HESSI

High Energy Spectroscopic Imager (HESSI)
Mission Requirements

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1. Introduction

This document is the official list of HESSI Mission Level 1 (Science & Programmatic) and Level 2 (Derived Project, System, Instrument, and Spacecraft Bus) requirements. These requirements form the basis for subsystem requirements. The Mission System Engineer shall flow down these requirements to the subsystems, and ensure that the designed systems, as described in the subsystem specifications, meet these requirements.

This document is under configuration control by the Mission System Engineer. Any changes must be routed to the Mission System Engineer, who will obtain the necessary agreement from scientists and engineers (starting with those people on the signature page, but also including subsystem leads for any affected systems) before posting it as the official version.

- Subsystem trades (including the spacecraft bus) may be made within the resources of the subsystem (with the knowledge of the System Engineer)

- Trades that impact subsystem (level 2) requirements, interfaces, or resource allocations are under configuration control, and require concurrence by the System Engineer and Project Manager.

- Trades that impact science or programmatic (level 1) requirements require concurrence by the PI.

- Trades that impact negotiated Program-Level requirements, as described in the "Mission Program-Level Requirements for the HESSI Project" document, or contractual requirements must have concurrence by NASA.

2. Level 1 Requirements

2.1. *Science Requirements*

SCI-1. Solar Spectroscopy

SCI-1.1. Energy Range: 3 keV to 20 MeV Goal, 20 keV to 7 MeV Required

SCI-1.2. Energy Resolution: 0.5 keV to 30 keV Goal, 3 keV at 1MeV Required

SCI-1.3. Sensitivity Goal: Detect Microflares, 20 keV photon flux 5×10^{-3} $(cm^2 \cdot sec \cdot keV)^{-1}$

SCI-1.4. Dynamic Range: Measure Large Flares:

Maximum 20 keV Photon Flux Capability:

High Energy Resolution: 400 $(cm^2 \cdot sec \cdot keV)^{-1}$

Broadband: 5,000 $(cm^2 \cdot sec \cdot keV)^{-1}$

SCI-1.5. Background (Note: mission mass/cost constraints mean no large or active shield):

SCI-1.5.1. Minimize/measure particle-induced background, Goal

SCI-1.5.2. Minimize x-ray background in front segments, Goal

SCI-1.5.3. Minimize scatter of flare x-rays into rear segments during a flare, Goal

SCI-1.6. Photometry: knowledge of absolute intensity of an observed flare in various continuum bands and lines to better than 10% Goal, 25% Required

SCI-2. Solar Imaging

SCI-2.1. Angular Resolution: <4 arcsec to 35 keV (goal ≈2 arcsec), 7 arcsec to 400 keV, 36 arcsec above 1 MeV

SCI-2.2. Angular Coverage: 4 – 180 arcsec

SCI-2.3. Field of View: Full Sun

SCI-2.4. Time resolution: 100 ms for coarse image, 2 s for detailed image

SCI-2.5. Image dynamic range 100:1 goal, 10:1 required

SCI-3. Mission Timing (Solar Maximum)

SCI-3.1. Launch mid 2000 Goal, before end of 2001 Required

SCI-3.2. Mission Life: 1 year Required, 2 year Nominal, 3 year Goal (2 year minimum 3 sigma)

SCI-4. Data Handling

SCI-4.1. System Capacity: Continuous imaging through large flares, including data collection, storage, transmission from the spacecraft, reception on the ground, analysis, and archiving (Goal), 50% coverage Required.

SCI-5. Secondary Science (Goals)

SCI-5.1. Hard X-ray / γ-ray all-sky monitor

SCI-5.1.1. Field of view of at least 2 pi steradians

SCI-5.1.2. Ability to see transient hard x-ray sources down to about 300 mCrab from 30-100 keV in a few days of integration

SCI-5.1.3. Detection at > 10-sigma significance of gamma-ray lines with flux of a few times 10-4 photons/cm2/s in a year's integration

SCI-5.1.4. <1ms time resolution for x-ray pulsar period determination

SCI-5.2. Crab Nebula Imaging: view Crab Nebula when within a few degrees of the Sun

SCI-5.3. High energy & temporal resolution measurements of terrestrial Hard X-ray / γ-ray emissions.

