STEREO
Science Operations Plan

Version 1.1
January 10, 2005

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Revision history

VERSION	DATE	COMMENTS
1.0	10-Dec-2004	Initial release, signed 18-Dec-2004
1.1	10-Jan-2005	Added Table 1.4, affecting relative rates between SECCHI Synoptic and Special Event partitions

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Preface

This document describes the concept and methodology of the STEREO science operations. It addresses the coordinated operation of the STEREO investigations, and will be a reference manual for that.

Reference Documents

STEREO Mission Requirements Document, NASA GSFC 460-RQMT-0001, August 2000.

STEREO Mission Operations Center (MOC) to Payload Operations Center (POC) and to STEREO Science Center (SSC) Interface Control Document (ICD), JHU/APL 7381-9045, August 2003.

STEREO Mission Operations Center (MOC) Data Products Document, JHU/APL 7381-9047, January 2004.

STEREO Solar-Terrestrial Probes (STP) Mission Project Data Management Plan, NASA GSFC 460-PLAN-0039, March 2002.

List of Acronyms

APL	Applied Physics Laboratory
AU	Astronomical Unit
CME	Coronal Mass Ejection
DFD	Downlink Format Descriptor
DSMS	Deep Space Mission System (a.k.a. Deep Space Network)
DSN	Deep Space Network
GSFC	Goddard Space Flight Center
IMPACT	In-situ Measurements of Particles and CME Transients
kbps	Kilobits per second
Mbits	Megabits
MOC	Mission Operations Center
NASA	National Aeronautics and Space Administration
PI	Principal Investigator
PLASTIC	PLAsma and SupraThermal Ion Composition
POC	Payload Operations Center
PS	Project Scientist
S/WAVES	STEREO WAVES
SECCHI	Sun Earth Connection Coronal and Heliospheric Investigation
SOWG	Science Operations Working Group
SSC	STEREO Science Center
SSR	Solid state recorder
STEREO	Solar TErrestrial RElations Observatory
STP	Solar Terrestrial Probes
SWG	Science Working Group
TBC	To be confirmed
TBD	To be determined

Chapter 1

Mission Overview

1.1 Scientific Objectives

STEREO (Solar TErrestrial RElations Observatory) is the third mission in NASA's Solar Terrestrial Probes program (STP). This two-year mission will employ two nearly identical space-based observatories—one ahead of Earth in its orbit, the other trailing behind—to provide the first-ever stereoscopic measurements to study the Sun and the nature of its coronal mass ejections.

STEREO's scientific objectives are to:

- Understand the causes and mechanisms of coronal mass ejection (CME) initiation.
- Characterize the propagation of CMEs through the heliosphere.
- Discover the mechanisms and sites of energetic particle acceleration in the low corona and the interplanetary medium.
- Improve the determination of the structure of the ambient solar wind.

Coronal mass ejections are powerful eruptions that can blow up to 10 billion tons of the Sun's atmosphere into interplanetary space. Traveling away from the Sun at speeds of up to 1.6 million kph, CMEs can create major disturbances in the interplanetary medium and trigger severe magnetic storms when they collide with planetary magnetospheres.

Large coronal mass ejections directed towards Earth can damage and even destroy satellites, are extremely hazardous to astronauts when outside of the protection of the Space Shuttle performing Extra Vehicular Activities (EVAs), and they have been known to cause electrical power outages. The solar energetic particle storms driven by shock acceleration in front of CMEs present an even greater threat to astronaut safety outside Earth's magnetosphere.

Solar ejections are the most powerful drivers of the Sun-Earth connection. Yet despite their importance, scientists don't fully understand the origin and evolution of CMEs, nor their structure or extent in interplanetary space. STEREO's unique stereoscopic measurements of the structure of CMEs will enable scientists to learn more about their fundamental nature and origin.

