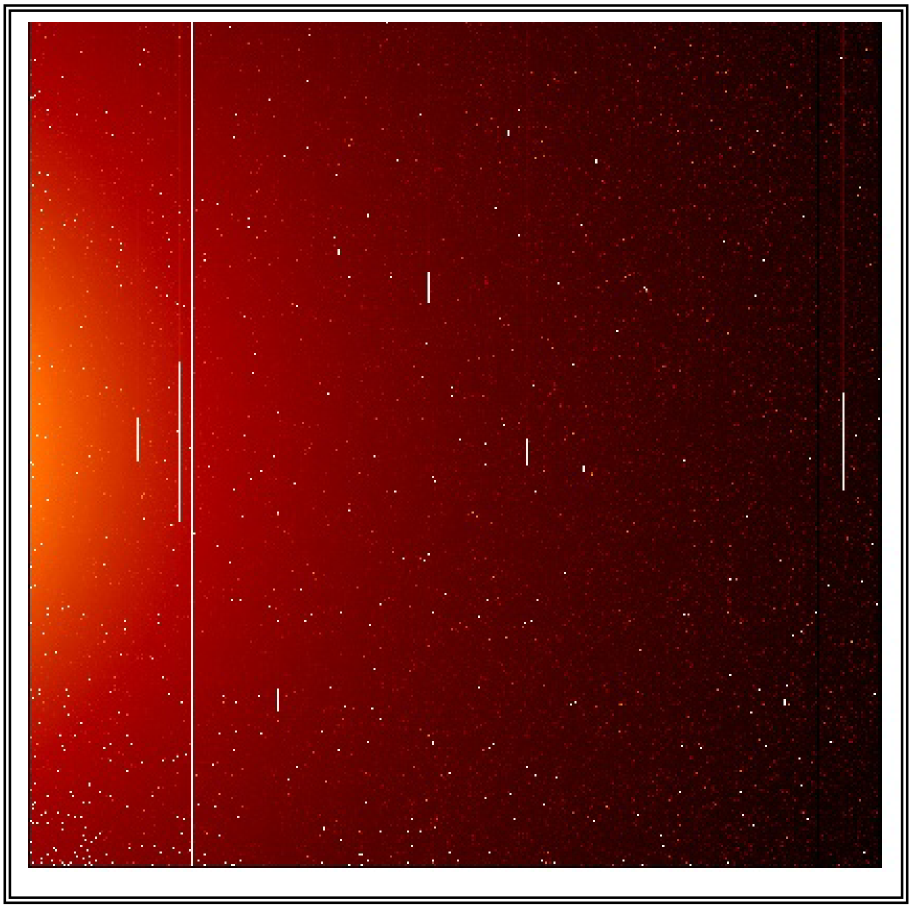
Heliospheric Imager: Operations Document



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1. Introduction

This document sets out the plans for the operation of the Heliospheric Imager (HI), which is part of the SECCHI instrument package on the STEREO spacecraft. It is intended that this information be used as an input to the discussion on payload operations planning, commanding, monitoring and data receipt, data handling and archiving, including the development of on-board and ground software (including planning tool software, archive software and data handling, inspection and analysis software).

2. The Heliospheric Imager (HI) in a Nutshell

The two NASA STEREO spacecraft, due for launch in 2005, will travel in 1 AU solar orbits, one leading and one lagging the Earth - separating from the Earth by 22^{o} per year each. The HI is designed to investigate the structure and propagation through the heliosphere of solar Coronal Mass Ejections (CMEs) (Figure 1), especially those that are Earth-directed. It does this through the use of two small telescope systems mounted on the side of each of the STEREO spacecraft, which view space by looking back at the Sun-Earth line, sheltered from the glare of the Sun by a series of baffles.

This provides us with several important new opportunities for CME research, including the following:

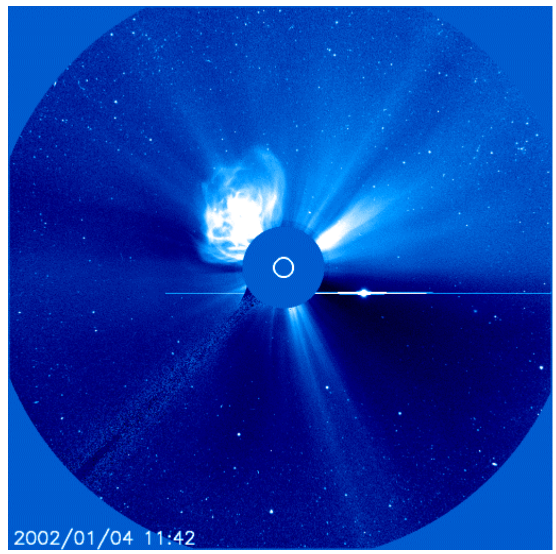

Figure 1 - A LASCO/SOHO C3 image showing a CME off the solar north-east limb. The image also shows stars, a planet and streamers.

- The first opportunity to observe geo-effective CMEs along the Sun-Earth line in interplanetary Space;
- The first opportunity to detect CMEs in a field of view which includes the Earth;
- The first opportunity to obtain stereographic views of CMEs in interplanetary space - to investigate CME structure, evolution and propagation in the heliosphere.

The basic instrumental approach is through occultation and a baffle system, with wide-angle views of the heliosphere, achieving light rejection levels of order 3×10^{-13} and 10^{-14} of the Solar Brightness. The basic design concept can be seen in Figure 2.

The instrument is basically a large shoe-box shape, of major dimension about 700 mm. A door covers the optical and baffle systems during launch and the initial cruise phase activities. The door is opened once during instrument commissioning and it remains open. The two telescope/camera systems, known as HI-1 and HI-2 are buried within a baffle system as shown in Figure 2. The direction to the Sun is shown; the Sun remains below the vanes of the forward baffle system. Figure 3 shows the original design concept and displays well how HI-1 and HI-2 are protected from the Sun and other light sources by the baffle system. The original inner baffle concept was changed and now consists of several plate-like layers. The detectors are CCD devices, which are cooled by radiators facing space.

