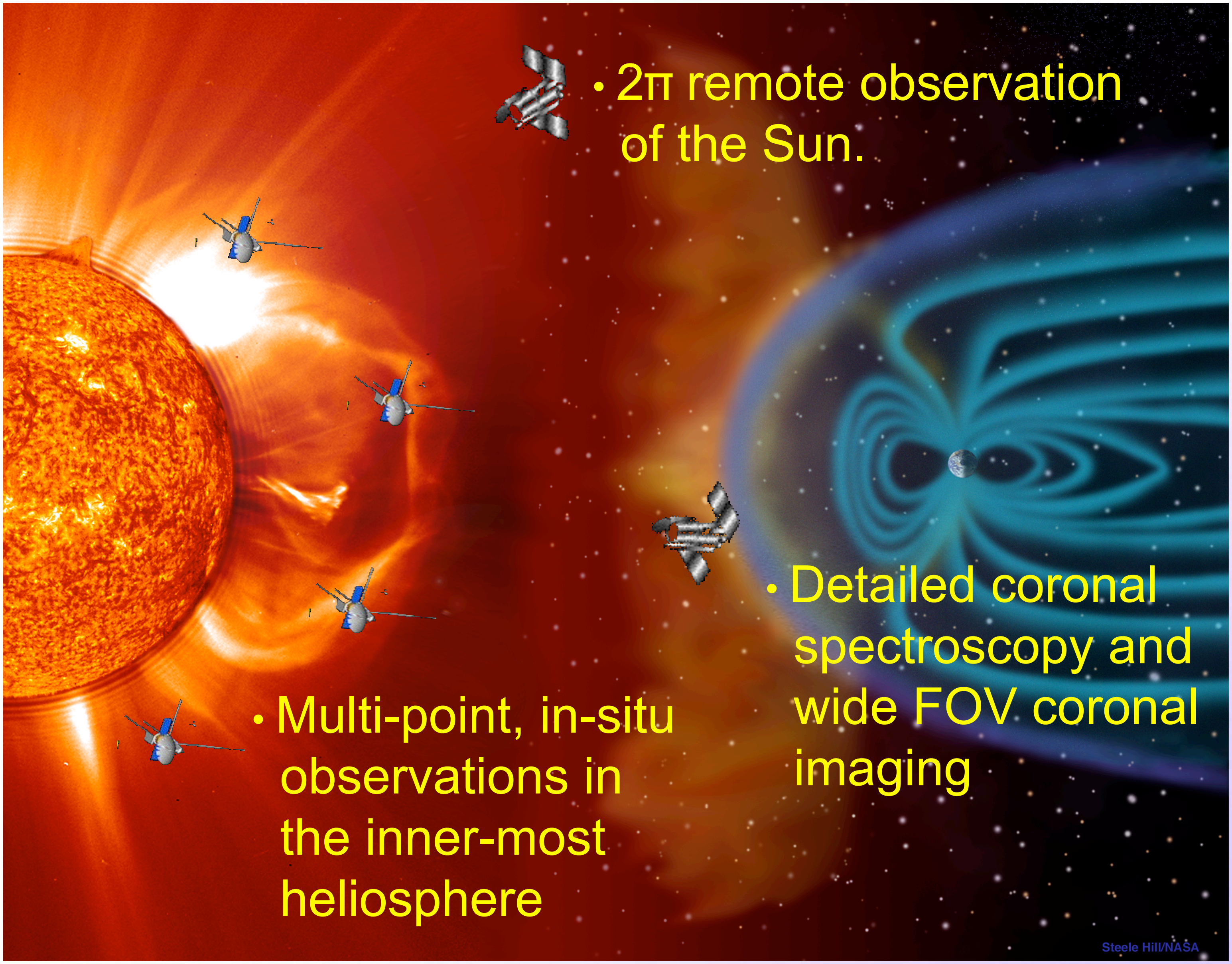
- SEP Acceleration and Transport Models

  Inputs: turbulence close to the Sun<br>source population and SEP properties near acceleration site<br>plasma and magnetic configuration at CME-driven shocks

