THE STEREO MISSION AND THE S/WAVES INSTRUMENT

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Abstract

In 2006, NASA will launch the twin STEREO spacecraft from Kennedy Space Center into a pair of heliocentric orbits near 1 AU such that the spacecraft will move away from Earth (ahead and behind) at about 22 degrees per year. The STEREO Mission will help us to understand the causes and mechanisms of coronal mass ejection (CME) initiation and to follow the propagation of CMEs through the heliosphere. STEREO will also study the mechanisms and sites of solar energetic particle (SEP) acceleration and determine the 3–D time-dependent magnetic topology, temperature, density and velocity of the solar wind between the sun and Earth. Each STEREO spacecraft will be equipped with optical and particles and fields instruments including the STEREO Waves (S/waves) instrument. S/waves will use radio Waves to track the location of CME-driven shocks (via type II bursts) and the 3–D topology of open field lines along which energetic particles flow (via the ubiquitous type III bursts). The radio tracking portion of S/waves is a direct descendant of the Cassini RPWS radio receiver with some important improvements.

1 Introduction

The Solar TErrestrial RElations Observatory (STEREO) Mission, to be launched in 2006, will provide a new perspective on the Sun by making stereoscopic measurements of coronal mass ejections (CMEs) and other solar phenomena. Each of the two nearly identical STEREO spacecraft carries a complement of imaging, remote-sensing and particle and fields instruments. STEREO will be the first mission to image CMEs continuously in 3D from the Sun to Earth. 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.

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- Develop a three–dimensional, time–dependent model of the magnetic topology, temperature, density, and velocity structure of the ambient solar wind.

STEREO is managed by NASA's Goddard Space Flight Center (GSFC) in Greenbelt, MD, USA. GSFC provides science instrument management, systems engineering, mission assurance and reliability, science and data analysis, data archiving, and coordination of education and public outreach 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.

