STEREO

IMPACT

Performance Specification

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Document Revision Record

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A	2001-Apr-5	Preliminary Draft	-
B	2001-May-3	Inputs from Reinhold for SEPT	-
C	2001-Jun-22	Inputs from Walpole for SIT	-
D	2001-Jul-9	Inputs from Larson for SWEA, STE	-
E	2001-Jul-17	Fix some typos, update SIT timing TBD, add HET/LET requirements	-
F	2001-Sep-7	Update MAG Requirements Add level 1 requirements	

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1. Introduction

This specification describes the performance goals and requirements for the IMPACT investigation on the STEREO mission. These specifications are at the derived science requirements level, listing verifiable instrument performance requirements. It does not include the derived engineering requirements (mass, power, interfaces, etc.), which are largely covered by documents like the Spacecraft ICD.

1.1. *Document Conventions*

In this document, TBD (To Be Determined) means that no data currently exists. A value followed by TBR (To Be Resolved) means that this value is preliminary. In either case, the value is typically followed by a code such as UCB indicating who is responsible for providing the data, and a unique reference number.

1.2. *Applicable Documents*

The following documents include drawings and STEREO Project policies. All documents and drawings can be found on the Berkeley STEREO/IMPACT FTP site:

http://sprg.ssl.berkeley.edu/impact/dwc/

1. PhaseAReport/ - Phase A Report, split into a number of files

2. Science Requirements

Table 2-1 lists the STEREO Project Objectives. Table 2-2 lists the STEREO Project Level 1 Science Requirements and how they connect to the objectives and instrumentation. Table 2-3 shows the IMPACT science requirements traceability matrix.

Table 2-1 Stereo Project Objectives

ITEM	OBJECTIVE
1	Understand the causes and mechanisms of CME initiation.
2	Characterize the propagation of CMEs through the heliosphere.
3	Discover the mechanisms and sites of energetic particle acceleration in the low corona and the interplanetary medium.
4	Improved determination of the structure of the ambient solar wind.

Level 1 Requirements:

1. Determine the evolution of the CME mass distribution as the CME propagates from the low corona to 1 AU (Objective 2)
2. Determine the CME speed as the CME propagates from the low corona to 1 AU (Objective 2) ***MAG, SWEA***
3. Determine the direction of CME propagation as the CME evolves from the low corona to 1AU (Objective 2) ***MAG,SIT,SEPT,LET,HET***

4. Determine the CME initiation time to an accuracy of order 10 minutes. (Objective 1)
5. Determine the location of CME initiation to within +/- 1 deg solar latitude and solar longitude. (Objective 1) ***STE***
6. Obtain the time series of solar wind temperature measurements at two points separated in solar longitude. (Objective 4) ***SWEA, STE***
7. Obtain the time series of solar wind velocity measurements at two points separated in solar longitude. (Objective 4) ***SWEA***
8. Obtain the time series of solar wind magnetic field measurements at two points separated in solar longitude. (Objective 4) ***MAG, SWEA, STE***
9. Obtain the time series of solar wind density measurements at two points separated in solar longitude. (Objective 4) ***SWEA***
10. Determine the location of particle acceleration in the low corona and through the interplanetary medium. (Objective 3) ***SIT, SEPT, HET, LET***
11. Characterize the energetic particle distribution functions in situ for electrons and ions at particle energies typical of solar energetic particles. (Obj. 3) ***STE, SIT, SEPT, HET, LET***

Table 2-2 STEREO Level 1 Requirements (Red=Primary, Yellow = Alternate)