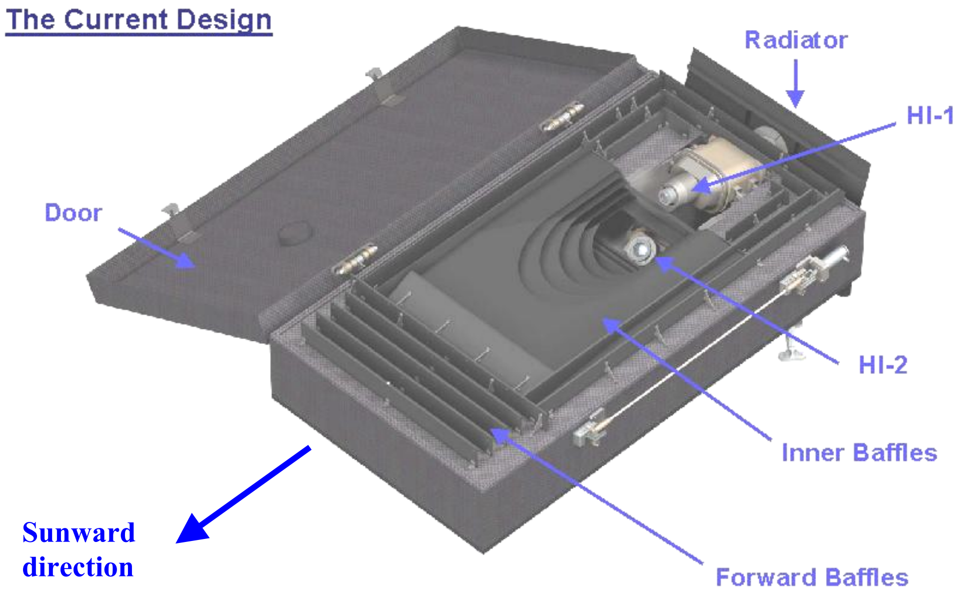

Figure 2 - The Heliospheric Imager design concept

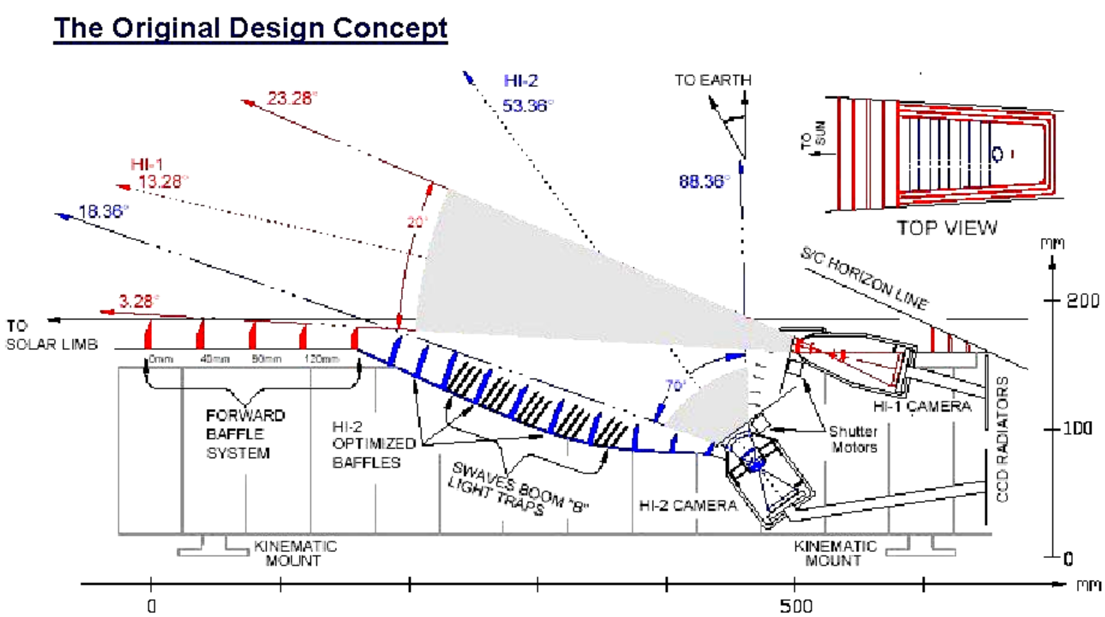

Figure 3 - The Original Design Concept

	HI-1	HI-2
Instrument Type	Externally-Occulted Coronagraph	Externally-Occulted Coronagraph
Centre of Field-of-View Direction	Along Sun-Earth Line $\theta = 13.65$ deg	Along Sun-Earth Line $\theta = 53.35$ deg
Angular Field-of-View	20 deg	70 deg
Coronal Coverage	12 - 84 R_{sun}	66 - 318 R_{sun}
Overlap With COR2	12 - 15 R_{sun}	N/A
Overlap With HI-1	N/A	66 - 84 R_{sun}
Baseline Image (2 x 2 Binning)	1024 x 1024	1024 x 1024
Image Pixel Scale (Binned)	70 arcsec	4 arcmin
Spectral Bandpass	630 - 730 nm	400 - 1000 nm
Exposure Time	12 - 20 sec	60 - 90 sec
Nominal Images Per Sequence	70	50
Required Cadence (Per Sequence)	60 min	120 min
Brightness Sensitivity	3×10^{-15} B_{sun}	3×10^{-16} B_{sun}
Straylight Rejection	3×10^{-13} B_{sun}	10^{-14} B_{sun}
Brightness Accuracy	10%	10%

Table 1 - Heliospheric Imager Specifications

The basic performance specifications for HI are listed in Table 1. The geometrical layout is shown in Figure 4. As can be seen from Table 1 and Figure 4, the two HI fields of view are centred on the Sun-Earth line (ecliptic plane), with two circular fields of width 20^o and 70^o, offset from the Sun at 13.65^o and 53.35^o, to enable us to view the entire Sun-Earth line from 12 solar radii to near-Earth orbit. Remember that this is done from two spacecraft at equal planetary angles (Earth-Sun-spacecraft), providing a stereographic view. At the start of the mission, Earth is just outside the HI-2 field of view; it moves into the field as the mission progresses, as shown in Figure 4. The HI-1 and HI-2 fields provide an opening angle from the solar equator at 45^o, which is the average size of a CME. This is indicated in the top part of Figure 4.

The HI CCDs are 2048x2048 pixels (13.5 micron pixels) normally binned on board to 1024x1024, with resolving elements of 70 arcsec (HI-1) and 4 arcmin (HI-2).

The contributions to the image intensities recorded by HI are explained and modeled in detail in the HI Image Simulation report ('Image Simulations for the Heliospheric Imager for the SECCHI/STEREO Project', by Chris Davis and Richard Harrison - see http://www.stereo.rl.ac.uk under 'Documents'). Figure 4 shows that the major contribution is the F-corona, which will be some two orders of magnitude brighter than the CME signals we are trying to detect. In principle, by exposing for long enough periods to ensure that the noise on the F-corona is less than the CME signal, we may extract the CME signal through image subtraction or base-image subtraction, much as is done using LASCO on SOHO. However, there are also contributions from the stellar background, planets, the Earth and Moon, scattered light, cosmic rays, the non-shutter read-out, blooming and the point spread function of the instrument and these are discussed in detail in the image simulation report.

