

<http://stereo.gsfc.nasa.gov>

SOLAR TERRESTRIAL RELATIONS OBSERVATORY

The Sun in 3D

STEREO



**A NEW FRONTIER  
IN SOLAR RESEARCH**

Despite the importance of solar mass ejections, scientists do not fully understand their origin and evolution, nor their structure or extent in interplanetary space. STEREO will provide a totally new perspective on solar eruptions by making 3D measurements of mass ejections and background events on the Sun from twin observatories.



For further information contact:  
NASA Goddard Space Flight Center  
STEREO Project Office • Code 463  
Greenbelt, MD 20771

Solar Terrestrial Probes Program • STEREO Project Office  
NASA Goddard Space Flight Center • Greenbelt, MD

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## VITAL STATISTICS

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**PROJECT MANAGEMENT:** STEREO Project Office (GSFC)

**LAUNCH:**

Target Date: February 2006  
Launch Vehicle: Delta-II 7925-10L  
Launch Site: Cape Canaveral Air Force  
Station, Florida

**MISSION LIFETIME:** 2 years (minimum)

**OBSERVATORY  
CONFIGURATION:** Two functionally identical  
spacecraft

For each spacecraft:

Dimensions: 1.1 h x 2.0 d x 1.2 w meters  
(launch configuration)

1.1 h x 2.0 d x 6.5 w meters  
(solar arrays deployed)

Mass: 547 kg (dry mass)  
610 kg (mass with  
propellant)

Average Power: 596 watts (EOL)

**ORBIT:** Heliocentric orbit at ~1 AU,  
one leading Earth, one  
lagging Earth

Inclination: Ecliptic

Period: 'Ahead' orbits around the Sun  
in ~347 days  
'Behind' orbits around the Sun  
in ~387 days

## **INSTRUMENT COMPLEMENT:**

Sun-Earth Connection Coronal and Heliospheric Investigation (SECCHI)

In situ Measurement of PArticles and CME Transients (IMPACT)

PLAsma and SupraThermal Ion Composition (PLASTIC)

STEREO/WAVES (S/WAVES)

## **OPERATIONS CENTERS:**

Mission Operations: Johns Hopkins University  
Applied Physics Laboratory

## **SCIENCE OPERATIONS:**

STEREO Science Center (SSC)/GSFC (Archiving; Space Weather)

Naval Research Laboratory (NRL), Washington, DC (SECCHI)

University of California, Berkeley (UCB) (IMPACT)

California Institute of Technology (CalTech) (IMPACT)

University of New Hampshire (UNH) (PLASTIC)

University of Minnesota (UMN) (S/WAVES)

University of California, Los Angeles (UCLA) (Archiving)

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## INTRODUCTION

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The Solar TERrestrial RELations Observatory (STEREO) mission is the third in a coordinated sequence of science missions within the Solar Terrestrial Probes (STP) Program detailed in the National Aeronautics and Space Administration's (NASA's) 1994 Strategic Plan. The STP Program focuses on understanding how the changing Sun affects the solar system and life on Earth.

STEREO is managed by NASA's Goddard Space Flight Center (GSFC) in Greenbelt, Md. GSFC also provides science instrument management, systems engineering, mission assurance and reliability, science and data analysis, data archiving, and coordination of Education and Public Outreach (EPO) efforts. The Johns Hopkins University Applied Physics Laboratory (JHU/APL) in Laurel, Md. is responsible for the design, construction, integration, testing, and mission operations of the observatories, as well as the ground system. During its 2-year life, STEREO will provide a new perspective on the Sun by providing stereoscopic measurements of the Sun and Coronal Mass Ejections (CMEs). Each of the two observatories carries a complement of imaging, remote-sensing and particle and fields instruments. STEREO will be the first mission to image CMEs continuously in three dimensions from the Sun to Earth.

The STEREO observatories will launch together on a Boeing Delta-II 7925-10L Expendable Launch Vehicle (ELV). Each spacecraft will use the Moon to escape Earth's orbit. The 'Behind' spacecraft will use one gravity assist maneuver, while the 'Ahead' spacecraft will encounter the Moon twice. Its first encounter will send it far beyond the Moon, while its second encounter will send it into heliocentric orbit ahead of Earth.

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## MISSION OBJECTIVES

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The STEREO mission objectives are consistent with the goals of NASA's Strategic Plan, which include understanding the influence of both the Sun and human activities on Earth's atmosphere, studying the least-explored regions of the atmosphere, and accelerating the development of reliable space weather forecast techniques. The principal mission objective for STEREO is to understand the origin and consequences of CMEs, the most energetic eruptions on the Sun.

Specific science objectives are to:

- ❖ Understand the causes and mechanisms of CME initiation.
- ❖ Characterize the propagation of CMEs through the heliosphere.
- ❖ Discover the mechanisms and sites of solar energetic particle acceleration in the low corona and the interplanetary medium.
- ❖ Develop a three-dimensional, time-dependent model of the magnetic topology, temperature, density, and velocity structure of the ambient solar wind.

To achieve these objectives, NASA will:

- ❖ Design, develop, and launch observatories capable of satisfying scientific measurement requirements and mission objectives.
- ❖ Operate the observatories for at least a 2-year period.

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## MISSION BACKGROUND

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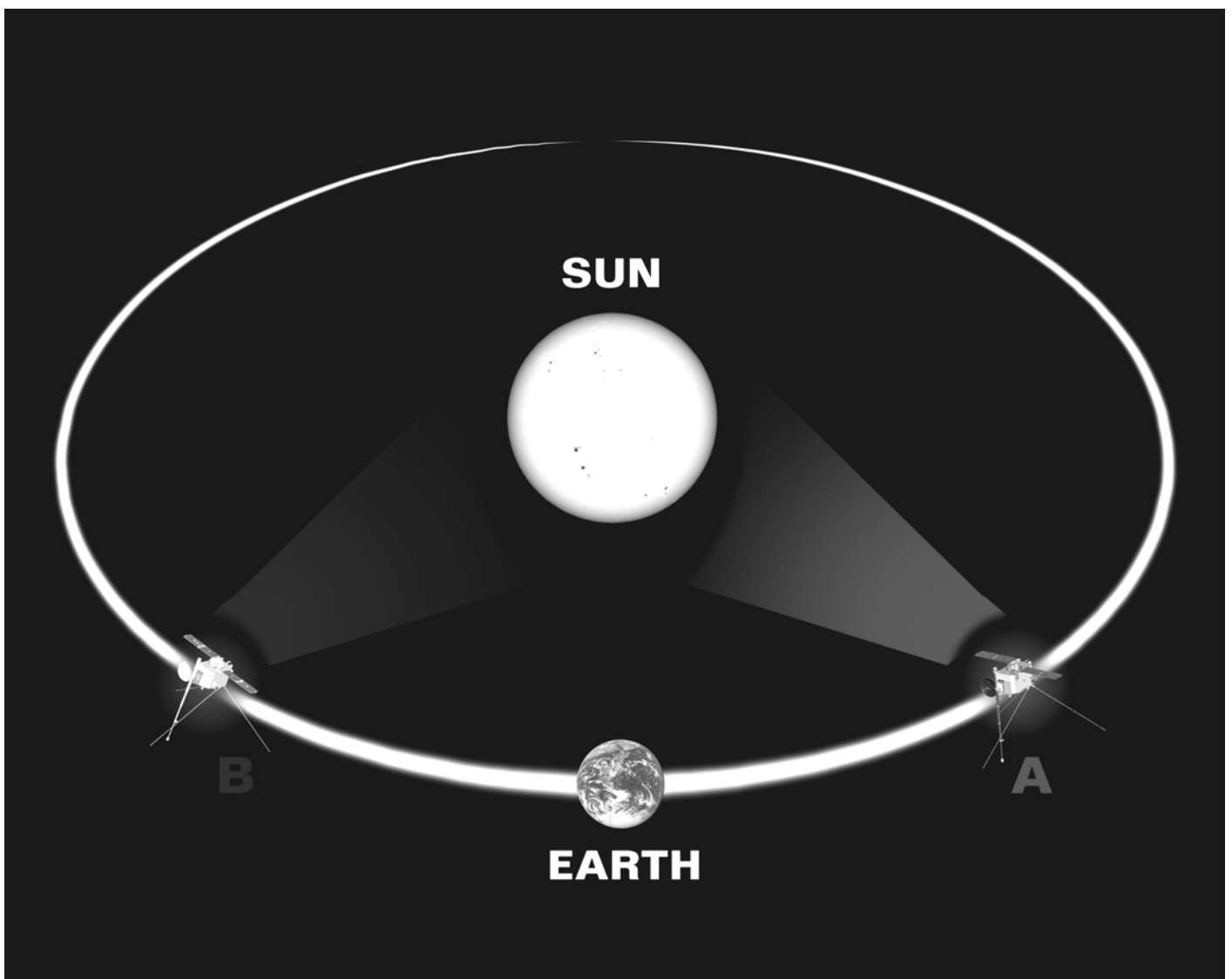
Scientists have long known that Earth is affected by the Sun's dynamic behavior. Even small variations in the energy flow from the Sun can have considerable consequences on Earth's climate and environment. Changes in climate can have extensive economic impacts, making it vital to understand space weather. Major advances in global communications have resulted from satellite technology. The dynamic Sun can affect satellite tracking, reliability, and safety as well as communications and navigation equipment. With the construction of the International Space Station, an increased human presence in space will require knowledge of changing space habitats.

The 2-year STEREO mission will provide a completely new perspective of the Sun by measuring in three dimensions the solar atmosphere and heliosphere from two functionally identical spacecraft simultaneously. STEREO will track disturbances from their onset at the Sun's surface to beyond Earth's orbit, measure energetic particles generated by CME disturbances, and sample fields and particles in the disturbances as they pass near Earth. The two spacecraft, one drifting ahead of Earth and one lagging behind, will obtain three-dimensional measurements at gradually increasing angular separations. This unique vantage point for observing the Sun-Earth connection will provide optimum conditions for developing predictive capabilities. The STEREO scientific program does not depend on the phase of the solar cycle because CMEs and other phenomena to be studied are common to all phases of the cycle. Although the CME rate varies from 0.5 per day at solar minimum to several per day at solar maximum, assuming a CME rate consistent with the minimum of the solar magnetic activity cycle, STEREO expects to observe at least 60 CMEs in remote sensing instruments and at least 24 interplanetary events in-situ.



STEREO will greatly accelerate the development of reliable space weather forecast techniques. Measurements from STEREO will provide early warnings of solar eruptions, which are important for forecasting radiation at the International Space Station, as well as having implications for communications and weather satellites and many other areas of human activity.

### **OVERLAP OF FIELDS OF VIEW FROM 'AHEAD' AND 'BEHIND' SPACECRAFT**



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## THE STEREO MISSION

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The STEREO mission is composed of four major elements:

- ❖ The two spacecraft and instruments collectively called the Observatories.
- ❖ Launch vehicle.
- ❖ The Mission Operations Center (MOC) where the observatories are controlled.
- ❖ The Payload Operations Centers (POCs) where the raw scientific data is calibrated, analyzed, and coordinated.

STEREO is the first mission to be able to create three-dimensional images of CMEs and routinely track them from their source on the Sun all the way to Earth and beyond.

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## STEREO ORBIT

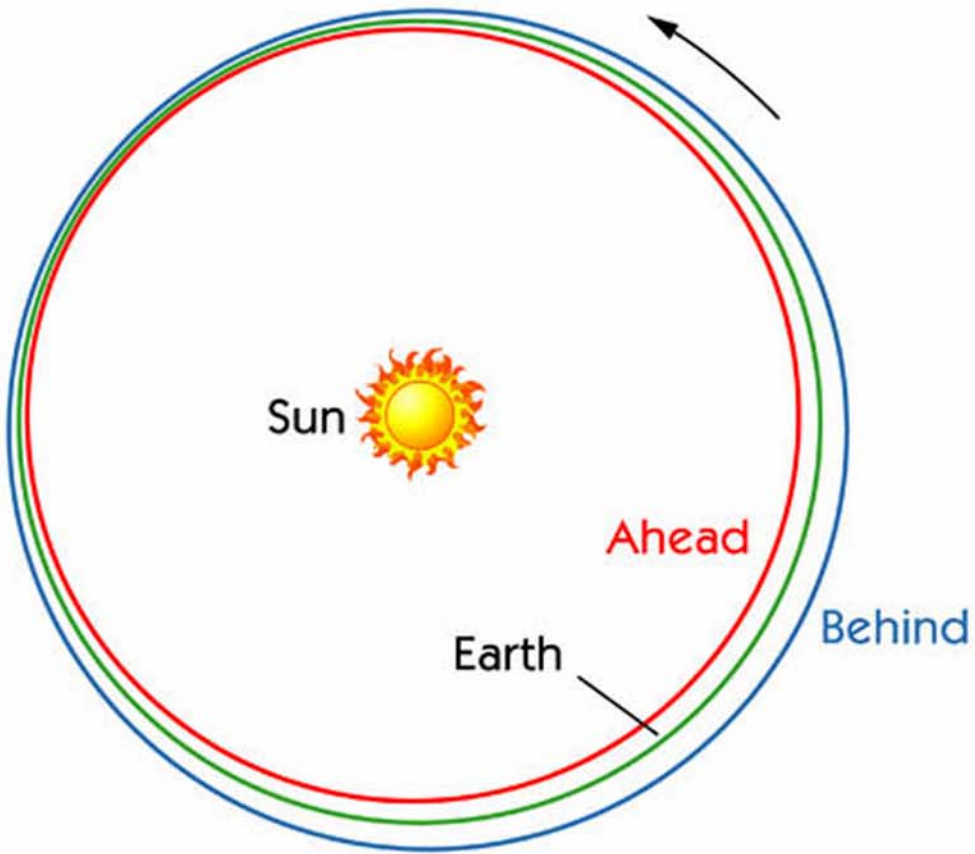
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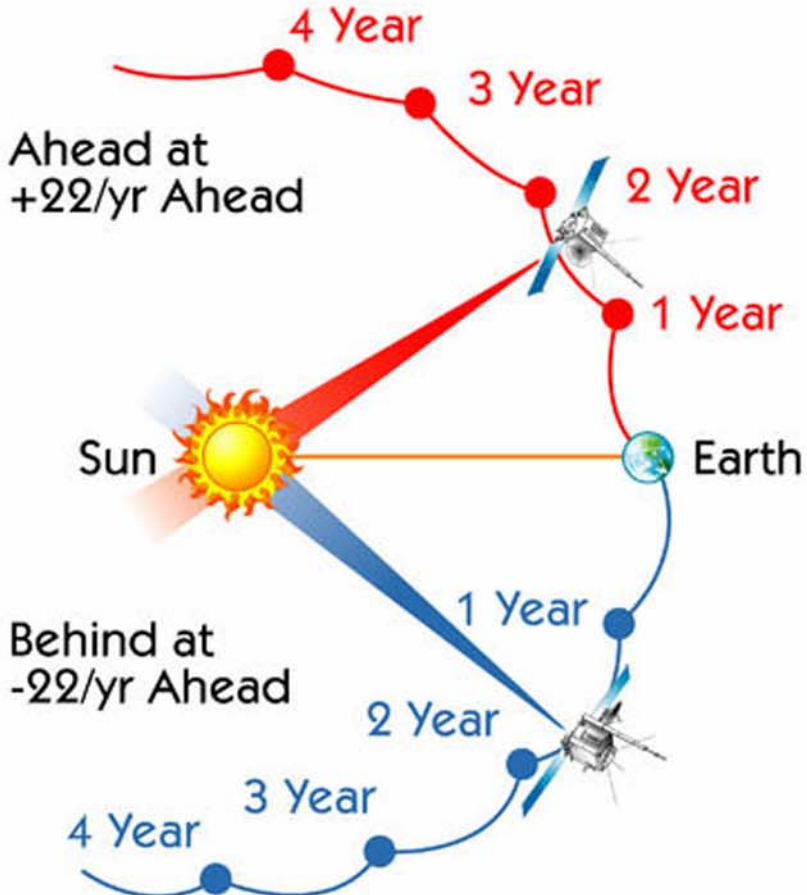
The STEREO observatories will orbit the Sun in a heliocentric orbit at ~1 Astronomical Unit (AU), with one leading Earth and one lagging.

To obtain unprecedented, three-dimensional measurements of the Sun, the twin observatories will be placed into a challenging orbit where they will be offset from one another. One observatory will be placed "ahead" of the Earth in its orbit and the other, "behind" using a series of lunar swingbys. Although lunar gravity has previously been used to manipulate the orbit of a single spacecraft, the STEREO mission is the first ever to use lunar swingbys for more than one spacecraft. Using this technique allows multiple payloads to be launched aboard a single launch vehicle, resulting in significant cost savings.