REQMT ID	MEASUREMENTS	ALLOCATION	REQUIREMENT	GROUPING	Science Objectives			
					1	2	3	4
01.01.0001	Mass		Determine the evolution of the CME mass distribution as the CME propogates from the low corona to 1 AU.			x		
		SECCHI/COR2						
		SECCHI/HI						
		SECCHI/COR1						
01.01.0002	Speed		Determine the CME speed as the CME propogates from the low corona to 1 AU.			x		
		SECCHI/COR2						
		SECCHI/HI						
		SECCHI/COR1						
		SWAVES						
		IMPACT/MAG						
		IMPACT/SWEA						
		PLASTIC						
01.01.0003	Direction		Detemine the direction of CME propogation as the CME evolves from the low corona to 1AU.			x		
		SECCHI/COR2						
		SECCHI/HI						
		SECCHI/COR1						
		SWAVES						
		IMPACT/MAG						
		IMPACT/SIT						
		IMPACT/SEPT						
		IMPACT/LET						
		IMPACT/HET						
01.01.0004	Initiation Time		Determine the CME initiation time to an accuracy of order 10 minutes.		x			
		SECCHI/EUVI						
		SECCHI/COR1						
		SWAVES						
01.01.0005	Initiation Location		Determine the location of CME intiation to within +/- 1 deg solar latitude and solar longitude.		x			
		SECCHI/EUVI						
		SECCHI/COR1						
		IMPACT/STE						
		SWAVES						
01.01.0006	Solar Wind Temperature		Obtain the time series of solar wind temperature measurements at two points separated in solar longitude.					x
		PLASTIC						
		IMPACT/SWEA						
		IMPACT/STE						
		SWAVES						
01.01.0007	Solar Wind Velocity		Obtain the time series of solar wind velocity measurements at two points separated in solar longitude.					x
		PLASTIC						
		IMPACT/SWEA						
		SWAVES						
01.01.0008	Solar Wind Magnetic Field		Obtain the time series of solar wind magnetic field measurements at two points separated in solar longitude.					x
		PLASTIC						
		IMPACT/MAG						
		IMPACT/SWEA						
		IMPACT/STE						
01.01.0009	Solar Wind Density		Obtain the time series of solar wind density measurements at two points separated in solar longitude.					x
		PLASTIC						
		IMPACT/SWEA						
		SWAVES						
01.01.0010	Location of Particle Acceleration		Determine the location of particle acceleration in the low corona and through the interplanetary medium.				x	
		SWAVES						
		IMPACT/STE						
		SECCHI/COR2						
		SECCHI/HI						
		IMPACT/SIT						
		IMPACT/HET						
		IMPACT/LET						
		IMPACT/SEPT						
01.01.0011	Energetic Particle Distribution Function		Characterize the energetic particle distribution functions in situ for electrons and ions at particle energies typical of solar energetic particles.				x	
		IMPACT/SIT						
		IMPACT/HET						
		IMPACT/LET						
		IMPACT/SEPT						
		IMPACT/STE						

Table 2-3 IMPACT Requirements

ITEM	REQMT ID			REQUIREMENT STATEMENT	ALLOCATION ELEMENT	ALLOCATION WBS	TRACEABILITY REQMT ID	TRACEABILITY CONTROL DOC	TRACEABILITY CONTROL DOC PARAGRAPH
1	03	01	0001	Measure the three components of the vector magnetic field on two platforms in heliocentric orbit with the performance shown in Table 3.1.	MAG		01.01.0002, 01.01.0003, 01.01.0008	L-1 Science Requirements	
2	03	01	0002	Measure the solar wind core and halo electron disttributuion on two platforms in heliocentric orbit with the performance shown in Table 3.2.	SWEA		01.01.0002, 01.01.0006, 01.01.0007, 01.01.0008, 01.01.0009	L-1 Science Requirements	
3	03	01	0003	Measure the solar wind superhalo electron disttributuion on two platforms in heliocentric orbit with the performance shown in Table 3.3.	STE		01.01.0005, 01.01.0006, 01.01.0008, 01.01.0011	L-1 Science Requirements	
4	03	01	0004	Measure the solar supra-thermal ion distributuion (with composition) on two platforms in heliocentric orbit with the performance shown in Table 3.4	SIT		01.01.0003, 01.01.0010, 01.01.0011	L-1 Science Requirements	
5	03	01	0005	Measure the solar energetic electron and proton distributuion on two platforms in heliocentric orbit with the performance shown in Table 3.5	SEPT		01.01.0003, 01.01.0010, 01.01.0011	L-1 Science Requirements	
6	03	01	0006	Measure the low energy end of the solar energetic ion distributuion (with composition) on two platforms in heliocentric orbit with the performance shown in Table 3.6	LET		01.01.0003, 01.01.0010, 01.01.0011	L-1 Science Requirements	
7	03	01	0007	Measure the high energy end of the energetic electron and ion distributuion (with composition) on two platforms in heliocentric orbit with the performance shown in Table 3.7	HET		01.01.0003, 01.01.0010, 01.01.0011	L-1 Science Requirements	