  Verification: in-situ SEP observations at different longitudes

  Enhancements: combining global, initiation and particle codes

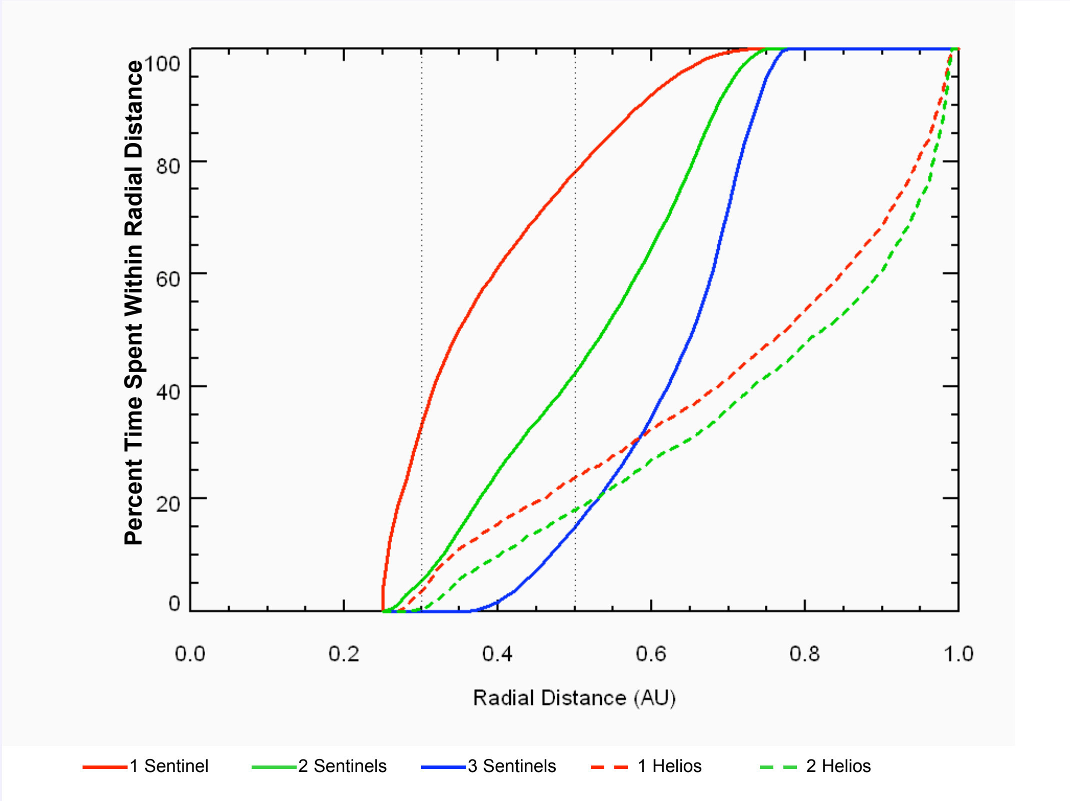
# Sentinels Measurement Requirements



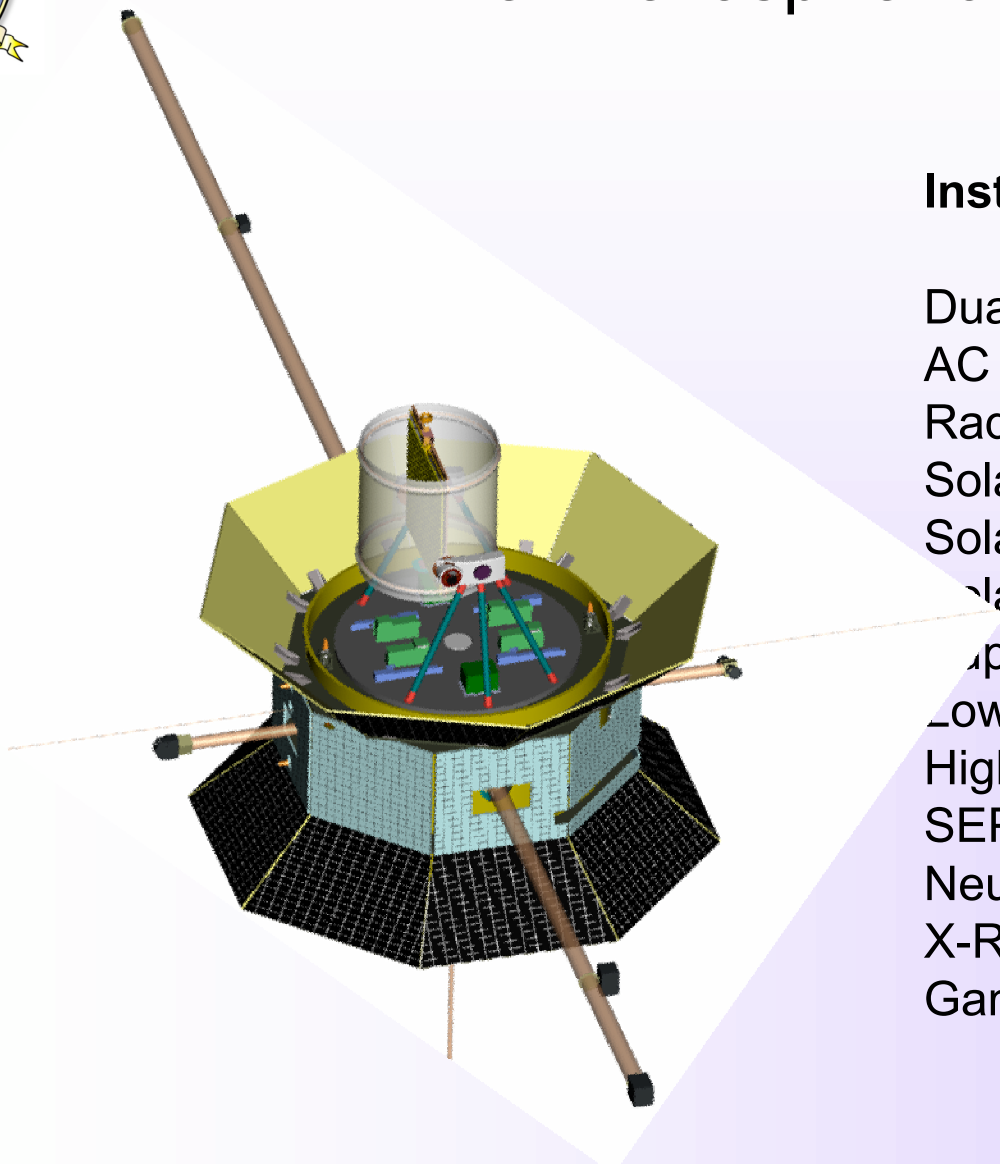