# STEREO ORBIT

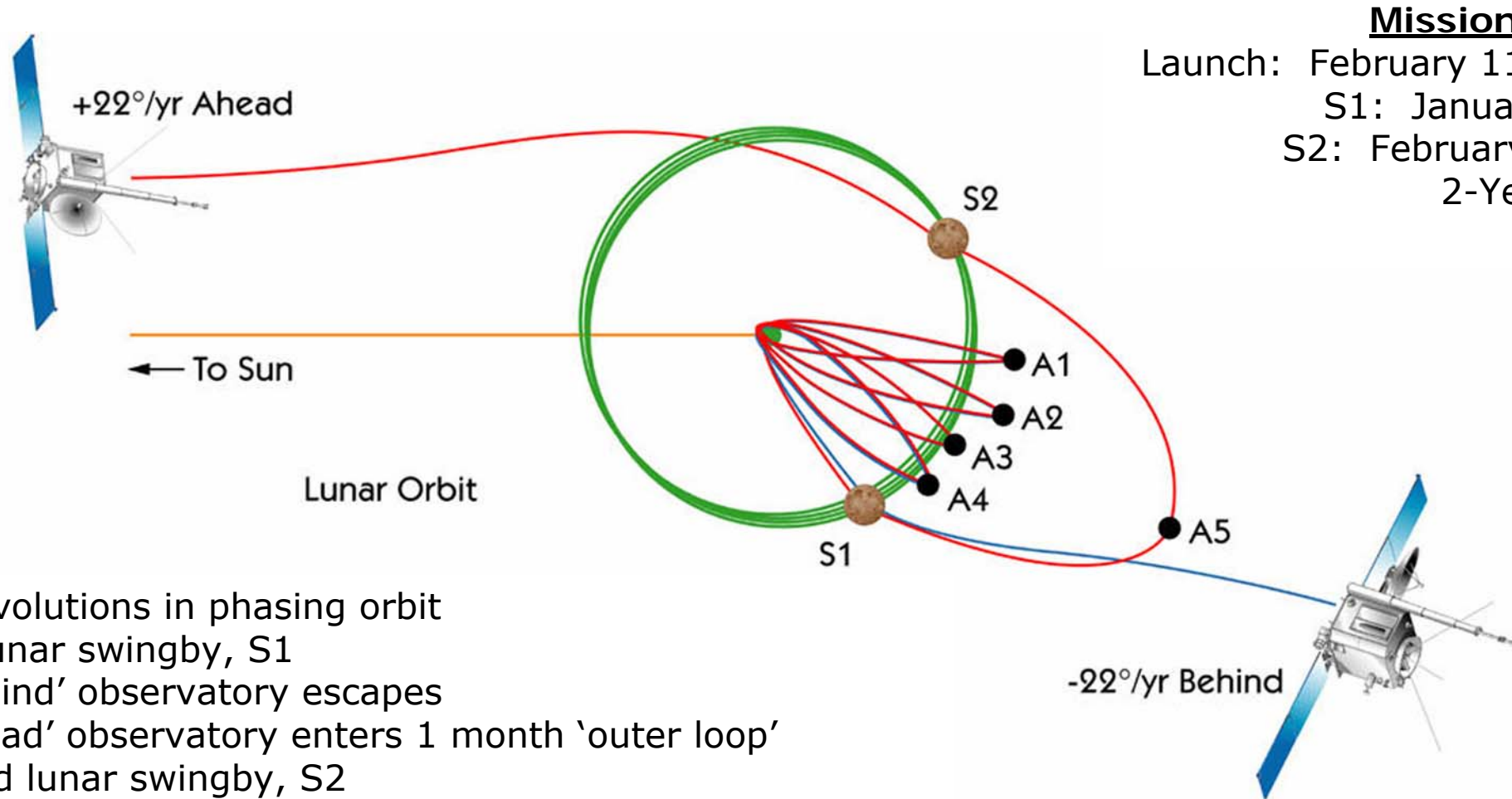


Heliocentric Inertial Coordinates  
(Ecliptic Plane Projection)



Geocentric Solar Ecliptic Coordinates  
Fixed Earth-Sun Line  
(Ecliptic Plane Projection)

# STEREO ORBIT DESCRIPTION



## Mission Timeline

Launch: February 11-24, 2006

S1: January 9, 2006

S2: February 15, 2006

2-Year Mission

- 4.5 revolutions in phasing orbit
- First lunar swingby, S1
  - 'Behind' observatory escapes
  - 'Ahead' observatory enters 1 month 'outer loop'
- Second lunar swingby, S2
  - 'Ahead' observatory escapes

For the first 3 months after launch, the observatories will fly in an orbit from a point close to Earth to one that extends just beyond the Moon's orbit. Mission operations personnel will synchronize the orbits of the two satellites to encounter the Moon about 2 months after launch. At that point, one observatory will use the Moon's gravity to redirect it to an orbit lagging "behind" Earth. About 1 month later, the second observatory will encounter the Moon again and be redirected to its orbit "ahead" of Earth.

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## **STEREO OBSERVATORY**

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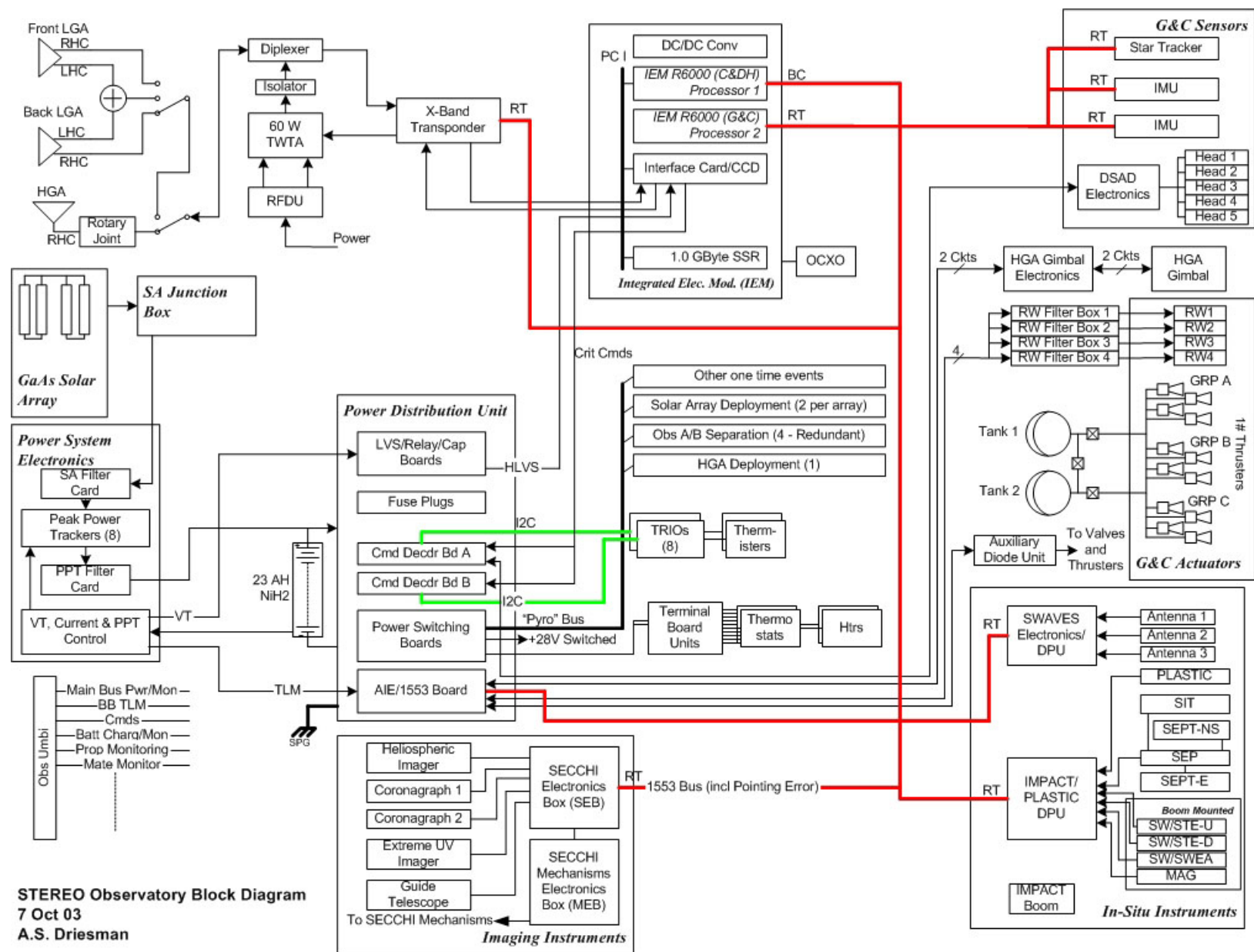
The STEREO spacecraft are to be designed, built, and tested by JHU/APL in Laurel, Md. Each spacecraft is box-shaped with one surface of the box always facing the Sun. The satellites are powered by two solar arrays that extend from the Sun-facing surface of the observatory.

The physical characteristics for each STEREO observatory are:

- ❖ Size (Volume): 1.1 h x 2.0 d x 1.2 w meters
- ❖ Weight 547 kg (dry mass)  
(610 kg with propellant)



# STEREO BLOCK DIAGRAM



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## STEREO INSTRUMENTS

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The STEREO science payload consists of four measurement packages, each of which has several components. Together, this suite of instruments will characterize the CME plasma from the solar surface to Earth's orbit. Using remote and local sensors to measure the physical characteristics of CMEs, they will determine the solar origins of CMEs, their propagation into the interplanetary medium, and their ultimate effects on Earth's magnetic field.

The science payload consists of the minimum set of instruments necessary to achieve the highest priority STEREO science. The payload will, for the first time, allow scientists to:

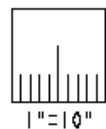
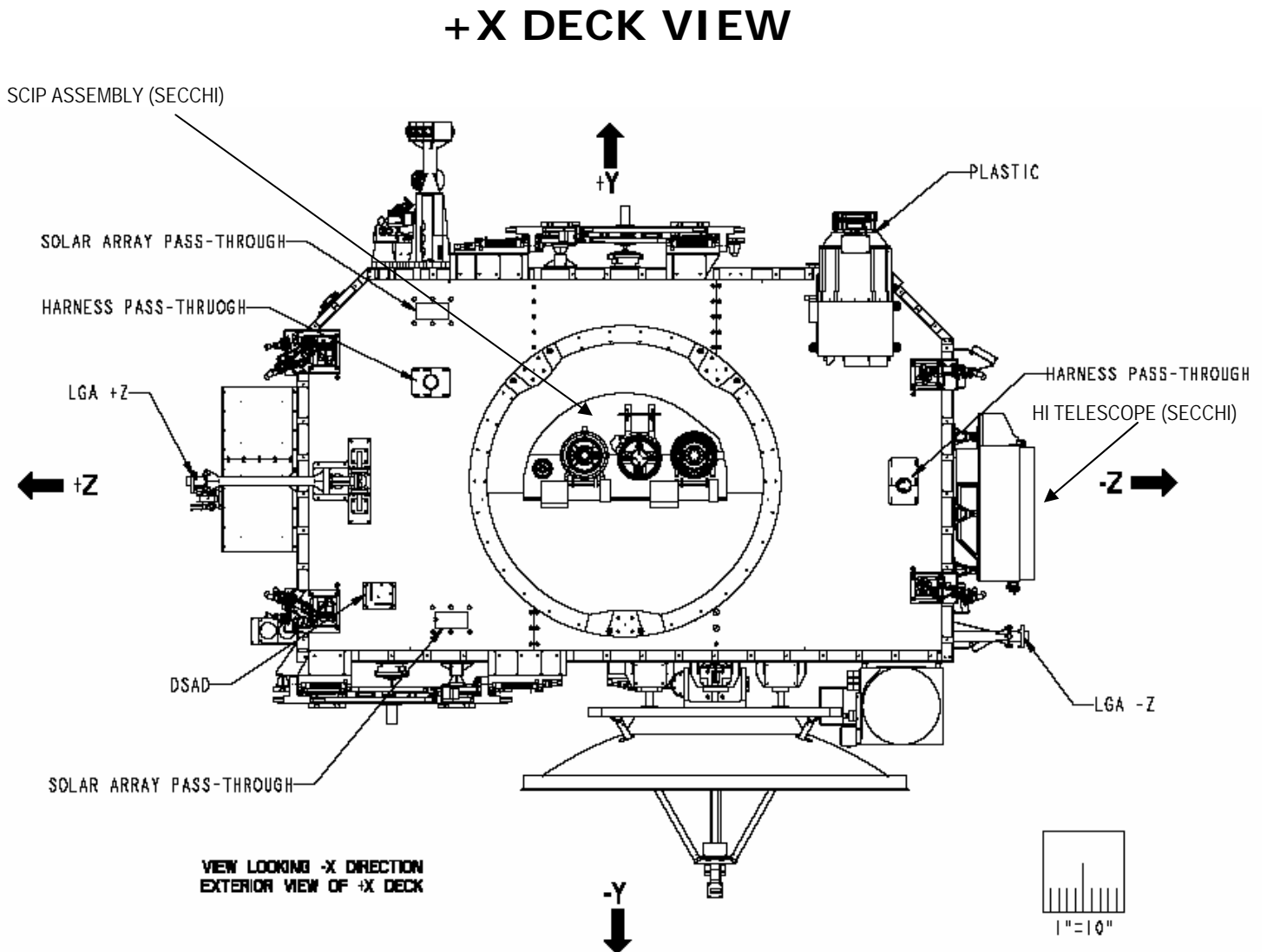
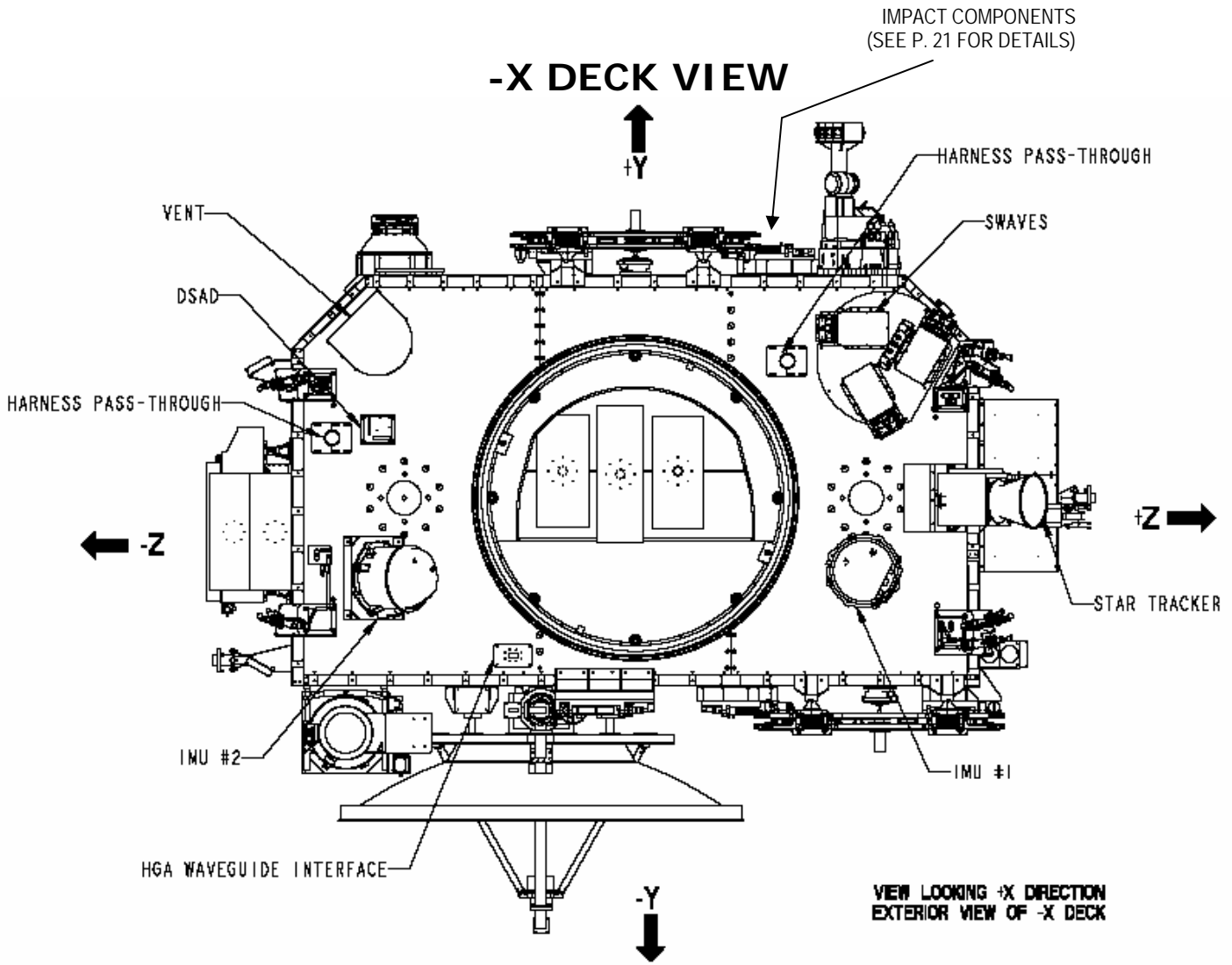
- ❖ Image the solar atmosphere and heliosphere from two perspectives simultaneously.
- ❖ Track disturbances in three dimensions from their onset at the Sun to beyond the Earth's orbit.
- ❖ Provide stereoscopic images of multi-point CMEs and coronal features.
- ❖ Provide multi-point remote and in-situ observations of a single event.
- ❖ Measure energetic particles generated by the multi-point CME disturbances.
- ❖ Sample fields and particles in the disturbances as they pass near the Earth and provide imaging for Earth-directed events.