1.2 Instrumentation

The following four instrument packages are mounted on each of the two STEREO spacecraft:

Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) will have four instruments: an extreme ultraviolet imager, two white-light coronagraphs and a heliospheric imager. These instruments will study the 3-D evolution of CMEs from birth at the Sun's surface through the corona and interplanetary medium to its eventual impact at Earth. Principal Investigator: Dr. Russell Howard, Naval Research Laboratory, Washington, D.C.

STEREO/WAVES (S/WAVES) is an interplanetary radio burst tracker that will trace the generation and evolution of traveling radio disturbances from the Sun to the orbit of Earth. Principal Investigator Dr. Jean Louis H. Bougeret, Centre National de la Recherche Scientifique, Observatory of Paris, and Co-Investigator Mr. Michael Kaiser of Goddard, lead the investigation.

In-situ Measurements of Particles and CME Transients (IMPACT) will sample the 3-D distribution and provide plasma characteristics of solar energetic particles and the local vector magnetic field. Principal Investigator: Dr. Janet G. Luhmann, University of California, Berkeley.

PLAsma and SupraThermal Ion Composition (PLASTIC) will provide plasma characteristics of protons, alpha particles and heavy ions. This experiment will provide key diagnostic measurements of the mass and charge state composition of heavy ions and characterize the CME plasma from ambient coronal plasma. Principal Investigator: Dr. Antoinette Galvin, University of New Hampshire.

1.3 Spacecraft, Orbit, Attitude

STEREO consists of two separate and nearly identical spacecraft, each in heliocentric orbit about the Sun. STEREO-A will drift ahead of Earth in it's orbit, while STEREO-B will lag behind Earth.

For the first three months after launch, the two observatories will fly in highly elliptical orbits (called "phasing orbits") extending from very close to Earth to just beyond the Moon's orbit. STEREO Mission Operations personnel at the Johns Hopkins University's Applied Physics Laboratory (APL) in Laurel, Maryland, will synchronize spacecraft orbits so that about two months after launch they encounter the Moon, at which time one of them is close enough to use the Moon's gravity to redirect it to a position "behind" Earth (STEREO-B). Approximately one month later, the second observatory will encounter the Moon again and be redirected to its orbit "ahead" of Earth (STEREO-A). The nominal mission starts when both spacecraft are in heliocentric orbit. Once in heliocentric orbit, each observatory will then drift away from Earth in opposite directions, at approximately 22° per year.

1.4 Operations

The STEREO Science Center (SSC) is responsible for coordinating the science plans of the various STEREO instruments, but is not involved in the actual telecommanding process. Instead, each