# Sentinels Observational Strategy

- **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

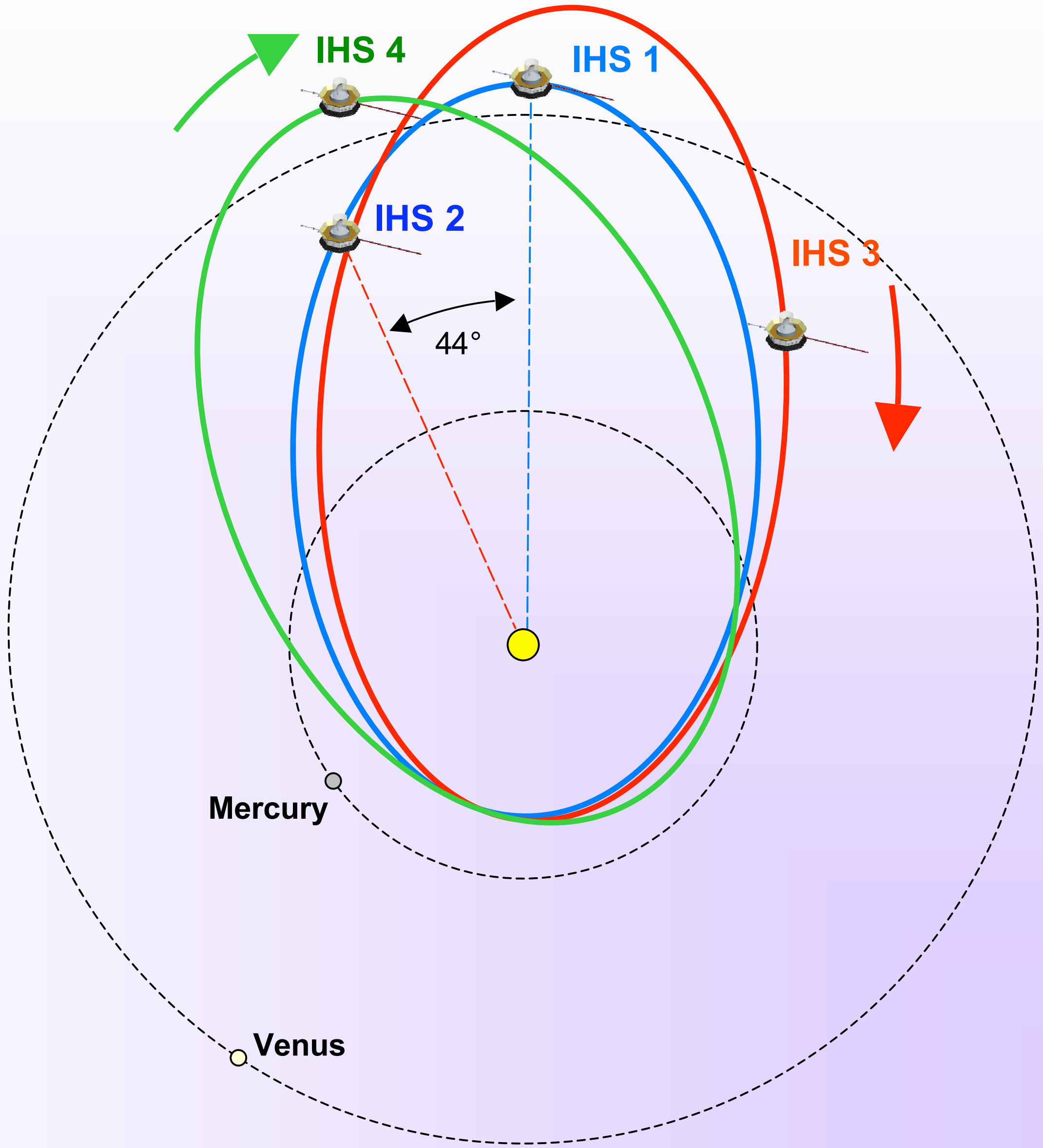


**Instruments**

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

# Inner Heliospheric Orbit Design

- 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