The STEREO observatory carries a complement of four scientific instruments (two instruments and two instrument suites, with a total of 13 instruments per observatory) as follows:



- ❖ Sun-Earth Connection Coronal and Heliospheric Investigation (SECCHI).
- ❖ In situ Measurements of PArticles and CME Transients (IMPACT).
- ❖ PLAsma and SupraThermal Ion Composition (PLASTIC).
- ❖ STEREO/WAVES (S/WAVES).

# STEREO INSTRUMENT LOCATIONS



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# **SUN-EARTH CONNECTION CORONAL AND HELIOSPHERIC INVESTIGATION (SECCHI)**

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SECCHI encompasses a suite of remote sensing instruments designed to study the three-dimensional evolution of CMEs from the Sun's surface through the corona and interplanetary medium to their eventual impact at Earth. The Naval Research Laboratory (NRL) of Washington, D.C. is leading this investigation.

SECCHI is composed of:

- ❖ Two White Light Coronagraphs (COR1, COR2) – COR1 explores  $<1.4$  to 3  $R_{\text{sun}}$ ; COR2 explores 3 to 15  $R_{\text{sun}}$  ( $R_{\text{sun}}$  is the radius of the Sun – the COR2 telescope can see the corona in an angular field of view from 3 solar radii to 15 solar radii).
- ❖ Extreme Ultraviolet Imager (EUVI) – looks at the upper chromosphere and innermost corona.
- ❖ Heliospheric Imager (HI1, HI2) – observes CMEs from the Sun to Earth (15 to 215  $R_{\text{sun}}$ ).

## **OBJECTIVES**

The major objectives of SECCHI are to determine:

- ❖ CME initiation time to an accuracy of order 1 minute.
- ❖ Evolution of CMEs, transition region structures, coronal structures, extreme ultraviolet waves, coronal dimming and global interactions at the highest cadence rate and matching positional accuracy.
- ❖ Three-dimensional evolution of CMEs and associated disturbances in ambient structures in the lower corona, the upper corona, and in the interplanetary medium at the highest cadence rate and matching positional accuracy.

- ❖ Evolution of the tracers of CME interaction with the corona and interplanetary medium, the CME shock formation, and the ambient material sweep-up at the highest cadence rate and matching positional accuracy.
- ❖ Candidate sites of energetic particle acceleration with a timing accuracy of  $\leq 1$  minute.
- ❖ Evolution of the CME front at the highest cadence rate and matching positional accuracy.
- ❖ Three-dimensional shape of coronal loops, coronal streamers, and large-scale coronal structures and solar wind tracers with a positional accuracy of  $\leq 1250$  km in the lower corona from the solar disk to 1.5  $R_{\text{sun}}$ ,  $\leq 4500$  km in the lower corona from 1.5 to 3.0  $R_{\text{sun}}$ , and  $\leq 11,500$  km in the upper corona.

## **PRINCIPAL INVESTIGATOR**

Russell Howard  
Naval Research Laboratory

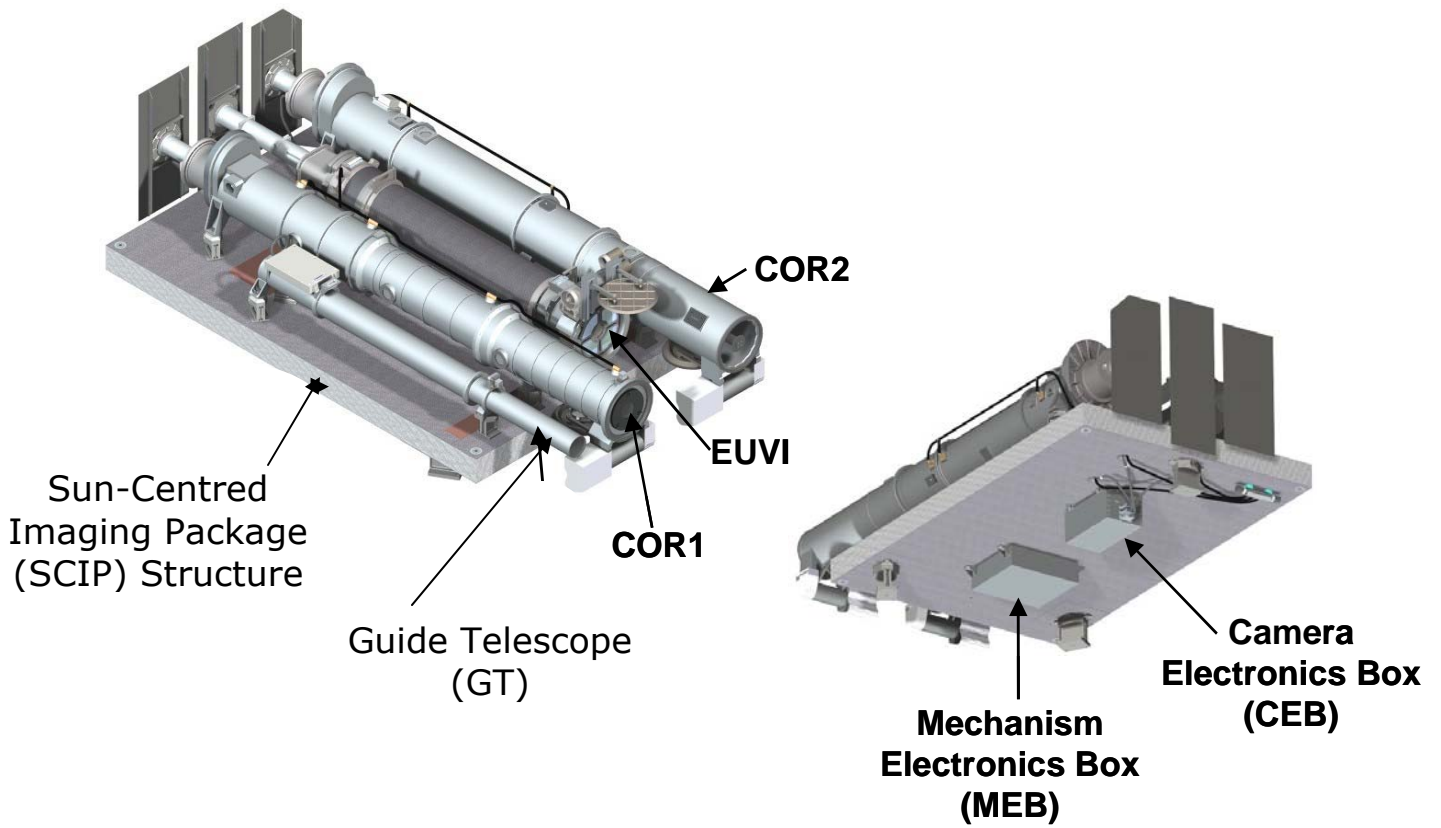
## **PROJECT MANAGER**

Rebecca Baugh  
Naval Research Laboratory

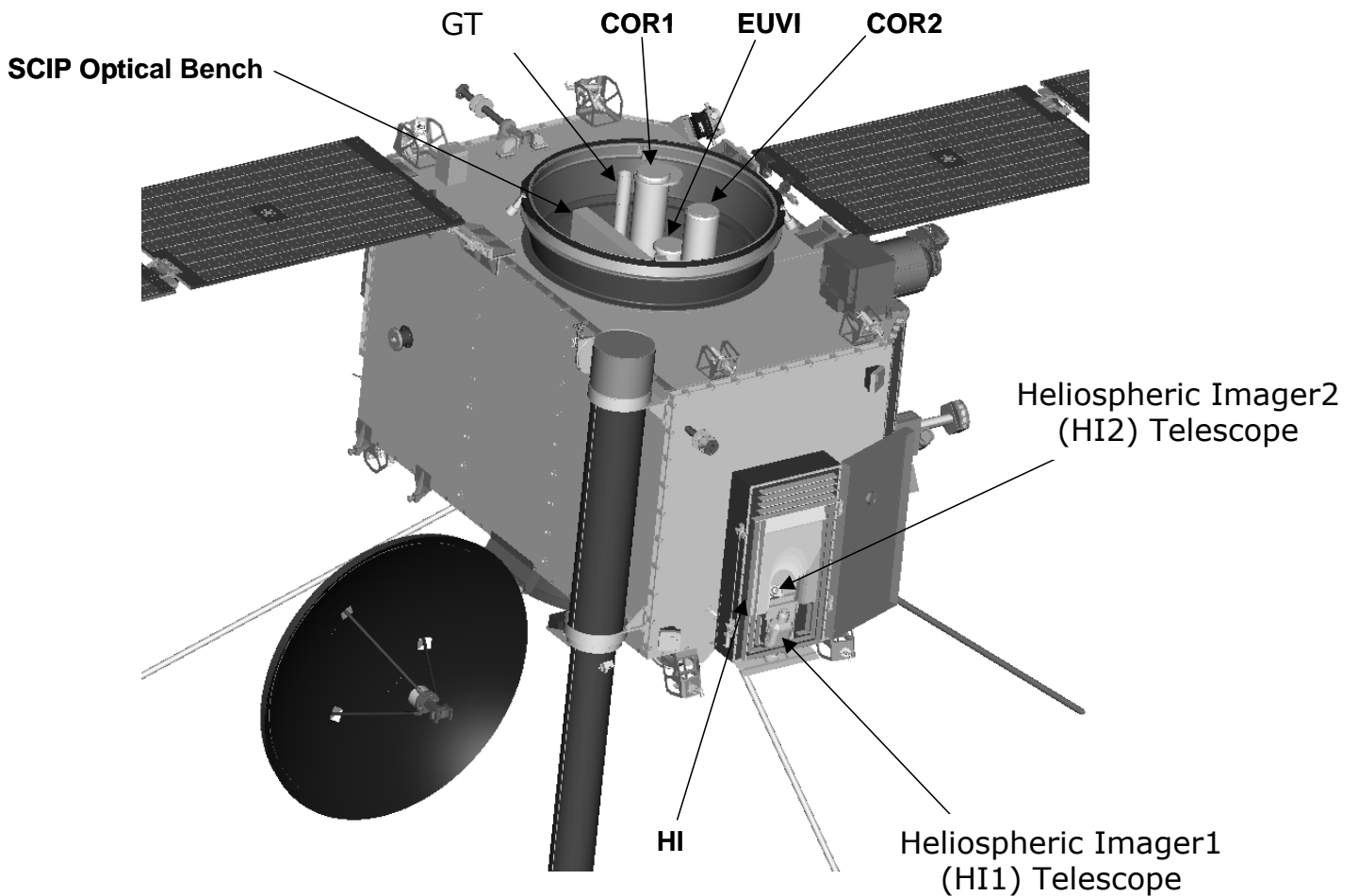
## **INSTRUMENT RESOURCES**

Weight: 82 kg  
Power: 64.5 W average  
Data Rate: 50 kbps average

# SECCHI INSTRUMENT



# SECCHI-B SPACECRAFT ACCOMMODATION



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## IN-SITU MEASUREMENTS OF PARTICLES AND CME TRANSIENTS (IMPACT)

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IMPACT, which will be designed, built, and tested for NASA by an international team led by the University of California, Berkeley (UCB), will measure the interplanetary magnetic field, thermal and suprathermal solar wind electrons, and energetic electrons and ions.

IMPACT is a suite of seven instruments, three of which are located on a 6-meter deployable boom, with the others located on the main body of the spacecraft. The Boom Suite includes:

- ❖ Solar Wind Experiment (SWEA) – measures  $\sim 0.2$  to 1 keV electrons with wide-angle coverage.
- ❖ Suprathermal Electron Telescope (STE) – measures electrons from 5 to 100 keV.
- ❖ Magnetometer Experiment (MAG) – measures the vector magnetic fields in the range of  $\pm 512$  nT range with 0.1 nT accuracy.

The Solar Energetic Particle (SEP) Experiment Suite includes:

- ❖ Suprathermal Ion Telescope (SIT) – He to Fe SEP ions; 0.03 to 2 MeV/nucleon.
- ❖ Solar Electron and Proton Telescope (SEPT) – 20 to 400 KeV electrons and 0.6 to 7 MeV protons in two orthogonal directions.
- ❖ Low Energy Telescope (LET) – Protons 1.5 to 6 MeV and heavier ions to mass 28 at 3 to 30 MeV/nucleon.
- ❖ High Energy Telescope (HET) – Electrons 1 to 6 MeV. Protons and Helium ions 13 to 100 MeV.

## OBJECTIVES

IMPACT, together with PLASTIC, covers the complete in-situ particle energy and composition range needed to address the key STEREO mission science objectives, especially the diagnosis of the interplanetary evolution of CMEs through their interaction with the ambient solar wind, and the acceleration and transport of the related solar energetic particles.

- ❖ STE measures the suprathermal halo/super-halo electron fluxes over electron energies 5 to 100 keV, spanning the gap between SWEA and SEP electron measurements, along the nominal interplanetary field direction with at least 1-minute time resolution from two vantage points. Measurements include fluxes, energy spectra, and direction of arrival.
- ❖ SEP measures the intensity, composition, and energy spectra and direction of energetic ions and electrons from two vantage points, including protons from 0.03 to 40 MeV, heavier ions from  $\sim 0.03$  to 40 MeV/nuc, electrons from  $\sim 0.03$  to 6 MeV, and 3 He-rich solar particle events.
- ❖ SWEA measures the core (bulk solar wind) and halo (strahl) electron fluxes with a 360 x 60 degree or better field of view at energies 20 to 1000 eV, with angular resolution of at least 45 x 45 degrees and 1-minute sampling from two vantage points.
- ❖ MAG measures the three components of the vector magnetic field in the range  $\pm 512$  nT with 0.1 nT accuracy at 1 second time resolution from two vantage points

