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A NASA Mission to Touch the Sun

Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

ISIS PI Introduction

Dave McComas

ISIS PI (SwRI)

Outline

- ISIS PI introductory remarks

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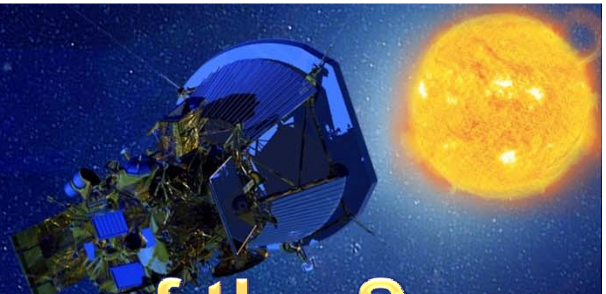

Integrated Science Investigation of the Sun (ISIS) – Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

Agenda and Meeting Logistics

Scott Weidner

ISIS PM (SwRI)

Outline

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- Meeting and Facility Logistics
- Teleconference and WebEx
- Day 1 Agenda
- Day 2 Agenda
- Maps

- Everyone needs to refer to the Maps !!!
- Main SwRI Entrance completely closed for construction
- The maps provide instructions to the East Gate and directions to Building 263 where the PDR will be held

Meeting and Facility Logistics

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- Public Wireless Internet available in the Presentation Room
- If you need to have messages delivered:
  - Messages through Maureen Ahr
  - Tel: (210) 522-2741
  - Fax: (210) 520-9935
  - E-mail: mahr@swri.edu
- Restrooms – leaving Presentation Room, turn left and left and they are on the right side of the hallway
- Splinter Meeting rooms will be available
- Lunch will be catered on both days
  - Contribution jar provided for Government employees or those that require it
- There will be a Social Hour in the Lobby of Building 263 on Tuesday (11/5/2013)

Teleconference and WebEx Day 1

- Topic: SPP - ISIS - PDR - Day 1
  Date: Tuesday, November 5, 2013
  Time: 8:00 am, Central Standard Time (Chicago, GMT-06:00)
  Meeting Number: 576 374 250

  To join the online meeting (Now from mobile devices!)
  ----
  1. Go to
  https://swri15.webex.com/swri15/j.php?ED=244875262&UID=1460668832&PW=NYWMzMmJmNzlj&RT=MiM3
  2. If requested, enter your name and email address.
  3. If a password is required, enter the meeting password
  4. Click "Join".

- The meeting password will be sent in a follow-up email

Teleconference and WebEx Day 2

- Topic: SPP - ISIS - PDR - Day 2
  Date: Wednesday, November 6, 2013
  Time: 8:00 am, Central Standard Time (Chicago, GMT-06:00)
  Meeting Number: 578 656 800

  To join the online meeting (Now from mobile devices!)
  ----
  1. Go to
  https://swri15.webex.com/swri15/j.php?ED=244875272&UID=1460668837&PW=NYTFkMzM5Njlh&RT=MiM3
  2. If requested, enter your name and email address.
  3. If a password is required, enter the meeting password
  4. Click "Join".

- The meeting password will be sent in a follow-up email (same as Day 1)

Day 1: ISIS PDR Agenda

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Start Time	Topic	Presenter
8:00 am	01: ISIS PI Introduction	McComas
8:05 am	02: Agenda and Meeting Logistics	Weidner
8:10 am	03: Review Board Introduction	Hersman
8:20 am	04: ISIS Overview	Weidner
8:40 am	05: ISIS Science	McComas
9:00 am	06: Systems Engineering	Dickinson
9:40 am	Break	
9:50 am	07: EPI-Lo Sensor Design	McNutt
10:20 am	08: EPI-Lo Technology Development	Gurnee
10:40 am	09: EPI-Lo Mechanical	Cooper
11:10 am	10: EPI-Lo Electronics	Gurnee
11:50 am	11: EPI-Lo Software	Hayes
12:10 pm	Lunch	

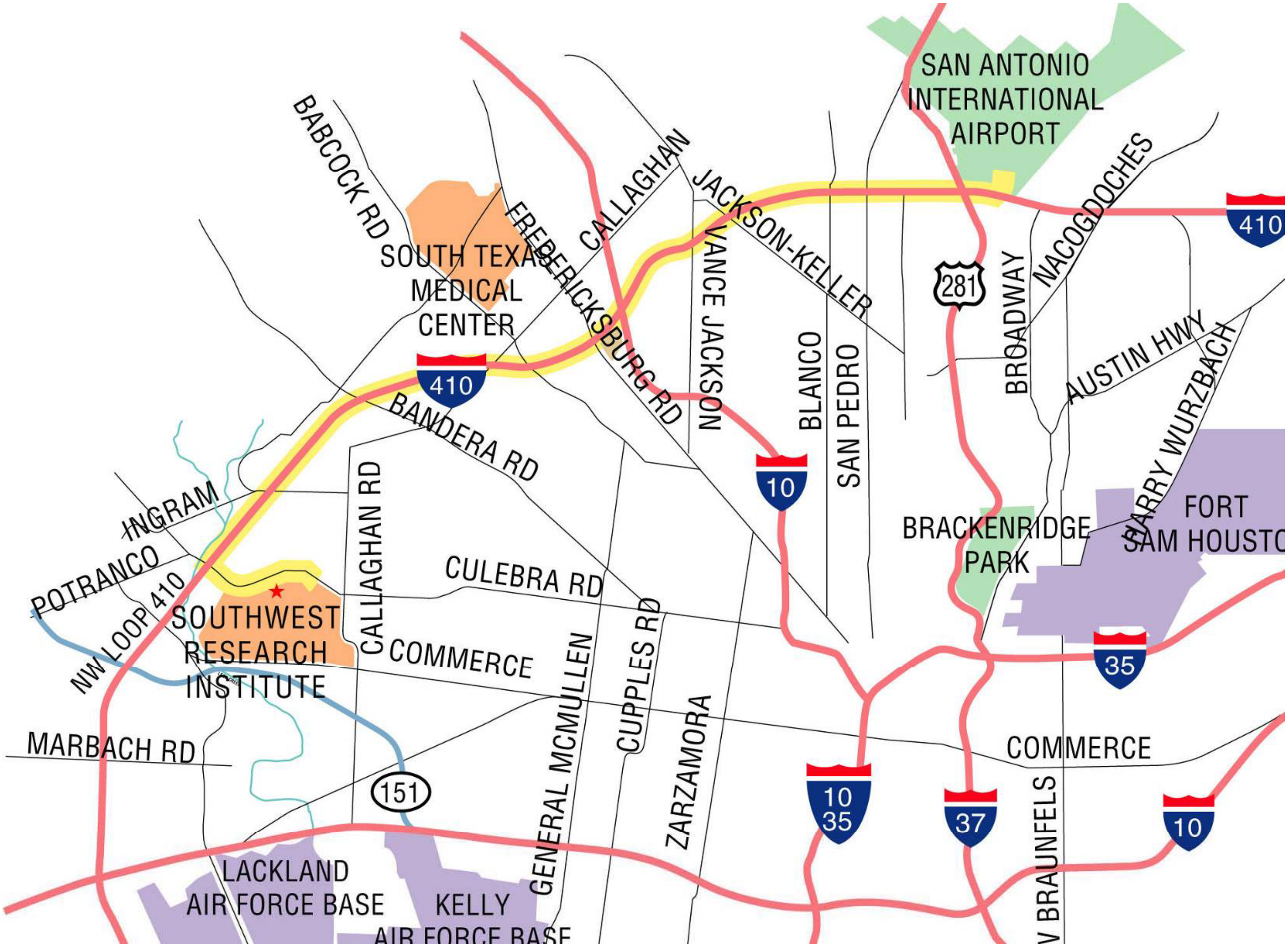
Day 1: ISIS PDR Agenda (Continued)

Start Time	Topic	Presenter
1:10 pm	12: EPI-Hi Sensor Design	Wiedenbeck
1:40 pm	13: EPI-Hi Technology Development	Wiedenbeck
2:00 pm	14: EPI-Hi Electronics	Cook/Kecman
2:40 pm	15: EPI-Hi Software	Davis
3:00 pm	Break	
3:10 pm	16: EPI-Hi Mechanical	Shuman
3:40 pm	17: ISIS Power	Do
4:10 pm	18: EMI/EMC	Gurnee
4:20 pm	19: ISIS Structural	Alexander
4:50 pm	Adjourn	
5:00 pm	Social Hour with Appetizers and Refreshments	