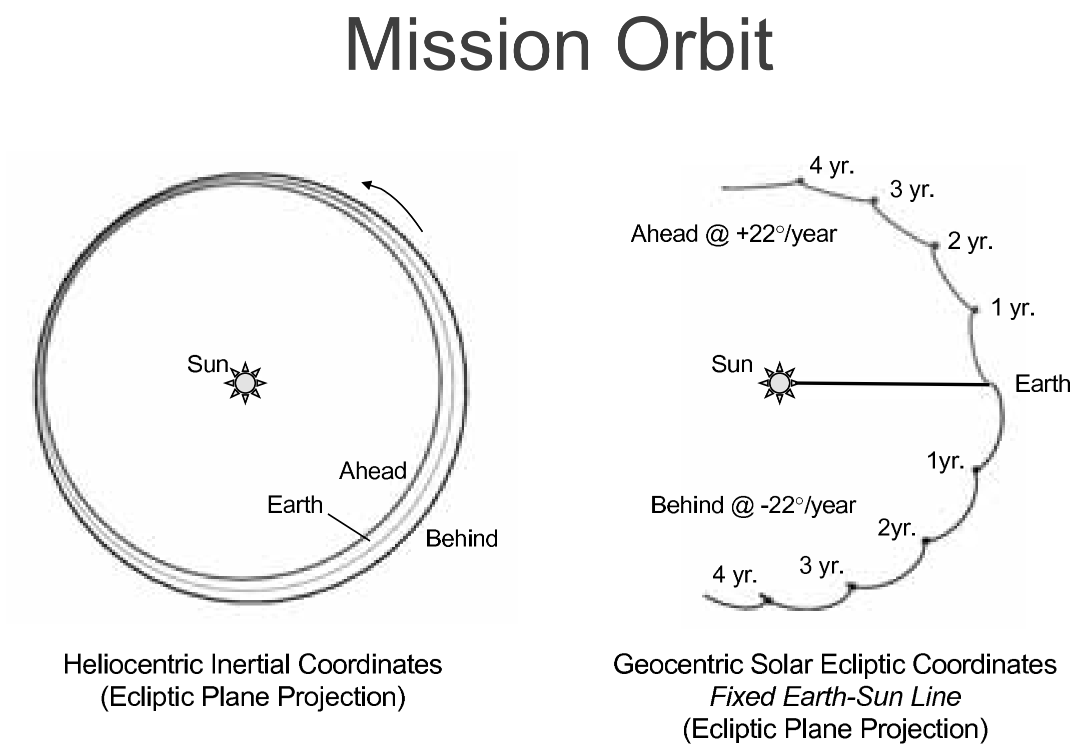

Figure 1: The left panel shows the orbits of the two STEREO spacecraft. The 'ahead' spacecraft is in an orbit slightly small than 1 AU and the 'behind' orbit is slightly larger than 1 AU. Thus, the 'ahead' spacecraft orbits the sun in about 342 days and the 'behind' in about 388. As viewed from a fixed Earth-sun line in the right panel, the spacecraft separate from one another about 45 degrees per year.

The STEREO observatories will be placed into solar orbits with semimajor axes of nearly 1 AU with one observatory "ahead" of Earth in its orbit and the other, "behind". The 'ahead' spacecraft will be in an orbit slightly closer to the sun than Earth's orbit and the 'behind' spacecraft will be in a slightly larger orbit (left panel, figure 1). As viewed from the sun, the two spacecraft will separate at an average of 45 degrees per year (right panel, figure 1).

The STEREO observatories carry 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)

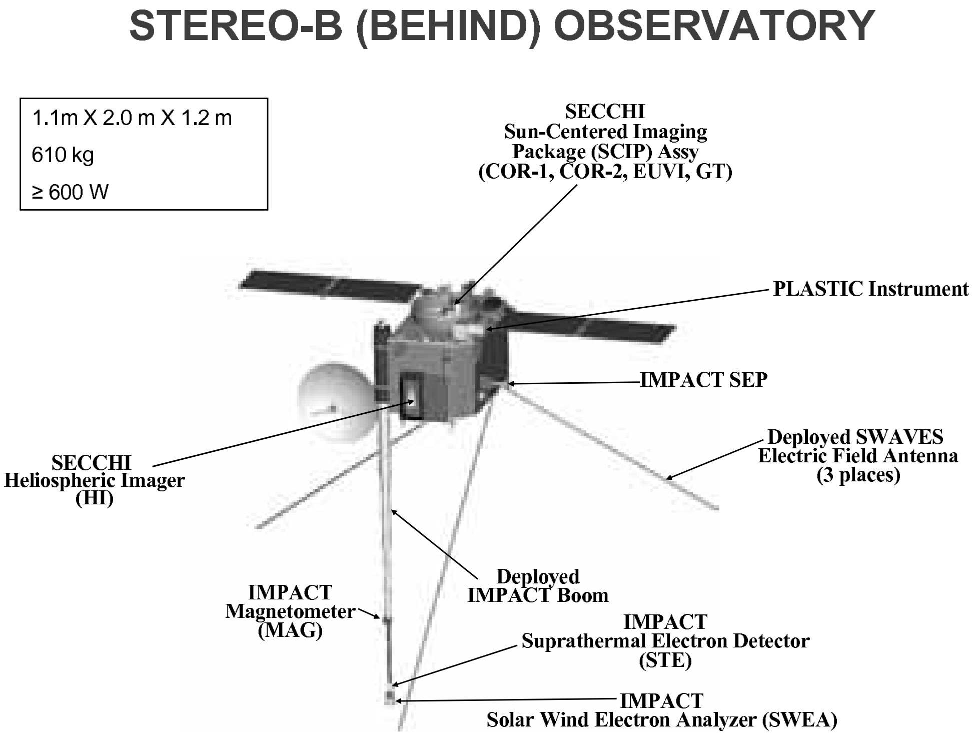

Figure 2: An artists conception of the "behind" spacecraft ("ahead" spacecraft nearly identical except for placement of some body-mounted experiments) with the locations of the instruments shown. The SECCHI instruments point at the sun and the IMPACT boom and S/waves antennas are on the opposite end. The spacecraft are three axes stabilized.

Figure 2 shows the STEREO behind spacecraft with the various instruments indicated.

S/waves will be described below in some detail. As for the other instruments, SECCHI (PI: Dr. Russ Howard, Naval Research Laboratory, Washington, DC) 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. SECCHI consists of two traditional coronagraphs, and extreme ultraviolet imager and two low light telescopes to image CMEs far from the sun. IMPACT (PI: Dr. Janet Luhmann, University of California, Berkeley, CA) 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 PLASTIC experiment (PI: Dr. Toni Galvin, University of New Hampshire, Durham, NH) 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.