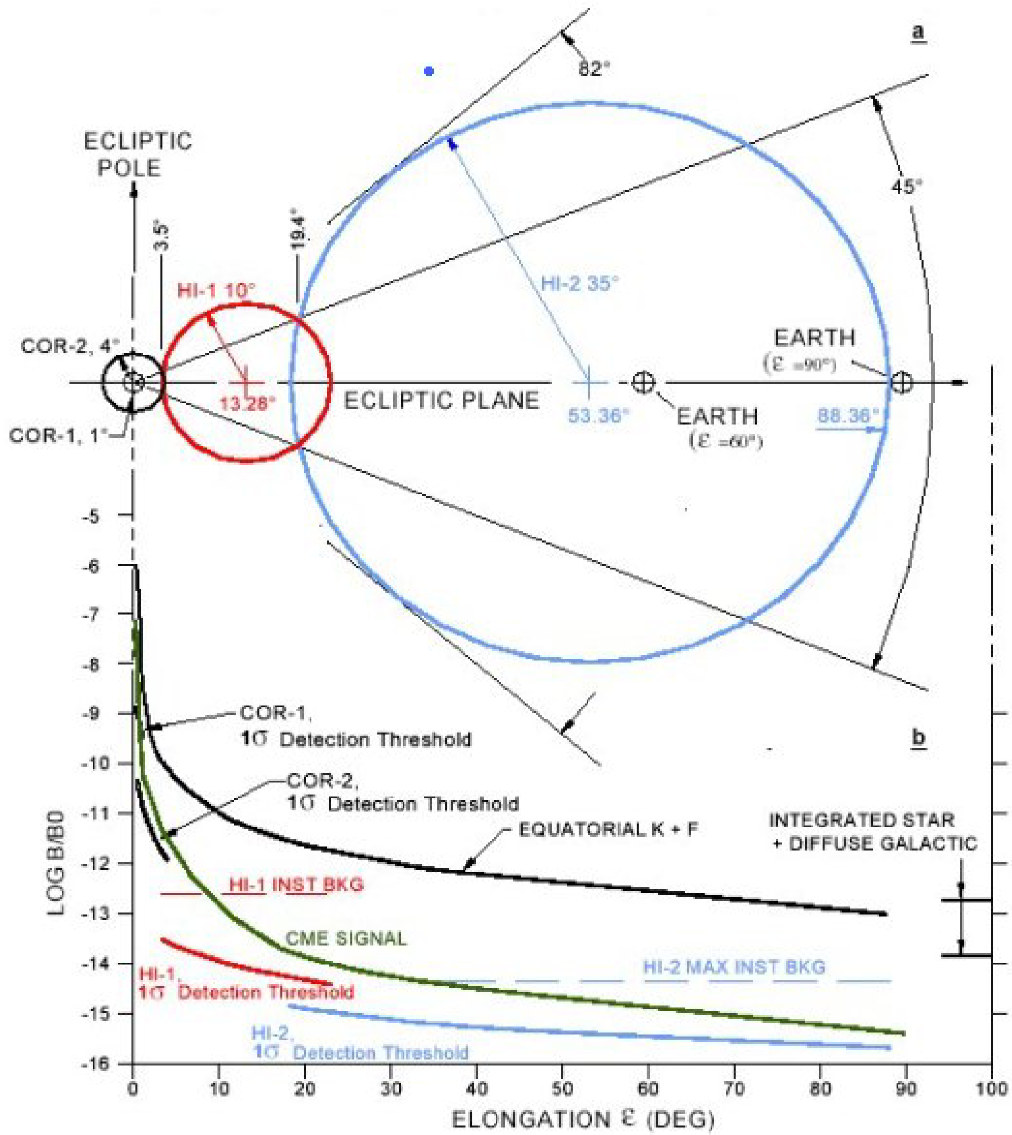

Figure 4 - The Geometrical Layout of the HI Fields of View and the Major Intensity Contributions.

More details about the HI and the STEREO and SECCHI projects can be found at http://www.stereo.rl.ac.uk or sites which are linked to that site. Also, see the HI instrument paper by Socker et al., 2000, Proc. SPIE, Vol. 4139, 284.

The hardware development for HI is centred at Birmingham University, led by Dr Chris Eyles, and includes camera design and development work at the Rutherford Appleton Laboratory. The HI concept originated at the US Naval Research Laboratory (Dennis Socker). The institutional responsibilities are listed below:

- Rutherford Appleton Laboratory - PI Institute (PI: Richard Harrison); Scientific leadership; Detector/camera development; Leadership of UK STEREO/SECCHI Science Team; Support with HI AIT.
- University of Birmingham - Project Management (PM: Chris Eyles); Mechanical, Thermal and Electrical Design; Fabrication and AIT of HI qualification and flight

models; Fabrication of focal plane assemblies and cameras; HI optical system procurement.

- Centre Spatial de Liege - Optical Design and Test; Optical Calibration; Straylight Analysis and Baffle Design; Support With HI AIT.
- Naval Research Laboratory - Focal plane assembly design and HI US Liason (Dennis Socker).

3. Operations Planning and Implementation

STEREO is very much a synoptic or monitoring mission in terms of the basic proposed operation. To date, each instrument within the SECCHI group has a standard scientific operation defined and little flexibility in the operation has been discussed in detail beyond that. In addition to the scientific operation, there must be operational procedures such as calibration, which will be required, which we address here.

The STEREO operation is not as 'hands-on' and flexible as SOHO. For SOHO we have experience of daily and weekly planning meetings, which refine numerous observations sequences daily on various selected targets for a user community, much as ground-based observatories are run. The instrument teams have real-time, hands-on contact with their instruments each day and monitor and command their own instruments from or through the same dedicated facility. The nature of the STEREO mission demands a more 'synoptic' approach.

For STEREO, there will be a dedicated Missions Operations Centre (MOC) at APL (Johns Hopkins University). There will be a SECCHI Payload Operations Center (POC). At times of commissioning or serious anomalies, the POC will be located at APL. At all other times the POC will be located at NRL. The POC will be staffed with a few operations staff and a Lead Operations Scientist (nominated in rota from the SECCHI consortium). There will also be sufficient facilities at the POC for guests to be on-site for extended periods of time. There will be a STEREO Science Center (SSC) located at GSFC. Its role is still under definition, but it will not be a facility such as the EOF/EAF on SOHO.

For most of the instrument teams, contact will be through the Internet; there is no scientific or operational need for a large presence at the MOC or POC. Instruments will be monitored at the SECCHI operations centre and, if appropriate, anomalous behaviour can be monitored and acted upon, or special campaigns can be run in close contact with the remote teams using Internet links. Remote teams will be able to monitor their own instruments or subsystems at home. All of this does require the HI team in the UK, for example, to provide some health monitoring of the instrument.