2.1. *MAG Science*

- **Identify ICMEs at one or two of the STEREO sites, providing information on their global scale and uniformity, including their associated interplanetary shocks (strength, surface orientations), compressed solar wind sheaths, and internal field configurations (e.g. flux rope or other, flux rope orientation, size, and handedness, and ejecta flux content)**
  - ***for relating to the solar observations and determining potential geoeffectiveness***
- **Define ambient solar wind conditions at the two spacecraft, including stream structures and interfaces, and heliospheric current sheet crossings**
  - ***for relating to solar observations, and determining potential geoeffects from high speed streams and stream interfaces alone, as well as the effects of the ICME on ambient conditions, and ambient conditions on the ICME***
- **Organize local particle (solar wind and SEP) distribution functions including IMPACT/SWEA, STE, and SEP electrons, and PLASTIC and IMPACT/SEP ions.**
  - ***SWEA heat flux electrons for inferring field topology and connections to the Sun, STE electrons for inferring field connections to active regions, PLASTIC solar wind and ICME ions for deducing plasma ion sources, and SEPs from SIT,SEPT,LET,HET for deducing SEP origin, acceleration, and propagation processes***
- **Determine properties of low frequency waves in the interplanetary medium**
  - ***for characterizing waves at ICME shocks that play a role in SEP acceleration and propagation, and large Alfven wavetrains that sometimes accompany ICMEs and produce geoeffects of their own***
- **Provide a measure of one of the fundamental heliospheric MHD parameters**

- ***for comparisons with 3-D models of shocks and other solar wind and ICME features that will be used to connect the SECCHI observations to the STEREO in-situ observations***

2.2. *SWEA Science*

SWEA measures the 3-D electron distribution function from ~0-3000 eV with nearly complete (90% of 4p) angular coverage. This energy range includes the thermal core population (<60 eV) and the highly anisotropic, suprathermal halo population (>60 eV) that carries the majority of the solar wind heat flux. Some specific goals of SWEA are to:

- **Provide direct comparison of in-situ density measurements with coronagraph images.** SECCHI coronagraph images are a measure of column integrated electron density and can be compared to electron density measured in-situ by SWEA on the complementary STEREO spacecraft.
- **Determine magnetic field topology.** Suprathermal (>60 eV) electrons are excellent tracers of magnetic field topology. For example, Bi-directional streaming is a signature of magnetic field lines that are connected at both ends to the Sun.
- **Provide a remote probe of coronal electron temperature.** Measurements of the slope of the distribution function at electron energies > 100 eV provide a tool for remote sensing of the inner coronal electron temperature.
- **Identify ICMEs at one or both of the STEREO spacecraft locations.** Bi-directional electron distribution are one of the primary signatures of ICMEs. These measurements are also useful for identifying ambient solar wind conditions such as stream structures, interfaces and heliospheric current sheet crossings.
- **Provide measurements of fundamental plasma parameters.** Density, velocity, electron temperature and pressure measurements are critical for comparison with 3-D models of solar wind and ICME propagation and relating to solar observations and determining potential geoeffectiveness.

2.3. *STE Science*

STE measures electron fluxes in the 2-100 keV energy range where shock acceleration and flare-site acceleration begin to become important sources.. Some specific goals of SWEA are to:

- **Identify the solar source and magnetic footpoints of ICMEs.** Impulsively accelerated electrons detected in an ICME can be tracked by the type III radio burst they produce from 1 AU back to the Sun, where the parent flare-like event can be imaged.
- **Determine the length of field lines in ICMEs.** The field line length can be obtained by analyzing the velocity dispersion (the arrival of the faster electrons first) in impulsive events.
- **Probe particle acceleration near the Sun in both impulsive and gradual (CME-related) solar energetic particle (SEP) events.** Energy loss effects in traversing the corona will show up in the STE energy range, thus providing the column depth to the acceleration region. Velocity dispersion studies of STE

electrons and SEP ions probe the timing and heights of the ion and electron acceleration.