Assisting the four instrument teams are several groups devoted to global modeling with a goal of understanding the connection between the solar activity observed near the sun by SECCHI and S/waves and the in situ measurements taken by IMPACT, PLASTIC, and S/waves when the disturbances finally reach the STEREO spacecraft.

In addition to normal data collection, the two STEREO spacecraft also broadcast continuously a low rate ($\sim$ 600 bps) set of data consisting of typically 1–minute summaries (or 5 minute in the case of SECCHI) to be used for space weather forecasting, much like is currently done with the ACE and SOHO data. Several participating NOAA and international ground tracking stations will collect the data and send them electronically to the STEREO Science Center (see below) where they will be processed into useful physical quantities and placed on the STEREO Web page. The goal is to have the processed data available within 5 minutes of receipt at the tracking stations.

Finally, the STEREO Science Center (SSC) serves as the central facility responsible for telemetry distribution and 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. Its Web site is `http://stereo.gsfc.nasa.gov`.

2 The S/waves Instrument

The S/waves instrument, being built by a team led by the Observatoire de Paris (PI: Dr. Jean-Louis Bougeret) and the University of Minnesota (PM: Mr. Keith Goetz), is an interplanetary radio burst tracker that observes 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 antenna elements, each 6 meters in length. The three monopoles, built by the University of California, Berkeley, will be deployed away from the Sun so that they remain out of the fields of view of Sun-facing instruments. The S/waves instrument includes:

- Radio receivers (HFR and LFRhi) that measure radio wave intensity, source direction, and angular size in the frequency range of 16 MHz to 40 kHz, corresponding to source distances of about 2 R_S to 1 AU (e.g. see [Leblanc et al., 1999])
- Low Frequency Receivers (LFRlo) that make sensitive measurements of radio and plasma Waves near the electron plasma frequency at 1 AU (2.5 to 40 kHz).

- A Fixed Frequency Receiver (FFR) that measures radio emissions at 32 to 34 MHz at high time resolution to complement ground-based radio-heliograph measurements.
- Time Domain Samplers (TDS) that simultaneously make wideband waveform measurements on three electric antennas at one of several commandable sample rates and bandwidths.

