# STEREO
# Science Operations Plan

Version 2.0

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1

## Revision history

| VERSION | DATE | COMMENTS |
|---|---|---|
| 1.0 | 10-Dec-2004 | Initial release, signed 18-Dec-2004 |
| 1.1 | 10-Jan-2005 | Added Table 1.5, affecting relative rates between SECCHI Synoptic and Special Event partitions |
| 2.0 | 9-Nov-2009 | Brought up-to-date to include information about the extended mission (Section 1.4.3). Added Tables 1.1, 1.7, and other tables related to extended mission operations. Revised Table 1.4 to reflect SECCHI repartitioning. Corrected typo in Table 1.5. Added commentary to Section 2.2. Added Section 3.2. Clarified the meaning of "kbps" and "Mbits". |

# Contents

# List of Figures

# List of Tables

## 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 those operations.

## 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

| | |
|---|---|
| APID | Application Identifier |
| APL | Applied Physics Laboratory |
| A.U. | 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 (1024 bits) per second |
| Mbits | Megabits ($1024^2$ bits) |
| MOC | Mission Operations Center |
| NASA | National Aeronautics and Space Administration |
| NOAA | National Oceanic and Atmospheric 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 |
| SWPC | Space Weather Prediction Center |
| 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 mission employs 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)** has four instruments: an extreme ultraviolet imager, two white-light coronagraphs and a heliospheric imager. These instruments 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 traces 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 Dr. Robert J. Macdowall, lead the investigation.

**In-situ Measurements of Particles and CME Transients (IMPACT)** samples 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)** provides plasma characteristics of protons, alpha particles and heavy ions. This experiment provides key diagnostic measurements of the mass and charge state composition of heavy ions, and characterizes 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 drifts ahead of Earth in its orbit, while STEREO-B lags behind Earth.

For the first three months after launch, the two observatories flew 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, synchronized spacecraft orbits so that about two months after launch they encountered the Moon, at which time one of them was close enough to use the Moon's gravity to redirect it to a position "ahead" of Earth (STEREO-A). Approximately one month later, the second observatory encountered the Moon again and was redirected to its orbit "behind" Earth (STEREO-B). Table 1.1 shows the major milestones during the early orbit phase. The prime science mission started on 22 January 2007 when both spacecraft were in heliocentric orbit. Once in heliocentric orbit, each observatory then drifts 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

Table 1.1: Important orbital milestones during the early orbit phase of the mission.

| | STEREO A | | STEREO B | |
|---|---|---|---|---|
| Launch | 26-Oct-2006 | 00:52 | 26-Oct-2006 | 00:52 |
| A1 Apogee | 31-Oct-2006 | 16:39 | 31-Oct-2006 | 15:56 |
| P1 Perigee | 6-Nov-2006 | 09:08 | 6-Nov-2006 | 07:44 |
| A2 Apogee | 11-Nov-2006 | 23:45 | 11-Nov-2006 | 21:44 |
| P2 Perigee | 17-Nov-2006 | 13:43 | 17-Nov-2006 | 11:18 |
| A3 Apogee | 23-Nov-2006 | 16:24 | 23-Nov-2006 | 14:52 |
| P3 Perigee | 29-Nov-2006 | 19:58 | 29-Nov-2006 | 19:20 |
| A4 Apogee | 6-Dec-2006 | 02:07 | 6-Dec-2006 | 02:29 |
| P4 Perigee | 12-Dec-2006 | 08:30 | 12-Dec-2006 | 09:54 |
| S1 Swingby | 15-Dec-2006 | 21:28 | 15-Dec-2006 | 21:03 |
| A5 Apogee | | | 2-Jan-2007 | 06:02 |
| S2 Swingby | | | 21-Jan-2007 | 09:03 |

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 has an allocated telemetry rate during realtime DSN contact. Outside of contact, instrument telemetry is written to the solid state recorder (SSR), which is downlinked during contact periods. Each instrument has 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.

### 1.4.1 Early Operations

During the initial phasing orbits, when the STEREO spacecraft were still close to Earth, telemetry rates were restricted compared to the rates during the prime science mission. Table 1.2 shows the available telemetry rates during the first few weeks of operation.