## **PRINCIPAL INVESTIGATOR**

Janet Luhmann

University of California, Berkeley

## **PROJECT MANAGER**

David Curtis

University of California, Berkeley

## **INSTRUMENT RESOURCES**

Weight: 26.3 kg

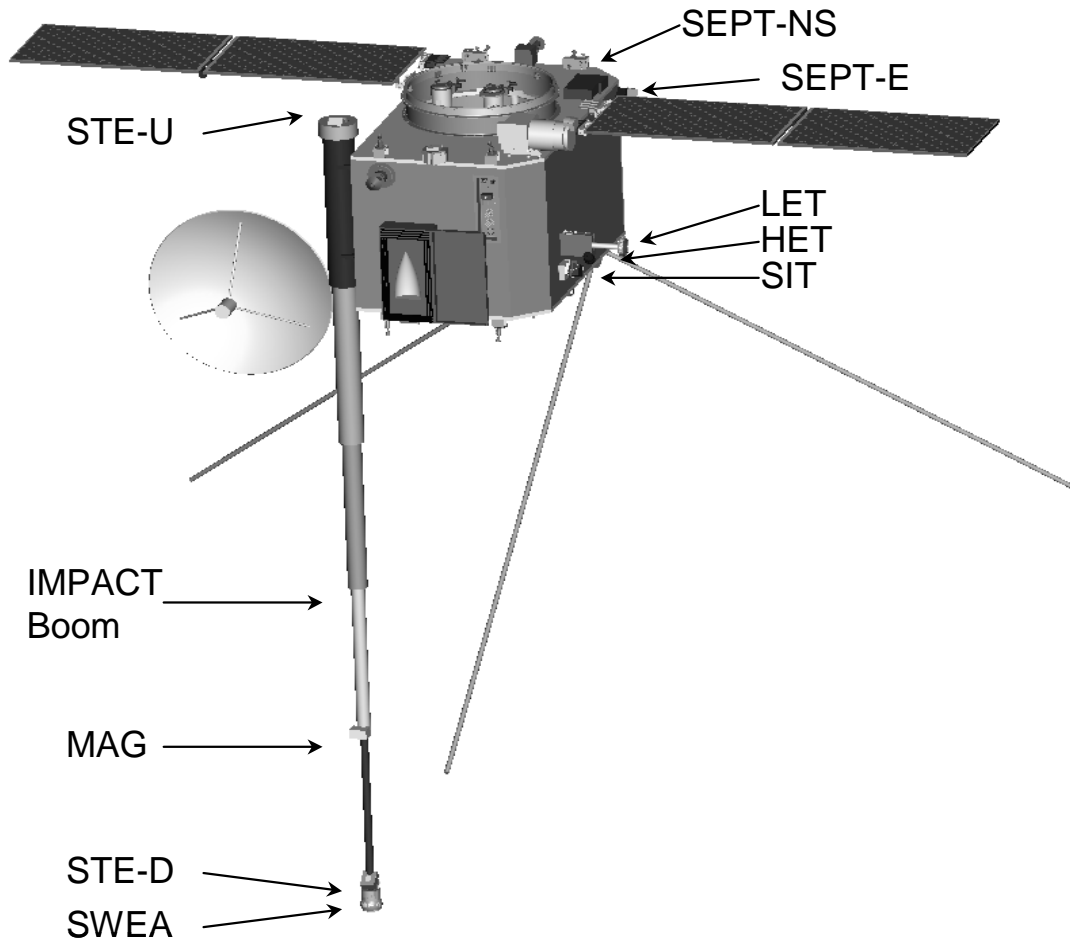
Power: 20.3 W average

Data Rate and Storage: 3.2 kbps

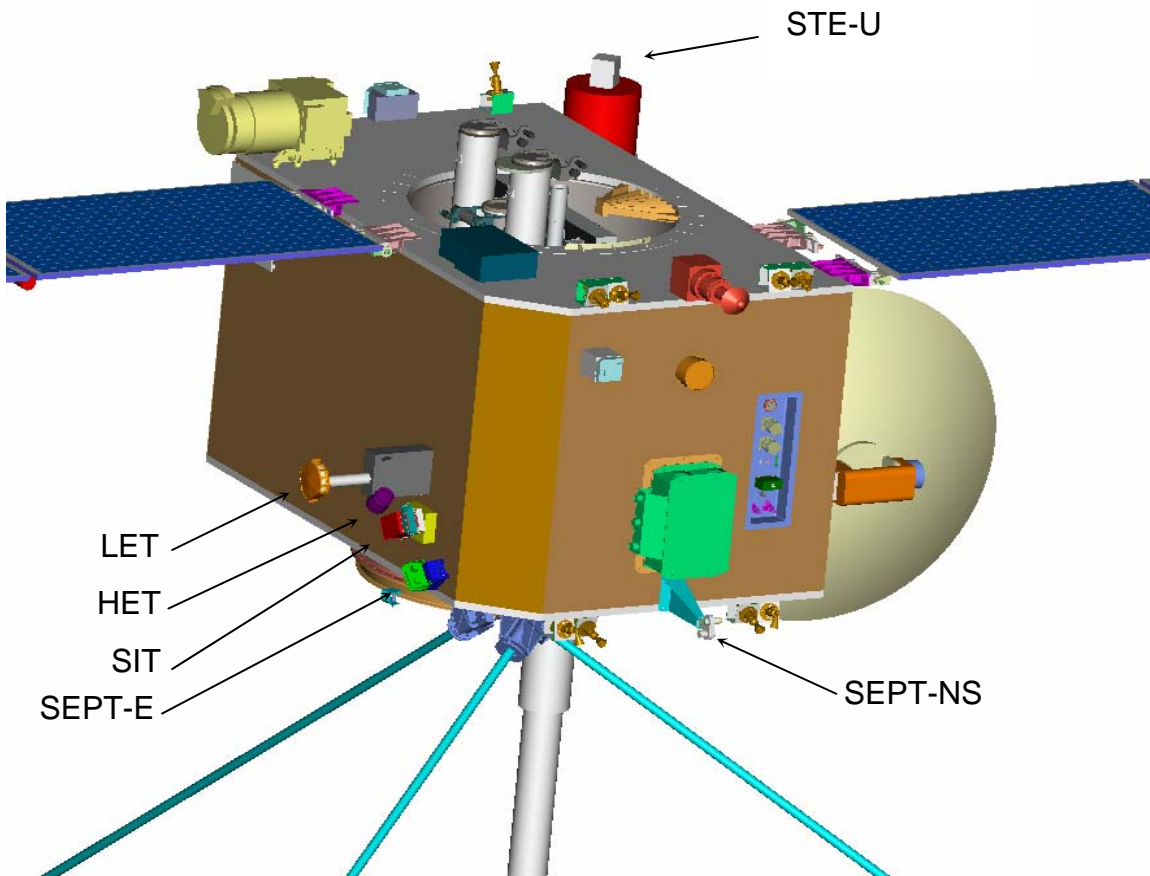


# IMPACT INSTRUMENT SUITE

## Behind Spacecraft



## Ahead Spacecraft



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## PLASMA AND SUPRATHERMAL ION COMPOSITION (PLASTIC)

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The PLASTIC experiment, built by an international consortium led by the University of New Hampshire (UNH), provides in-situ plasma characteristics of protons, alpha particles, and heavy ions. It supplies key diagnostic measurements of the mass and charge state composition of heavy ions and characterizes the CME plasma from ambient coronal plasma.

PLASTIC incorporates three science sensor functions into one package:

- ❖ Solar Wind Sector (SWS) Proton Channel measures the distribution functions of solar wind protons and alphas, providing proton density, velocity, kinetic temperature and its anisotropy, and alpha to proton ratios with a time resolution up to about 1 minute (60 seconds). (Time resolution may depend on instrument cycle.)
- ❖ Solar Wind Sector (SWS) Main (Composition) Channel measures the elemental composition, charge state distribution, kinetic temperature, and speed of the more abundant solar wind heavy ions (e.g., C, O, Mg, Si, and Fe) by using Electrostatic Analyzer (E/Q), Time-of-Flight (TOF), and Energy (E) measurement to determine Mass and M/Q. Typical time resolution for selected ions will be  $\sim 5 \times 60 = 300$  seconds. (Time resolution depends on telemetry allocation.)
- ❖ Wide-Angle Partition (WAP) measures distribution functions of suprathermal ions, including interplanetary shock-accelerated (IPS) particles associated with CME-related SEP events, recurrent particle events associated with Co-rotating Interaction Regions (CIRs), and heliospheric pickup ions. Typical time resolution for selected ions will be several minutes to hours. (Time resolution depends on telemetry allocation and event statistics.)

## **OBJECTIVES**

The primary objectives of PLASTIC are to examine:

- ❖ **Solar Wind Ions and Solar Processes.**
  - Elemental composition: fractionation effects, including Interplanetary CMEs (ICMEs).
  - Charge states: coronal processes and solar wind (including ICME) formation.
  - Origins (slow solar wind, transition with fast solar wind).
  - Characterization of the ambient solar wind, including proton bulk parameters and solar wind composition, sampling from two vantage points.
  
- ❖ **Gradual Solar Energetic Particles and the Heliosphere.**
  - Acceleration of ions at CME-driven shocks.
  - Global structure of stream interfaces and heliospheric current sheet dynamics.
  - Global structure of co-rotating interaction regions.
  - Pickup ions (longitudinal and solar wind parameter dependence).

## **PRINCIPAL INVESTIGATOR**

Antoinette Galvin

University of New Hampshire

## **PROJECT MANAGER**

Steven Turco

University of New Hampshire

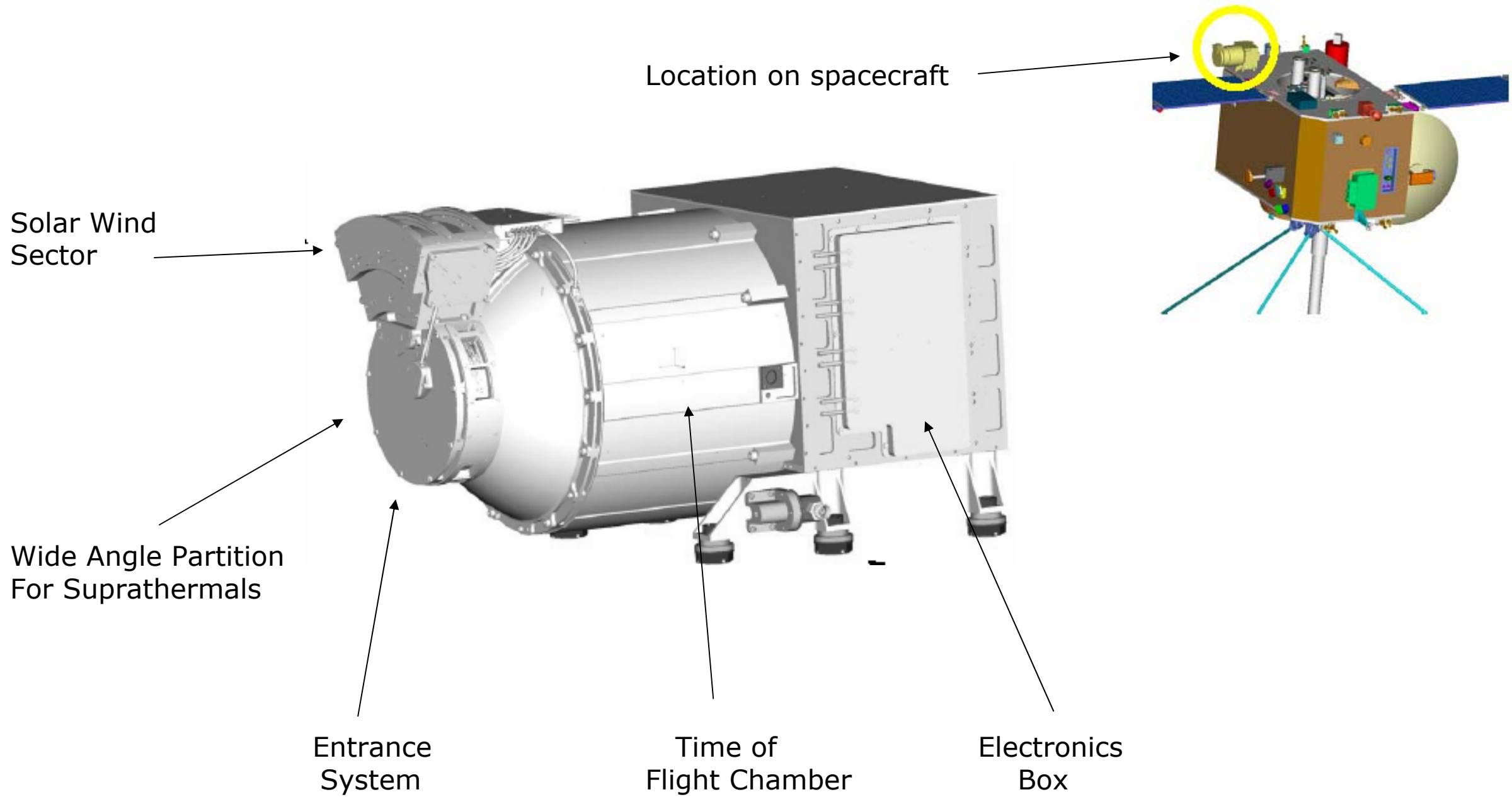
## **INSTRUMENT RESOURCES**

Weight: ~11 kg (minus radiator)

Power: 12 W average, 16 W Peak

Data Rate and Storage: 3.2 kbps

# PLASTIC INSTRUMENT



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## STEREO/WAVES (S/WAVES)

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The S/WAVES instrument, being built by a team led by the Observatoire de Paris and the University of Minnesota (UMN), is an interplanetary radio burst tracker that tracks the generation and evolution of traveling radio disturbances from the Sun to the orbit of Earth. As its primary sensors, S/WAVES will use three mutually orthogonal monopole stacer antenna elements, each 6 meters in length. The three monopoles, built by the University of California, Berkeley (UCB), will be deployed away from the Sun so that they remain out of the fields of view of Sun-facing instruments. All three antennas are mounted at the same location on the spacecraft body. A Data Processing Unit (DPU) on each spacecraft controls and coordinates the various instrument components and performs digital signal processing.

The S/WAVES instrument includes:

- ❖ High Frequency Receivers (HFRs) that measure radio wave intensity, source direction, and angular size in the frequency range of 16 MHz to 125 kHz, corresponding to source distances of about 1 to 100 Rs.
- ❖ Low Frequency Receivers (LFRs) that make sensitive measurements of radio waves from about 80 Rs to 1 AU and plasma waves near the electron plasma frequency at 1 AU (2.5 to 160 kHz).
- ❖ A Fixed Frequency Receiver (FFR) that measures radio burst emissions at about 30 MHz to complement ground-based radio-heliograph measurements.
- ❖ Time Domain Samplers (TDS) that simultaneously make high time resolution wideband waveform burst measurements of three electric field components at one of several commandable sample rates.

## **OBJECTIVES**

The primary objectives of S/WAVES are to:

- ❖ Track and probe CME-driven shocks and flare electrons from genesis in the low corona to interaction with the terrestrial magnetosphere, with high frequency and time resolution, creating the link between coronagraph images and in-situ CME observations.
- ❖ Measure in-situ the spatial extent and structure of CME-driven shocks and flare and CME-associated electron beams, which can be mapped back to the Sun.
- ❖ Make remote and in-situ measurements of the radio sources that enable the understanding of the generation of type II (CME) and type III (flare) radio bursts.
- ❖ Measure electron density and temperature, from quasi-thermal noise properties, in regions of cold, dense plasma within CME-associated magnetic clouds. These regions are thought to be solar prominence material associated with filament disappearance at CME genesis.
- ❖ Study the role of plasma microphysics in CME-driven shocks.

## **PRINCIPAL INVESTIGATOR**

Jean-Louis Bougeret

Centre National de la Recherche Scientifique,  
Observatoire de Paris, Meudon

## **PROJECT MANAGER**

Keith Goetz

University of Minnesota

## **INSTRUMENT RESOURCES**

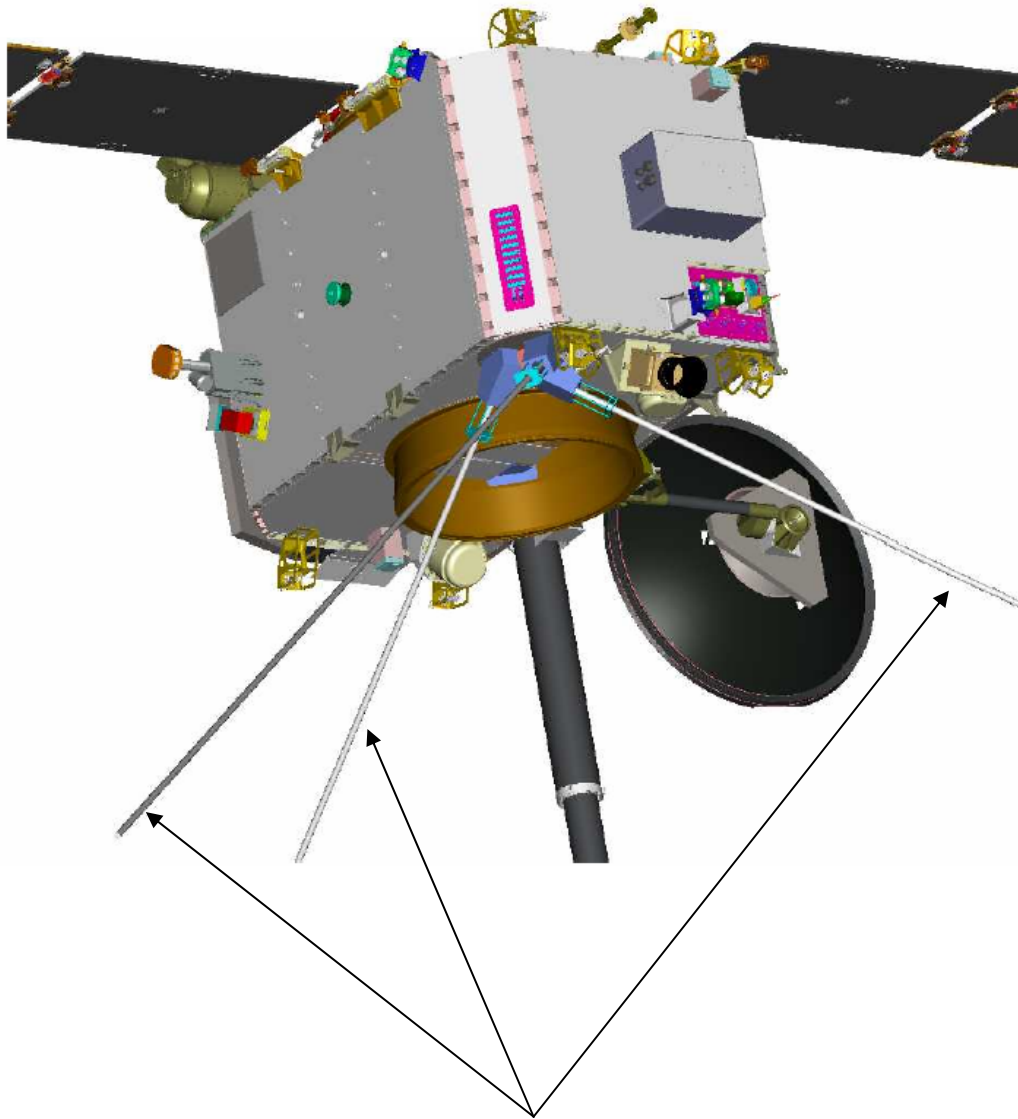
Weight: 13.6 kg

Power: 11.0 W average

Data Rate: 2.04 kbps

Science Data Generated: 8 Gbytes per year

# S/WAVES INSTRUMENT ANTENNA SET



**3 Orthogonal Electric Antennas**

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## SPACECRAFT COMPONENTS

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The STEREO observatories each contain six major subsystems in addition to the scientific instrument payload of two instruments and two instrument suites. The following is a basic description of the structure, subsystems, and other components that support operations of the observatory during its mission.