From a practical point of view, then, the HI consortium will expect to provide the following:

- A UK facility for monitoring HI scientific and operational performance at Birmingham and/or RAL, including staff effort to provide such monitoring.
- A duty Scientific Planner – who communicates with the SECCHI Lead Operations Scientist either directly, as a visitor on-site at the POC, or remotely, from his/her own home institute. He or she will be on call for scientific operational anomalies.
- A duty Operations Engineer – who monitors the HI instrument on behalf of the HI consortium and communicates with the SECCHI operations staff. He or she will be on call for operational and instrumental anomalies.

These two staff would be selected, in rota, from one of the HI consortium institutes (Birmingham, RAL, CSL, NRL etc…). The manager of the rota would be the PI.

A quarterly, monthly, weekly and daily planning cycle was outlined in the SECCHI Phase A Concept Study Report. However, given the need to combine the operations of two spacecraft as well as the limited command loads, the basic planning period will be one week. Anything shorter would be very difficult to handle.

For each week, we would anticipate that the HI Scientific Planner would interact with the SECCHI Lead Operations Scientist to establish a HI operations plan for the week. The Planner would take responsibility to ensure that the HI scientific operations requirements are met, and, in addition, that any technical requirements such as calibration runs are scheduled.

It is anticipated that most of the time the HI instruments will run a pre-defined Synoptic Programme (section 4) but other sequences will be run periodically (section 5).

Once an activity plan has been agreed upon for a particular week, it is anticipated that a SECCHI Planning Tool will be used to generate a command uplink for the defined period. This activity is at the SECCHI (multi-instrument) level, not at the HI (instrument) level.

The operations of HI fall into two categories:

(i) Science Operations, and
(ii) Instrument Maintenance Operations.

Current plans for both categories are included below. Any sequence (for both categories) must be run through the SECCHI Planning Tool and will then exist as pre-defined sequences in a SECCHI operations library. In addition, there will be two classes of HI scientific observations, namely:

(i) Synoptic Operations, and
(ii) Flexible Scientific Operations.

Requests for using HI may be made from the HI or SECCHI teams, or from any outside user. Scientific operations requests must be made to the PI team. Most scientific requests will be satisfied by the Synoptic Operation but, on occasions, different sequences will be run (the Flexible Scientific Operations) in response to particular scientific goals.

Our operations and planning scenario, as well as the planning tools and software must allow us to cope with flexible scientific operation. This is discussed in greater detail later.

In particular, for outside users, we must set up a facility for straightforward and open access to instrument information and use, probably through the Internet where requests for observations can be made and where data can be accessed. Thus, we anticipate an operations Web page for HI which will feed into the suite of pages for SECCHI but acts as the interface to the HI user community.

Another issue, which is particularly important, is the communication within the HI consortium both in operational matters and scientific discussion and planning – especially because of the degree to which remote planning and operations activity are anticipated. The PI takes responsibility for coordination and information exchange within the HI team, and, although the methods to be adopted are still under discussion, it must include HI consortium meetings, information exchange through the Web site, perhaps regular telecon discussions and e-mail distributions.

4. HI Scientific Operation: The Synoptic Operation

The Synoptic Operation of HI is outlined in Table 2.

Table 2: The HI Synoptic Operation

	HI-1	HI-2
Image array	1024x1024 (2kx2k summed)	1024x1024 (2kx2k summed)
FOV	20^0 (3.65-23.65)	70^0 (18.35-88.35)
Nominal Exposure	12 s	60 s
Summed Exposures	70	60
Synoptic Cadence	1 hr	2 hr
Telemetry Rate	2.9 kbit/s	1.5 kbit/s

The basic exposed image in HI-1 or HI-2 is a 2048x2048 pixel array. After the exposure, the array is read out, cleaned of cosmic rays and, during standard operations would be summed to 1024x1024 pixels. It is possible for the resolution to be retained and only a partial field returned. The subsequent exposures are treated in the same way and the images are integrated for a pre-defined number of exposures - nominally 70 and 60 for HI-1 and HI-2, respectively. Only then is the image telemetered to the ground.

Although a circular field of view is shown in Figure 4, the full CCD area is, in fact, illuminated. The optical performance at the corners may be slightly degraded but may be useful. Thus, we may return the data from the full CCD or a selected area, such as the circular field.

Returning the circular field only would give a factor of 0.785 saving, but the final compression won't achieve this factor, because of the need to block the image into 64 x 64 pixels, resulting in some non-imaging pixels being transmitted. For the initial SECCHI telemetry calculations, a compression factor of 2.5 was selected for both HI-1 and HI-2. Note that the summed image contains 32 bit pixels, not the 16 bit pixels returned from the camera.

Figure 5 shows the basic format of the HI images, taken from the image simulation report. The image shows the distribution of the zodiacal light expected in HI-2, plus stars to 12th magnitude, Venus, Jupiter, Mars and Mercury, scattered light, the instrument point spread function, the effects of the non-shutter operation, saturation and blooming (from the brightest sources) and cosmic rays. For details, see the image simulation report, which also includes discussion on the extraction of the CME signal.

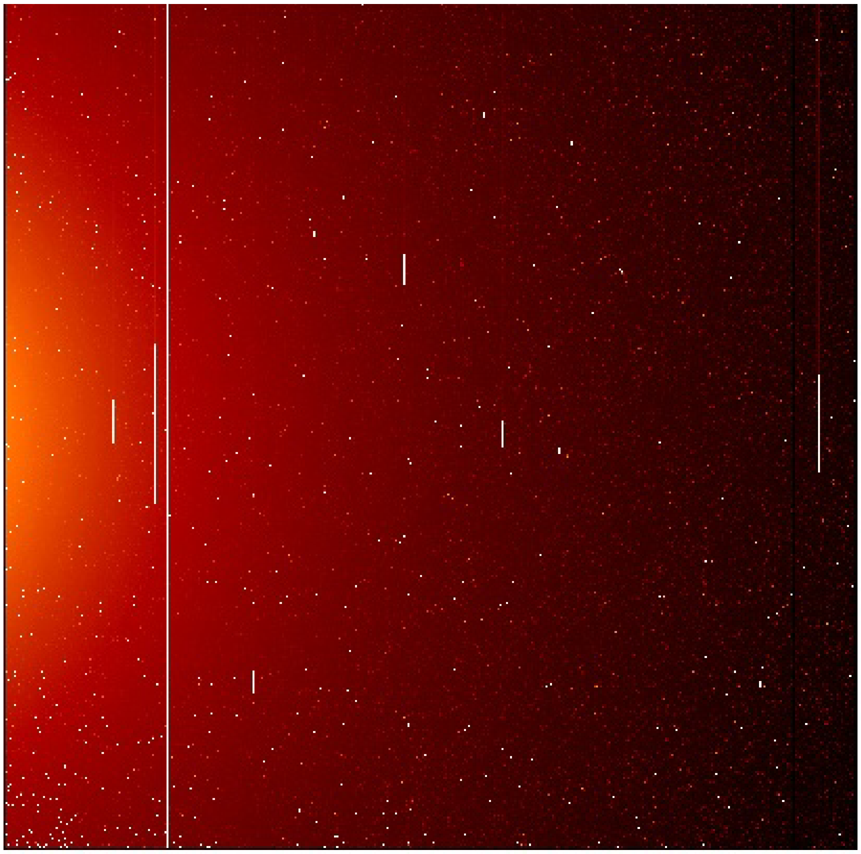

Figure 5: The basic layout of the HI images.