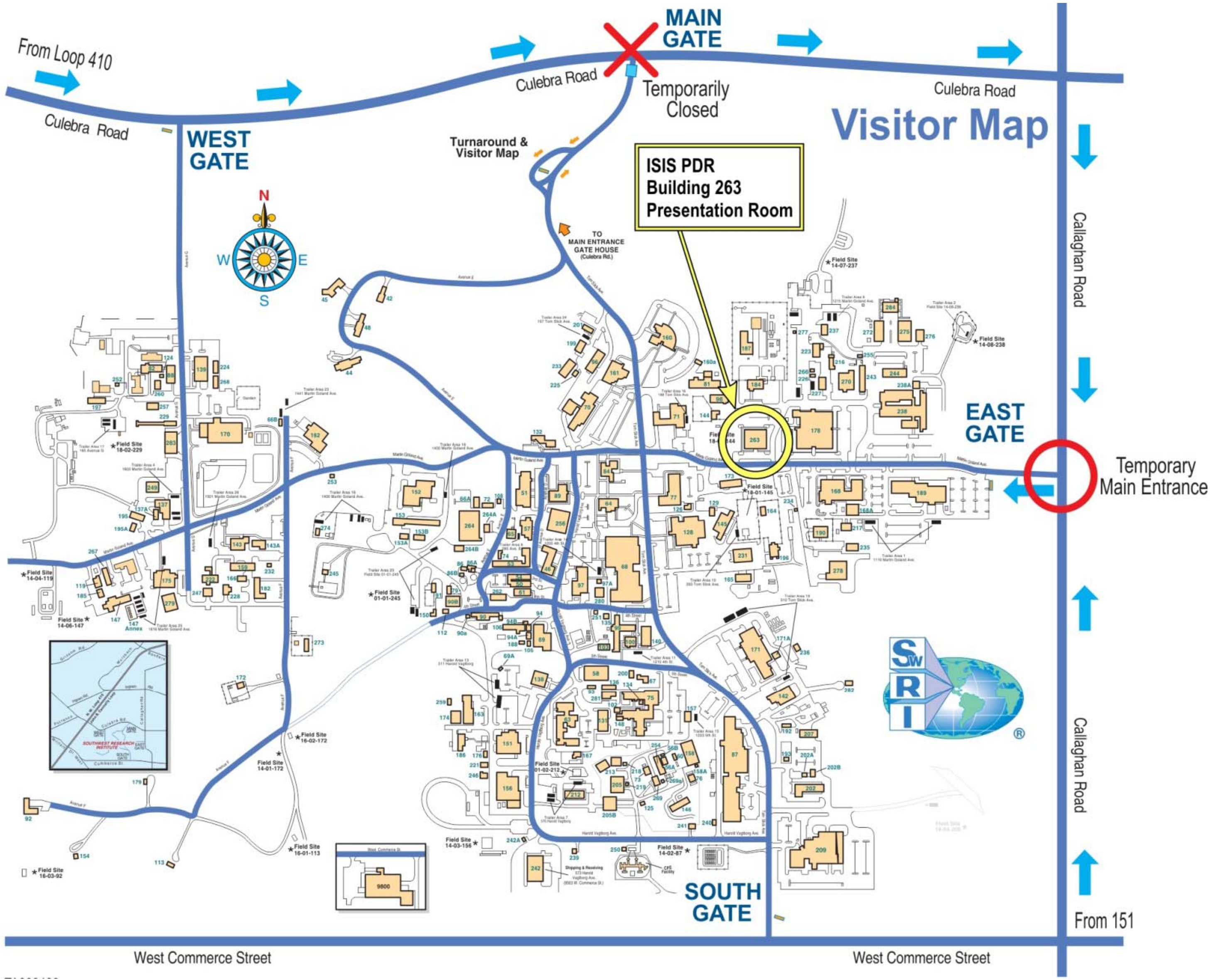
Day 2: ISIS PDR Agenda

Start Time	Topic	Presenter
8:00 am	20: ISIS Thermal	Dirks
8:40 am	21: Assembly, Integration, and Test	Dickinson
9:00 am	22: Flight Operations	Christian
9:20 am	23: Ground Support Equipment	Gurnee
9:40 am	Break	
9:50 am	24: Verification	Angold
10:10 am	25: EPI-Lo Calibration	Mitchell
10:25 am	26: EPI-Hi Calibration	Mewaldt
10:40 am	27: Performance Assurance	Gerhardus
11:00 am	28: Risk Status	Dickinson
11:20 am	29: Action Items	Angold
11:30 am	30: Instrument Development Status	Weidner
11:50 am	Lunch and Review Board Caucus	
1:00 pm	31: Review Board Debrief	Hersman
1:30 pm	Adjourn	

Map to SwRI


SAN ANTONIO INTERNATIONAL AIRPORT
BABCOCK RD
SOUTH TEXAS MEDICAL CENTER
FREDERICKSBURG RD
CALLAGHAN
JACKSON-KELLER
VANCE JACKSON
BLANCO
SAN PEDRO
281
BROADWAY
NACOGDOCHES
410
AUSTIN HWY
HARRY WURZBACH
BANDERA RD
10
BRACKENRIDGE PARK
FORT SAM HOUSTO
INGRAM
POTRANCO
NW LOOP 410
CALLAGHAN RD
CULEBRA RD
CUPPLES RD
SOUTHWEST RESEARCH INSTITUTE
COMMERCE
35
GENERAL MCMULLEN
ZARZAMORA
MARBACH RD
151
COMMERCE
10
35
37
N BRAUNFELS
LACKLAND AIR FORCE BASE
KELLY AIR FORCE BASE

Main Gate is CLOSED for Construction
Directions to PDR Location (Bldg 263)



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Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

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Review Board Introductions

Chris Hersman

Review Board Chairman

Outline

- Review Board Chair introductory remarks
- Introduction of review team

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ISIS Overview

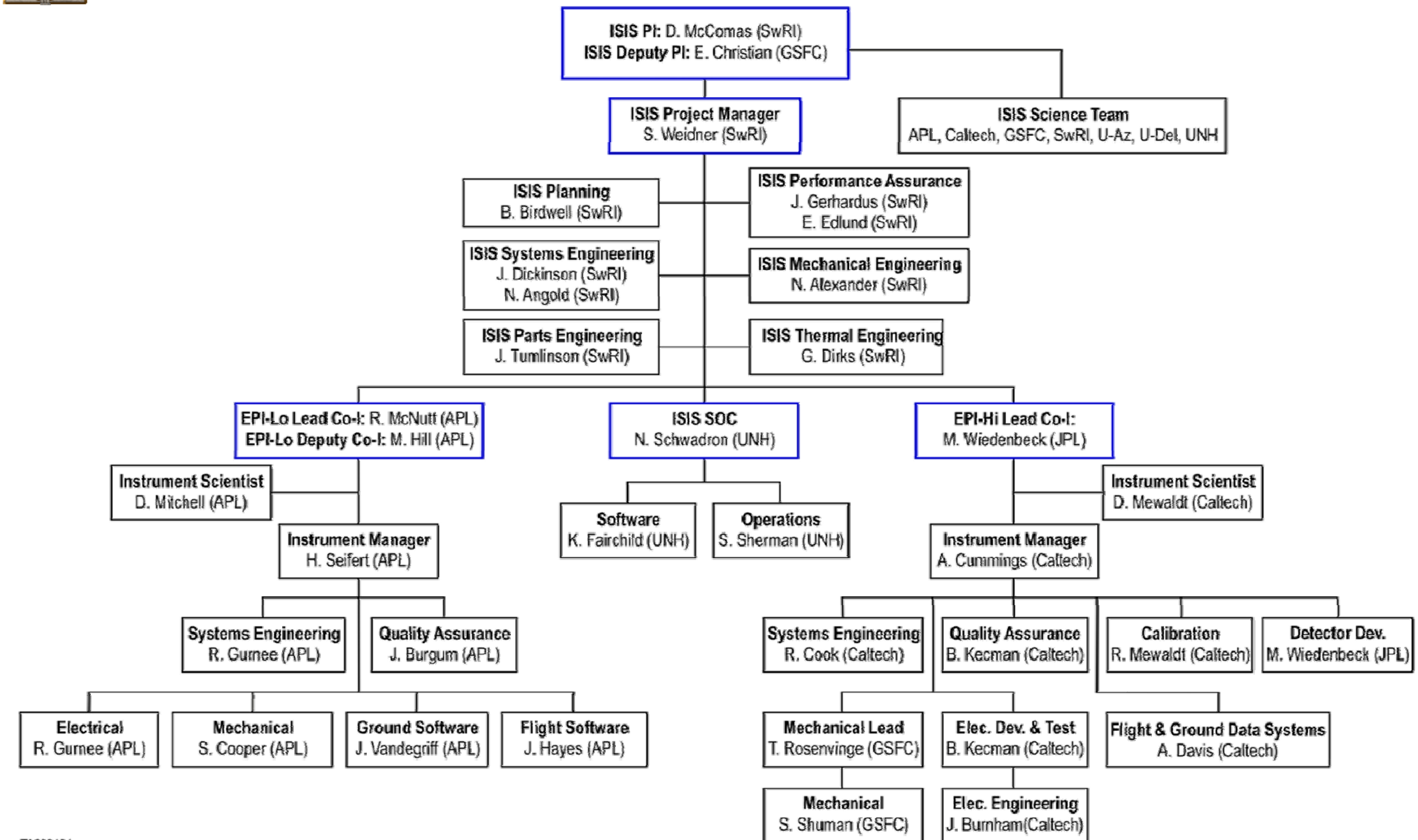
Scott Weidner

ISIS PM (SwRI)

Outline

- ISIS Organization Chart
- ISIS Suite
- Spacecraft Accommodation
- Changes since MDR
- Development Status
- Summary