SCI-5.3.1. Field of view requirement as for cosmic all-sky monitor

SCI-5.4. Location and Spectroscopy of Gamma-Ray Bursts

SCI-5.5. Polarization Detector

SCI-5.5.1. Sensitivity to hard x-ray polarization levels < 10% for the largest flares

SCI-6. Context / Ground Observations (Goal)

2.2. *Programmatic Requirements*

These requirements are called out in:

- The 1997 SMEX Announcement of Opportunity
- The HESSI contract between UCB and NASA
- The HESSI Proposal Commitments (Co-Is, Spacecraft Selection).
- Appropriate Government regulations (e.g. ITAR, FCC, etc.)

A summary of key programmatic requirements follows:

PRO-1. NASA SMEX Mission

PRO-1.1. Cost Constrained per AO section 3.6 and Proposal

PRO-1.2. NASA Provided SELVS II Launch Vehicle (small fairing)

PRO-1.2.1. Pegasus or Athena-1

PRO-1.2.2. Launch from Wallops or KSC

PRO-1.2.3. Launch Site Requirements (safety, etc.)

PRO-1.3. Subject to cancellation if not launched before November 2000 (Contract)

PRO-1.4. NASA oversight, reporting, and reviews per AO

PRO-1.5. Quality Assurance per AO Appendix H

PRO-1.6. ITAR

PRO-1.7. Space Debris – all orbits decay in less that 25 years

PRO-1.8. Education & Outreach per AO

PRO-1.9. Small & Disadvantaged Business Contracting Goal per AO

PRO-2. Proposal Commitments

PRO-2.1. Co-I Contributions

PRO-2.2. Spectrum Astro Spacecraft

3. Level 2 Requirements

3.1. ***System Requirements***

SYS-1. Communications:

SYS-1.1. Ground Station At Berkeley: AO constraints encourage purchasing ground system up-front rather than renting time (PRO-1.1). Cost of a ground station is comparable with cost of renting station time for 3-year mission.

SYS-1.2. S-Band, STDN-compatible, CCSDS-compatible, COP-1 compatible to simplify backup by other existing stations and use of off-the-shelf hardware (PRG-2.4, SCI-4.1)

SYS-1.3. >3.5 Mbps downlink, $<10^{-6}$ BER, >2.7 dB link margin minimum @ 5° above horizon (SCI-4)

SYS-1.3.1. Worst case ground station G/T = 19.3dB @ 5° above horizon (Allocated, spacecraft / ground station trade)

SYS-1.4. 2000bps uplink, $<10^{-7}$ BER, >3db uplink margin @ 5° above horizon

SYS-1.4.1. Transmit EIRP > 58dBW (Allocated, spacecraft / ground station trade)

SYS-2. Mission Ops:

SYS-2.1. Ground station and mission ops co-located at Berkeley to save $ (PRO-1.1)

SYS-2.2. Tracking by NORAD (PRO-1.1, SYS-1.1)

SYS-3. Orbit:

SYS-3.1. Launch sites preclude low-background equatorial orbit. 38 degree orbit maximizes telemetry downlink to a ground station at Berkeley (SYS-1, SCI-4)

SYS-3.2. 600 km (TBR) orbit - high enough to meet the lifetime requirement (SCI-3.2), and as low as possible to minimize the background (SCI-1.5) and meet the Debris requirement (PRO-1.7)

SYS-4. < 333 kg launch mass (PRO-1.2 & SYS-3)

SYS-4.1. Spacecraft not-to-exceed = 158 kg (Allocated)

SYS-4.2. Instrument not-to-exceed = 160 kg (Allocated)