The synoptic operation caters for the most basic CME observational needs. For the HI-1 field of view (from 12-84 solar radii), we can estimate the time taken for CMEs with different speeds to cross the field. It is desirable to have at least 10 frames showing the propagation of the CME, to get a good determination of the CME speed and direction, evolution and structure. For a speed of 400 km/s (about 2 solar radii per hour) it takes 36 hours to cross the field of view, i.e. we obtain some 36 images. Similarly, at 600 km/s the crossing time would be 24 hours, and for the fastest CMEs the crossing time would be over 7 hours. From this, we conclude that a nominal cadence of 1 hour is fine for most purposes.

Similarly, for the HI-2 field (66-318 solar radii), speeds of 400 km/s and 600 km/s give crossing times of 126 and 84 hours, respectively. However, the Earth will move towards the centre of the field of view as the mission progresses and our desire is for at least 10 frames between the near-Sun side of the HI-2 field and the Earth, giving values of order 63 hours and 42 hours. Thus, for HI-2 a cadence of a few hours would be fine. However, the desire to obtain predictions of good arrival times at Earth (during the approach of a CME) suggests that a value of order 2 hours is adequate; this is the nominal value.

From a software and operational point of view, the following requirements must be made to ensure the best synoptic operation:

- The synoptic operation is to consist of a series of exposed images of predefined exposure times, summed on board and returned after a predefined number of

images. Typically, this will be 60-70 images, but in the limit it would be 1; it must be selectable.
- The cosmic ray cleaning must be made prior to the image summing, on board, and should be enabled or disabled as required.
- The exposure times must be flexible to ensure that we can adjust for any degradation of the optical systems or, indeed, to allow the selection of revised nominal exposure times in flight.

5. HI Scientific Operation: Flexible Scientific Operations

There are many scientific applications for an instrument such as HI. Most of these will be addressed using the Synoptic Operation. However, some parameters can be considered to be flexible, in particular:
- exposure time,
- number of images to accumulate (cadence times),
- cosmic ray cleaning,
- partial field imaging (at greater cadence),
- telemetry rate,
- relative use of HI-1 and HI-2.

In an initial assessment of the demand for HI operations scenarios other than the Synoptic Operation, the UK SECCHI/STEREO Science Team has considered a set of different scientific questions and the ideal SECCHI operations required to investigate those questions. The suggested operations scenarios are included in a separate report. It must be noted that they are preliminary in nature, and that we anticipate a refinement in this work as other HI, and indeed SECCHI, team members suggest further schemes and adjustments to those listed. This work will continue, ultimately bringing a much more complete operations picture to the fore prior to operations.

Despite the preliminary nature of the scenarios thus far, they do highlight a range of operational requirements, which can usefully feed into the software and operations efforts of HI and STEREO even at this time.

The scenarios are listed in Table 3. We discuss the basic requirements of the 13 scenarios already designed, and list the operational and software requirements needed to satisfy such scientific investigations.

Table 3: The SECCHI/HI Operations Scenarios – These are presented in detail in an accompanying report.

Title	Author
1. Impact of CME on the Earth	R. Harrison (RAL)
2. CMEs in Interplanetary Space	P. Cargill (Imperial College)
3. Understanding the Relationship between L1 & SECCHI Observations	P. Cargill (Imperial College)
4. 3-D Structure of Interplanetary CMEs	L. Green (MSSL)
5. CME Onset	S. Matthews (MSSL)
6. Relationship between CMEs and Magnetic Clouds	S. Matthews (MSSL)
7. Particle Acceleration at CME Shocks	S. Matthews (MSSL)
8. Synoptic CME Programme	R. Harrison (RAL)
9. Solar Wind Microstructure	A. Breen (Aberystwyth)

10. Development of Corotating Interaction Regions	A. Breen (Aberystwyth)
11. Differential Drift Velocities in the Fast and Slow Solar Winds	A. Breen (Aberystyth)
12. Boundaries Between Fast and Slow Streams in the Solar Wind	A. Breen (Aberystwyth)
13. Remote Solar Wind Speed and Direction Measurements from 3-D Observations of Cometary Ion Tails	G. Jones (Imperial College)
14. Interplanetary acceleration of ICMEs	M. Owens (Imperial College)
15. Beacon mode	S. Matthews, R. Harrison & C. Davis (RAL)

More scenarios are being considered by members of the community; the aim is to provide as complete a view as possible of the operations demands on HI well before launch. Full analysis of the proposed scenarios is given in the document which details them, but we provide some general comments here.

One must note that the scientists generating these scenarios are not necessarily familiar with the limitations of the instrument or operation. In a sense, this makes the analysis important. It serves to stress the value of the instrument for serving the user community.

It turns out that in general the pre-designed synoptic operation is sufficient to cater for the needs of all of the listed scenarios, except for those numbered 2, 4, 5 and 15 in Table 3. Of these, number 5 does not even use HI (the community were asked to suggest the way STEREO can address specific scientific goals – using HI was not a pre-requisite). The area in which the demands of numbers 2 and 4 depart from the performance of the synoptic programme are in terms of temporal resolution. In both cases, the proposers suggest cadences of order 'tens of minutes'. This is rather a loose definition of temporal resolution and may be unrealistic when considering the count-rates. Item 15 is the Beacon Mode, which we discuss later.

However, this scenario study will be extended considerably, and the outcome will be – and is being – fed into the operations and software discussion.

The key issues, which must be taken into consideration for operational and software purposes, are the following:

- The standard Synoptic Operation for SECCHI and for HI is fine for many scientific applications.
- Many observational scenarios are being suggested where only the partial SECCHI instrument package is required. We may wish to include a facility to operate only part of the payload for specific campaigns.
- Most scenarios use the full fields of view of the HI instruments. However, for some, we will wish to return only a partial field of one or both instruments, with a corresponding improvement in cadence. We must have a capability to return any selected area of the HI fields.
- We must be able to select and vary the exposure times and cadence of HI-1 or HI-2.