The Stereo Science Center (SSC) was responsible for coordinating the early operations plans of the instrument teams, and for transmitting that plan to the MOC. This phase of the mission ended on 22 January 2007.

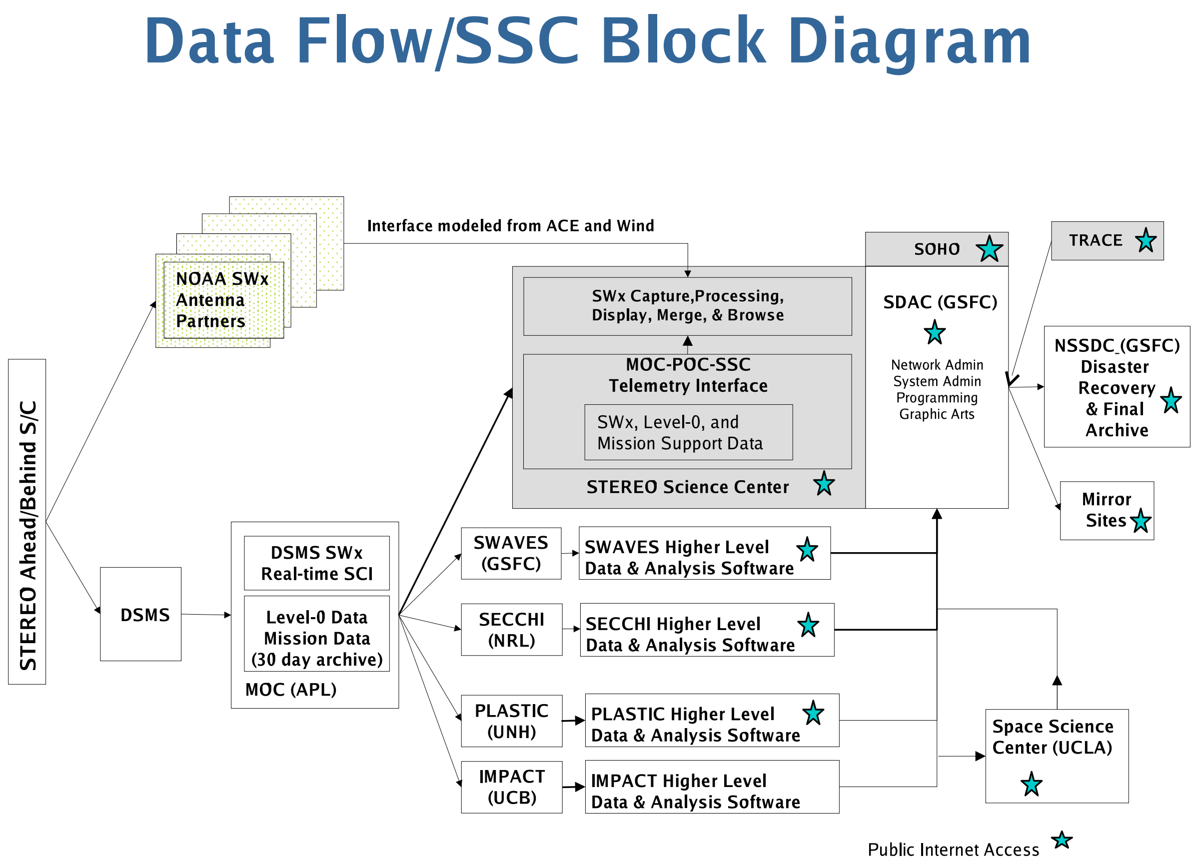


Figure 1.1: Telemetry processing flow diagram.

Table 1.2: 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 depended on the geocentric distance of each spacecraft. Also shown is the total amount of data which could 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 1.3: Nominal instrument telemetry allocations during the prime mission phase, not including space weather telemetry. The daily data volumes and average SSR write rates are given for three different periods in the mission: high rate (720 kbps), medium rate (480 kbps), and low rate (360 kbps), depending on the geocentric distance of the spacecraft. See Table 1.7 for a list of dates when the various telemetry rates are expected to be used.

| | High | | Med | | Low | |
|---|---|---|---|---|---|---|
| | 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 |

### 1.4.2 Prime Science Phase

Once the commissioning phase ended for each STEREO spacecraft, and both spacecraft were in heliocentric orbit, the prime science mission began. This occured on 22 January 2007. 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 1.3 shows the nominal time-averaged telemetry allocations during the prime science mission. The nominal SSR partition allocations are shown in Table 1.4.