ISIS Team



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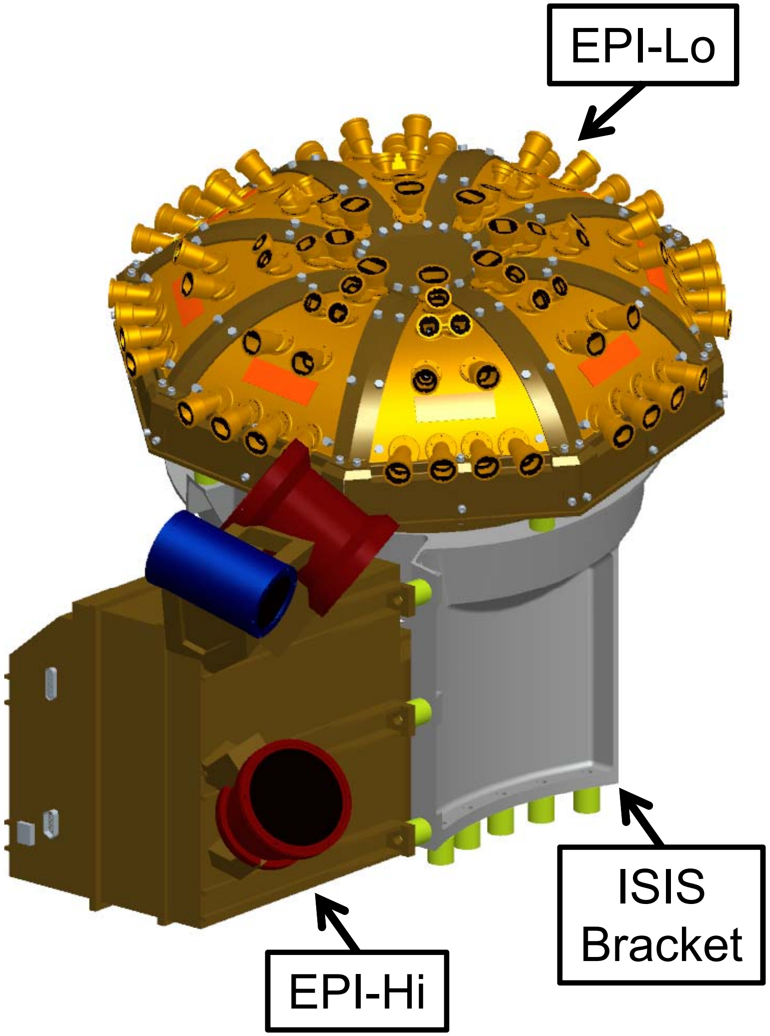
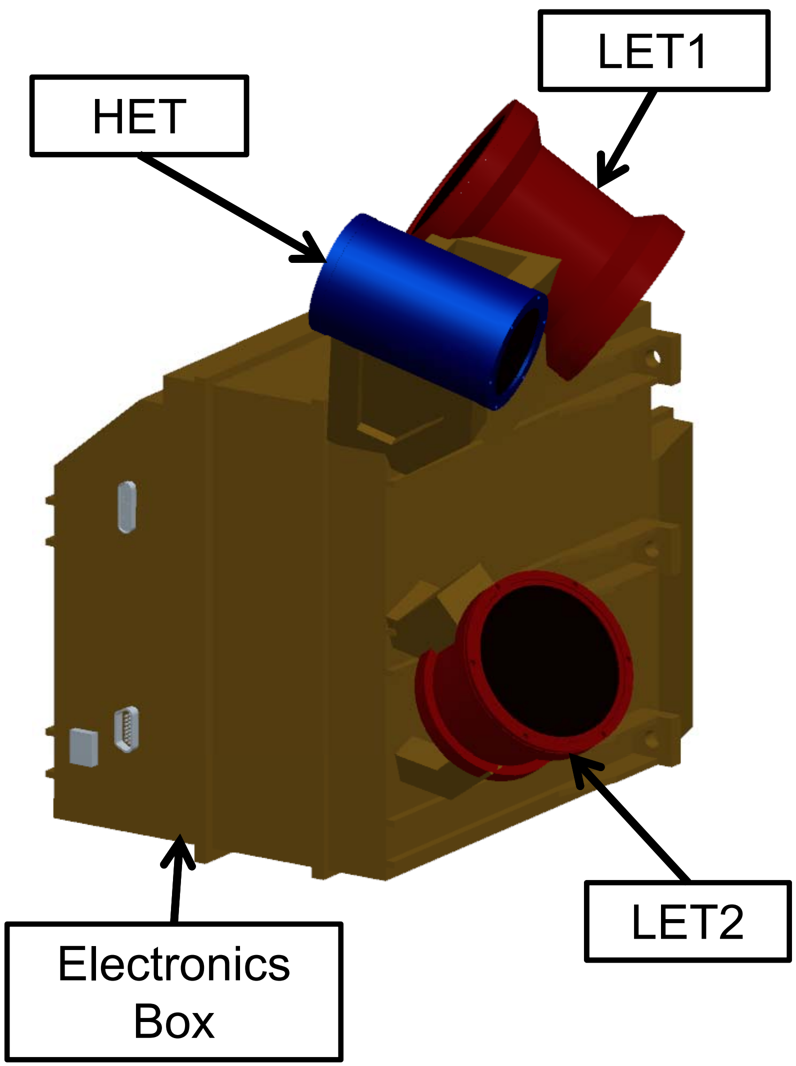
ISIS Suite



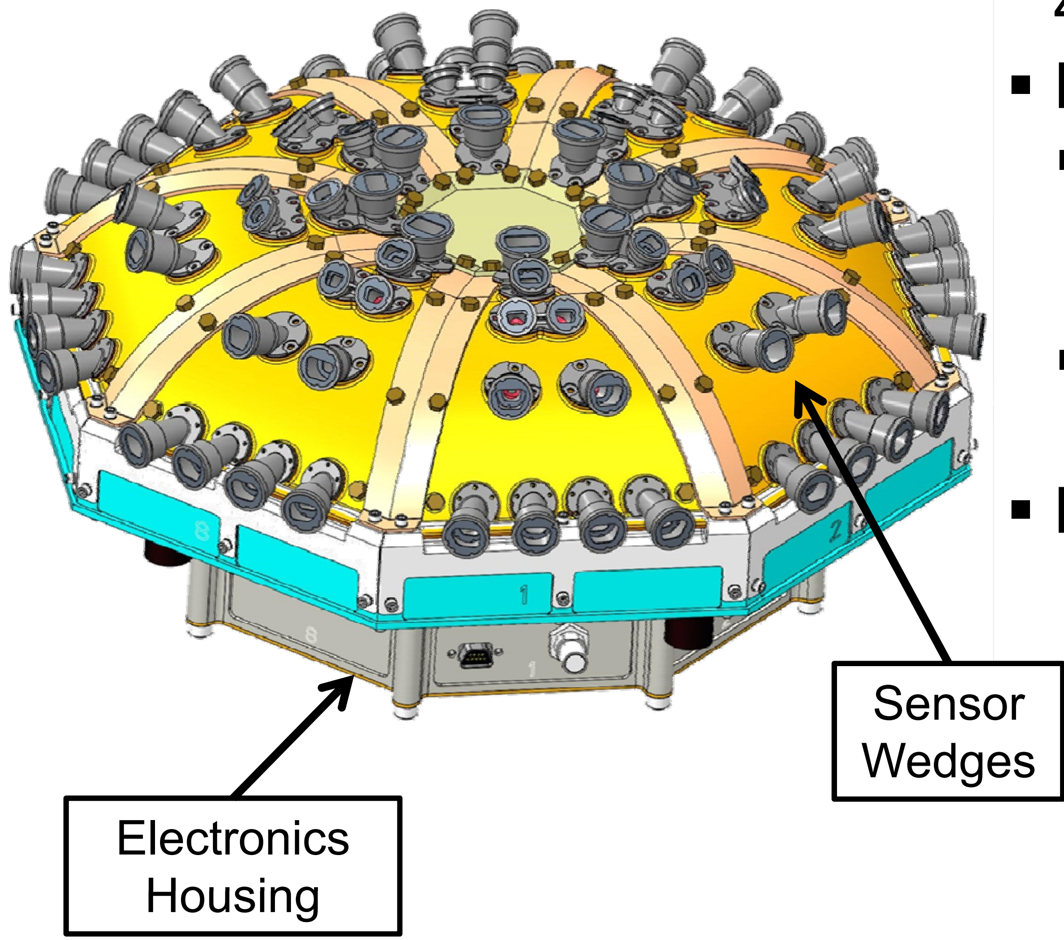
- ISIS Energetic Particle Suite
  - Measures energetic particles, including electrons, protons, and heavy ions
- Two instruments for wide energy coverage
  - EPI-Hi (Caltech, JPL, & GSFC)
  - EPI-Lo (JHU/APL)
- ISIS Allocations
  - Mass: 9.383 kg
  - Power: 11.768 W
  - Telemetry: 12 Gbit/orbit

ISIS EPI-Hi



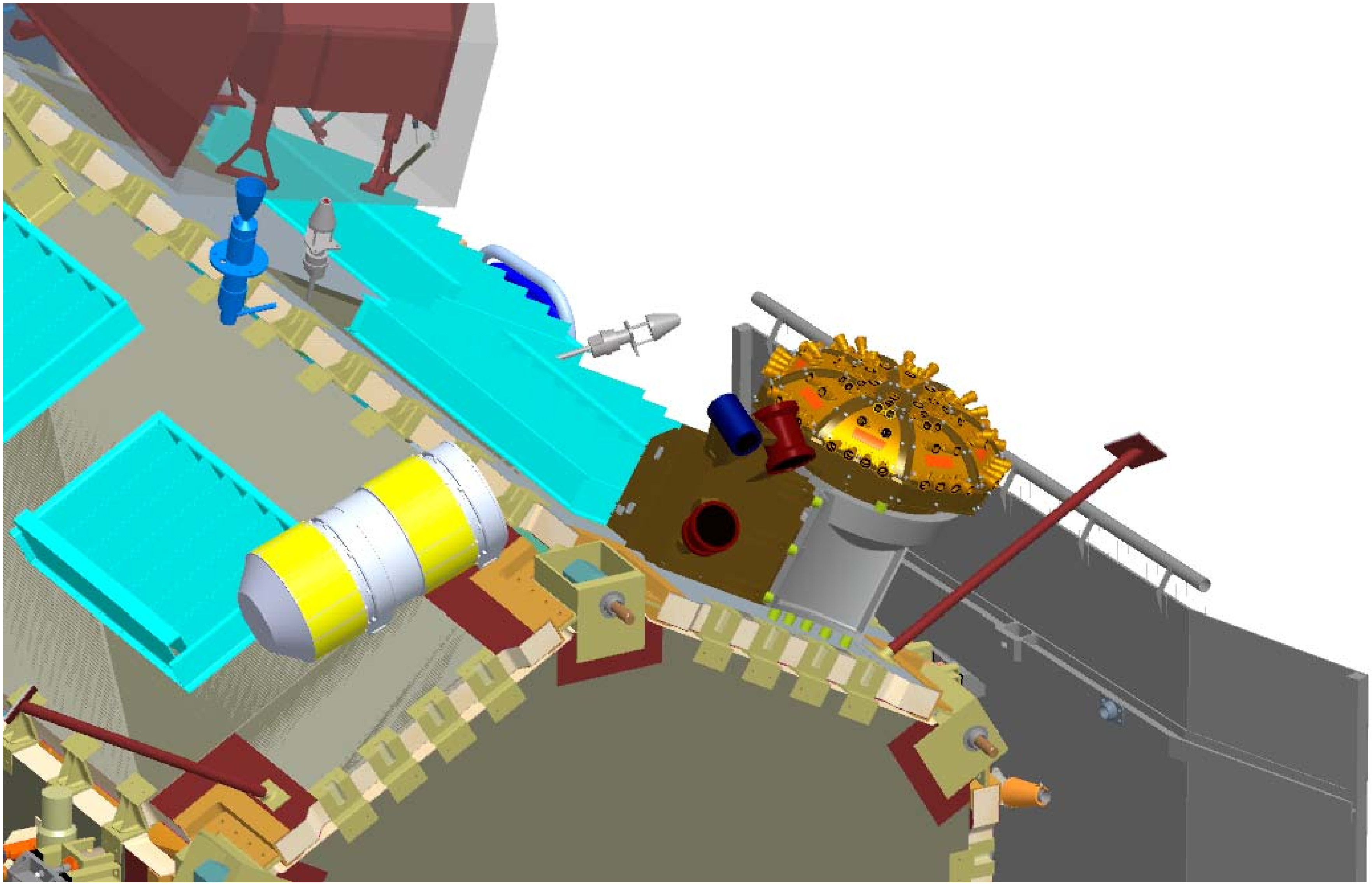
- Three Telescopes
  - HET – High energy
  - LET1 – Low energy
  - LET2 – Low energy, single-ended
- Energy Range
  - Ions:
    - 1 MeV/nucleon – 50 MeV/nucleon
  - Electrons:
    - 0.5 MeV – 3 MeV
- FOV: ≥π/2 sr in sunward and anti-sunward hemispheres (incl. 10° from S/C-Sun line)