- We must be able to return data from only HI-1 or HI-2 or vary the order of returned images (e.g. the cycle of returned HI-1 and HI-2 frames).
- Many scenarios require close collaboration within the STEREO payload, beyond the SECCHI instruments, IMPACT in particular is highlighted. However, several scenarios are dependent on good links with ACE, and other particle and field missions in the near-Earth region (Cluster, Polar, Wind…)
- Similarly, some scenarios involve collaboration with Solar-B, RHESSI and SOHO. For these we need links at the planning stage to ensure co-operative operations during campaigns. Such links should be established. For any collaboration with 'aging' missions such as RHESSI and SOHO it might be advisable to run campaigns together early in the mission.
- It has been suggested that COR1 could provide a CME trigger which could be used within SECCHI to change the operational scenario at selected times.
- Redistribution of telemetry between SECCHI instruments is not addressed specifically in the scenarios. However, given that some scenarios do not use the full SECCHI payload and given the possibility of instrument failures at some time in the mission, the SECCHI software must be able to allocate different telemetry distributions among the instruments.
- Given the limited uplink capability, we need to keep the schedule simple. For the execution of some programmes this may mean that it is desirable to run some non-synoptic campaigns over several days.
- In the event of a loss of uplink capability or command capability to an instrument, it would be advisable to ensure that the Synoptic Operation is set up as an emergency sequence which will kick-in automatically after a specified period during which no commands are received. In this way, given a loss of command capability, we still receive the basic scientific information.

The study of operational scenarios will continue to develop. As mentioned above, it is assumed that prospective users of HI and SECCHI will contact the operations team via e-mail or a Web page and discuss their operational requirements. Such requests could be satisfied by filling in a template much as in Appendix 1 and the scenario can be designed by the operations team. Appendix 1 provides the template plus one observing scheme for illustration – namely the Synoptic Scheme.

It is important to note that for HI the principal operation scenario is the Synoptic Operation. This is the normal operation mode, which will dominate the operation of HI. Before any other scenarios are run in response to a request, it must be established firmly that the Synoptic Operation is not sufficient to cater for the requested observation.

6. <u>Data Monitoring and Archiving</u>

Data from SECCHI will be received as (i) science and housekeeping data which are stored on the solid state recorder and telemetered to the ground during a real-time pass, (ii) real-time science and housekeeping data that are telemetered to the ground during real-time passes, (iii) science data that are broadcast within the beacon mode, and (iv) Level 0 data that are received after all packets have been recovered. All data-sets will be received at the NRL POC. The beacon mode data will be acquired at the SSC and processed using algorithms supplied by the SECCHI team. Item (iv) is the final 'play-back' data, i.e. of the highest quality; the rest is 'quick look' data.

The tasks of data acquisition, decommutation, and housekeeping and science data display, and archiving, are to be done in an automated fashion at the POC. The housekeeping displays will be available on the Web, allowing remote analysis of the instrument health and operation. The processes will include trending analyses and health and safety checks. When a housekeeping parameter exceeds an out of limits condition the operator will be alerted automatically.

SECCHI science data will be decompressed and some level of processing may be applied. This would include any unchanging calibration steps. Calibration aspects which may change with time or require potential updates during the mission would be applied using IDL routines when required by the user.

SECCHI data will be available via the Web as soon as the routine processing has been completed – perhaps under 30 minutes after receipt. Users may download data electronically from an on-line archive. However, for large data requirements this may not be practical and the complete SECCHI data-set will be distributed to other sites. This could include all PI groups and perhaps some CoI groups, or to local archives, such as the RAL SOHO/TRACE Archive or the MEDOC Archive, in Paris.

Thus, the HI PI group would expect to maintain a local Web site for data access as well as for HI planning and information purposes. For the HI PI team this would be expected to contain all of the facilities of the current CDS/SOHO Web site (gallery or images and movies, mission and instrument information, operations schedule information, user access information and software, data access etc...).

The HI duty Operations Engineer would be responsible for monitoring the housekeeping data and would be on-call in case of limit violations. In addition, the scientific data from HI should be monitored routinely for quality and the HI duty Scientific Planner should take responsibility for this during his/her duty period. This would include running basic test routines to check alignment, intensities, data-gaps, stray light etc…

7. Image Processing and Calibration Requirements

After an exposure has been extracted from the HI CCD, it is corrected for cosmic ray hits. This is to be done before images are summed from 2kx2k to 1kx1k formats and prior to image integration. Most other image processing activities occur on the ground.

The images must be corrected for flat-fielding. The flat-fielding profile must be determined prior to the scientific operation through pre-launch laboratory measurement and, perhaps, through intensity measurement checks in flight both prior to the door opening and during scientific operation. Any further corrections for vignetting and geometrical distortion must also be applied. These can be established from optical modeling and pre-launch optical measurements.

We must have facilities on the ground for the extraction of CME intensities and this demands the capability for the removal of a regularly updated base-frame as is done with LASCO and simple image-image subtraction. These are discussed in the image simulation report. The base-frame would be calculated from recent data, and would effectively remove the F-corona, scattered light and stars. The base-frame would be updated regularly and stored, i.e. there would be a base-frame archive for use in image analysis. Other methods for CME identification and extraction are under study. These include wavelet analysis applications.

For some applications we would also want to remove only the contribution due to the F-corona. This can be modeled and the resulting images checked for validity of the model used. The F-corona contribution will appear to vary due to the varying radial distance from the Sun (which can be accounted for) and due to the motion of the spacecraft above and below the plane of symmetry of the zodiacal dust cloud (which cannot be accounted for). We don't expect the F-coronal (zodiacal light) model to be structured, although time variations due to local additions of dust due to comets or asteroids may be possible. This model will be an extension of the LASCO model, which extends to 30 solar radii.

Two other procedures, which we must consider for HI, are the image alignment calibration, which can be done using stellar sources, and the intensity calibration which, again, can be done using stellar and planetary intensities. The methods for this must be established but, in principle, we should be able to check the absolute and relative alignment (to the other instruments on SECCHI and between HI-1 and HI-2) and absolute intensity of the HI instruments to a good precision. This may not require special observing sequences. Thus, the processing requirements include:

- Cosmic ray cleaning (on board, before image summing)
- Flat-fielding, vignetting and geometrical distortion correction
- Regular base-frame calculation and archiving for the extraction of the F-corona and stellar background etc..
- Model of the F-corona for removal of the regular F-corona
- Image alignment calibration and intensity calibration

In addition to the processing requirements, the HI community must have access to basic inspection, display and analysis tools. This would include the following:

- HI image display and movie display software, for full or partial frames (including different sky projections)
- HI image differencing facilities, for any image pair
- Stellar and planetary identification routines
- NEO and cometary identification and tracking routines
- CME identification routines and, possibly, speed/direction estimates, as automated sequences for use on board (for broadcast data) as well as on the ground (for data inspection)
- 3-D reconstruction codes which combine the two HI data-sets in an attempt to identify the actual CME direction and speed and 3-D topology
- Variable star location and identification.