SYS-5. I&T

SYS-5.1. System integration and test at Berkeley, using the same resources & personnel that will do mission ops. (PRO-1.1, PRG-2.3)

SYS-5.2. Cleanliness/Contamination: Class 100,000 at system level, as required at subsystem level. (Derived from Instrument requirements)

SYS-5.3. Environmental Tests (SCI-3.2, PRO-1.5, PRG-2.3):

SYS-5.3.1. Subsystem level thermal or thermal vac, vibration

SYS-5.3.1.1. Thermal to stress subsystems at least 10C beyond expected environments Required, -34 to +55°C Goal

SYS-5.3.1.2. At least 4 thermal cycles at acceptance levels.

SYS-5.3.1.3. Vibration levels to be determined from SELVS-II input function and computed coupling through spacecraft, or computed using GEVS-SE

SYS-5.3.2. System level vibration, thermal vac / thermal balance, EMI

SYS-5.3.2.1. Vibration level to envelope of SELVS-II launch loads (PRO-1.2) (reduced to selected launch vehicle at time of selection)

SYS-5.3.2.2. System level thermal balance to verify thermal model

SYS-5.3.2.3. EMI to verify no self-interference between subsystems, compatibility with launch vehicle & launch site

SYS-5.3.3. GEVS-SE test procedures

SYS-6. Power

SYS-6.1. Instrument power Not-to-Exceed 162W orbit average (Allocated)

SYS-6.2. Spacecraft bus to meet Instrument and Bus Not-to-Exceed power requirements at End-of-Life (3 years)

SYS-6.3. Spacecraft battery capacity sufficient to power Instrument plus Bus through orbit shadows without exceeding battery manufacturer's suggested Depth-of-Discharge for the predicted number of cycles (3 years)

SYS-6.4. Spacecraft battery sufficient to power bus through worst case orbit insertion scenario until the bus achieves positive power balance on its arrays.

3.2. *Instrument Requirements*

INS-1. Spectrometer

INS-1.1. Detectors: Nine 7cm diameter segmented Germanium detectors (GeDs) cooled to 75°K Goal, 85°K Requirement to minimize radiation damage to meet SCI-3.2, meet SCI-1, and be consistent with number and placement of grids in INS-2.1.

INS-1.1.1. Minimize thermal cycling of cryostat to minimize contamination issues to meet SCI-3.2

INS-1.1.2. Cool down detectors as soon as possible after launch to minimize radiation at elevated temperatures (more than 1 week above 100°K may require an anneal cycle) to meet SCI-3.2 and SCI-1.1

INS-1.1.3. Avoid exceeding 100°K except during a anneal cycle (may require an anneal cycle) to meet SCI-3.2 and SCI-1.1

INS-1.1.4. Maintain HV on whenever temperature is below 100°K to minimize radiation damage to meet SCI-3.2 and SCI-1.1

INS-1.1.5. Goal: Provide ability to anneal detectors to about +100°C to reduce the effects of accumulated radiation damage or contamination (requires venting the cryostat to space).

INS-1.2. Shutters (Goal): A system to mechanically insert mass between the imager and detectors to decrease the low energy photon flux in order to increase the counting rate dynamic range to meet/exceed SCI-1.4 Alternatively, must provide fixed mass profile to achieve SCI-1.4.

INS-1.3. Goal: Material in FOV limited to 0.040” thickness beryllium windows plus 39 blanket layers, including front and back of collimators plus inside cryostat; each blanket is 0.25 mil mylar film + 0.3 mil equivalent nylon netting (SCI-1.1,1.3,1.4)

INS-2. Rotating Modulation Collimator Imager (Meets SCI-2.)