ISIS EPI-Lo



- 8 Wedges configured in 4 independent quadrants
- Energy Range
  - Ions:
    - 50 keV/nucleon – 15,000 keV Total E
  - Electrons:
    - 50 – 500 keV
- Nearly 2-π FOV

Spacecraft Accommodation



Late-Breaking Trade with the S/C

- New Solar Limb sensor appeared in S/C model near ISIS
- Analysis of the effect on our FOV is on-going
- No “show stoppers” expected but analysis and accommodation needs to be completed
- Working the process-issues with the Spacecraft team

Changes Since MDR

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- No changes to Science
- EPI-Lo electronics box reduced in diameter and fits inside the ISIS bracket
- Updated design for EPI-Hi electronics box
- ISIS bracket modified to accommodate the Ebox changes
- Mass increased as part of risk-reduction process run by the SPP spacecraft when the nominal orbit was modified
- Power and telemetry have held steady with some reductions in uncertainty
- Two small additions
  - EPI-Hi added a background pixel
  - EPI-Lo added an anti-coincidence detector
  - Both of these use spare resources of existing electronics and provide large payoff for dynamic range

Development Status

- Successfully completed TRL6 Technology Developments
- Developed requirements flow-down with SPP Spacecraft
- ICDs with the Spacecraft are signed-off
- Preliminary analyses completed
- Prototypes of new circuits have been built and tested
- Completed preliminary designs
  - In most areas we are right on track
  - In some areas we are beyond a PDR-level and EM fabrication is underway
- Five different ASICs within ISIS
  - All have completed EM build or FM build
- We've brought in coast-to-coast teams to help Peer Review details of each subsystem

Summary

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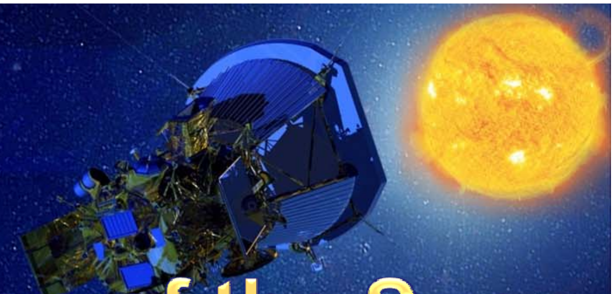
- In Phase B, the ISIS team has completed definition, preliminary design, and analysis work for the suite
- The presentations ahead will be taking you through all of the details
- We look forward to your feedback on our plans and preliminary designs



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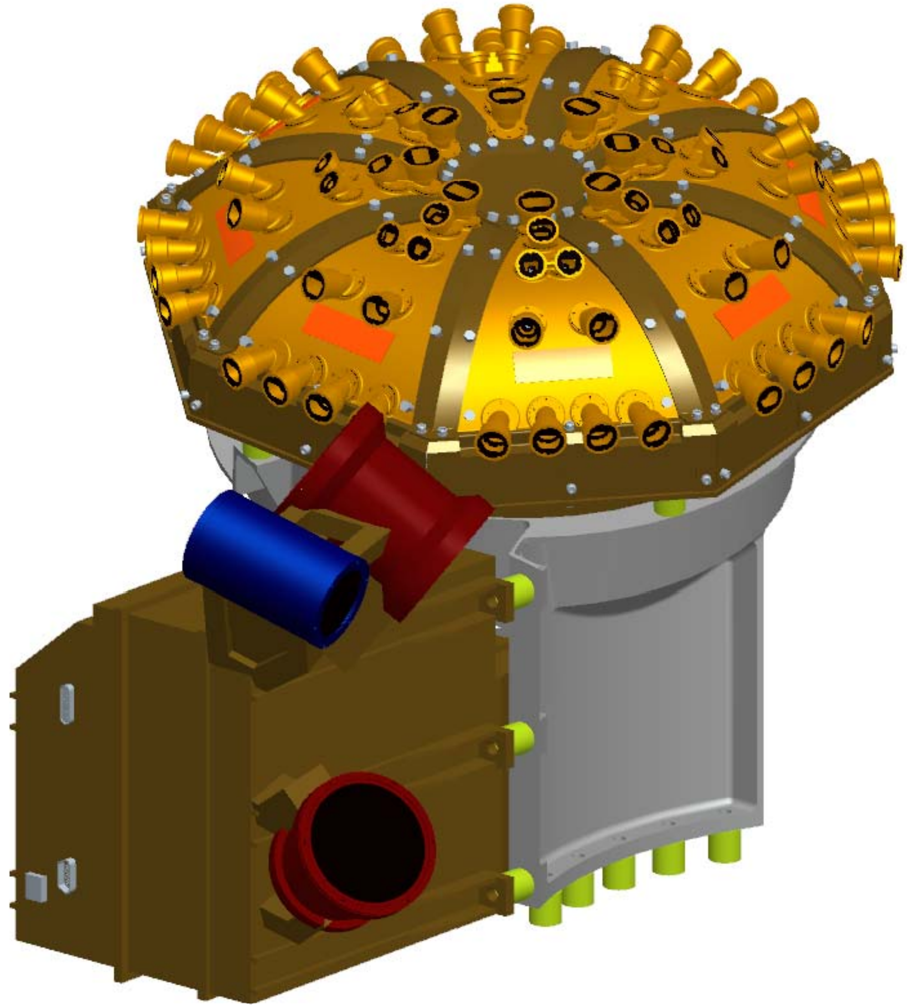
ISIS Science

Dave McComas

ISIS PI (SwRI)

Outline

- Science Team
- SEP Events
- Measurement Near the Sun
- Science Goals
  - Origins
  - Acceleration
  - Transport
- Measurement Summary
- Driving Requirements
- Primary Measurement Requirements
- Summary

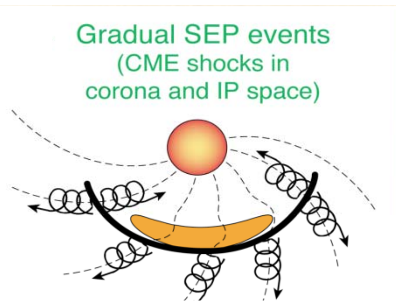


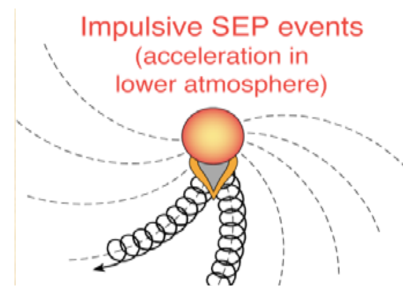
ISIS Science Team

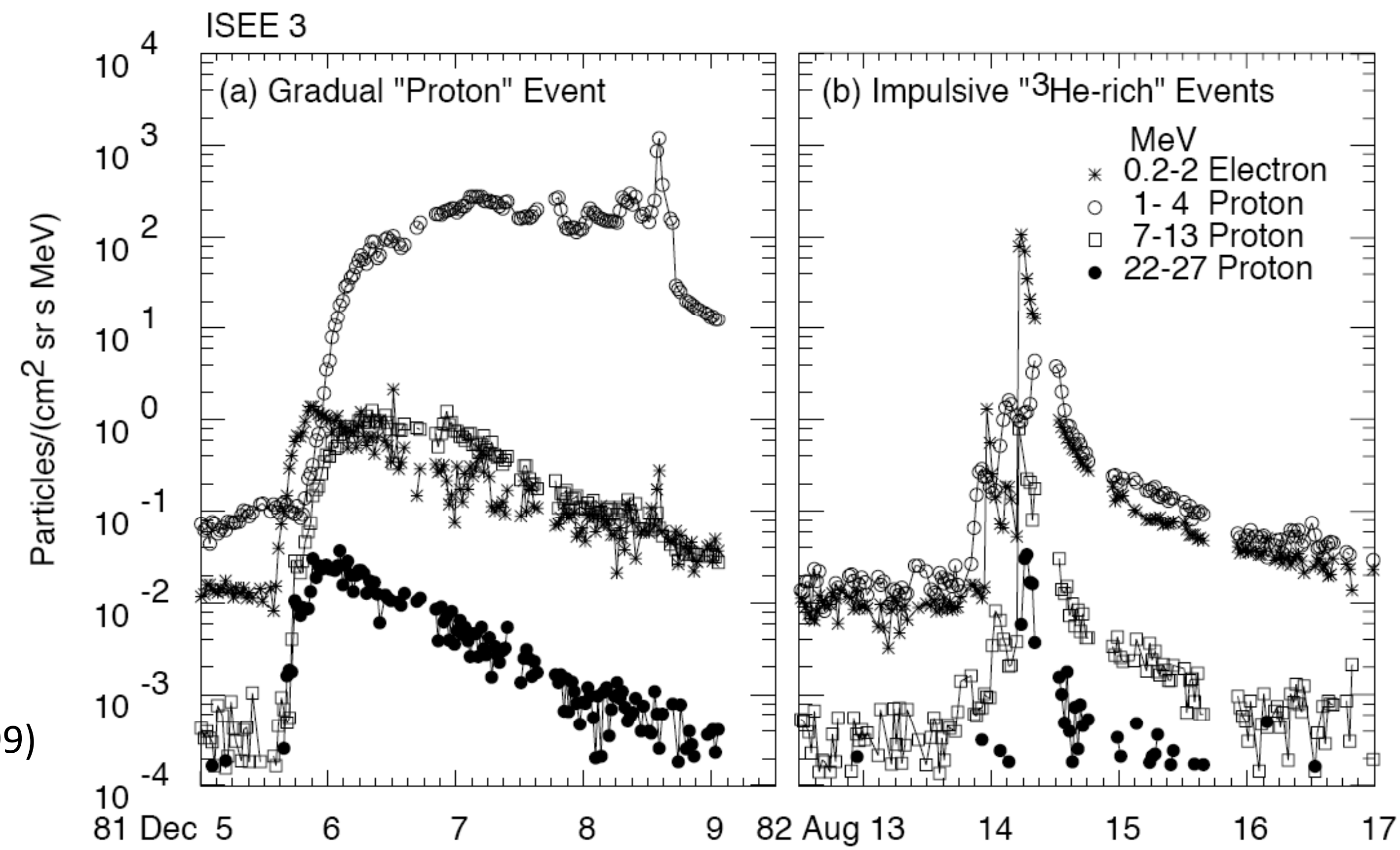
- PI: Dave McComas* (SwRI)
- Co-I: Eric Christian (GSFC), Deputy PI
- Co-I (Lo Lead): Ralph McNutt* (APL)
- Co-I (Hi Lead): Mark Wiedenbeck* (Caltech/JPL)
- Co-I (SOC Lead): Nathan Schwadron (UNH)
- Co-Is: Alan Cummings (Caltech), Mihir Desai (SwRI), Joe Giacalone (UArizona), Matt Hill (APL), Stefano Livi (SwRI), Bill Matthaeus (UDelaware), Dick Mewaldt (Caltech), Don Mitchell (APL), Tycho von Rosenvinge (GSFC)
- Senior Science Mentor (SSM) Team Members: Rob Gold (APL), Tom Krimigis (APL), Ed Roelof, (APL) and Ed Stone (Caltech)