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 1.5 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, which has been in use since the start of the prime science mission, each of the instrument teams except SECCHI get their full science telemetry rate, and SECCHI gets 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 1.6 shows the 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.

### 1.4.3 Extended Mission Phase

As the two STEREO spacecraft continue to drift away from Earth, eventually a point is reached at which the telemetry rates of the prime science mission can no longer be maintained. When

Table 1.4: Nominal SSR partition allocations.

| Partition | Size (Mbits) |
|---|---|
| IMPACT | 453 |
| IMPACT Space Weather | 10 |
| PLASTIC | 453 |
| PLASTIC Space Weather | 10 |
| SECCHI Synoptic | 5651[a] |
| SECCHI Special Event | 802[b] |
| SECCHI Space Weather | 100 |
| S/WAVES | 281 |
| S/WAVES Space Weather | 10 |
| S/C Housekeeping | 820 |

[a]5161 Mbits at launch.
[b]1292 Mbits at launch.

Table 1.5: Suggested relative allocations between the SECCHI synoptic and special event partitions for three different periods in the prime science mission: high rate (720 kbps), medium rate (480 kbps), and low rate (360 kbps).

| | High | Med | Low |
|---|---|---|---|
| SECCHI Synoptic | 94% | 94% | 93% |
| SECCHI Special Event | 6% | 6% | 7% |

Table 1.6: Realtime telemetry allocations during the prime science mission, in kbps, not including space weather telemetry. Except for SECCHI, each instrument gets either their full science telemetry, or only their housekeeping.

| | IMPACT | PLASTIC | S/WAVES | SECCHI |
|---|---|---|---|---|
| Nominal | 3.2 | 3.2 | 2.04 | 3.56 |
| SECCHI-prime | 0.108 | 0.25 | 0.07 | 11.57 |

Table 1.7: Projected dates for telemetry rate changes. It has not yet been confirmed whether the 60 kbps rate will be available. Accomplished dates are shown in italics.

| Rate (kbps) | Ahead | Behind |
|---|---|---|
| 720 | *22-Jan-2007* | *22-Jan-2007* |
| 480 | *13-Oct-2008* | *15-Sep-2008* |
| 360 | *17-Aug-2009* | *8-Sep-2009* |
| 240 | 26-Apr-2010 | 7-Dec-2009 |
| 160 | 13-Sep-2010 | 13-Sep-2010 |
| 120 | 11-Apr-2011 | 15-Nov-2010 |
| 96 | 26-Sep-2011 | 19-Sep-2011 |
| (60) | (TBD) | (TBD) |
| 30 | Aug-2012 | Aug-2012 |

Table 1.8: Realtime telemetry allocations during the extended science mission, in kbps, not including space weather telemetry.

| | IMPACT | PLASTIC | S/WAVES | SECCHI |
|---|---|---|---|---|
| Nominal | 0.106 | 1.183 | 0.071 | 2.2[a] |
| IMPACT-prime | 3.125 | 1.183 | 0.071 | 2.2[a] |
| PLASTIC-prime | 0.106 | 3.274 | 0.071 | 2.2[a] |
| S/WAVES-prime | 0.106 | 1.183 | 2.090 | 2.2[a] |
| All-full-rate | 3.125 | 3.274 | 2.090 | 2.2[a] |
| SECCHI-emergency | 0.106 | 1.183 | 0.071 | 16.0 |

[a]Will drop to 1.2 kbps for rates of 96 kbps and below.

the telemetry drops below 360 kbps, STEREO will enter the extended mission phase for science operations. There are three tested rates available during this phase: 160 kbps, 96 kbps, and 30 kbps. There are also some untested rates which may be available, which include 240 kbps, 120 kbps, and 60 kbps. Table 1.7 shows when each rate is expected to be used. The current version of the STEREO Science Operations Plan will consider rates down to 96 kbps. Consideration of rates lower than this will be postponed to a later version of this document.