INS-2.1. Grids: 9 grids with characteristics indicated in table INS-2.1 (SCI-2.1, SCI-2.3) (Allocated: Compromise among attenuation, field-of-view, spectroscopic throughput, and mass)

Table INS-2.1

Grid	Pitch, mm	Slit Width, mm	Slat Width, mm	Thickness, mm
1	0.034	0.020	0.014	>0.055, 1.2 goal
2	0.059	0.035	0.024	>0.055, 2.1 goal
3	0.102	0.061	0.041	>3.0, 3.6 goal

4	0.177	0.106	0.071	>3.0, 6.2 goal
5	0.306	0.184	0.122	>3.0, 10.7 goal
6	0.530	0.318	0.212	18.6
7	0.918	0.477	0.441	>3.0, 6.2 goal
8	1.590	0.811	0.779	>3.0, 6.2 goal
9	2.754	1.487	1.267	>30.0, 30 goal

INS-2.2. Spin stabilized spacecraft 12-20RPM (SCI-2.4)

INS-2.3. Alignment requirement: Telescope axis aligned to sun direction to < 0.2 degrees (INS-2.7.1)

INS-2.4. White Light Imaging (Goal): measure white light features on the sun to correlate images with ground observations (SCI-6)

INS-2.4.1. Absolute Solar Aspect Solution 1 arcsecond 3σ Goal, 1.8 arcsecond 3σ requirement.

INS-2.5. Modulation > 70% (SCI-2.1, 2.5). Budget: (3σ Allocations, based on resolution goal; 1.8x to meet requirement)

INS-2.5.1. Relative twist of grid trays: < 1 arcminute

INS-2.5.2. Grid Imperfections: < 4.5 microns on finest grid, proportionally on coarser grids

INS-2.5.3. Grid Matching: < 1 part in 3E4

INS-2.5.4. Solar Aspect solution good to < 1.5 arcseconds

INS-2.5.5. SAS to Grid alignment, knowledge < 3 arcsecond, stability < 1 arcsecond

INS-2.5.6. Roll Phase solution good to < 3 arcminutes

INS-2.5.6.1. Spacecraft spin rate stable to 180 arcseconds in 10 spins

INS-2.6. Twist Monitoring System to monitor relative grid twist during integration and test (SCI-2.1)

INS-2.7. Other Aspect Sensor Requirements:

INS-2.7.1. Solar Aspect Field Of View >0.8 degrees (Allocated)

INS-3. Particle Detector (Goal): to measure particle flux that will increase the detector background (SCI-1.5.1) and lead to radiation damage of the GeDs

INS-3.1. Energy range 100keV – >30MeV

INS-3.2. Dual discriminator (electrons and protons)

INS-3.3. Count rate capability sufficient to not saturate in SAA

INS-3.4. Minimum counting dynamic range 100x

INS-4. Data Handling

INS-4.1. Photon list telemetry, each event containing measured energy, time tag sufficient for imaging (100 μs or better for finest spatial resolution grids), detector identification, live time information, and coincidence information. (SCI-2.1, SCI-1.2, SCI-1.6)

INS-4.2. When event rate is too high to do high energy resolution, extend count rate dynamic range by counting events for each detector in broad energy channels with counter readout rate sufficient for imaging (SCI-1.4)

INS-4.3. Telemetry storage on board for at least 5E8 photon events (SCI-4.1)

INS-4.4. Telemetry downlink sufficient to transfer at least 5E8 photon events in 2 days. (SCI-4.1)

INS-4.5. Photon decimation scheme to limit data rate if memory approaches full. (SCI-4.1)

INS-4.6. Take data during quiet time as well as flare times (SCI-1.5.2, SCI-5.1, SCI-5.3)

INS-4.7. Relative Timing: relative timing of photon events and aspect sensor data must be known to 60 μs (SCI-2)

INS-4.8. Absolute timing: To correlate with ground observations (SCI-6), need to be able to reconstruct absolute time of event data on the ground to better than 5 ms (Goal).

INS-5. Calibration (SCI-1.1, SCI-1.2, SCI-1.6)

INS-5.1. Laboratory measurements of detector efficiency with calibrated sources at the detector and spacecraft level

INS-5.2. Computer simulations of X-ray and gamma-ray response to extend and interpolate between laboratory measurements.