*SPP Science Working Group (SWG) Members

SEP Events: Gradual vs. Impulsive



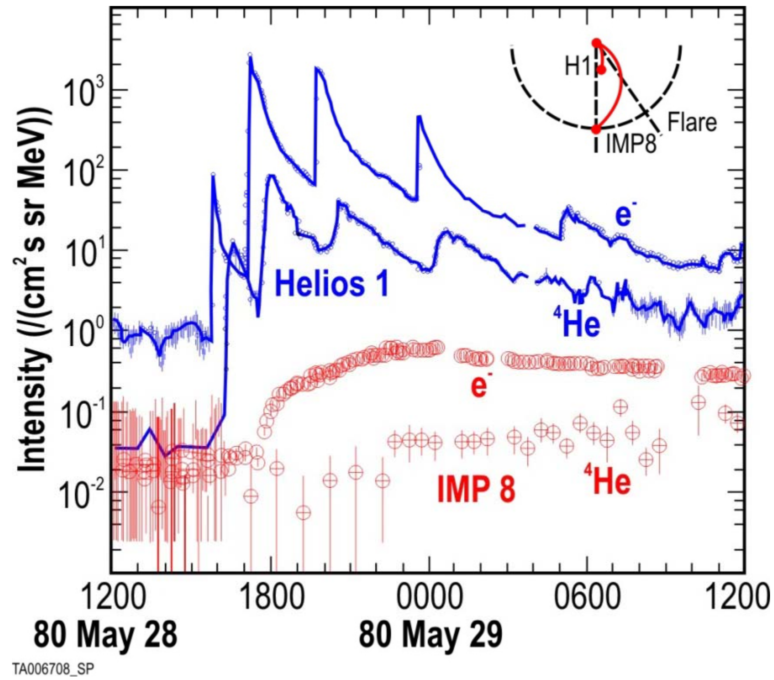




(Reames 1999)

Need to Measure Near the Sun

- Testing, discriminating, and refining SEP acceleration models is difficult at 1 AU due to distance from sources and mixing during transport
- Helios showed advantages of near-Sun observations of SEP processes near origin
- ISIS explores corona and inner heliosphere with state-of-the-art sensors; refines our understanding of acceleration, seed particles and transport; advances new models; and discovers new phenomena



Electron (e) and He (α) time profiles from Helios-1 (0.3 AU) and IMP-8 (1 AU) during five ISEP events in 1980 (from Wibberenz and Cane 2006). Magnetic connections to the flare site are indicated at upper right. Helios-1 observed five injections; IMP-8 only one. ISIS samples ~50-100 ISEP and ≳50 large SEP events inside 0.25 AU, where each event will be sharply peaked and 100-1000 times as intense, enabling detailed studies of (1) flare and CME-shock acceleration, (2) seed particle identities, and (3) the effects of particle transport in the interplanetary medium.

ISIS Science Goals

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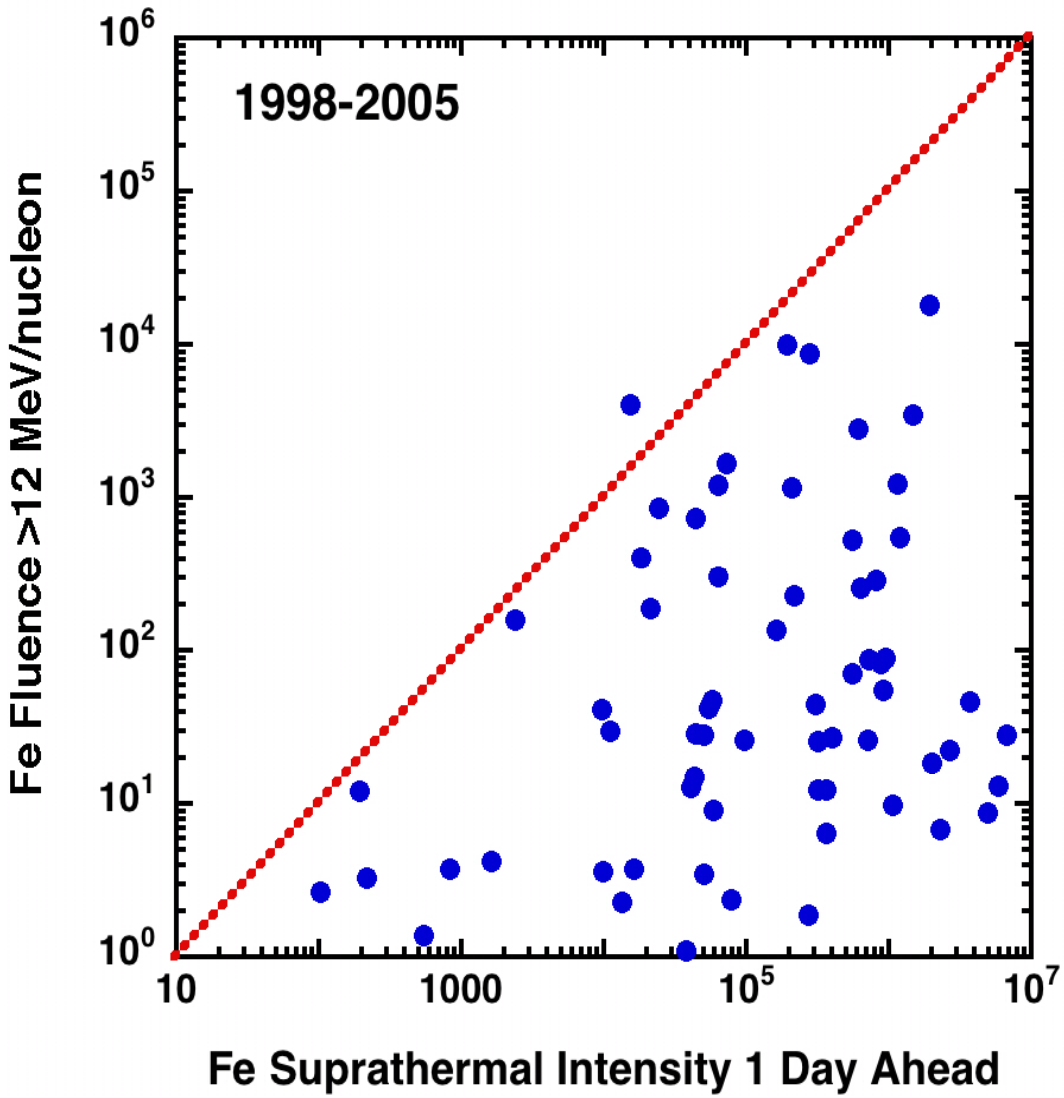
- Explore mechanisms that accelerate and transport energetic particles
  - Origin: Determine the seed populations and physical conditions necessary for energetic particle acceleration
  - Acceleration: Determine the roles of shocks, reconnection, waves, and turbulence in accelerating energetic particles
  - Transport: Determine how energetic particles propagate from the corona out into the heliosphere

Note: Includes coordinated analysis between ISIS and other SPP instruments of solar wind plasma, fields, and waves