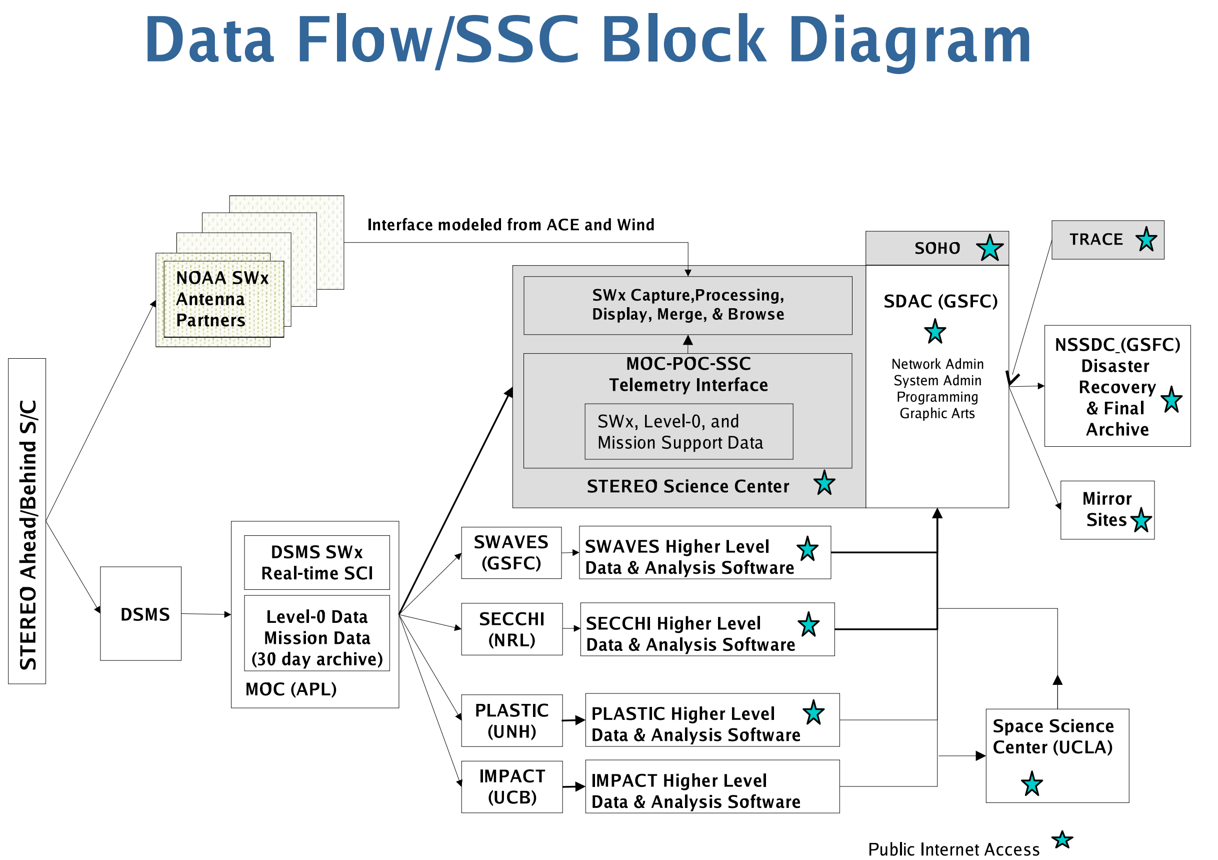

Figure 1.1: Telemetry processing flow diagram.

instrument team's Payload Operations Center (POC) connects directly to the Mission Operations Center (MOC) at JHU/APL.

Details of the telecommand and telemetry processes are described in the MOC/POC/SSC ICD (JHU/APL 7381-9045). Figure 1.1 shows the telemetry data flow.

Each instrument will have an allocated telemetry rate during realtime DSN contact. Outside of contact, instrument telemetry will be written to the solid state recorder (SSR), which will be downlinked during contact periods. Each instrument will have allocated space within the SSR for writing the telemetry data. Both the SSR allocations and the realtime telemetry rates are configurable by the MOC. Control of the rate at which realtime and playback telemetry are downlinked from the spacecraft is realized through Downlink Format Descriptors (DFDs).

It is the responsibility of the SSC to coordinate the STEREO instrument science plans, and inform the MOC of the requested telemetry rates in sufficient time for a suitable DFD to be formulated.

Table 1.1: Telemetry rates available to the instrument teams during early operations. Rates are for realtime and playback telemetry combined. Three rates are shown from the third week onward—the exact rate for any given day will depend on the geocentric distance of each spacecraft. Also shown is the total amount of data which can be downlinked each day, and the scheduled duration of the daily telemetry pass.

Week	Rate (kbps)	Available (kbps)	Total (Mbits)	Duration
1	30	21	-	24 hrs
2	30	9	220	8 hrs
3+	96	30	220	3 hrs
	160	93	670	
	360	288	2070	

Table 1.2: Nominal instrument telemetry allocations. The daily data volumes and average SSR write rates are given for three different periods in the mission: high rate (0–14 months), medium rate (14–18 months), and low rate (18-24 months), counting from the beginning of the nominal mission.