INS-5.3. In-flight sensitivity calibration using a low-level radiation source

INS-5.4. In-flight alignment using Crab data (verification of pre-launch alignment); imposes requirement to be sure collect crab data (backup ground station plan) (SCI-2.1)

3.3. *Spacecraft Bus Requirements*

BUS-1. Spacecraft Bus

BUS-1.1. Total bus mass shall not exceed 158 kg (SYS-4.1)

BUS-1.2. Bus Design Life: 3 years (SCI-3.2)

BUS-1.3. Commandability: The s/c shall be capable of receiving ground commands at all times

BUS-1.4. All autonomous functions shall be capable of being initiated and disabled by ground command

BUS-2. Attitude Control

BUS-2.1. The spacecraft shall be spin stabilized. (INS-2.2)

BUS-2.2. The nominal spacecraft spin rate shall be 15 RPM. (INS-2.2)

BUS-2.3. Pointing Control: The spin axis shall be within 0.2° of the sun center (INS-2.3)

BUS-2.4. Spacecraft spin rate stable to 180 arcseconds in 10 spins (INS-2.5.6.1)

BUS-2.5. ACS will accommodate use of RAS/SAS data for attitude determination

BUS-3. Telecommunications

BUS-3.1. Antenna Coverage shall be 4π steradian (BUS-1.5)

BUS-3.2. S-band uplink and downlink (SYS-1.2)

BUS-3.3. Downlink Data Rates

BUS-3.3.1. High Data Rate Downlink: 4.0 Mbps (SYS-1.3)

BUS-3.3.2. Low Data Rate Downlink: 32 kbps (BUS-1.5)

BUS-3.4. Uplink Data Rate: 2000 bps (SYS-1.4)

BUS-4. Electrical Power

BUS-4.1. Bus Voltage shall be 28 +6/-4 volts D.C.

BUS-4.2. Single Point Ground

BUS-4.3. Bus shall provide up to 162 Watts orbital average power to the instrument (SYS-6.1, SYS-6.2)

BUS-4.4. Bus shall accommodate full power operation during eclipse without exceeding a battery depth of discharge of 50% (SYS-6.3)

BUS-4.5. Spacecraft battery sufficient to power bus through worst case orbit insertion scenario until the bus achieves positive power balance (SYS-6.4)

BUS-4.6. Instrument Power Interface

BUS-4.6.1. Current limiting on all instrument power services (150% of expected current)

BUS-4.6.2. Current monitoring of all instrument power services telemetered in state of health (SOH) telemetry

BUS-4.6.3. Cryocooler power will be drawn from the bus as a 60Hz rectified sinusoidal current waveform

BUS-5. Command and Data Handling

BUS-5.1. Data storage: 2.0 Gbytes of science data storage (INS-4.4)

BUS-5.2. Microsecond Clock: 2^{20}Hz Clock for performing timing accurate to within +/-1ms over any 15 hour period (INS-4.7, INS-4.8)

BUS-5.3. Telemetry Requirements

BUS-5.3.1. Provide real-time state of health telemetry at all times when in contact with ground

BUS-5.3.2. Limited real-time science data to be provided during ground contacts

BUS-5.3.3. All telemetry to be time-tagged with transmission time accurate to within +/- 1ms

BUS-5.3.4. Reed-Solomon encoding of all downlinked data

BUS-6. Structure and Mechanisms

BUS-6.1. Instrument mass capability of up to 160kg (SYS-4.2)

BUS-6.2. Capability to align spacecraft spin axis with instrument boresight in orbit (INS-2.3)

BUS-6.3. Moment of inertia ratio: spin axis to transverse axis moment of inertia ratio must be at least 1.10 (for spin stability) (INS-2.2)

BUS-6.4. Design factor of safety: 2.0

BUS-6.5. Instrument radiator of 4450 cm^2 to be provided, anti-sun facing orientation