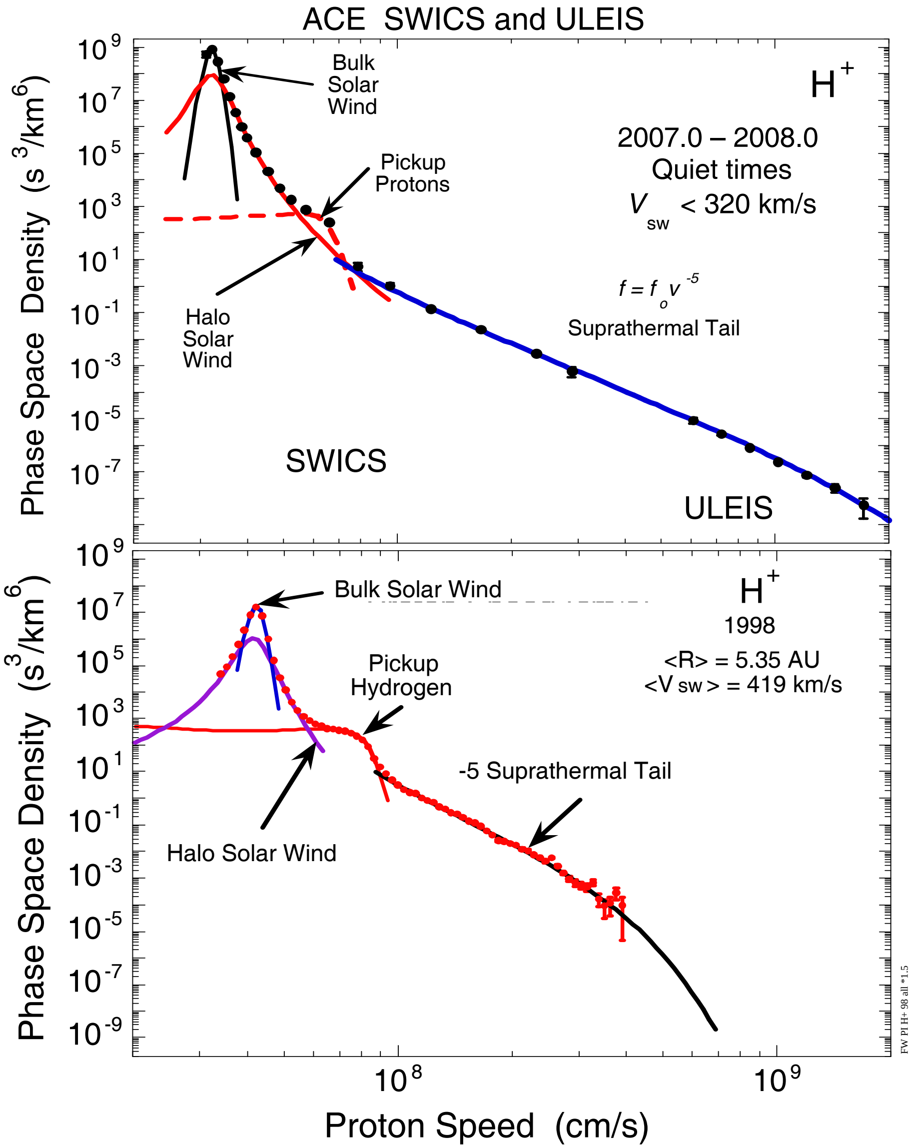
Origin: Suprathermal Seeds of SEPs



How does the suprathermal particle population through which a shock moves influence the resulting intensity of Energetic Particles that are accelerated?

(Mewaldt et al. 2006)

Origins:
SW Ion Suprathermal Tail Observations

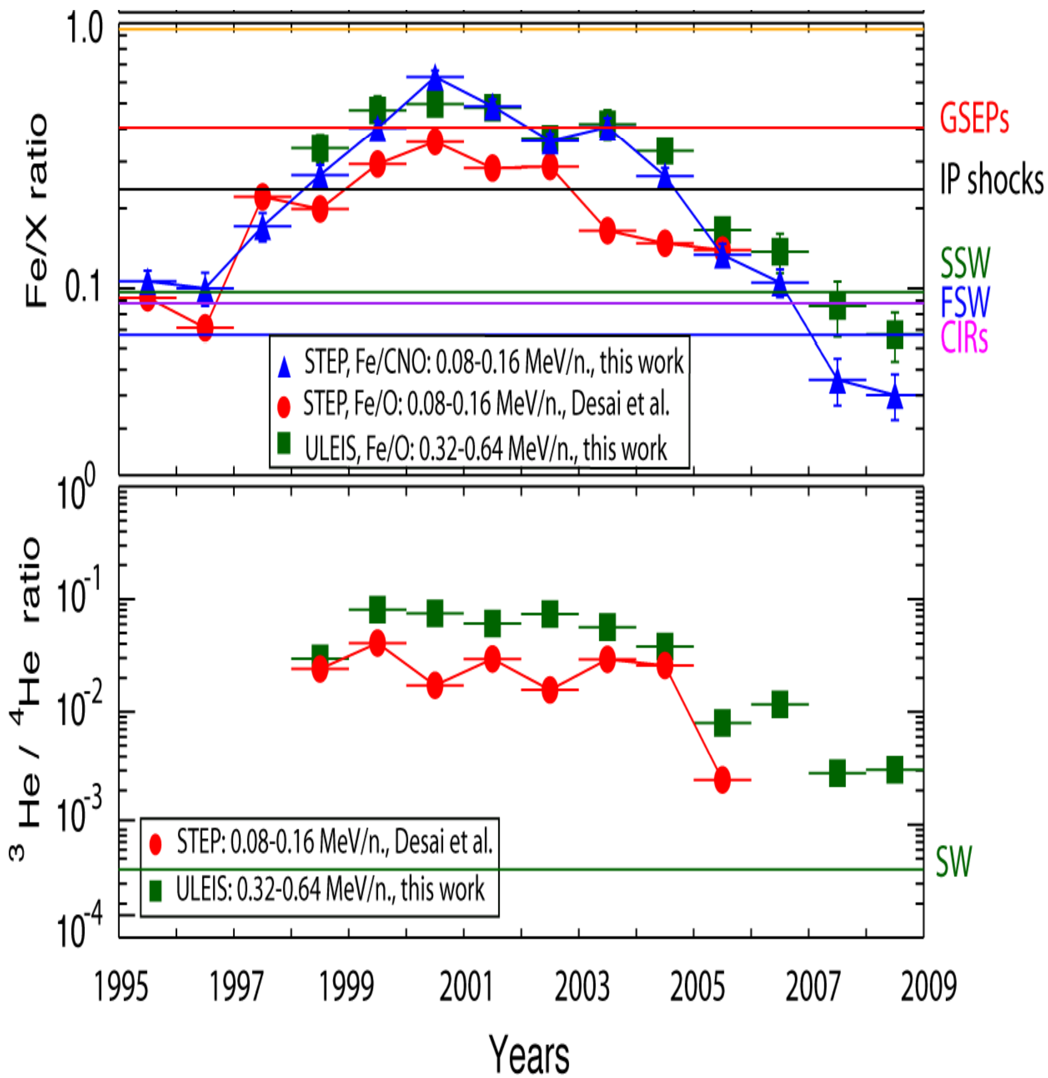


What mechanisms produce the widely observed suprathermal tails and how do they feed into SEP acceleration?

Are they produced in the corona by flares or are they produced in the heliosphere by stochastic acceleration?

(Fisk and Gloeckler 2007)

Origins: Temporal Variation of Composition



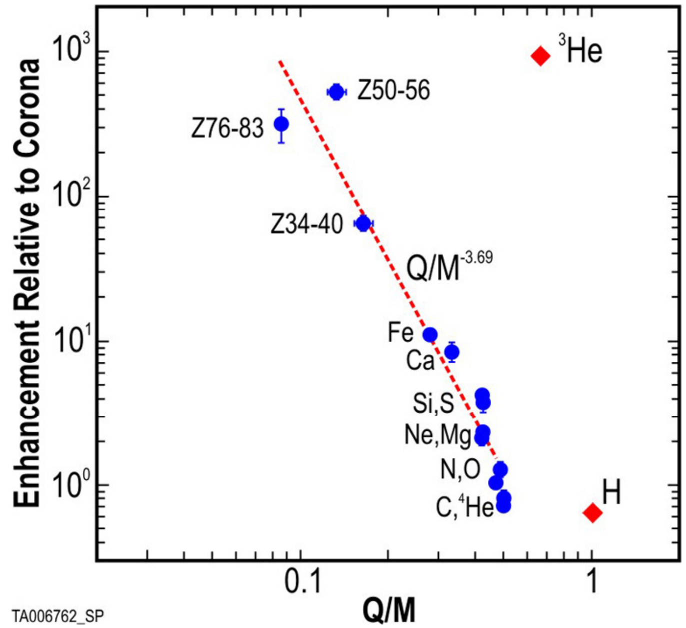
What causes the temporal variability in composition of the suprathermal tails?

Is the variation due to flare activity or changes in the physical conditions (turbulence, CMEs, compressions, prior shocks, etc.) in the inner heliosphere?

(Dayeh et al. 2009)

Acceleration: Impulsive Acceleration in Flares

- Explosive reconnection in X-class flares accelerates electrons to >10 MeV and ions to >100 MeV/nuc, but are not well understood
  - Fermi acceleration in collapsing magnetic islands
  - Possibly in conjunction with other mechanisms, e.g., stochastic acceleration by plasma waves, MHD turbulence, shocks, or direct electric field acceleration
- Impulsive SEPs at 1 AU reveal correlations between MeV ions and electrons and have large enrichments in 3He, heavy ions such as Fe and rare trans-Fe species (see Fig)
- Many large SEP events are "hybrids" with enrichments in 3He, heavy ions, and high-ionization states as well as shock-accelerated particles - Flare and shock contributions can only be separated near the Sun
- Acceleration of ever-present suprathermal tails in the solar wind is not well understood - understanding has broad implications for particle acceleration in nature



Multi-event average impulsive SEP abundance enhancements (relative to coronal composition) plotted vs Q/M for equilibrium charge states at 3 MK (from Reames & Ng 2004). A fit to all ions except H and 3He gives a slope of (Q/M)-3.69. Note that trans-Fe species are enriched by factors of ~50-500. ISIS measures the Q/M-fractionation in multiple ISEP events and provides constraints for reconnection-driven particle acceleration models.