Once the telemetry rate drops below 360 kbps, a number of changes in science operations will be made. The first change will be to increase the pass duration from 6 hours to 7 hours. The second change will be in how realtime telemetry from the instruments will be sent down. For the in-situ instruments, the normal mode of operation will be to only send down selected housekeeping parameters in realtime, with the remainder of the data going only to the SSR. Each in-situ instrument will also have a mode where they receive their full SSR telemetry rate for special operations. Table 1.8 shows the various realtime modes which will be used during the extended mission. The APIDs to be used in both the nominal and full cases are shown in Table 1.9. To simplify operations, only the rates in Table 1.8 labeled "nominal", "all-full-rate", and "SECCHI-emergency" may actually be implemented.

The third change in science operations during the extended mission will be to decrease the

Table 1.9: APIDs to be sent down in realtime during the extended mission for the nominal and full cases in Table 1.8. Space weather telemetry is also sent down in realtime, and consists of the range $x70$–$x7$F for each instrument.

| Instrument | Nominal | Full |
|---|---|---|
| IMPACT | 200, 240, 241 | 200–26F |
| PLASTIC | 313–317 | 300–36F |
| SECCHI | 400–43F | 400–43F |
| S/WAVES | 501 | 500–56F |

Table 1.10: Instrument telemetry allocations during the extended mission, not including space weather, for various total spacecraft telemetry rates. Both daily data volumes in megabits and average SSR write rates in kilobits per second are listed. The assumed pass duration in hours is also shown.

| Rate | Dur | IMPACT | | PLASTIC | | S/WAVES | | SECCHI | |
|---|---|---|---|---|---|---|---|---|---|
| (kbps) | (hrs) | Mbits | kbps | Mbits | kbps | Mbits | kbps | Mbits | kbps |
| 240 | 7 | 264 | 3.13 | 276 | 3.27 | 176 | 2.09 | 3689 | 43.72 |
| 160 | 8 | 239 | 2.83 | 213 | 2.77 | 163 | 1.88 | 2763 | 32.75 |
| 120 | 8 | 203 | 2.40 | 180 | 2.46 | 145 | 1.67 | 1970 | 23.35 |
| 96 | 8 | 203 | 2.40 | 172 | 2.21 | 135 | 1.57 | 1560 | 18.48 |

telemetry rates of each of the instruments to fit within the total allocation. During the prime science phase of the mission, the reductions in the overall telemetry rates are borne primarily by SECCHI, while the insitu instruments are relatively unaffected. This philopsophy changes during the extended mission. Most of the decrease will still be borne by SECCHI, but the rates of the insitu instruments will also drop. Table 1.10 shows the instrument allocations during the extended mission, as a function of telemetry rate. The IMPACT, PLASTIC, and S/WAVES rates are true rates based on information provided by the instrument teams. The SECCHI rates are rough estimates based on the following assumptions: that the increase in pass duration provides correspondingly more daily downlink, less one hour of overhead, and that the total telemetry available to all instruments together decreases proportionally to the telemetry rate relative to a pass of the same length at 360 kbps. The telemetry savings from the above planned changes in operations are also factored in.

Additional telemetry savings will be made by not downlinking the SECCHI space weather partition. The SECCHI space weather images are degraded versions of the normal synoptic images, and are not useful except for predicting space weather. With the current SECCHI pipeline processing, only the images which come down in realtime through the DSN and antenna partner stations are useful. By the time the level-0 telemetry files are available, the SECCHI beacon telemetry is no longer relevant. Eliminating the SSR playback of SECCHI space weather telemetry will free up 43 Mbits/day to be used for science data. The space weather partitions of the other instruments will continue to be read out.

Balanced against the telemetry savings to be gained by not downloading the SECCHI space weather SSR partition is that the antenna partner stations may eventually lose the realtime space weather beacon signal as the distances to the two spacecraft increase. Therefore, the option to return to downloading the SECCHI space weather partition will remain. In particular, the current SECCHI space weather partition on the SSR will not be eliminated. Additional steps can be taken within the SSC to increase the speed at which the downloaded space weather telemetry is ingested and processed, so that the images are available before the normal processed level-0 files, if substantial realtime coverage is lost. Since the option of writing SECCHI space weather telemetry to the SSR is being kept, the telemetry savings of 43 Mbits/day is *not* factored into Table 1.10.