### STRUCTURE

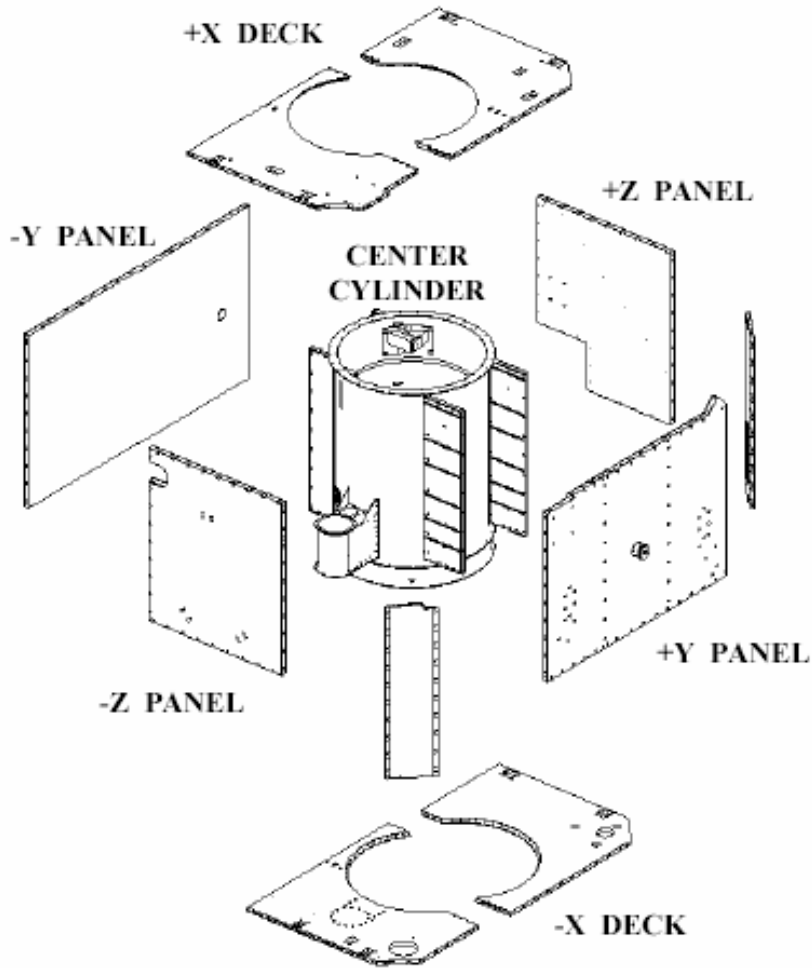
The STEREO observatory is designed to support the scientific instrument payload and support subsystems required for operation during the mission. This includes:

- ❖ Primary structure to withstand anticipated ground, launch and in-orbit environment.
- ❖ Structural interface to the launch vehicle Payload Attach Fitting (PAF).
- ❖ Mechanisms for deployment of the solar array wings and high gain antenna (HGA) after reaching orbit.
- ❖ Mechanism for the orientation of the HGA.

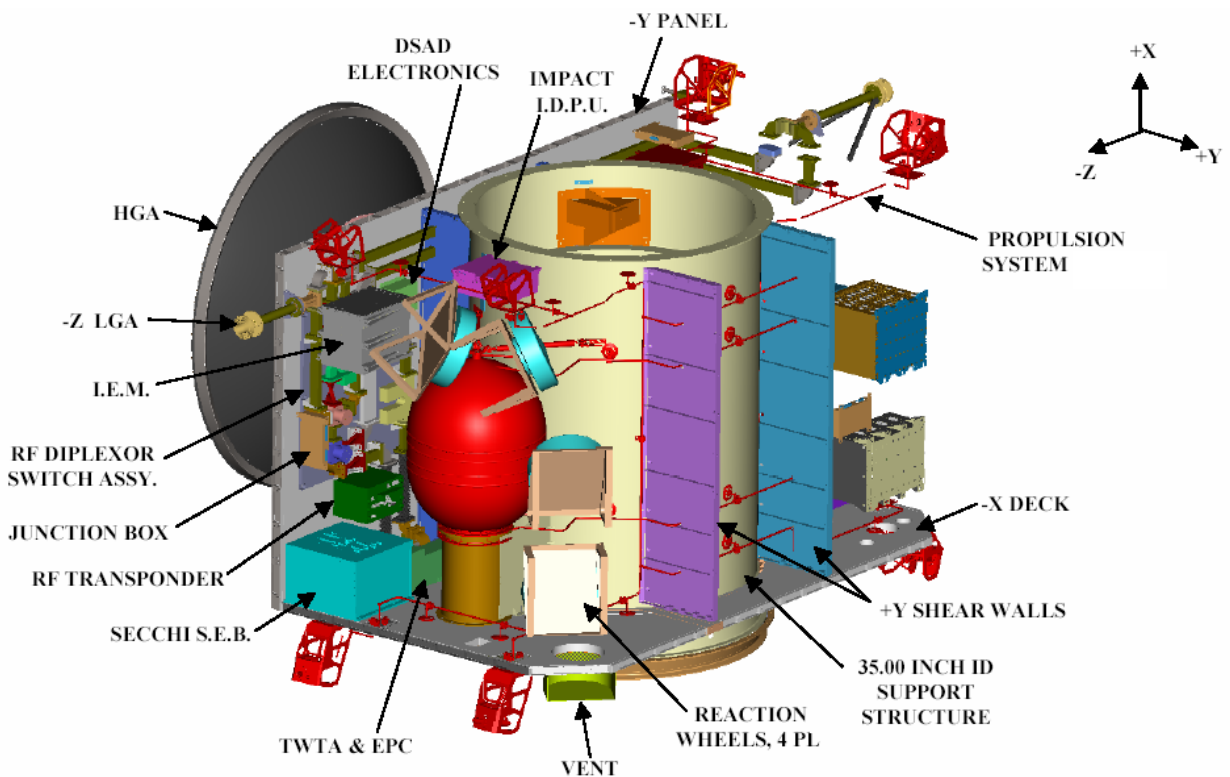
An aluminum and honeycomb panel framework provides the overall structure for supporting and positioning the instruments, supporting the propulsion tanks and components and for maintaining pointing and alignment. The structure also provides the surface for mating mission-unique elements to the observatory. The body of the spacecraft is built around a central thrust tube 37 inches in diameter. The box-like exterior is connected to the central tube by radial struts. The two spacecraft are connected by a SAAB V-band clamp separation system. The SECCHI optical benches are mounted in the center of the thrust tubes.



# STEREO OBSERVATORY PRIMARY STRUCTURE



## INTERIOR VIEW WITH +X, +Y, -Z PANELS



## GUIDANCE AND CONTROL SUBSYSTEM

The Guidance and Control (G&C) subsystem autonomously maintains attitude orientation and stability of each observatory during all phases of the mission, including and following separation from the Delta II launch vehicle. It supports observatory functions associated with science data collection, communications, power, thermal control, and propulsive maneuvers. Controlled by an on-board computer, the G&C subsystem is capable of pointing the spacecraft anywhere in the sky. The G&C subsystem is a closed loop, three-axis control system, capable of very fine pointing.

### ❖ Sensors.

- Star Tracker for absolute attitude reference.
- The Star Tracker provides "coarse" Sun pointing to allow the SECCHI Guide Telescope to find the Sun. It also provides roll knowledge and control.
- Redundant Inertial Measurement Units (IMU).
- The IMUs are used during initial detumbling off the rocket, attitude control during thrusting maneuvers, and enhance fine pointing when in science mode.
- Five Digital Sun Sensors providing full sky coverage.
- The Sun Sensors are used in emergency situations to find the Sun.
- SECCHI Guide Telescope for fine pointing.
- The Guide Telescope provides exceedingly accurate pointing at the Sun. The Guide Telescope is capable of allowing the SECCHI telescopes to point at the sun with a long-term average of less than 7 arc-seconds.

### ❖ Actuators.

- Four Reaction Wheels for fine pointing control. The four low-noise reaction wheels are mounted in a tetrahedral pyramid configuration.

- Twelve 4.4N thrusters for attitude control and momentum management.

The twelve Rocket Engine Assemblies (REAs) are mounted on the corners of the spacecraft in four groups of two and four single REAs.

- HGA Gimbal for HGA pointing.

The 1.2-meter diameter antenna is kept at the Earth by a combination of two motions. One motion rotates the whole spacecraft around the spacecraft X-axis (the spacecraft to Sun line); the other motion is created by a motor and rotates the antenna about the Y-axis.

## **PROPULSION SUBSYSTEM**

Each STEREO observatory has a propulsion subsystem designed and built by Aerojet Redmond Rocket Center (RRC) of Washington. The monopropellant "blow-down" system is composed of three sets of four hydrazine thrusters to allow propulsive maneuvering on orbit. The twelve thrusters are orientated so that any can apply thrust about any axis of the spacecraft along any axis. Each thruster is 4.4N (about 1 lb. of force). The thrusters can be fired individually or in combinations. The propulsion subsystem is used to adjust the orbit of the spacecraft to fly-by the Moon at just the right location to generate the gravity assist maneuver to place the spacecraft in the correct heliocentric orbit. The thrusters are also used to stop the spacecraft from tumbling immediately after the spacecraft separate from the rocket and from each other. The final use of the thrusters is to de-saturate the reaction wheels when they have absorbed their maximum momentum capability. There is a small but important pressure created by sunlight falling on the spacecraft; this steady pressure slowly spins up the reaction wheels. The thrusters are fired to allow the wheels to be de-spun.

## **POWER SUBSYSTEM**

The power subsystem supplies, controls, and converts electrical power for operation of the STEREO instruments and support subsystems. Sunlight falling on the two solar arrays generates electricity that is converted by the Peak Power Tracker (PPT) to the correct voltage for the battery and spacecraft components. The power available from the solar arrays varies depending on the distance from the Sun and the amount of radiation damage from CMEs and solar radiation. At the end of life, the solar arrays on the 'Behind' spacecraft (farthest from the Sun) supply approximately 600 W.

Two deployable solar array wings (two panels per wing) are folded along the sides of the observatory at launch. After the observatory achieves orbit, the wings deploy into a position for exposure perpendicular to the Sun.

The Nickel-Hydrogen battery supplies power during prelaunch operations, launch phase, eclipse periods, or when observatory power requirements exceed solar array capability.

The Power Distribution Unit (PDU) provides fusing and switching for each of the spacecrafts components. The Power System Electronics (PSE) controls battery charging and controls the PPT and PDU.

### **PEAK POWER TRACKER**

The Peak Power Tracker (PPT) operates the solar arrays so as to get the maximum power from the arrays; it then converts this voltage to the correct voltage for the battery.

## Power Subsystem Characteristics

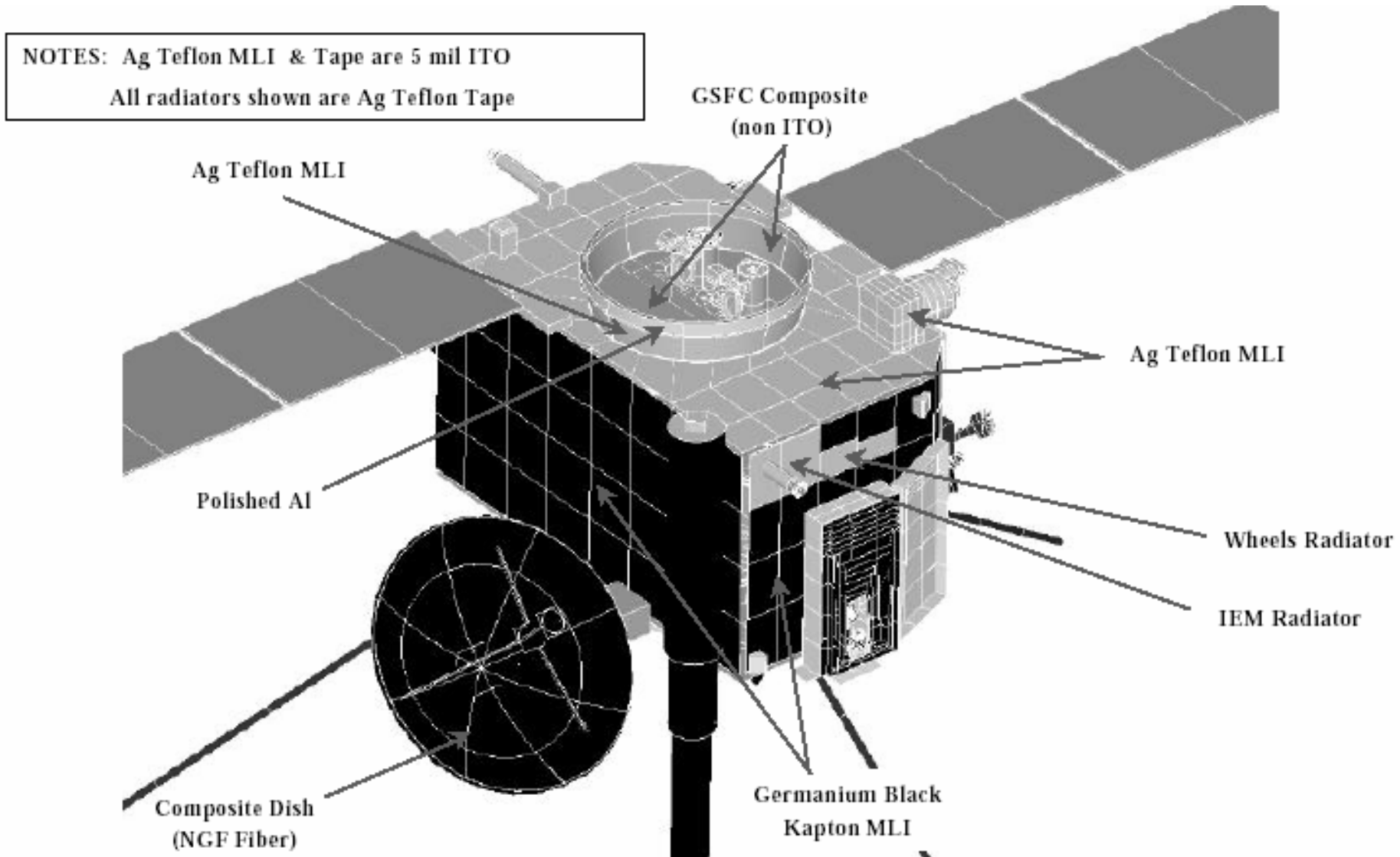
Parameter	Value
Unregulated Bus	24 to 35 V
Solar Array BOL Power	637 W
Solar Array EOL Power	596 W
Average Load Power Requirement at EOL	515 W

## THERMAL CONTROL SUBSYSTEM

The thermal control subsystem uses both active and passive methods to keep the observatory instruments and support subsystems within acceptable temperature ranges during all phases of the mission, including parking orbit, phasing orbit, heliocentric (on-station) orbit, and occasional off-solar pointing. Thermal sensing is provided by various types of thermistors, placed throughout the observatory in the vicinity of critical components. The 'Ahead' spacecraft approaches closer to the Sun than the 'Behind' spacecraft, so without thermal control the 'Ahead' spacecraft would be unacceptably hotter than the 'Behind' spacecraft.

Heaters and passive thermal controls are used to keep critical components within safe temperature ranges. Passive thermal control is provided by thermal paints and coatings, and multilayer blankets. A complicating factor in the design of the coatings and paints is that they must be electrically conductive so as not to disturb the plasma environment measured by the SWEA instrument but must also not flake or create particles that would interfere with the telescopes. A silver-coated Teflon blanket with a coating of Indium-Tin Oxide is used on the Sun-facing surfaces of the spacecraft to minimize the amount of heat absorbed, whereas a black Kapton blanket is used on the back or space-facing surfaces to minimize the heat lost to cold space.

# THERMAL DESIGN OVERVIEW



## COMMAND AND DATA HANDLING SUBSYSTEM

The Command and Data Handling (C&DH) subsystem provides command and control of all observatory functions. The C&DH subsystem provides on-board commanding, data collection, formatting, processing, and storage of telemetry (science and engineering) data from the observatory instruments (science) and support subsystems (engineering). It then distributes this data to the on-board communications subsystem for transmission to the ground.

The C&DH subsystem provides the following basic functions:

- ❖ Receives, decodes, and distributes all commands for STEREO mission operation.
- ❖ Collects, formats, and stores observatory telemetry (science and engineering).
- ❖ Monitors the observatory state of health and is responsible for fault detection and correction.

The C&DH computer is housed in the Integrated Electronics Modules (IEM) along with the G&C computer, instrument data storage memory, and the interfaces to the communications transponder. The C&DH computer is responsible for autonomous operation of the spacecraft. In the event of problems the computer may switch off the instruments and enter a special "Earth Acquisition" mode where the spacecraft points at the Sun and slowly rolls so as to allow the ground to communicate with the spacecraft using its low gain antennae.