8. Instrument Monitoring and Maintenance

As mentioned above, the HI instruments will be monitored at the MOC as well as by a HI duty Operations Engineer. Access to the housekeeping data will be via the Web or at the POC facility. When housekeeping parameters cross pre-defined limits, an alarm will be raised automatically. The duty Engineer will be on-call to address the anomaly, in close contact with the SECCHI Lead Operations Scientist and operations staff at the POC.

In addition to the routine monitoring, there will be a range of maintenance and monitoring activities, which require attention during the mission. Some of these are yet to be defined in detail but typical activities will include:

- CCD bakeout activities
- Calibration sequences (alignment and intensity; although special runs may not be required)
- Spacecraft offpointing and roll maneuvers.

Such activities must be scheduled with the SECCHI Lead Operations Scientist, as with the scientific operation.

9. Commissioning Plan

During launch and for a specified period after launch, the HI doors will remain closed. Indeed, for the first few days, the HI instruments should be switched off or in a sleep mode. The doors will remain shut during the lunar phasing orbits and thruster firing periods, and for a period afterwards to allow outgassing. The CCD decontamination heaters will be applied during this outgassing period. The precise duration of this period is TBD but HI may not open its doors for some weeks after launch. The timing will be decided when the exact timing of the thruster firings is known.

Even with the doors shut, initial tests of the HI systems can be made, including the initial switch on, measurements of dark current, calibration lamp images, voltages, temperatures etc… Basic housekeeping and health checks, and optical checks can be made.

On opening the doors in addition to the housekeeping instrument checks (temperatures, voltages etc…) the HI team will begin to run calibration sequences to check alignment and intensities and will respond with optimising exposures as necessary, ready for the scientific operation. The only mechanism is the door, so there are no mechanisms to check out at this stage.

Once the instrument operation is well understood and the scientific operation has been optimised, the nominal scientific operations phase can begin.

These activities are outlined in Table 4, but it must be noted that this is a first draft, which will be subject to discussion and changes.

Table 4: Early Operations of HI

Mission Phase	HI Activity
Launch and Early Operations Phase (L+24hr)	Door closed. Outgassing

Commissioning Phase (to L+87d)	Part 1: Door closed, outgassing (to L+28d?) Part 2: Door closed, outgassing, turn on HI instruments and check out voltages, temperatures, dark current, calibration lamp and optical system. Part 3: Open doors. Run HI instruments to assess voltages, temperatures in operation, optimise exposure times. Run first calibration sequences.
Nominal Operations	Run science programme along with routine instrument monitoring and calibration activities

10. The Beacon Mode

STEREO will provide a beacon mode of data receipt, i.e. a quick-return method for providing basic space weather information. During the 2003 Brussels meeting, the nature of this mode was discussed.

Beacon mode data from HI could include resolution-degraded (icon) images, partial frames, or the return of a N-S strip of pixels (which would see the crossing of an event). Given the nature of these possibilities, it is important to ensure that the beacon mode input from HI is flexible, i.e. we can programme for different scenarios.

The currently favoured mode is a 256x256 reduced resolution image defined in the following table:

Returned image	256x256 pixel image (summed from 2048x2048 array on board)
Rate	1 image per hour, alternately HI-1 and HI-2.
Pixel depth	32 bits (defined by on board summed data)
Nominal telemetry	582 bit/sec.

This mode would be made up from images summed on board, with cosmic rays removed in the normal way. The data are not additional to the main data stream but are effectively extracted data-sets from the Synoptic Operation.

11. Software Requirements

This document has identified a wide range of software and operational requirements. These are all listed, for completeness, in this section:

On board software requirements

- The synoptic operation is to consist of a series of exposed images of predefined exposure times, summed on board and returned after a predefined number of images. Typically, this will be 60-70 images, but in the limit it would be 1; the number (i.e. cadence) must be selectable.
- The cosmic ray cleaning must be made prior to the image summing, on board, and should be enabled or disabled as required.
- The exposure times must be flexible to ensure that we can adjust for any degradation of the optical systems or, indeed, to allow the selection of revised nominal exposure times in flight.
- We must have a capability to return any selected area of the HI fields, from the full CCD square area, to the circular nominal field of view, to partial image frames. Most scenarios use the full fields of view of the HI instruments. However, for some, we will wish to return only a partial field of one or both instruments, with a corresponding improvement in cadence.
- We must be able to return data from only HI-1 or HI-2 or vary the order of returned images (e.g. the cycle of returned HI-1 and HI-2 frames).
- We must be able to return raw 2048x2048 image arrays (not 2x2 binned), though these would not normally be used for scientific operation.
- It has been suggested that COR1 could provide a CME trigger which could be used within SECCHI to change the operational scenario at selected times. The implementation of such a scheme should be discussed.
- Given that some scenarios do not use the full SECCHI payload and given the possibility of instrument failures at some time in the mission, the SECCHI software must be able to allocate different telemetry distributions among the instruments with relative ease.
- Given the limited uplink capability, we need to keep the schedule simple. For the execution of some programmes this may mean that it is desirable to run some non-synoptic campaigns over several days.
- In the event of a loss of uplink capability or command capability to an instrument, it would be advisable to ensure that the Synoptic Operation is set up as an emergency sequence which will kick-in automatically after a specified period during which no commands are received. In this way, given a loss of command capability, we still receive the basic scientific information.
- HI data must be considered for use in the beacon mode. The nominal beacon mode is a 256 x 256 pixel array of 32 bits depth per pixel every hour, alternating between HI1 and HI2. This requires a nominal telemetry rate of 582 bit/sec.
- The beacon mode must be programmable, i.e. we can change the reduced-resolution image to, for example, the return of a simple N-S strip sunward of the Earth, or to the return of partial images.
- Facilities to enable a CCD bakeout operation must be included.

<u>Ground software requirements</u>

- There must be a SECCHI planning tool for generating the operations scenarios for HI from the PAC.
- HI image flat-fielding, and vignetting and geometrical distortion corrections must be done either on board or on the ground.
- HI image display and movie display software, for full or partial frames, including different sky projections and base-frame removal or subtraction (see below).
- Base-frames, to subtract the F-corona and stellar intensities, must be regularly calculated from recent data, and archived.