### 1.4.4 Instrument strategies for extended mission

In the sections below we discuss the strategies that the instrument teams have adopted to lower their telemetry rates for the extended mission. The strategy for all instruments at the 240 kbps rate is to eliminate from the real-time telemetry everything except essential housekeeping data.

#### IMPACT

The following strategies are used to lower IMPACT's telemetry rate:

**160 kbps:** In addition to the above, the IMPACT team will do the following

- Eliminate STE-U data from the telemetry. The STE-U detectors are blinded by light and have been rendered unusable.
- Eliminate the SWEA onboard PADS and moments products from the telemetry. SWEA measurements below about 50 eV, which significantly affect the moments, require corrections that cannot be done on-board. Much better PADs and moments are calculated on the ground using the full SWEA 3D distributions (in combination with MAG and S/WAVES data) giving much more flexibility in their generation and allowing a much better handle on their integrity/believability.

**120 kbps:** Reduce the amount of burst data to the equivalent of one 20-minute burst/day. Would also eliminate a diagnostic product from the telemetry known as the "Burst Criteria". The elimination of the burst criteria data has minimal impact at this stage. It is used to fine-tune the IMPACT burst system which, by the time this reduction is made, will have been tuned as well as can be done. There is, of course, a science impact in reducing the amount of burst data. However, with the aforementioned fine-tuning, the instrument should catch, most of the time, the most interesting burst period in a given day. The science this probably hurts the most is using the highest time resolution (32 Hz) MAG burst data for turbulence studies. Given the alternatives, however, the IMPACT team feels that this is the least scientifically undesirable route.

**96 kbps:** If needed, the IMPACT team would eliminate burst data completely. The obvious science impact here is on science relying on that extremely high resolution MAG and SWEA data during "interesting" or non-"interesting" periods. Burst data is generally used on other missions to look in detail at shocks, reconnection events, and turbulence. These things can still be studied using the normal IMPACT telemetry (particularly since the normal 8 Hz MAG data is still available), but it does make it difficult to do certain types of studies in those areas.

Because the IMPACT team considers this reduction undesirable, it has not been factored into Table 1.10.

**PLASTIC**

The following strategies are used to lower PLASTIC's telemetry rate:

**160 kbps:** Delete high resolution matrix rates (APIDs 31A, 31B).

**120 kbps:** Reduce the time resolution for ion species "matrix" rates from five (ten) minutes to twenty (twenty) minutes.

**96 kbps:** The PLASTIC team is examining two options:

1. Delete one of the solar wind alpha rates.
2. Reduce the time resolution for ion species "matrix" rates from five (ten) minutes to thirty (thirty) minutes.

**S/WAVES**

The following strategies are used to lower S/WAVES's telemetry rate:

**160 kbps:** Reduce the frequency resolution in the high frequency band of the receiver. In the band from 2MHz to 16MHz S/WAVES now produces frequency samples every 50kHz. This gives very good coverage at the high end of the spectrum. This can be changed to 100kHz steps and still have good frequency coverage close to the sun.

**120 kbps:** Reduce the time resolution such that S/WAVES produces one full spectrum per minute, from the current rate of about 2 full sweeps per minute).

**96 kbps:** maintain the time and frequency resolution of the frequency domain receivers. Going lower than one minute cadence would be bad. So to achieve this reduction, S/WAVES will dial back on the number of time domain bursts it produces. S/WAVES has a burst memory system such that the "best" bursts make it to the ground eventually. To reduce the bit-rates, S/WAVES can send fewer of these bursts to the ground.

**SECCHI**

During the extended mission, SECCHI will continue to use SSR1 observations to provide the baseline synoptic program, with reduced image cadence and/or spatial resolution compared to the nominal mission. There will be an increased reliance on SSR2 observations to meet specific science objectives as the telemetry rate decreases. The current sizes of the SSR1 and SSR2 partitions may be altered to reduce the emphasis on synoptic observations in favor of better coverage of selected events, particularly as solar activity increases. SECCHI may also request two new playback DFD tables: one to downlink only SSR1 and the other to emphasize downlink of SSR2 at the expense of SSR1 when a CME event has been detected by the onboard software. This would optimize the return of data from SSR1 when no suitable event has been detected.

Progressive reductions in the synoptic observing programs of each SECCHI telescope will be made to fit within the available telemetry resources. Each telescope team has identified a series of reductions, listed below in order of priority for each telescope. Note that this list does not prioritize telemetry reductions between the different telescopes.