	High (0–14)		Med (14–18)		Low (18–24)	
	Mbits	kbps	Mbits	kbps	Mbits	kbps
IMPACT	276.48	3.274	303.82	3.590	276.48	3.274
PLASTIC	276.48	3.274	303.82	3.590	276.48	3.274
S/WAVES	172.80	2.074	189.89	2.272	172.80	2.074
SECCHI	4668.56	54.888	4309.00	50.727	3921.26	46.239

1.4.1 Early Operations

During the initial phasing orbits, when the STEREO spacecraft are still close to Earth, telemetry rates will be restricted compared to the nominal mission rates. Table 1.1 shows the available telemetry rates during the first few weeks of operation.

The Stereo Science Center (SSC) is responsible for coordinating the early operations plans of the instrument teams, and for transmitting that plan to the MOC.

1.4.2 Heliocentric Orbit

Once the commissioning phase ends for each STEREO spacecraft, and the spacecraft is in heliocentric orbit, the nominal mission can begin. This should occur about 3 months after launch. During the heliocentric orbit phase of the mission, most instrument telemetry is stored on-board in the solid state recorder (SSR). This telemetry is then downlinked during the daily realtime passes. Table 1.2 shows the nominal time-averaged telemetry allocations during heliocentric orbit. The nominal SSR partition allocations are shown in Table 1.3.

Since SECCHI has both a synoptic and special event partition, the playback of the SECCHI telemetry will consist of either the synoptic partition, or the special event partition, or both simultaneously. When both partitions are being downlinked, if one partition is empty, the spacecraft will continue to fill the telemetry stream with packets from the other partition. Otherwise, the partitions are downlinked at a rate nominally proportional to the sizes of their SSR allocations. Within limits, the relative rates between the SECCHI synoptic and special event partitions can be modified to adjust the priorities between these two partitions—the rates of other spacecraft and instrument partitions would not be affected. Table 1.4 shows a suggested relative allocation for normal operations at different points in the mission. SECCHI will provide adequate notice to the MOC of a request to change downlink modes.

Along with the stored telemetry, there are 12 kbps available to the intrument teams during the realtime pass. There are two planned allocations for this realtime stream. In the nominal case, each of the instrument teams except SECCHI would get their full science telemetry rate, and SECCHI would get the rest. The optional case would give most of the telemetry rate to SECCHI, with the other instruments sending down only housekeeping in realtime. Table 1.5 shows the anticipated allocations for these two cases. The STEREO Science Center is responsible for coordinating which telemetry allocation is used. It is anticipated that the SECCHI-prime case would be used sparingly for instrument checkout and problem resolution.

Table 1.3: Nominal SSR partition allocations.

Partition	Size (Mbits)
IMPACT	453
IMPACT Space Weather	10
PLASTIC	453
PLASTIC Space Weather	10
SECCHI Synoptic	5161
SECCHI Special Event	1292
SECCHI Space Weather	100
S/WAVES	281
S/WAVES Space Weather	10
S/C Housekeeping	820

Table 1.4: Suggested relative allocations between the SECCHI synoptic and special event partitions for three different periods in the mission: high rate (0–14 months), medium rate (14–18 months), and low rate (18-24 months), counting from the beginning of the nominal mission.

	High (0–14)	Med (14–18)	Low (18–24)
SECCHI Synoptic	94%	94%	95%
SECCHI Special Event	6%	6%	7%

Table 1.5: Realtime telemetry allocations, in kbps. Except for SECCHI, each instrument gets either their full science telemetry, or only their housekeeping.