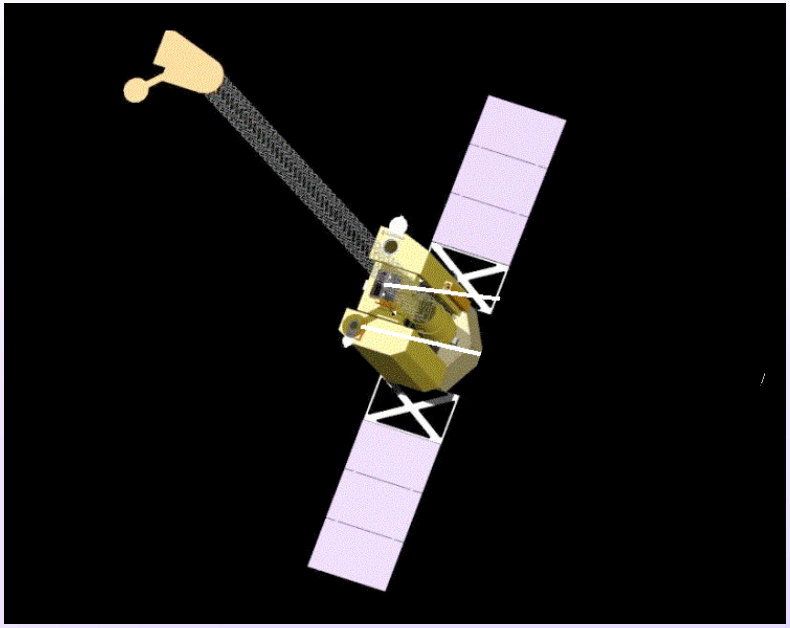
- Sun-sync Earth orbit.

- Significant overlap with IHS and SDO.

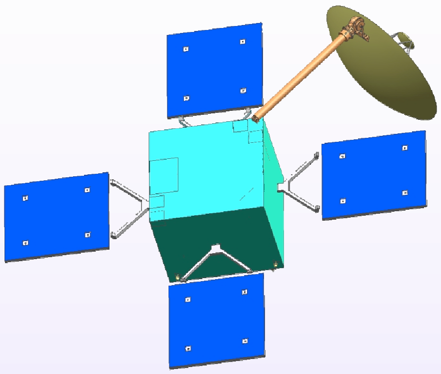
- Instrumentation:

  Inner Coronagraph (1.3 – 5 Rs)
  Outer Coronagraph (4 – 55 Rs)
  UV Spectroscope

- Similar concept previously proposed under Midex.