- EUVI:
  - Increase compression for majority of images in highest-cadence wavelength.
  - Reduce image cadence to 2 hours in other wavelengths ($\times 2.7$ combined telemetry reduction).
- COR1:
  - Bin images to $512\times512$ pixels, and increase compression ($\times 3$ telemetry reduction);
  - Sum images onboard and send down a single $512\times512$ total B image, instead of three polarized images ($\times 3$ telemetry reduction);
  - Reduce image cadence.
- COR2:
  - Bin images to $1024\times1024$ pixels, and increase compression ($\times 3$ telemetry reduction);
  - Change all polarization sequences to total B images (currently interleave pB and B) ($\times 2.25$ telemetry reduction);
  - Reduce image cadence.
- HI:
  - Reduce cadence of high resolution calibration images from once per day to once per week;
  - Change HI-1 image cadence from 40 minutes to 60 minutes;
  - Use subfield masks to send down only a portion of each image;
  - Change HI-2 image cadence from 2 hours to 3 hours;
  - Bin images to $512\times512$ pixels.

In addition, the real-time rate (used for housekeeping telemetry) will be reduced to increase the playback data volume. Since real-time data are also recorded on the SSR, the playback volume increases by double the amount of the reduction in the real-time data volume. The real-time rate will initially be reduced from 3.6 kbps to 2.2 kbps, and can later be reduced to 1.2 kbps by lowering the sampling rate of selected ApIDs. An emergency mode with a 16 kbps downlink rate will be maintained for anomaly resolution.

# 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 several times per year to 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 SWG meeting. The long-term plan will then be refined during the monthly and/or weekly planning teleconference calls (see Section 2.2) of the Science Operations Working Group (SOWG), composed of the PIs or their team members, together with representatives of the Mission Operations team and the STEREO Science Center (SSC), which will allocate observing sessions to specific programs. As a result of these planning activities, 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

It was originally anticipated that the SOWG would hold both monthly teleconferences to discuss medium range planning, and weekly "virtual meetings" to discuss shorter range planning. In practice it was found that these functions are best combined in a single teleconference call held weekly. STEREO science planning is relatively simple compared to other solar missions such as SOHO or Hinode. The principal reason for this simplicity is that most of the variation in the day-to-day operations is combined within a single instrument suite, SECCHI, and almost no coordination is required between instruments. In the discussion below, however, we retain the distinction between the functions of the monthly and weekly planning cycles, even though both sets of functions are combined within a single weekly teleconference system. Both sets of functions are required, and it may be necessary to split these functions into separate parts in the future, depending on the additional complexity of operations in the extended mission.

### 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 SWG meeting, with refinements at the monthly and/or 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 (or other agreed upon protocol) 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/SWPC 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 Operational considerations

As the distance of the two STEREO spacecraft increases, some changes will need to be made in the operations of the space weather beacon. The initial space weather configuration used convo-