### C&DH Subsystem Characteristics

Parameter	Value
Science Data Recording	~57 kbps
Storage Capacity	8 Gb

## COMMUNICATIONS SUBSYSTEM

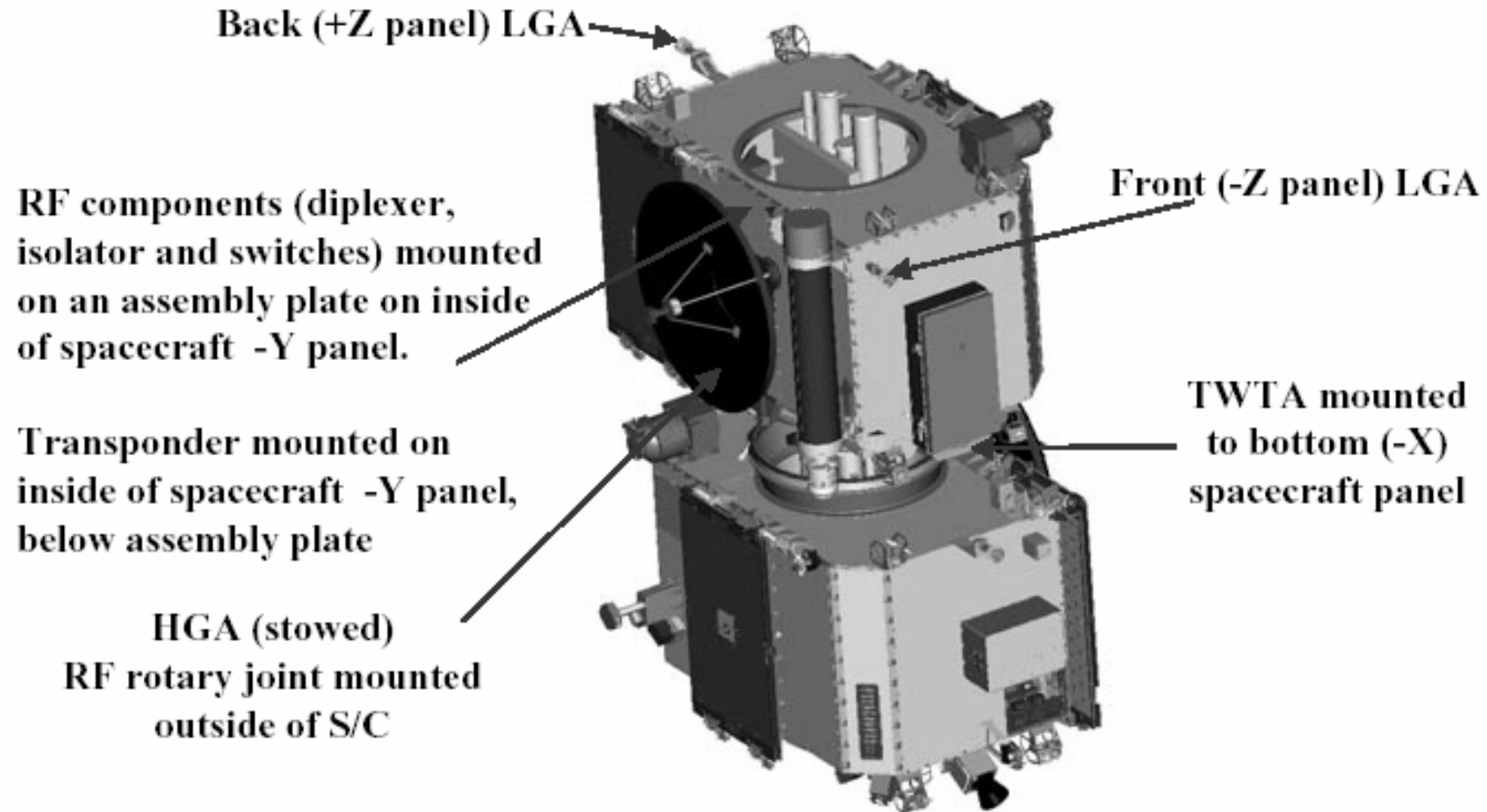
The communications subsystem provides the capability to receive commands and transmit instrument (science) and telemetry (engineering) data to the ground. Normal communications with the ground use a 1.2-meter parabolic HGA. Because of the extreme range of the spacecraft (after 2 years in orbit each spacecraft is approximately 120 million kilometers from the Earth), a 60-Watt X-band Traveling Wave Tube Amplifier (TWTA) is used to amplify the signal and provide enough power for the signal to reach Earth. A transponder is used as the receiver and transmitter and to drive the TWTA because it has the capability to measure the Doppler shift in the radio signal. By measuring the Doppler shift from two different ground stations the position of the spacecraft can be measured by triangulation.

### Communications Subsystem Characteristics

Parameter	Value
Telemetry Rate	<ul style="list-style-type: none"><li>• 720 kbps early in the mission</li><li>• 480 kbps during normal mission operations</li><li>• 360 kbps at the end of the mission</li><li>• 11.7 bps emergency</li></ul>
Command Rate	<ul style="list-style-type: none"><li>• 78 bps emergency command rate</li><li>• 125 normal command rate</li><li>• 500 to 2000 bps software upload rates</li></ul>
Carrier Frequency	<ul style="list-style-type: none"><li>• 8.44 GHz (down)</li><li>• 7.189 GHz (up)</li></ul>
Data Format	Consultative Committee for Space Data Systems (CCSDS)



## COMMUNICATIONS HARDWARE



RF Telecommunications hardware is identical on both Observatories (except for communications frequencies)

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# STEREO LAUNCH SYSTEM

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## LAUNCH COMPLEX

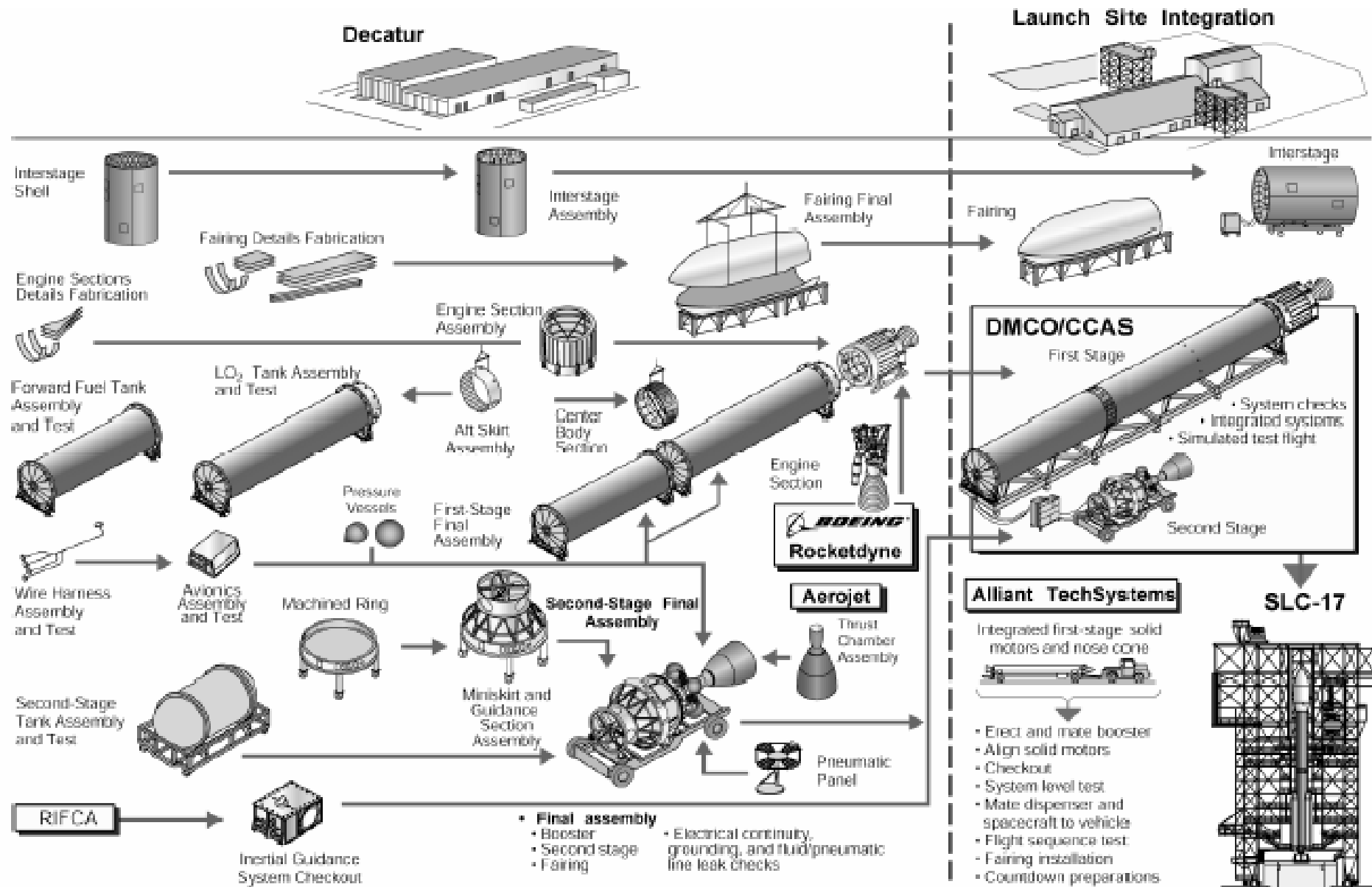
The STEREO observatories will launch from the Cape Canaveral Air Force Station (CCAFS) near the Kennedy Space Center (KSC) in Florida. The major tasks of this center are to:

- ❖ Launch the observatories.
- ❖ Perform range and flight safety operations.
- ❖ Maintain launch vehicle tracking and control during ascent and spacecraft separation.

## LAUNCH OPERATIONS FLOW

The two STEREO observatories will be prepared for launch and fueled at the Astrotech Payload Processing Facility (PPF) close to the Eastern Range (ER). After the observatories are checked out, cleaned, fueled, balanced, and cleaned again they are ready for stacking and mating to the Delta-II third stage (Star-48) rocket. This configuration will then be transported to Space Launch Complex (SLC)-17 at CCAFS where it will be assembled to the remaining Delta-II stages. After this procedure, final observatory testing, payload fairing encapsulation, countdown, and launch take place.

# DELTA II PRODUCTION FLOW FOR CCAFS LAUNCH



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## LAUNCH VEHICLE

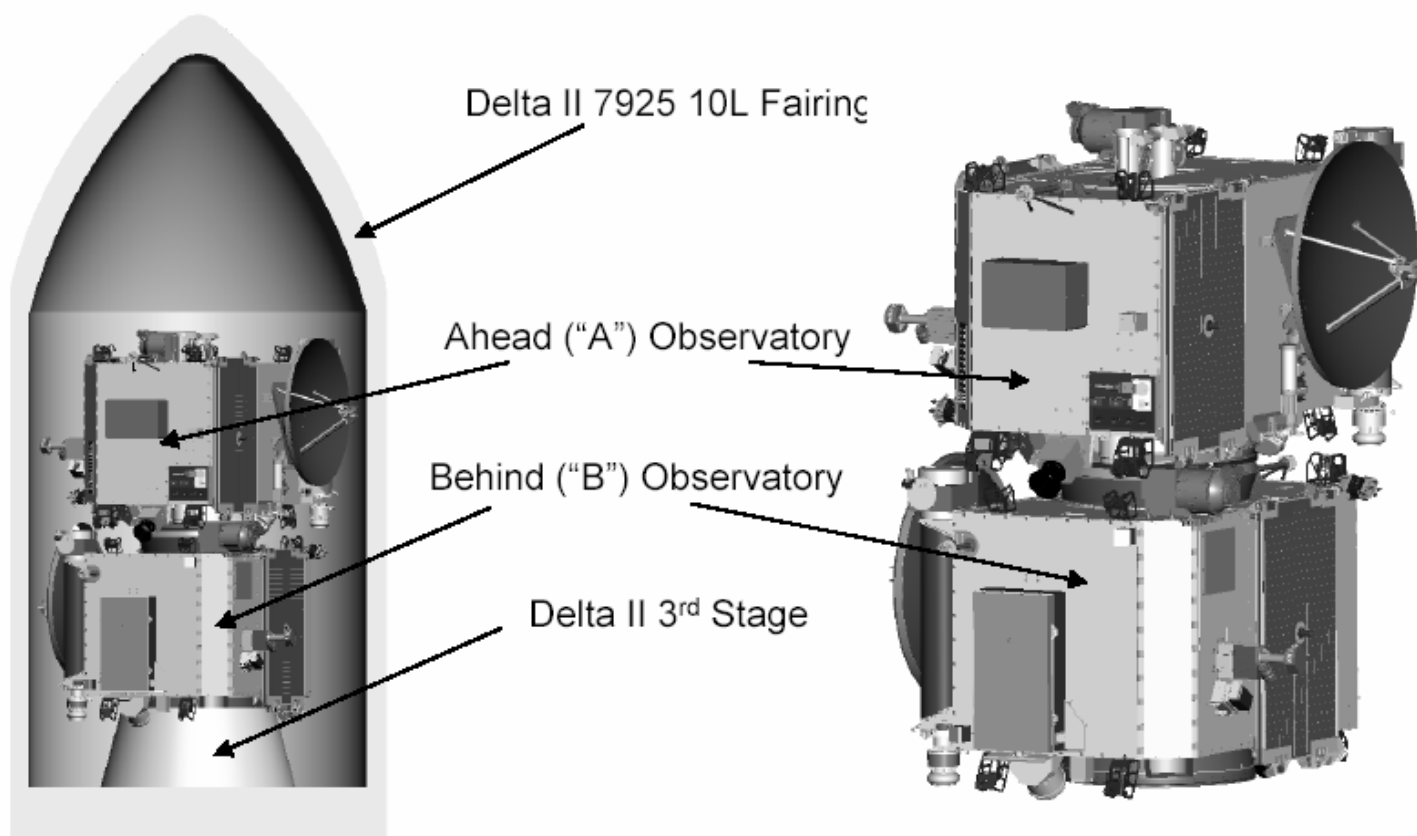
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A Delta-II Model 7925-10L (three-stage, with nine solids and an extended composite fairing) rocket, designed and built by the Boeing Company under the technical direction of NASA/KSC, is used to launch the STEREO observatories.

### LAUNCH VEHICLE CONFIGURATION

The twin STEREO observatories are housed within the launch vehicle's third stage, one on top of the other, using a specially designed Payload Attach Fitting (PAF). The "A" (Ahead) and "B" (Behind) observatories are stacked to fit within a 274.3-cm diameter by 330.7-cm high cylinder and will be dynamically balanced.



Observatory "A" has a Saab-Ericsson SS 937B separation system consisting of an upper ring, lower ring (including band catchers), clamp band, eight separation springs, and two bolt cutters. Observatory "B" mates to the Delta-II launch vehicle by means of a 3712A PAF.

## **FIRST STAGE**

The Delta first stage is powered by an RS-27A Rocketdyne engine using liquid propellants and nine strap-on Alliant graphite-epoxy motors (GEMs) solid rockets to augment the performance. Six motors are ignited at liftoff and the remaining three are air-lit.

## **SECOND STAGE**

The Delta second stage is powered by an AJ10-118K engine using liquid propellants. The second stage takes the observatories to a low circular orbit configuration.