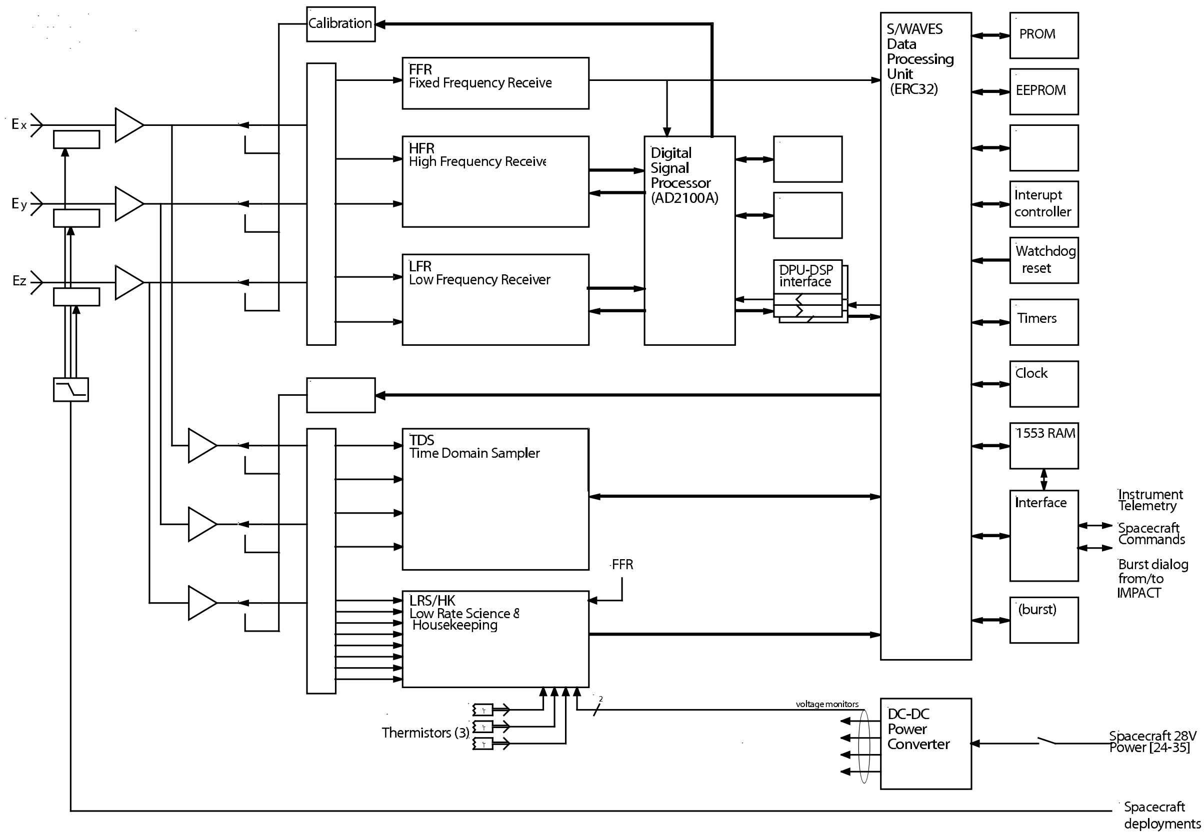

Figure 3: S/waves block diagram with portions built by the Observatoire de Paris/Meudon, the University of Minnesota (UMN), and the University of California at Berkeley (UCB).

The S/waves instrument, including antennas, has a mass of about 13.25 kg and consumes about 15.4 W. The instrument bit rate is about 2 kbps. Figure 3 shows a block diagram of the S/waves instrument with shaded sections indicating which institution is responsible for each section of the instrument.

Since the STEREO spacecraft are three axes stabilized, the traditional direction finding technique of modeling the sinusoidal modulation on the received signals imposed by a spinning spacecraft cannot be used. Instead, cross correlations between all three antennas are measured and the resulting sets of equations are inverted to produce direction of arrival azimuth and elevation and source size. This is the same technique successfully used by the Cassini Radio and Plasma Wave instrument [Cecconi and Zarka, 2005; Gurnett et al., 2004]; in fact, the STEREO radio receiver is only a minor modification of the Cassini receiver (12 bit cross correlations instead of 8 bit).

Combining the direction finding results from the two S/waves instruments results in stereoscopy of solar radio sources. Specifically, the measurements include:

- intensity as seen from each spacecraft, which gives some measure of directivity
- polarization which, if measurable, could give some important information about emission modes
- time-of-flight differences provide a helpful auxiliary measurement to localization
- dynamic spectra, which give a good overview of the overall solar activity
- source direction and size

When these measurements are applied to the specific radio emissions, and combined with information from the other STEREO instruments, the following results should be obtained:

- Type III bursts (energetic electrons)
  - Radiation mechanism, association with electron events
  - Structure and topology of large scale magnetic field
  - Improved models of the electron density structure of the inner heliosphere
  - Understanding propagation phenomena and scattering
- Type II bursts (shocks)
  - Association with visible CME structures
  - Formation and evolution of CME-driven shocks
  - Acceleration of energetic particles from shocks and interacting CMEs

Much of the low frequency portion of the S/waves instrument is in the form of a time-domain sampler (a direct descendant of a similar instrument on the Wind spacecraft [Bougeret et al., 1995]), which is capable of providing rapid samples from all three antennas simultaneously up to about 125 kHz. From this information, combined with frequency-domain observations and rapid samples from IMPACT, we should be able to make progress on studies of radiation modes and wave-particle interactions.

Typical daily data products that will be available via an S/waves Web site (TBD) are:

- Dual daily dynamic spectra
- One minute averages of all frequency channels
- A catalog of type II and type IV activity
- Selected source location versus time

- *In situ* electron density, when possible

When STEREO is launched, it will join a fleet of existing spacecraft dedicated to solar and heliospheric studies such as, SOHO, Wind, TRACE, RHESSI, and Ulysses. Later in 2006, the Solar-B spacecraft will also be launched. Thus, the later half of the decade should be a remarkably productive period in the study of solar phenomena.

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