- **Probe the in situ acceleration of electrons by ICME shocks waves, and identify the shock parameters that lead to type II radio emission.** The ICME shock accelerated ~1-10 keV electrons produce the type II radio emission used to track ICMEs from the Sun to 1 AU. STE measurements will probe the in situ acceleration of electrons by ICME shocks and determine the shock parameters that lead to type II radio emission.
- **Identify the source (presently unknown) of the superhalo (~1-100 keV) electrons that are always present in the interplanetary medium.** STE's high sensitivity will enable unambiguous measurements of angular distributions and spectra to identify the source.

2.4. *SEP Science*

- Solar Energetic Particle (SEP) studies with STEREO have four main objectives:
    - To understand how and where CMEs accelerate charged particles
    - To characterize properties of the subset of CMEs that do accelerate particles
    - To complement STEREO images by sensing remotely ICME and magnetic field structures
    - To develop tools for improved forecasts of large SEP events and/or to warn of their onset
- To address these objectives requires:
    - Composition over a broad energy/intensity range
    - Excellent temporal resolution
    - Spatially separated spacecraft
- Composition data from LET, SIT and HET will:
    - Distinguish flare-accelerated & CME-shock accelerated particles
    - Identify seed populations (coronal, solar wind, suprathermal ions, pickup ions)
    - Investigate the physics of particle acceleration with ions of differing charge/mass ratios (Fe/O, 3He/4He,22Ne/20Ne, p/e)
    - Investigate how proton-generated waves throttle escape of various species from the shockBroad energy coverage (HET/LET/SIT for composition;

  SEPT for protons/electrons) will:
    - Allow comparison of measured energy spectra with acceleration models
    - Provide a larger event sample (from small flare-related events to large CME-driven events)
    - Investigate acceleration processes continuously from injection energies to their upper limit
    - Measure 10 to 100 MeV/nucleon proton & alpha-particle intensities of space weather interest
    - Provide a broad range of particle intensities for the STEREO Beacon Mode
- Spatially separated measurements are needed to:
    - Investigate the spatial extent of acceleration along the shock

    - Measure in situ interplanetary parameters of CMEs that accelerate particles seen by trailing S/C
    - Develop tools to enable forecasts of SEP radiation hazards with future interplanetary networks
- In summary, SEP IMPACT Measurements will address key objectives for STEREO and Living with a Star:
    - Provide “ground-truth” for interpreting CME images in terms of energetic-particle production and transport, and for investigating the consequences of CMEs
    - Provide the tools to understand and eventually forecast large solar particle events
    - Provide key data for the STEREO Beacon Mode
    - Address important LWS goals that include investigating the solar-cycle and spatial dependence of solar-particle events and mitigating solar-particle risks

3. Performance Requirements

The requirements are listed below by instrument. The table lists both the desired goal as well as the minimum acceptable requirement. Inability to meet requirements within the allocated resources must be waived by the Principal Investigator, and STEREO PROJECT will be informed.

3.1. *MAG Requirements*

Description	Goal	Requirement
Noise level	0.01 nT	0.01nT
Absolute Accuracy	+/- 0.1 nT	+/-0.1nT
Range	+/-512 nT, +/-65536 nT	+/-512 nT
Drift	+/-0.2 nT/yr	+/-0.2nT/yr
Time Resolution	1/4 sec. 1/32 sec. (Burst)	1 sec

3.2. *SWEA Requirements*

Description	Goal	Requirement
FOV	360 x 130 degree	360 x 60 degrees
Resolution	22.5 degree	45 degrees
Energy	1 to 5000eV	20 to 1000eV
Energy Resolution (Telemetry)	65%	100%
Geometric Factor	0.01 cm^2 ster E(eV)	0.001 cm^2 ster E(eV)
Max Count Rate (per 22.5 degree sector)	1E6 counts/sec	1E5 counts/sec
Time Resolution	1 minute (3D) to 2 seconds (moments, burst)	1 minute

3.3. *STE Requirements*

Description	Goal	Requirement
FOV	Two opposite 80 x 80 degree	60 x 60 degree
Resolution	80 x 20 degrees	60 x 20 degrees
Energy	2 - 100 keV	5 – 100 keV
Energy Resolution (Telemetry)	35%	100%
Energy Resolution (Electronic)	300eV FWHM	2keV
Geometric Factor	0.4 cm^2 ster	0.1 cm^2 ster
Background	<1c/s/detector	<30c/s/detector
Max Count Rate (per detector)	100,000 counts/sec	10,000 counts/sec
Time Resolution	16 seconds 2 seconds (burst)	1 minute