	IMPACT	PLASTIC	SWAVES	SECCHI
Nominal	3.2	3.2	2.04	3.56
SECCHI-prime	0.108	0.25	0.07	11.57

Chapter 2

STEREO Operations Policy and Requirements

2.1 Operations Plan

2.1.1 Overview

Routine Operation

The STEREO Science Working Group (SWG), consisting of the STEREO Project Scientist, and the Principal Investigators and designated members of each of the instrument teams, will set the overall science policy and direction for mission operations, set priorities, resolve conflicts and disputes, and consider observing proposals. During STEREO science operations, the SWG will meet every three months to consider the quarter starting in one month's time and form a general scientific plan. If any non-routine operations are required—such as non-standard telemetry allocations—the requests must be formulated at this quarterly meeting. The three-month plan will then be refined during the monthly planning teleconference calls (see 2.2.1) of the Science Operations Working Group (SOWG), composed of the PIs or their team members, together with a representative of the STEREO Science Center (SSC), which will allocate observing sessions to specific programs. At weekly "virtual meetings" of the SOWG (2.2.2), coordinated timelines will be produced for the instruments, together with detailed plans for spacecraft operations.

Responsibilities

While the Project Scientist (PS) will be responsible for the implementation of the scientific operations plan, execution of the plan will be carried out by the SOWG, led by the SSC.

2.2 Planning cycle

2.2.1 Monthly Detailed Planning

On a monthly time scale the SOWG will hold a teleconference to assess progress in achieving the scientific goals of their investigation and to discuss the objectives for operations starting in a month's time. This gives time for coordinated observations to be set up, and any deficiencies in observing sequences to be identified. Inputs to the monthly meeting are made by each instrument team and common objectives are identified. The output of this meeting is a schedule showing when each instrument will be operating, whether joint or individual observations are being made, ground observatory support and a backup plan if these conditions are not met. Requirements for telemetry rate switching should be identified together with any spacecraft operations which may affect the observations, for example momentum dumping. Conflicts between instruments for resources are resolved and disturbances identified.

2.2.2 Weekly Optimization

A weekly "virtual meeting" considers the week starting in approximately three days time and this is when the detailed plans for all the STEREO instruments are synchronised. It will be convened by the SSC, and will be either a teleconference or computerized communication, depending on the complexity of that week's operations. The intention is to lay out a definitive plan with timings, flag status, disturbances, etc. This meeting will have the conflict-free DSN schedule available.

Any conflicts in the planned use of the spacecraft command buffers will be resolved during the weekly optimization meeting.

The weekly meeting will also be the forum for instrument teams to give advance notice of any special operations or changes to the plan for future weeks. The DSN forecast schedule will be available for the week commencing in 10 days time and the strawman proposal will be available for the week following that.

2.2.3 Coordinated Campaigns

During agreed periods one or several experiment teams and, if agreed, teams from other spacecraft or ground observatories will run, in collaboration, observation campaigns to address specific topics. For each campaign, a campaign leader will be responsible for the coordination. Campaigns will be initially planned at the quarterly SWG meeting, with refinements at the monthly and weekly planning events.

Chapter 3

Space Weather Beacon

3.1 Telemetry

Along with the normal science telemetry, the instruments on the two STEREO spacecraft will generate a special low-rate telemetry stream, known as the space weather beacon. Outside of DSN contacts, this space weather beacon stream will continue to be broadcast at a rate of approximately 633 bits per second. Various antenna partners around the world will collect this telemetry and pass it on to the SSC in near-real-time via a socket connection over the open internet. The SSC will collate these data from the antenna partners, sort the packets together into time-order, and run software provided by the instrument teams to process this telemetry into data files. These data will be put on the web in near-real-time, within five minutes of receipt of all needed telemetry. The space weather beacon data flow is shown in Figure 3.1.

The NOAA/SEC is responsible for recruiting the ground stations, and the day-to-day scheduling of the stations. The SSC is responsible for managing the day-by-day interactions with the ground station, except for the scheduling of antenna time.

Table 3.1 shows the nominal telemetry allocation for the space weather beacon data.

3.2 Products

The following sections list the space weather products for each of the STEREO instrument suites. These product lists are to be considered as preliminary, and subject to change.

Table 3.1: Nominal telemetry allocation for space weather beacon data.