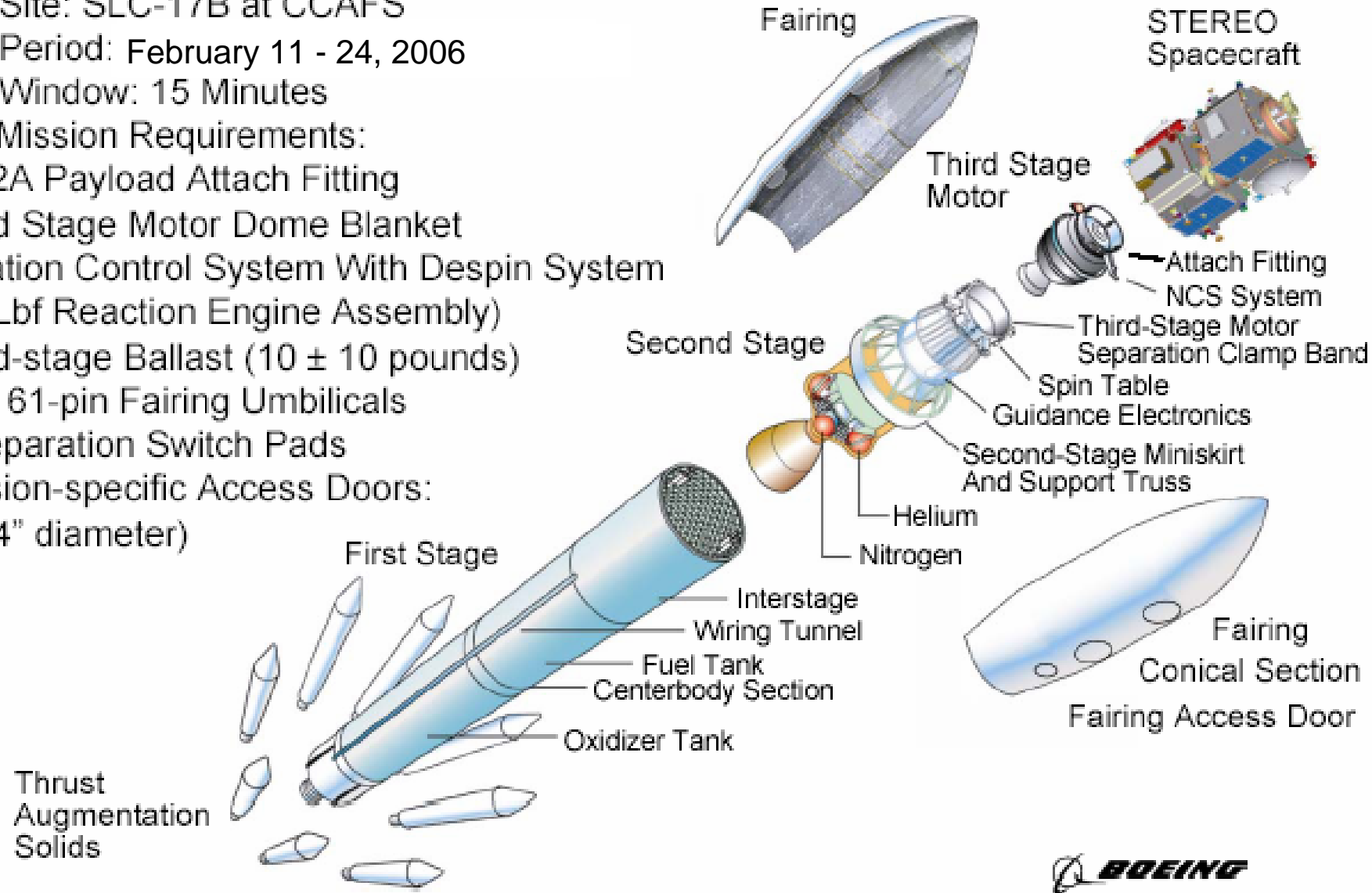
A 10-foot (3-meter) diameter payload fairing protects the STEREO observatories from aerodynamic heating and is jettisoned shortly after second-stage ignition.

## **THIRD STAGE**

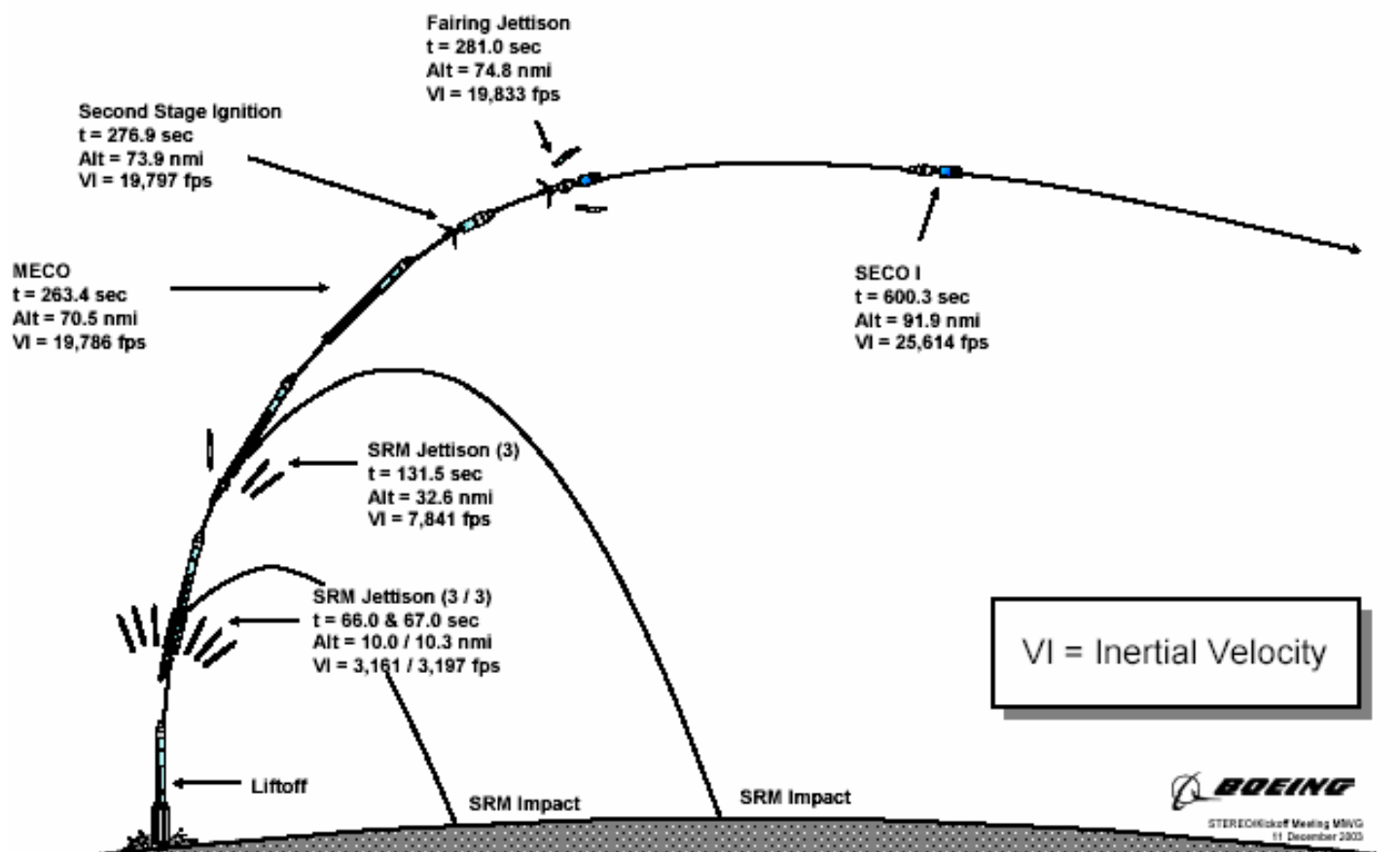
The Delta third stage is propelled by a Thiokol Star-48B solid rocket motor. The third stage boosts the two observatories from a low-Earth orbit (approximately 100 km) to an orbit that has its apogee close to the Moon.

# DELTA-II 7925-10L LAUNCH VEHICLE

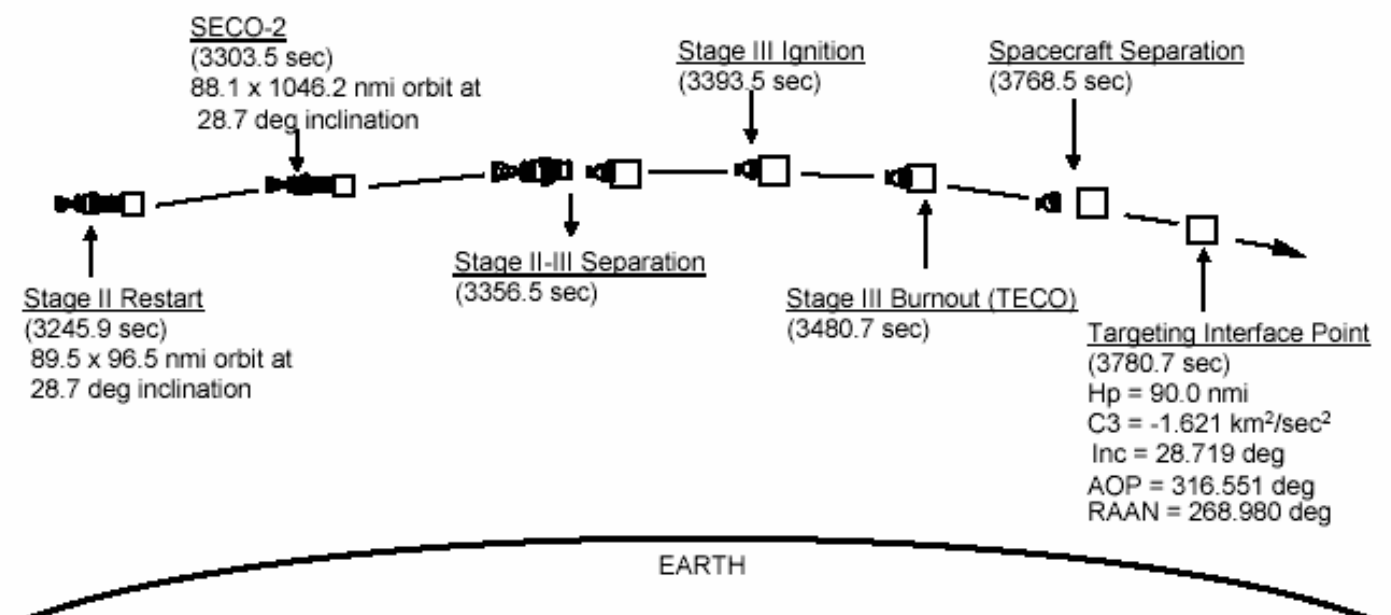
- Vehicle Configuration: 7925-10L
- Launch Site: SLC-17B at CCAFS
- Launch Period: February 11 - 24, 2006
- Launch Window: 15 Minutes
- Unique Mission Requirements:
  - 3712A Payload Attach Fitting
  - Third Stage Motor Dome Blanket
  - Nutation Control System With Despin System (37 Lbf Reaction Engine Assembly)
  - Third-stage Ballast (10 ± 10 pounds)
  - Two 61-pin Fairing Umbilicals
  - 2 Separation Switch Pads
  - Mission-specific Access Doors: 2 (24" diameter)



# LAUNCH AND INJECTION INTO ORBIT



## SECO-1 TO SPACECRAFT SEPARATION FLIGHT PROFILE



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## **STEREO FLIGHT OPERATIONS**

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The Deep Space Mission System (DSMS) provides the antennae which contact the observatories daily. Because of the extreme distance, large 34-meter dishes, located in Madrid, Spain, Canberra, Australia, and Goldstone in California, are used. Each observatory will transmit science data back to the ground for 4 hours every day. For the remainder of the day the spacecraft will be transmitting a low-rate Space Weather signal. This signal will give a continuous picture of the Sun and the weather in the vicinity of the spacecraft. The STEREO Science Center (SSC) will coordinate and distribute this data. It is anticipated that the National Oceanic and Atmospheric Administration (NOAA) and other international partners will receive the space weather signal on smaller 13-meter dishes.

### **STEREO GROUND SYSTEM FACILITIES**

When designing the STEREO spacecraft, several choices were made to save on Mission Operation and Data Analysis (MO&DA) costs without compromising on scientific goals. For the STEREO Ground System, these include:

- ❖ Single shift of operators during daytime hours.
- ❖ Common ground system for integration and test (I&T) and MO&DA.
- ❖ Ground system autonomous to the greatest extent possible.

The ground system facilities that provide special support for the STEREO mission include:

The DEEP SPACE NETWORK (DSN) ground stations provide space-to-ground services for transmitting commands and telemetry/tracking data, as well as signal processing and science data handling during the mission.



The MISSION OPERATIONS CENTER (MOC), located at JHU/APL, serves as the focal point for the STEREO on-orbit operations control. It provides the hardware and software necessary for the successful conduct of operations activities.

The SCIENCE DATA SYSTEM (SDS) is a distributed system with elements that are part of several different facilities. The SDS Manager at JHU/APL coordinates these elements. Many of the facilities that are part of the SDS support elements (external users) are not related to the data system. Only functions that are directly related to the routine production, acquisition, archiving, or distribution of data are within the scope of the SDS. The SDS is required to supply data to both STEREO program elements and external users. STEREO program elements require science data products as input to instrument operations and data analysis. For external users, the STEREO SDS is the principal means of access to STEREO data products during the course of the mission.

The FLIGHT DYNAMICS FACILITY (FDF) will be responsible for collecting and processing tracking data (range and doppler) from the DSN tracking stations. Orbit determination will be performed on a bi-weekly basis using the Goddard Trajectory Determination Software (GTDS). The orbit determination solutions will be used to produce definitive and predictive ephemeris files that will be delivered to the STEREO MOC for science data processing and mission planning.

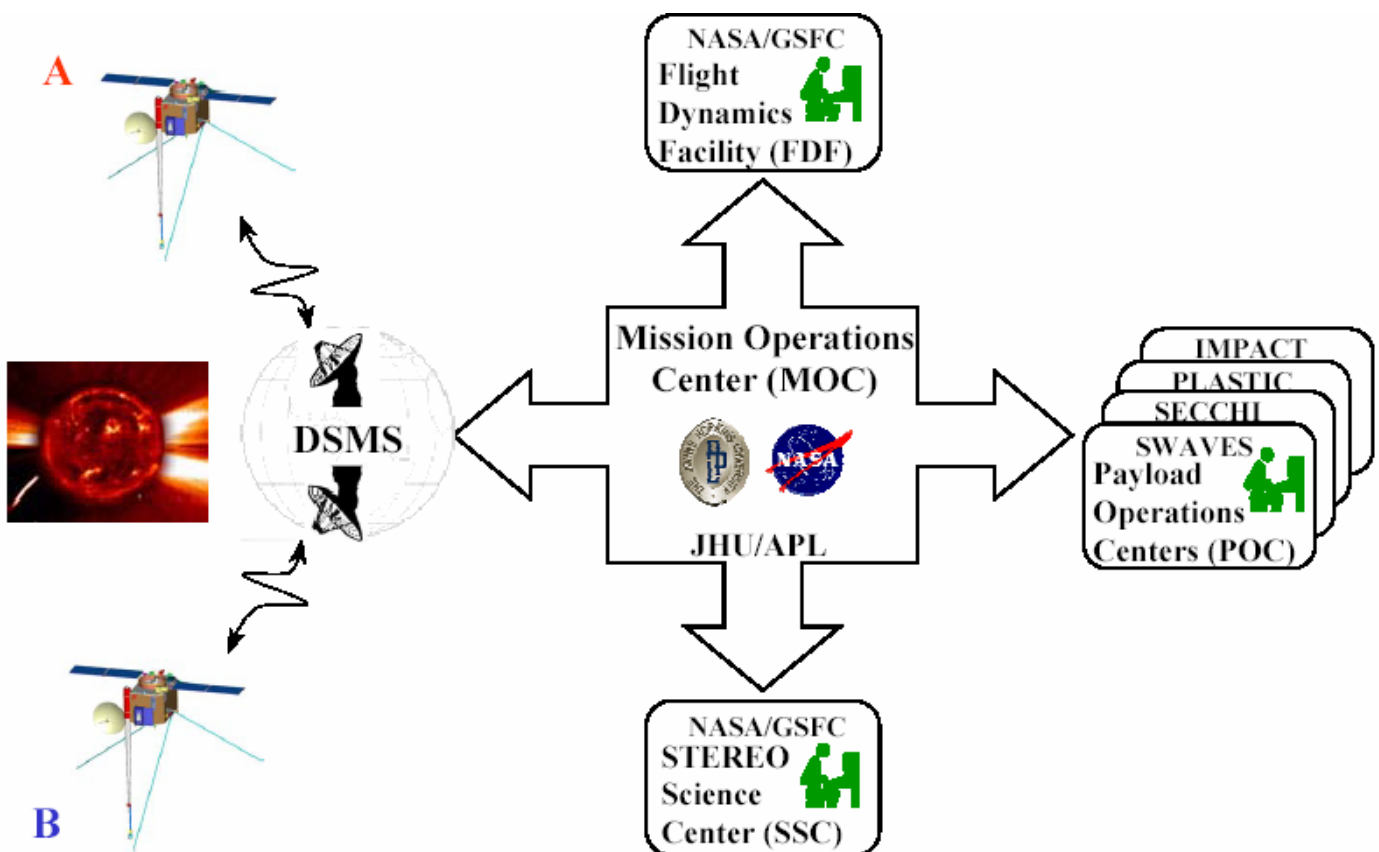
The STEREO SCIENCE CENTER (SSC) serves as the central facility responsible for telemetry distribution, archiving, and other central functions, such as long-term science planning and coordination with the science teams. The SSC is also responsible for the receipt and processing of the real-time Space Weather data. The SSC is the principal interface with the scientific community and the public at large.