3.4. *SIT Requirements*

Description	Goal	Requirement
FOV	17 x 44 degrees	17 x 44 degrees
Energy	30-2,000 keV/nuc He-Fe	30-2,000 keV/nuc He-Fe
Mass Resolution	0.85 AMU (^{16}O at 100keV/nuc)	0.85 AMU (^{4}He at 1MeV/ Nuc)
Energy Resolution	20keV FWHM	35keV FWHM @ 22C
Geometric Factor	0.4 cm^2 ster	0.4 cm^2 ster
Background	10^{-2} events/sec in quiet time	10^{-2} events/sec during vac test
Max Event Rate	1000 events/sec	1000 events/sec
Time Resolution	1 Minute	15 Minutes

3.5. *SEPT Requirements*

Description	Goal	Requirement
FOV	2 sets of oppositely directed 52 degree cones each for electrons and protons	2 sets for electrons and protons, each with: 2 oppositely directed view cones in-ecliptic, 2 oppositely directed view cones off-ecliptic, 45 degree full opening angle
Energy	20-400 keV electrons, 20-7000 keV protons	30-400 keV, electrons 30-2000 keV, protons
Energy Resolution (Telemetry)	20% electrons, 20% protons	30%, electrons 30%, protons
Geometric Factor	0.52 cm^2 ster, electrons, 0.68 cm^2 ster, protons	0.4 cm^2 ster, electrons, 0.4 cm^2 ster, protons
Background	< 0.2 counts/s on ground, 20°C	< 2 counts/s on ground, 20°C
Max Event Rate	25,000 counts/s at 2.2 MeV 250,000 counts/s at 55 keV	25,000 counts/s at 2.2 MeV 250,000 counts/s at 55 keV
Time Resolution	60 sec	60 sec

3.6. *LET Requirements*

Description	Goal	Requirement
FOV	2 oppositely directed 130 x 30 degree fans	2 oppositely directed 100 x 30 degree fans
Energy Range (MeV/nucleon)	H: 1.4 - 6 He: 1.4 - 13 O: 2.5 – 25 Fe: 2.5 - 50	H: 1.5 - 3 He: 1.5 - 13 O: 3 – 25 Fe: 3 - 25
Geometric Factor cm^2 ster	H, He: 0.9 6=Z=26: 4.5	H, He: 0.5 6=Z=26: 2
Element Resolution	Also resolve Na, Al, S, Ar, Ca	Resolve H, He, C, N, O, Ne, Mg, Si, Fe
^{4}He Mass Resolution	=0.25 AMU	=0.35 AMU
Max Event Rate	5000 events/sec	1000 events/sec
Energy Binning	8 intervals per species for Z=2 4 intervals for H	6 intervals per species for Z=2 3 intervals for H
Species Binning	Add S, Ar, Ca	H, ^{3}He, ^{4}He, C, N, O, Ne, Mg, Si, Fe
Time Resolution	1 minute H, He, 15 minutes Z=6 4 prioritized events/sec	15 minutes 1 prioritized event/sec
Beacon Telemetry:	1 minute for H, He, 6=Z=26	1 minute for H, He, 6=Z=26

3.7. *HET Requirements*

Description	Goal	Requirement
FOV (full angle)	58 degree cone	50 degree cone
Energy Range (MeV/nucleon)	e: 1 - 8 H, He: 13 - 100 ^{3}He: 16 – 50 ~30 to 80 for 6 = Z = 26	1 – 6 13 – 40 16 – 40 ~30 to 80 for 6 = Z = 14
Geometric Factor, cm^2 ster	0.7	0.5
Element Resolution, dZ (rms), for stopping particles	= 0.3 for 16 = Z = 26	= 0.2 for 1 = Z = 14
^{4}He Mass Resolution	=0.20 amu	=0.25 amu
Max Event Rate	5000 events/sec	1000 events/sec
Energy Binning	Eight intervals per species	Six intervals per species
Species Binning	Add 16 = Z = 26	H, ^{3}He, ^{4}He, 6=Z=14, Electrons
Time Resolution	15 minutes 1 prioritized events/sec	15 minutes 0.3 prioritized event/sec
Beacon Telemetry:	1 minute H, He, e	1 minute H, He, e