Instrument	pkt/min	bps
IMPACT	1	37
PLASTIC	1	37
S/WAVES	1	37
SECCHI	13.9	504

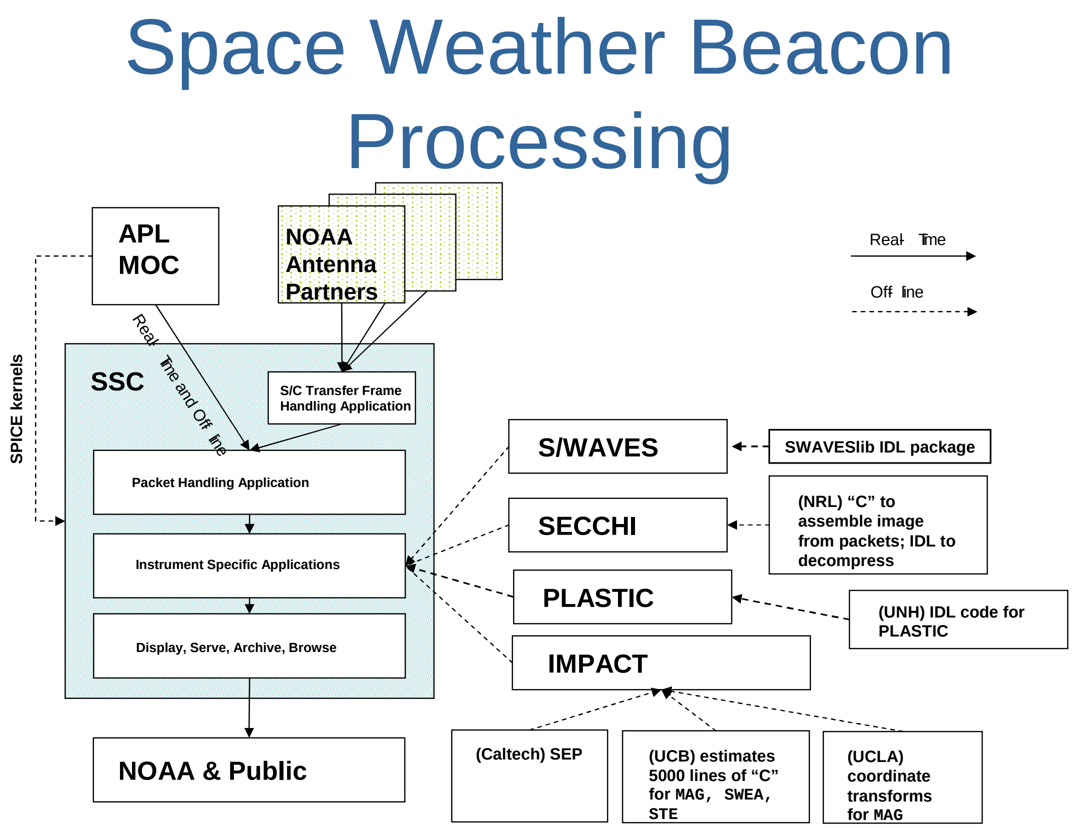

Figure 3.1: Space weather beacon processing flow diagram.

3.2.1 IMPACT

Exact format of the Beacon Mode Telemetry packet is TBD (UCB). The following data will be included in the Beacon Mode Data set:

MAG:

- 10 sec-averaged (6 samples/minute) B vectors (all 3 components every 10 seconds).
- MAG Housekeeping.

STE:

- 3 different electron flux-energy spectra (just one sample each):
  - 2 from STE-U (one for the solar electron population, one for the non-solar) at 5 energies.
  - 1 from STE-D at 5 energies.
- STE-U + STE-D LLD Rate.

SWEA:

- Moments (electron density, bulk velocity, pressure tensor, heat flux) just one sample.
- SWEA V0 Value.
- Just one SWEA PAD at 2 energies in 12 look directions.
- Magnetic field direction in SWEA coordinates.