Acceleration: Diffusive Shock Acceleration (DSA)

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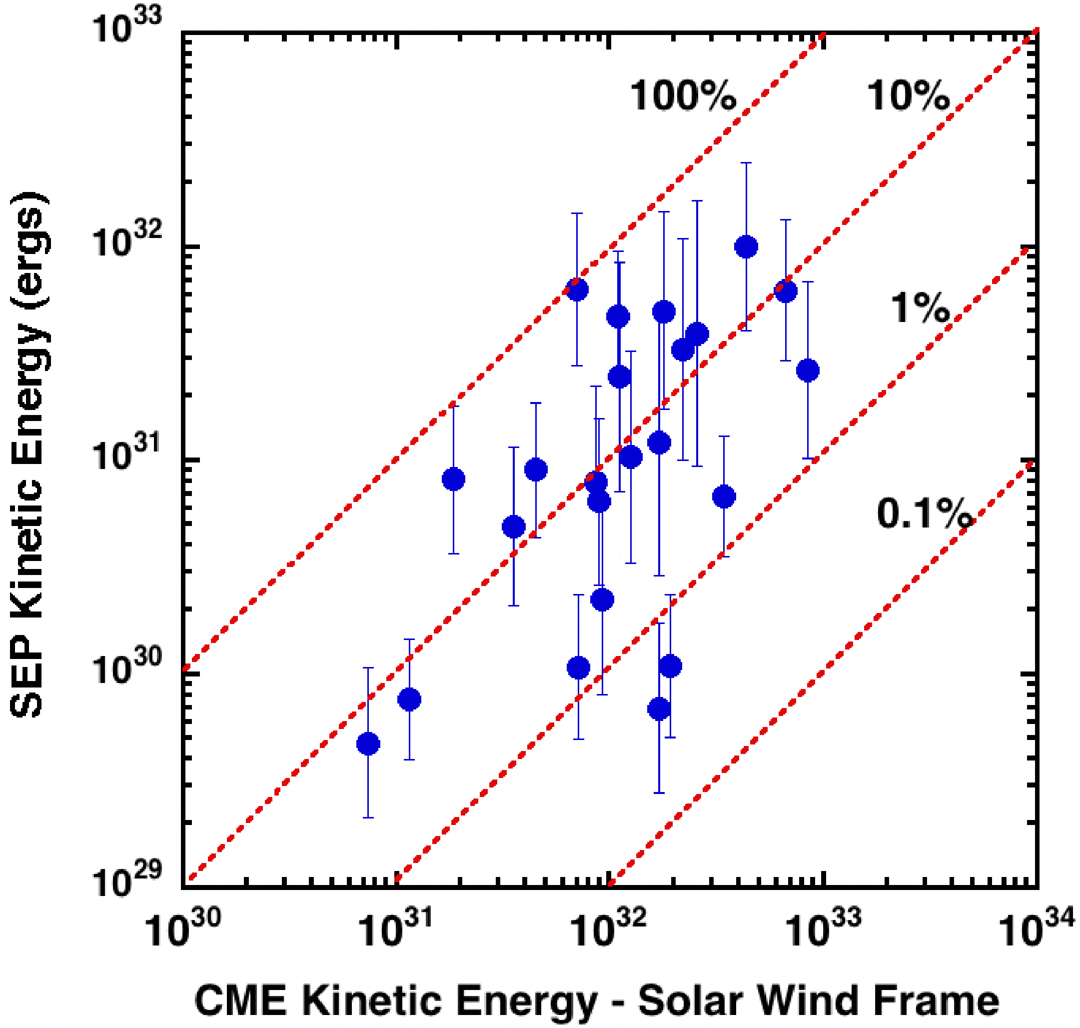
- Thought to be the primary acceleration mechanism at CME-driven shocks, however unresolved issues continue to hamper the development of theoretical models of large gradual SEP events:
  - existence and effects of proton-amplified Alfvén waves near quasi-parallel shocks
  - conditions that affect acceleration efficiencies of CME shocks
  - roles played by shock geometry on the injection thresholds
- DSA models invoke proton-amplified Alfvén waves to trap ions near quasi-parallel shocks to increase acceleration efficiency
- Near-Sun observational evidence of the roles of diffusion and wave amplification in SEP events
- CME shock acceleration efficiencies are highly variable, likely due to different shock geometries, differing coronal conditions, and other poorly understood effects (e.g., seed particles) – can not be studied at 1 AU

Acceleration: SEP Energy Sources - CMEs

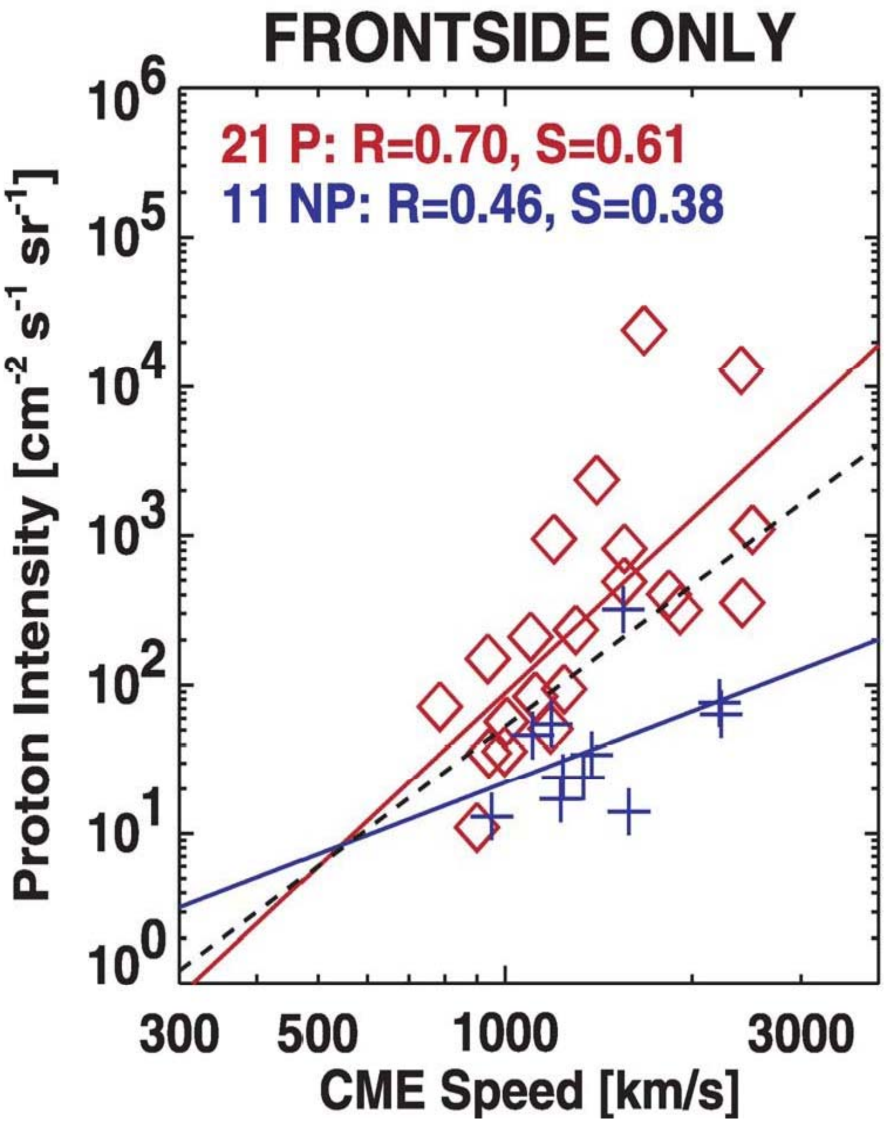


What fraction of the CME kinetic energy goes into accelerating energetic particles?

Is it controlled by turbulence levels, self excited waves, seed particles, shock properties, prior CMEs?

SEP-CME: Comparison of the kinetic energy of accelerated SEPs with the CME kinetic energy indicate that as much as ~10% of the CME energy goes into accelerated particles (Mewaldt et al. 2008).

Acceleration: CME-Driven Shock Efficiency

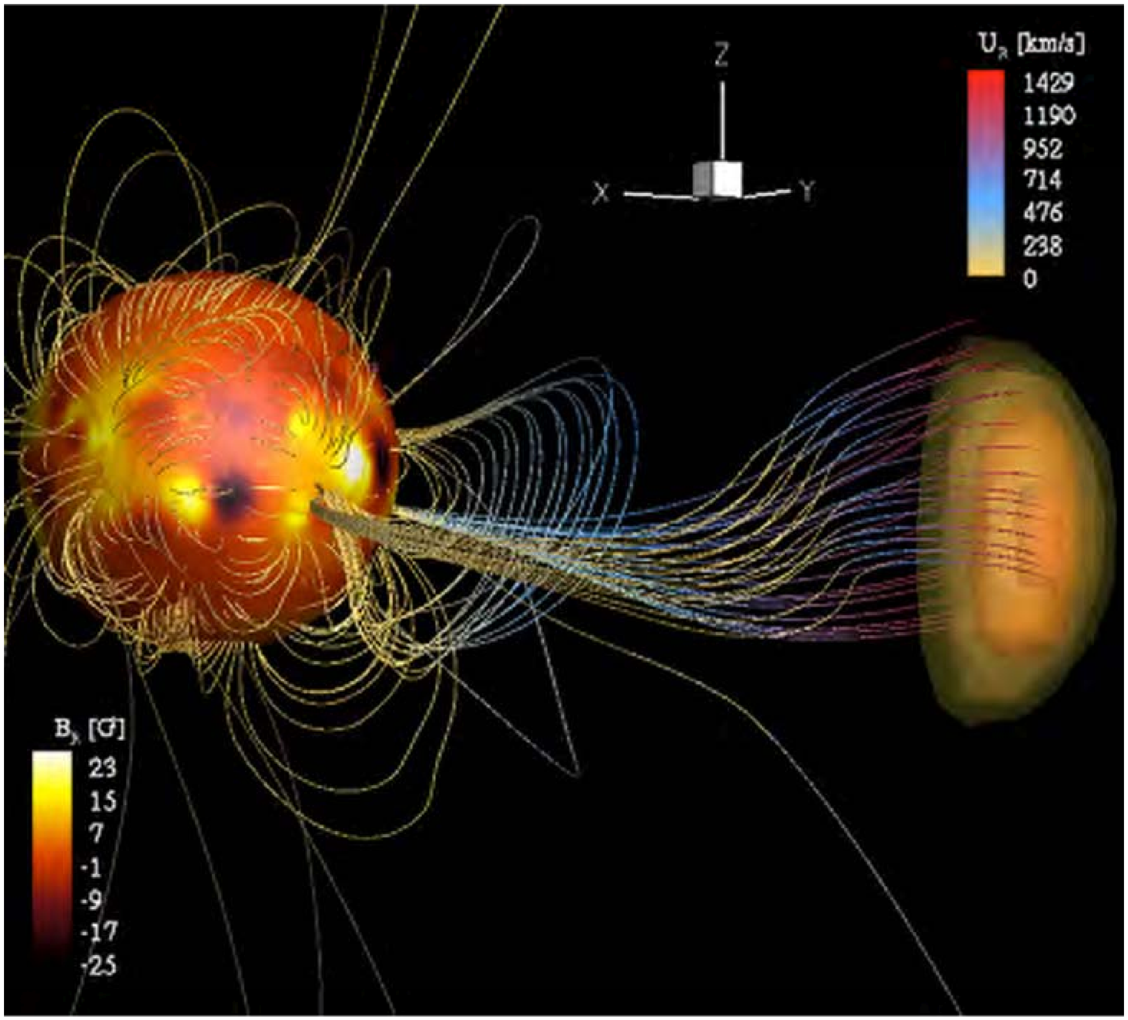


Why is the efficiency of CME-driven shock acceleration apparently greater when there has been a preceding CME?