- An image subtraction capability, for the subtraction of any image pair, must be available.
- An F-corona model must be maintained to extract the F-corona (this is NOT the same as the base-frame).
- CME identification routines, possibly including routine monitoring of beacon data from HI.
- Software for mass estimates of CMEs similar to LASCO.
- Software for speed/direction/'altitude' analyses.
- HI image alignment checks will be done by the comparison of stellar locations and software will be required to do this for both HI-1 and HI-2 (will use Synoptic Observations).
- HI-1 and HI-2 intensity calibrations can be done by the comparison of stellar intensities with time. (will use Synoptic Observations).
- HI housekeeping and science data must be accessible via a Web-based facility for regular inspection by the UK PI/PM teams.
- Data acquisition, decommutation, decompression and archiving, as well as science and housekeeping monitoring are to be done at the POC. Instrument health parameters will be monitored at the POC.
- Archived data are to be transferred to an archive in the UK on a regular basis, probably at RAL.
- Stellar and planetary identification routines are required.
- NEO and cometary identification and tracking routines are required.
- 3D CME reconstruction codes, combining the two HI instruments are needed, to identify actual CME direction and speed, and 3D topology.
- Variable star location/identification is needed.

Other issues

- Many observational scenarios are being suggested where only the partial SECCHI instrument package is required. We may wish to include a facility to operate only part of the payload for specific campaigns, possibly with a redistribution of telemetry.
- Many scenarios require close collaboration within the STEREO payload, beyond the SECCHI instruments, IMPACT in particular is highlighted. However, several scenarios are dependent on good links with ACE, and other particle and field missions in the near-Earth region (Cluster, Polar, Wind…). Good planning links and data exchange must be available.
- Similarly, some scenarios involve collaboration with Solar-B, RHESSI and SOHO. For these we need links at the planning stage to ensure co-operative operations during campaigns. Such links should be established. For any collaboration with ‘aging’ missions such as RHESSI and SOHO it might be advisable to run campaigns together early in the mission.

Appendix 1: SECCHI Scientific Sequences

Science studies submitted by members of the UK SECCHI/STEREO Science Team for use with the suite of instruments on SECCHI have been used to design operations scenarios. Some 13 such scenarios exist currently and these are described in detail in a separate document.

The idea is that the scientific desires are used to design scenarios and the outcome is used as an input to consider the instrument and spacecraft operations, to define the software requirements, and to define methods for running the instrument.

SECCHI OBSERVING PROGRAMME TEMPLATE

Observation Title:

Name:
Institute:
E-mail:

Version Date:

Brief Scientific Objective and Observation Overview:

Sequence Details

EUVI: [Bands - He II 304, Fe IX 171, Fe XII 195, Fe XV 284 Å; Resolution - 1.6 arcsec/pixel; FOV - 0.9 deg Sun-centred; Nominal cadence 30 s]

- Required (yes/no) -
- Which bands? -
- Image cadence? -
- FOV (full Sun, partial Sun (define area and pointing)) -
- Other details -

COR1: [Bandpass - 650-660 nm (brightness and pB); Resolution - 7.5 arcsec/pixel; FOV - 1.3-4.0 R (full revolution; Sun centred); Nominal cadence 20 s (3 images/min in different polarisation angles)]

- Required (yes/no) -
- Image cadence? -
- FOV (full or partial field (define area and pointing)) -
- Other details -

HI-1: [Bandpass - 650-750 nm (brightness); Resolution - 35 arcsec/pixel; FOV - 20° circle centred at 13.28° to Sun centre (3.28-23.28° along ecliptic); Nominal cadence 1 hr]

- Required (yes/no) -
- Image cadence? -
- FOV (full or partial field (define area and pointing)) -
- Other details -

HI-2: [Bandpass - 400-1000 nm (brightness); Resolution - 240 arcsec/pixel; FOV - 70° circle centred at 53.36° to Sun centre (18.36-88.36° along ecliptic); Nominal cadence 3 hr]

- Required (yes/no) -
- Image cadence? -
- FOV (full or partial field (define area and pointing)) -

Other details

Other Spacecraft/Instruments Required (give details of observation)?

Other relevant details?

Special Operational/Software Requirements? (i.e. requirements to feed into operations planning and software during mission development)

Ability to automatically change cadence of observations upon CME detection?

SECCHI OBSERVING PROGRAMME TEMPLATE

Observation Title: *Synoptic CME Programme*

Name: Richard A. Harrison
Institute: RAL
E-mail: r.harrison@rl.ac.uk

Version Date: 6 June 2002

Brief Scientific Objective and Observation Overview:

One of the major objectives of the STEREO effort is the routine monitoring and identification of CMEs which are Earth-directed. Thus, we require a standard synoptic observation programme, which is described here.

Sequence Details

EUVI: [Bands - He II 304, Fe IX 171, Fe XII 195, Fe XV 284 Å; Resolution - 1.6 arcsec/pixel; FOV - 0.9 deg Sun-centred; Nominal cadence 30 s]

- Required (yes/no) — Yes
- Which bands? — All
- Image cadence? — 20 min
- FOV (full Sun, partial Sun (define area and pointing)) — Full field
- Other details — Standard synoptic cadence

COR1: [Bandpass - 650-660 nm (brightness and pB); Resolution - 7.5 arcsec/pixel; FOV - 1.3-4.0 R (full revolution; Sun centred); Nominal cadence 20 s (3 images/min in different polarisation angles)]

- Required (yes/no) — Yes
- Image cadence? — 8 min
- FOV (full or partial field (define area and pointing)) — Full field
- Other details — Standard synoptic cadence

COR2: [Bandpass - 650-750 nm (brightness and pB); Resolution - 15 arcsec/pixel; FOV - 2-15 R (full revolution; Sun centred); Nominal cadence 100 s]

- Required (yes/no) Yes
- Image cadence? 20 min
- FOV (full or partial field (define area and pointing)) Full field
- Other details Standard synoptic cadence

HI1: [Bandpass - 650-750 nm (brightness); Resolution - 35 arcsec/pixel; FOV - 20° circle centred at 13.28° to Sun centre (3.28-23.28° along ecliptic); Nominal cadence 1 hr]

- Required (yes/no) Yes
- Image cadence? 1 hour
- FOV (full or partial field (define area and pointing)) Full field
- Other details Standard synoptic cadence

HI2: [Bandpass - 400-1000 nm (brightness); Resolution - 240 arcsec/pixel; FOV - 70° circle centred at 53.36° to Sun centre (18.36-88.36° along ecliptic); Nominal cadence 3 hr]

- Required (yes/no) Yes
- Image cadence? 2 hours
- FOV (full or partial field (define area and pointing)) Full field

Other details Standard synoptic cadence

Other Spacecraft/Instruments Required (give details of observation)?

Standard monitoring of STEREO particle, field and radio data would be advantageous as would coincident space weather monitoring programmes. Little planning is required as these would be standard operations.

Other relevant details?

None

Special Operational/Software Requirements? (i.e. requirements to feed into operations planning and software during mission development)

None