SEP:

- SEP status.

SEP-SEPT:

- Electron flux at 2 energies in 4 look directions averaged over 1 minute.
- Electron flux at 2 energies summed over 4 look directions averaged over 1 minute.
- Ion flux at 2 energies in 4 look directions averaged over 1 minute.
- Ion flux at 2 energies summed over 4 look directions averaged over 1 minute.
- SEPT status.

SEP-LET:

- Proton flux at 1 energy in 2 look directions averaged over 1 minute.
- Proton flux at 2 energies summed over all look directions averaged over 1 minute.

- 4He flux at 2 energies in 2 look directions averaged over 1 minute.
- 4He flux at 1 energy summed over all look directions averaged over 1 minute.
- 3He flux at 2 energies summed over all look directions averaged over 1 minute.
- CNO flux at 3 energies summed over all look directions averaged over 1 minute.
- FE flux at 4 energies summed over all look directions averaged over 1 minute.
- Livetime counter.
- Trigger rate.
- Hazard rate.
- Accepted event rate.
- LET Status.

SEP-HET:

- Electron flux at 1 energy averaged over 1 minute.
- Proton flux at 3 energies averaged over 1 minute.
- He flux at 3 energies averaged over 1 minute.
- CNO flux at 2 energies averaged over 1 minute.
- Fe flux at 1 energy averaged over 1 minute.
- Livetime counter.
- Stop efficiency.
- Penetration efficiency.
- HET status.

SEP-SIT:

- HE flux at 4 energies averaged over 1 minute.
- CNO flux at 4 energies averaged over 1 minute.
- Fe flux at 4 energies averaged over 1 minute.

IMPACT (in general):

- Instrument status.
- Packet overhead.

3.2.2 PLASTIC

The PLASTIC Beacon Mode data will be a subset of the normal data stream, with some small additional processing. The following table lists the data products for beacon mode, and the source of the data. There will also be a data quality flag associated with each parameter.

Parameter	Resol. (min)	Items	Bits	Total bytes/min	Source	Additional Processing
SW H density	1	1	2	2	Moments	None
SW bulk H velocity (vx,vy,vz)	1	3	16	6	Moments	None
SW H+ temperature tensor	1	6	16	12	Moments	None
SW H+ heat flux tensor	1	6	16	12	Moments	None
SW He++ peak distribution	1	125	8	125	He++ Peak	Choose center 5-energy x 5-position x 5-defl matrix from alpha distribution
SW He++ energy step	1	1	8	1	He++ Peak	Info from header
SW He++ peak deflection step	1	1	8	1	He++ Peak	Info from header
SW He++ peak position	1	1	8	1	He++ Peak	Info from header
Representative SW Charge states	5	5	8	1	SW Z>2	Summing selected bins from SW Z>2 matrix rates
Suprathermal rates	5	30	8	6	WAP_SSD_TCR WAP_SSD_CDR	Summing selected bins from Suprathermal matrix rates
PAC Value	1	1	16	2	HK	None
MCP Value	1	1	16	2	HK	None
Total bytes/minute				171		

3.2.3 S/WAVES

The S/WAVES space weather beacon data will consist of 1 minute averages for 8 channels per octave from 16 kHz to 16 MHz.

3.2.4 SECCHI

The exact plan for the SECCHI space weather beacon telemetry is still TBD. The sequences and compression will be adjusted to fit within the allocation, and can be modified after launch, if required.

The current plan is to supply the following products:

1. SECCHI will be able to downlink about 7 256×256 images per hour. SECCHI will send

down a combination of COR2 taken at about 15 minute intervals, and HI1 and HI2 images each every other hour.

2. A 4 byte sum of the EUVI total intensity. This can be used to generate the EUV total flux, such as the E10.7.

3. A flag indicating that a CME has been detected by the on-board software. This can be used as an alert to the operator.