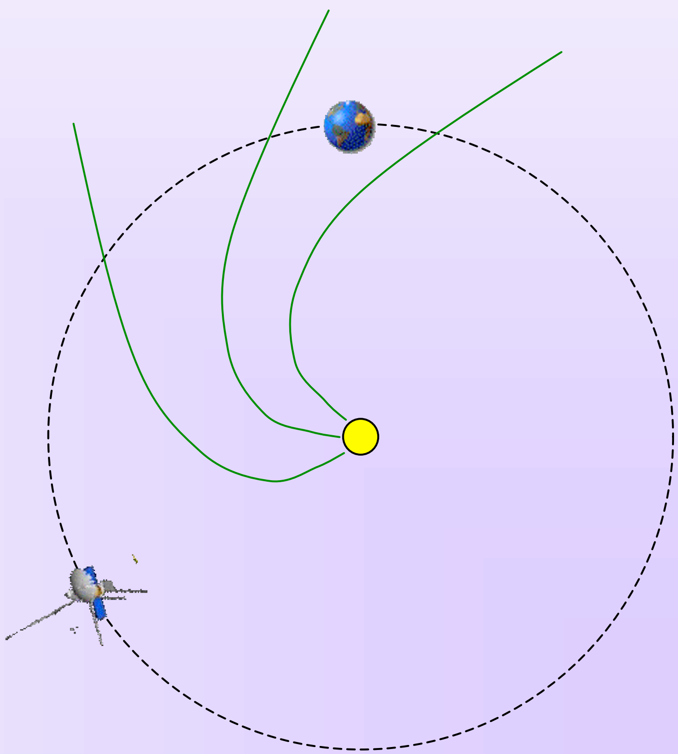
# Far Side Sentinel



- 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

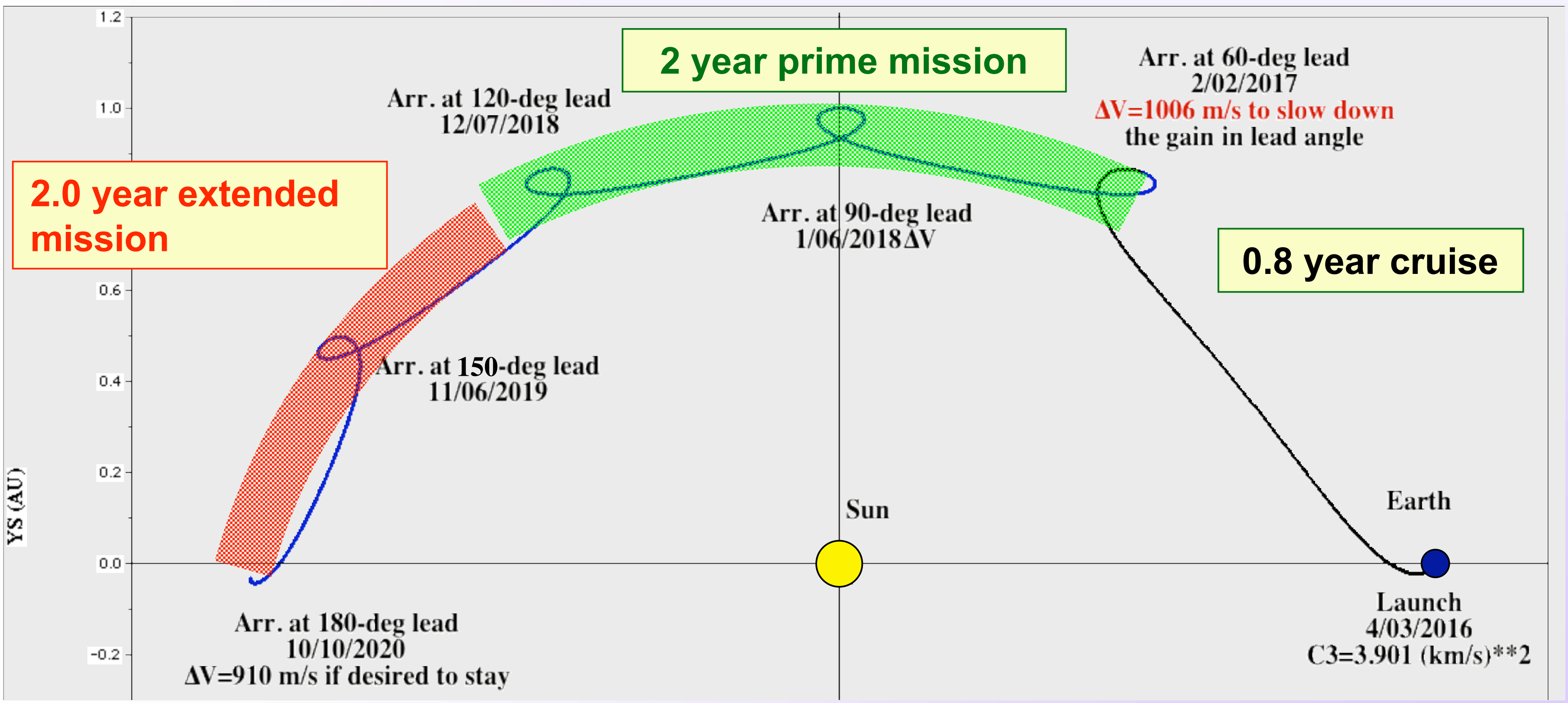
  Optional small in-situ package