(<http://stereo.gsfc.nasa.gov/>)

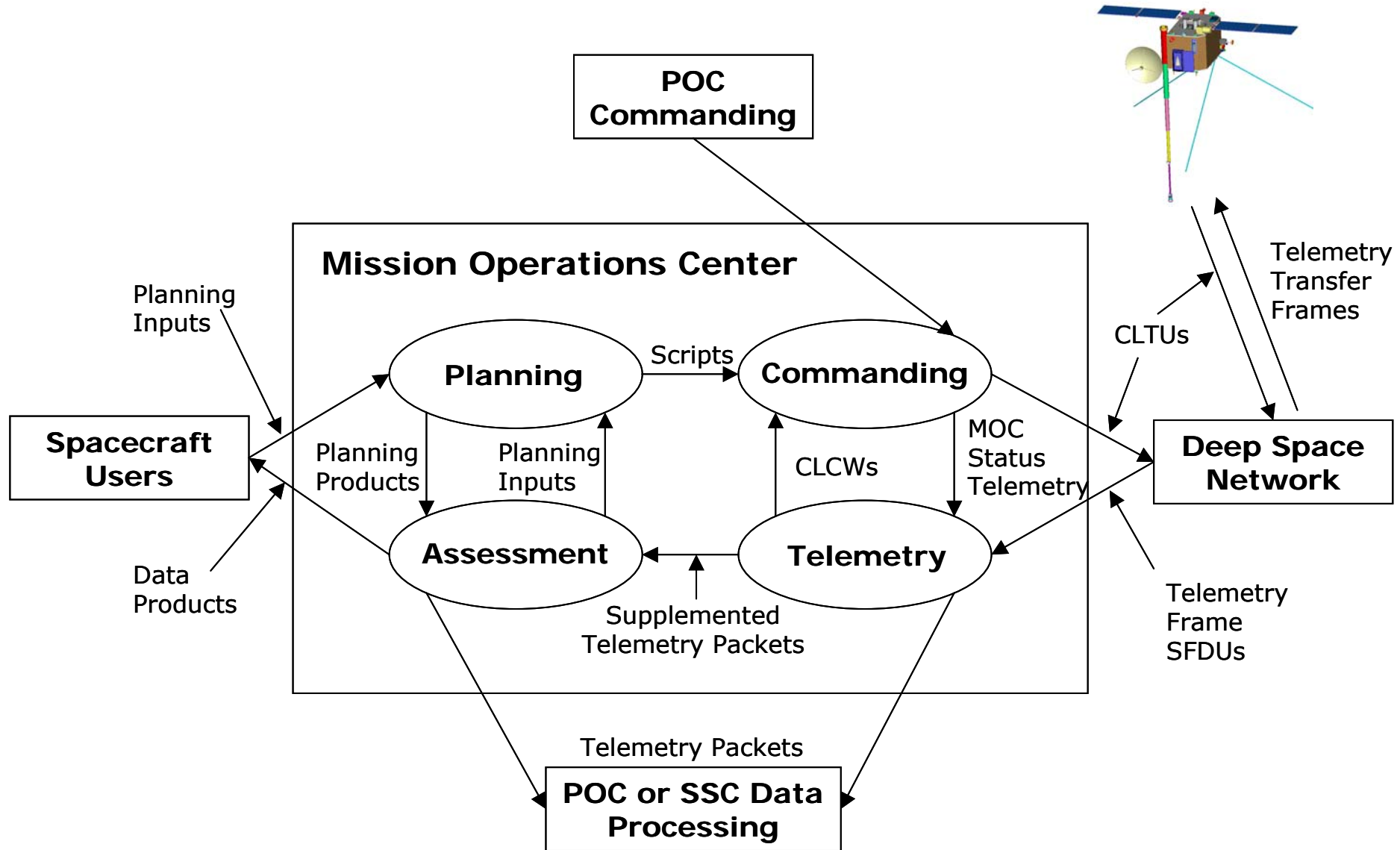
The PAYLOAD OPERATIONS CENTER (POC) facilities, located at NRL, UMN, UCB, CalTech, and UNH, are responsible for STEREO instrument operations and assessment as well as data operations (i.e., data reduction, processing, and distribution of data analysis products).

STEREO data will be available on-line from the SSC to support modeling.

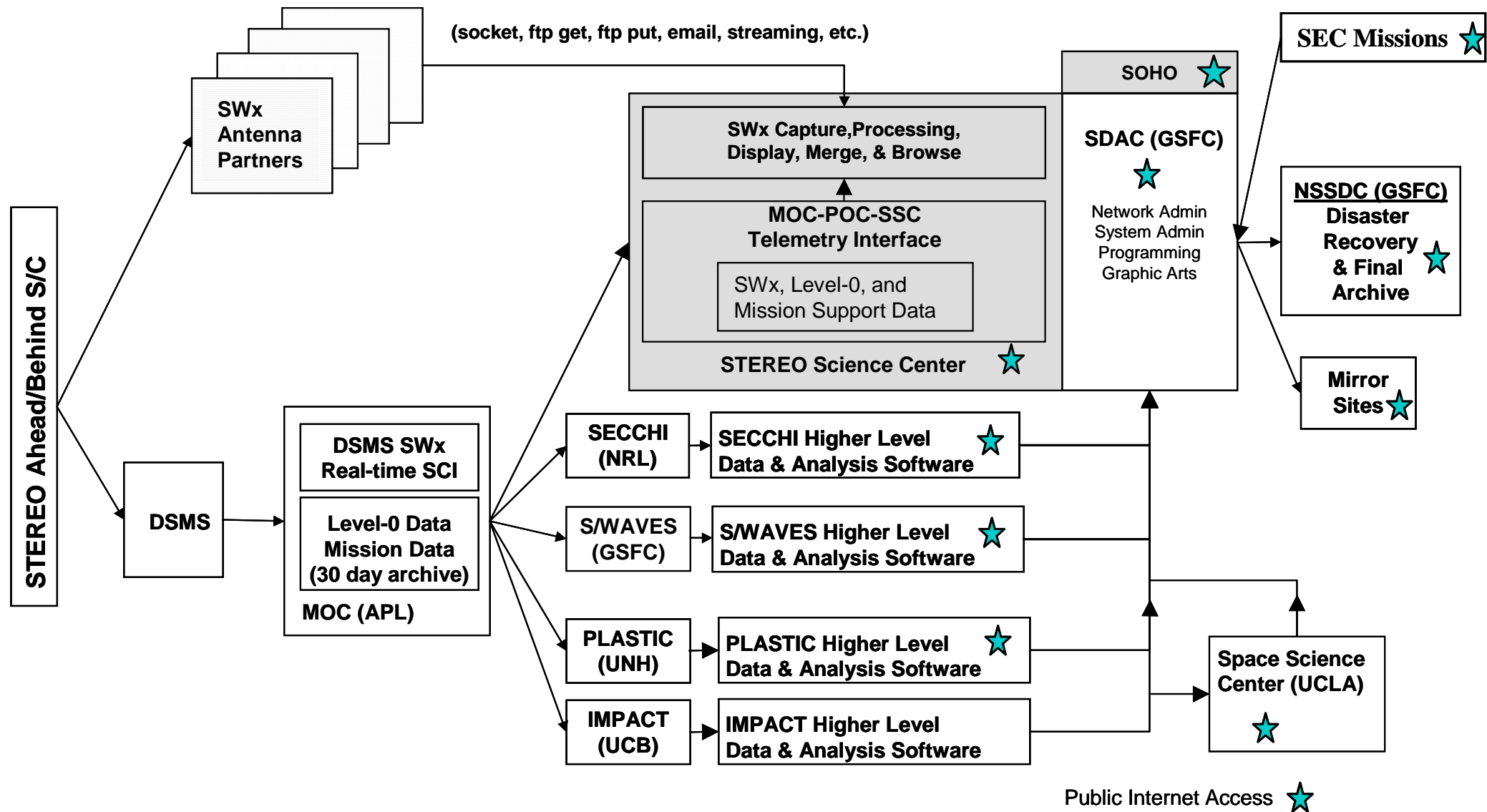
## STEREO GROUND SYSTEM



# GROUND SOFTWARE ARCHITECTURE



# SCIENCE DATA SYSTEM FUNCTIONAL DATA FLOW



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## STEREO MISSION OPERATIONS

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The STEREO mission operations approach allows for the direct control of scientific instruments by the Principal Investigators (PIs) who are located at seven POCs across the U.S. Unlike many spacecraft, where requests for activities must be balanced against regular maintenance activities, STEREO is designed to allow the instruments to be operated independently of each other. In addition, daily spacecraft maintenance activities do not interfere with data collection activities.

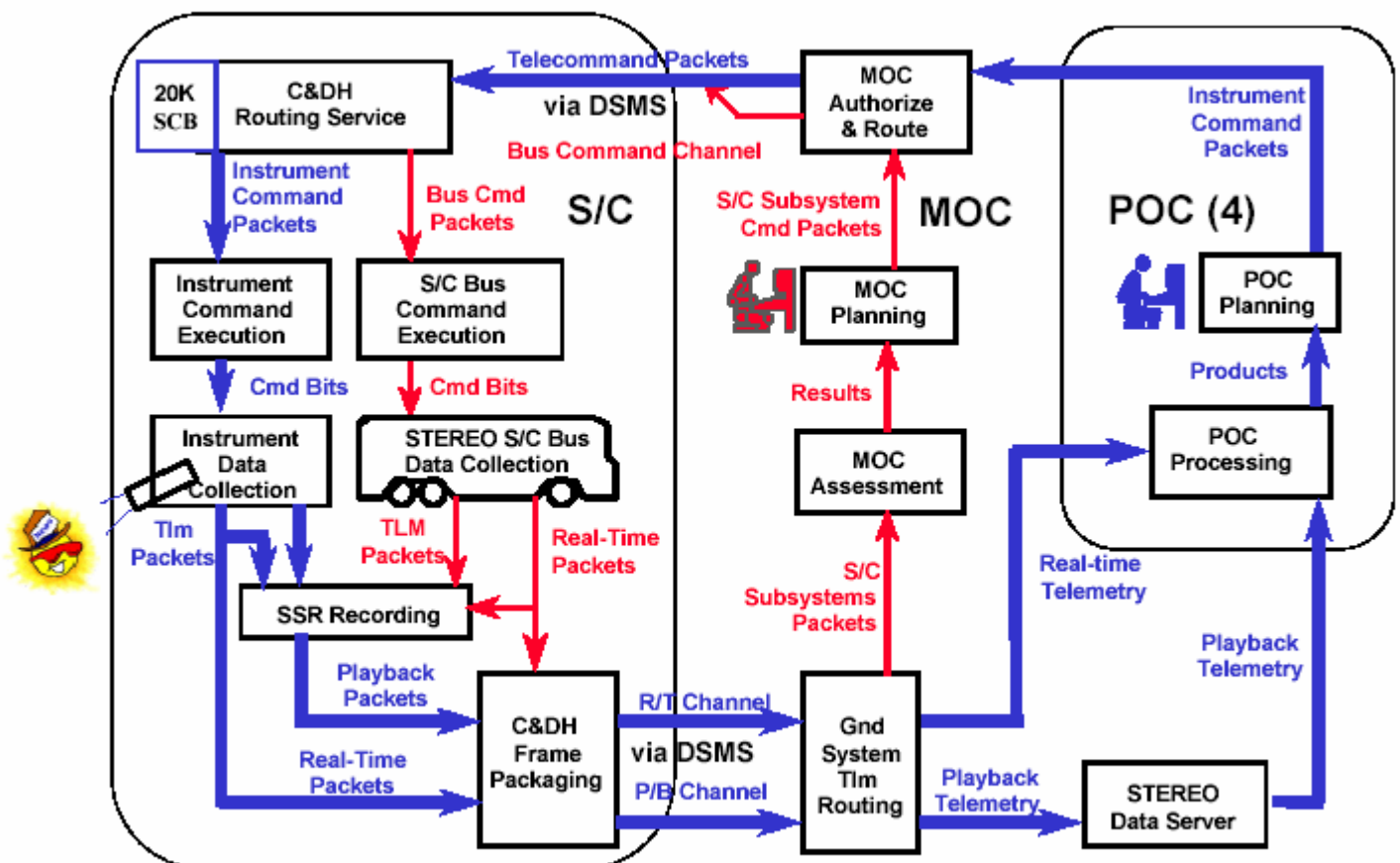
The POCs are located at:

- ❖ STEREO Science Center/NASA Goddard Space Flight Center (Archiving; Data Distribution; Space Weather)
- ❖ Navel Research Laboratory, Washington, DC (SECCHI)
- ❖ University of California, Berkeley (IMPACT)
- ❖ California Institute of Technology (IMPACT)
- ❖ University of New Hampshire (PLASTIC)
- ❖ University of Minnesota (S/WAVES)
- ❖ University of California, Los Angeles (Archiving)

The PIs at these POCs send instrument commands each day to the STEREO MOC at JHU/APL where the commands are combined and uplinked to the observatories once a day. This interdisciplinary approach allows data to be collected at low cost and data products to be distributed in an efficient manner.

# STEREO DATA FLOW

As with mission operations, STEREO's data management system is innovative in its approach. STEREO's Mission Data Center (MDC) – part of the MOC – downlinks raw data from the observatories and sends it directly to the POCs. Teams from each POC process the data from their respective instruments and generate data products. When these data products are complete, the MDC is notified that the product is ready for distribution. The MDC then updates its central catalog of STEREO data products, which is accessible over the web to scientific and educational communities as well as the general public. Typical turnaround time from data acquisition by the observatory to distribution on-line is only 3 to 24 hours – a fraction of the time taken by a typical space science mission.



\* TIMED mission heritage

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# STEREO SCIENCE TEAM

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## MISSION MANAGEMENT

NASA Program Executive: Victoria Elsbernd  
NASA Program Scientist: Madhulika Guhathakurta  
NASA Program Manager: Gilberto Colón  
NASA Project Manager: Nicholas Chrissotimos  
NASA Project Scientist: Michael Kaiser  
JHU/APL Project Manager: Edward Reynolds

## INSTRUMENT PRINCIPAL INVESTIGATORS

Janet Luhmann	University of California, Berkeley
Russell Howard	Naval Research Laboratory
Antoinette Galvin	University of New Hampshire
Jean-Louis Bougeret	Centre National de la Recherche Scientifique Observatoire de Paris

<http://stereo.gsfc.nasa.gov/>

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## ACRONYMS AND ABBREVIATIONS

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AU	Astronomical Unit
BOL	Beginning Of Life
bps	Bits per second
C&DH	Command and Data Handling
CalTech	California Institute of Technology
CCAFS	Cape Canaveral Air Force Station
CCSDS	Consultative Committee on Space Data Systems
CEB	Camera Electronics Box
CIR	Co-rotating Interaction Region
CME	Coronal Mass Ejection
COR	Coronagraph
DPU	Data Processing Unit
DSMS	Deep Space Mission System
DSN	Deep Space Network
E/Q	Electrostatic Analyzer
ELV	Expendable Launch Vehicle
EOL	End Of Life
EPO	Education and Public Outreach
ER	Eastern Range
EUVI	Extreme Ultraviolet Imager
FDF	Flight Dynamics Facility
FFR	Fixed Frequency Receiver
fps	feet per second
G&C	Guidance and Control
GEM	Graphite-Epoxy Motor
GSFC	Goddard Space Flight Center
GT	Guide Telescope
GTDS	Goddard Trajectory Determination Software
HET	High Energy Telescope
HFR	High Frequency Receiver
HGA	High Gain Antenna
HI	Heliospheric Imager
I&T	Integration and Test
ICME	Interplanetary CME
IEM	Integrated Electronics Module



## ACRONYMS AND ABBREVIATIONS (cont.)

IMPACT	In-situ Measurement of PArticles and CME Transients
IMU	Inertial Measurement Unit
IPS	Interplanetary Shock
JHU/APL	Johns Hopkins University Applied Physics Laboratory
KSC	Kennedy Space Center
LET	Low Energy Telescope
LFR	Low Frequency Receiver
LGA	Low Gain Antenna
MAG	Magnetometer
MDC	Mission Data Center
MEB	Mechanism Electronics Box
MECO	Main Engine Cut-Off
MOC	Mission Operations Center
MO&DA	Mission Operations and Data Analysis
NASA	National Aeronautics and Space Administration
nmi	nautical miles
NOAA	National Atmospheric and Oceanic Administration
NRL	Naval Research Laboratory
nT	nana Tesla
PAF	Payload Attach Fitting
PDU	Power Distribution Unit
PI	Principal Investigator
PLASTIC	PLAsma and SupraThermal Ion Composition
POC	Payload Operations Center
PPF	Payload Processing Facility
PPT	Peak Power Tracker
PSE	Power System Electronics
REA	Rocket Engine Assembly
RRC	Redmond Rocket Center
Rsun	Radius of the Sun
S/C	Spacecraft
SCIP	Sun-Centred Imaging Package
SDS	Science Data System

## ACRONYMS AND ABBREVIATIONS (cont.)

SECCHI	Sun-Earth Connection Coronal and Heliospheric Investigation
SECO	Second Engine Cutoff
SEP	Solar Energetic Particle
SEPT	Solar Electron and Proton Telescope
SIT	Suprathermal Ion Telescope
SLC	Space Launch Complex
SRM	Solid Rocket Motor
SSC	STEREO Science Center
STE	Suprathermal Electron Telescope
STEREO	Solar TERrestrial RELations Observatory
STP	Solar Terrestrial Probes
S/WAVES	STEREO/WAVES
SWEA	Solar Wind Experiment
SWS	Solar Wind Sector
TDS	Time Domain Samplers
TECO	Third Engine Cut-Off
TLM	Telemetry
TOF	Time of Flight
TRACE	Transition Region And Coronal Explorer
TWTA	Traveling Wave Tube Amplifier
UCB	University of California, Berkeley
UCLA	University of California, Los Angeles
UMN	University of Minnesota
UNH	University of New Hampshire
VI	Inertial Velocity
WAP	Wide-Angle Partition

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# NOTES

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