BUS-6.6. Instrument fields of view to be provided per ICDs

BUS-6.6.1. Imager FOV: 2π steradian

BUS-6.6.2. Spectrometer FOV: 2π steradian

BUS-6.6.3. RAS FOV: ±6° Azimuth, ±15° Elevation

BUS-6.7. Instrument Alignments

BUS-6.7.1. Imager aligned concentric to spacecraft Z-axis to 1mm, aligned with Z-axis to ±1mm

BUS-6.7.2. Spectrometer concentric with imager to 1mm, cryocooler free piston aligned with spacecraft Y-axis to ±1°

BUS-6.7.3. RAS alignment

BUS-6.7.3.1. RAS boresight direction 15° up from X-Y plane

BUS-6.7.3.2. RAS pointing stable to <1.0 arc-minute (INS-2.5.6)

BUS-7. Flight Software

BUS-7.1. Stored command capability of at least 1000 64-bit commands

BUS-7.2. Capabilitly to upload or modify spacecraft operational code

3.4. *Ground Segment Requirements*

GND-1. Antenna at Berkeley (SYS-1)

GND-1.1. Communications Compatibility with Spacecraft (SYS-1)

GND-1.2. Autonomous Operations, controlled by MOC (SYS-1, SYS-2)

GND-1.3. Antenna Pointing (SYS-3)

GND-1.3.1. Track spacecraft: auto (Goal) and programmed (Required) track

GND-1.3.2. Support Zenith passes

GND-1.3.3. Operate at wind speeds up to 40MPH, Survive up to 120MPH

GND-1.3.4. Pointing accuracy <0.1 degree goal, <0.2 degree required (SYS-1.3.1)

GND-1.4. Antenna located where it has an unobstructed view to 5 degrees above the horizon for >90% of HESSI pass time (INS-4.4)

GND-1.5. Time-tag Transfer Frame receive time to 1ms accuracy (INS-4.8)

GND-1.6. Data Handling: Real time & stored telemetry and command capability between ground station and MOC.

GND-2. Backup Antenna Compatibility (Risk Mitigation)

GND-2.1. Availability:

GND-2.1.1. Backup antenna required for Launch and Early Orbit backup in case of trouble with Berkeley Antenna, and possibly to help with tracking. Support should be negotiated in advance for the first day's passes so there is no delay.

GND-2.1.2. Backup antennas may be required later in the mission in case of Berkeley antenna trouble or if it is desired to increase the downlink capability during a large series of flares. These backups will be negotiated as needed, and should take < 24 hours to set up. (INS-4.4)

GND-2.2. Compatible with the HESSI spacecraft (SYS-1). A lower telemetry rate can be used, allowing use of an antenna with lower G/T figure.

GND-2.3. Compatible with MOC; MOC must be able to command spacecraft and receive state of health telemetry in near real time. Science telemetry may be delayed.

GND-3. Mission Operations Center (MOC) at Berkeley (SYS-2)

GND-3.1. Compatible with Berkeley and Backup Antennas (GND-1, -2)

GND-3.2. Real-time monitor and control of spacecraft

GND-3.2.1. Autonomous operations capability with automatic operator dial-up in case of alarm

GND-3.3. Mission Planning (Autonomous)

GND-3.3.1. Fetch NORAD orbit predicts & generate spacecraft ephemeris to control Antenna pointing and contact schedule

GND-3.3.2. Generate spacecraft command sequences

GND-3.4. Data trending and Analysis

GND-3.5. Maintain Telemetry and Command Database

GND-3.6. Pass stored (not real-time) telemetry to SOC

GND-4. Science Operation Center (SOC) at Berkeley (SYS-2)

GND-4.1. Instrument state of health monitoring

GND-4.2. Level Zero Processing (LZP) of telemetry

GND-4.3. Quick-look & catalog data products generation

GND-4.4. Distribute Level Zero & Derived data to SDAC and ETH

GND-4.5. Generate Instrument commands and pass to MOC for inclusion in Command loads