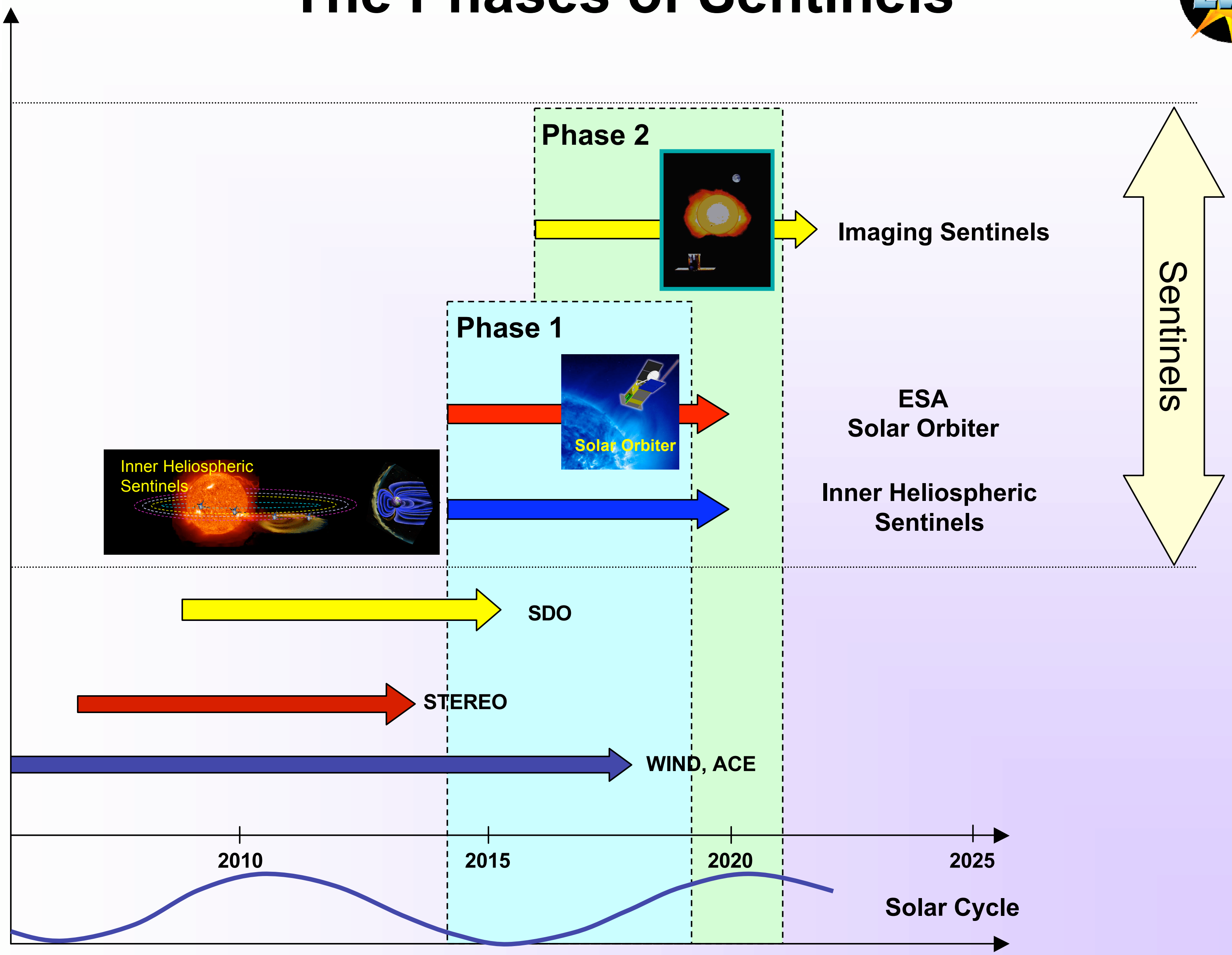
# Far Side Sentinel

Ballistic trajectory that minimizes time to 60 degrees and then drifts from 60 to 180 degrees in < 4 years

- C3 = 3.9-4.5 km2/s2
- Delta-V = 85 m/s
- Launch Vehicle: Taurus 2130



# The Phases of Sentinels



# 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.

- 2nd half of mission to latitudes above 30°.