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 |

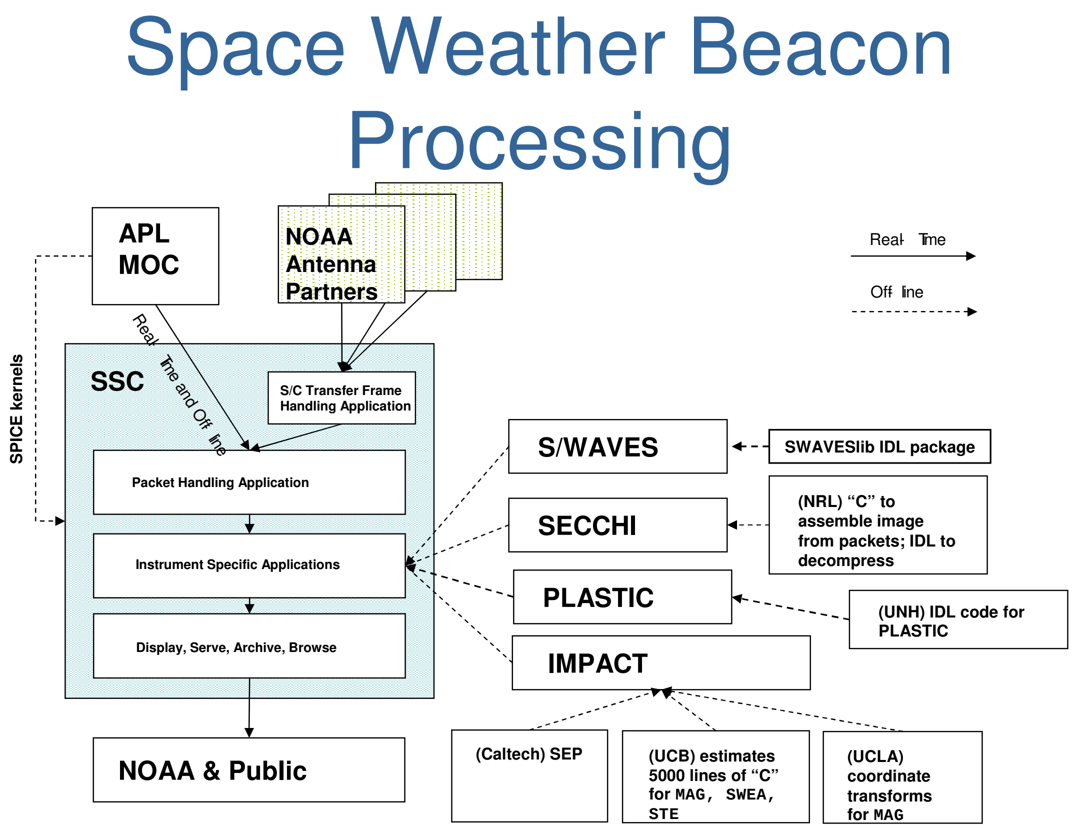


Figure 3.1: Space weather beacon processing flow diagram.

lutional 1/2 encoding. This was changed to convolutional 1/6 encoding on 27 July 2007. It is estimated that the spacecraft will need to switch to Turbo 1/6 when the spacecraft reach 1 A.U., which is projected to occur on 26 September 2009 on Ahead, and 3 October 2009 on Behind. The NOAA/SWPC will develop Turbo decoding software and distribute this to the ground stations in time for this switch, with adequate time for testing.

Eventually, as the spacecraft continue to separate, antenna partner ground stations may lose the ability to receive the space weather beacon telemetry. The date that this will happen is still TBD, and will differ between stations. Some stations are expected to never lose the beacon signal, except for a short period in 2015 when the angular separation with the Sun is too small.

## 3.3 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.

### 3.3.1 IMPACT

The following data are 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.

### 3.3.2 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 | | |

### 3.3.3 S/WAVES

The S/WAVES space weather beacon data consists of 1 minute averages of spectral data from 2.5kHz to 16Mhz. The low frequency band has samples centered at 5kHz, 20kHz and 80kHz. The high frequency band from 125kHz to 16MHz is swept with a nominal frequency resolution of 100kHz. Spectral values are in relative amplitude (dBs). It also includes a gross indication of the number of bursts of transient activity during the period.

### 3.3.4 SECCHI

SECCHI space weather beacon images are formed from the regular SECCHI synoptic images with additional processing applied to enable them to fit within the telemetry limitations. With the exception of HI2, very high compression ratios are applied to the images, so the data quality is considerably lower than that of the synoptic data. The current schedule for SECCHI space weather images (as of 2009-08-17) is shown in the following table. For COR2 there are three polarized images making up a $pB$ series once every hour, and a single double-exposure total brightness image every 15 minutes following.

| Telescope | Type | Cadence | Image size | Telemetry share |
|---|---|---|---|---|
| EUVI | 195Å | 10 minutes | 512×512 | 32.7% |
| COR1 | $pB$ series | 1 hour | 128×128 | 9.9% |
| COR2 | $pB$ series | 1 hour | 256×256 | 41.1% |
| COR2 | total $B$ | 15 minutes | 256×256 | |
| HI1 | | 2 hours | 256×256 | 2.7% |
| HI2 | | 2 hours | 128×256 | 13.5% |

There are special event packets with important instrument status information, or an event flag indicating that a CME has been detected by the on-board software, to alert the SECCHI operations team in real time.

The SECCHI schedule of space weather images is a subject of continuing discussion between NRL and the NOAA/SPWC, and is subject to change.