Do prior CMEs modify the turbulence and other physical parameters or simply provide different seed particles?

(Gopalswamy et al. 2004)

Transport: How do SEPs Get to Earth?



How are SEP properties affected by transport through the heliosphere?

What are the roles of diffusion, adiabatic deceleration, magnetic structure, self excited waves, shock properties, etc.?

(Roussev et al. 2007)

Transport: Energy Spectral Breaks

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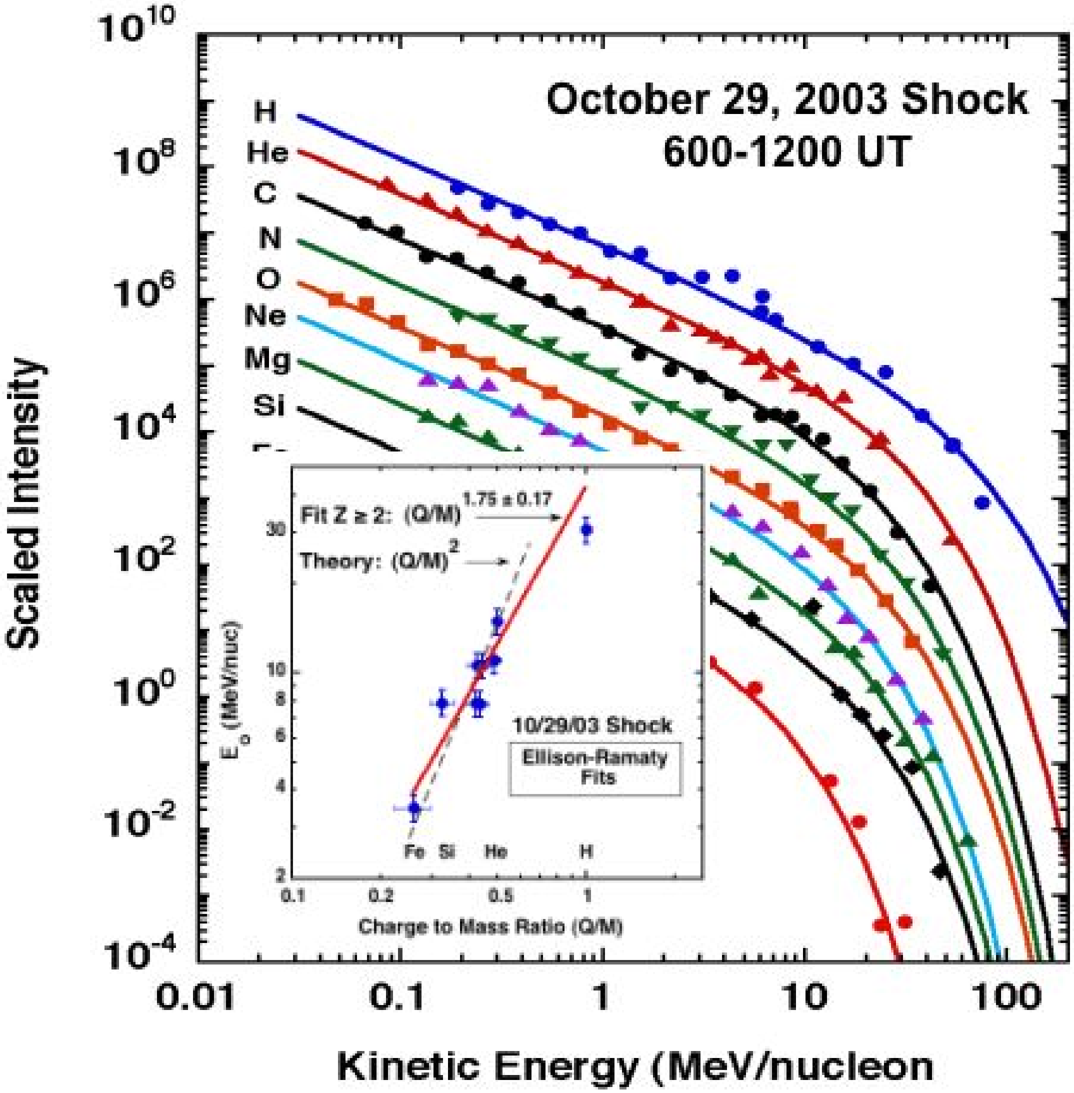


Why does shock acceleration suddenly become less efficient at high energy?

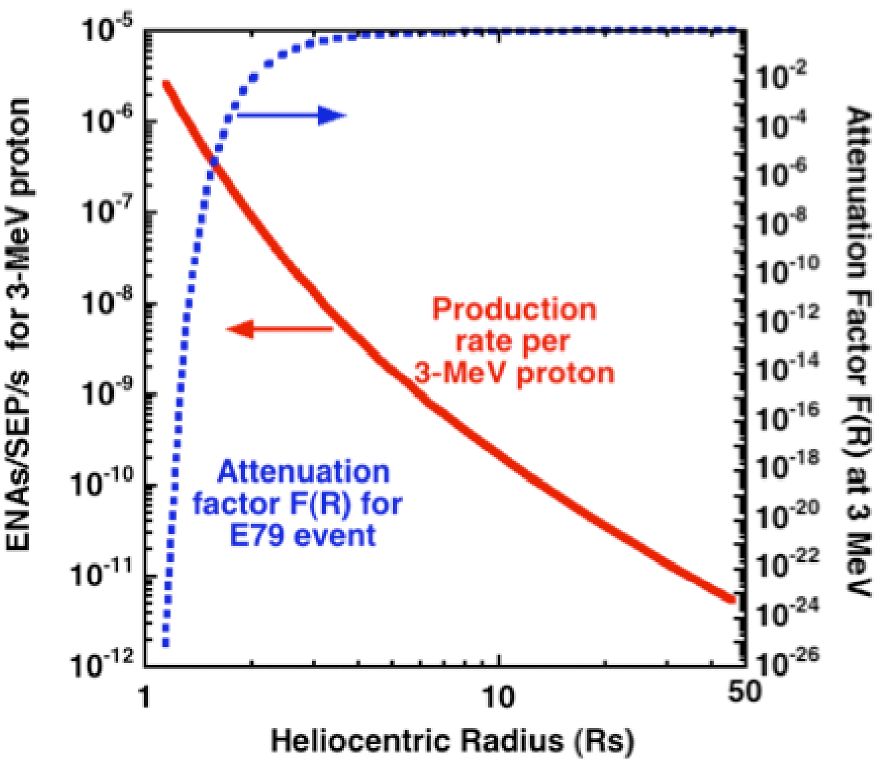
Is it because of M/q dependant escape or shock shape, or lack of waves…?

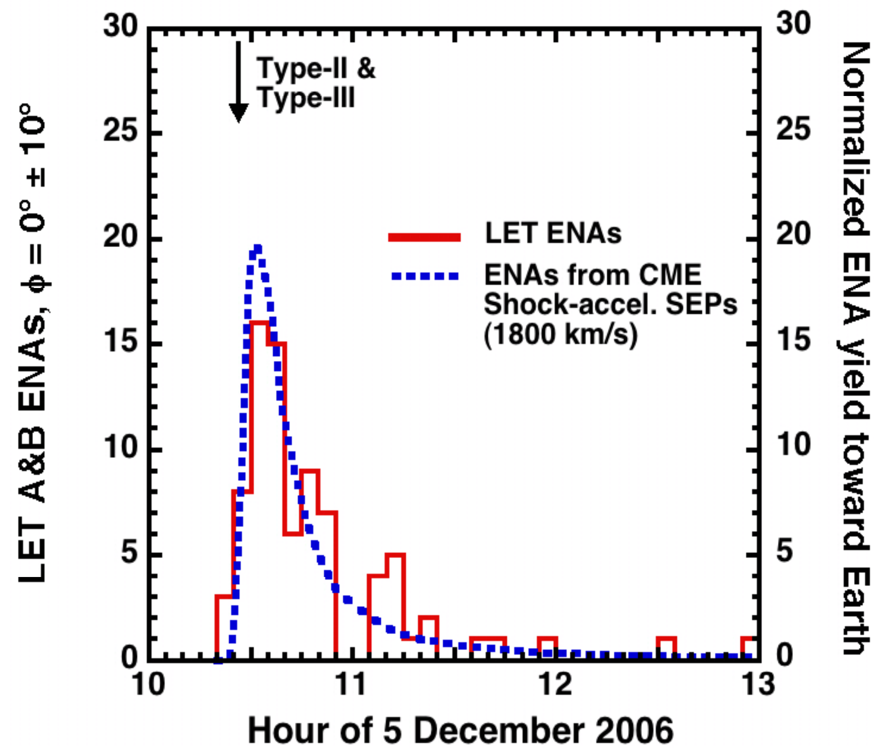
…Or, what else causes spectral breaks?

(Mewaldt et al., 2006)

Energetic Neutral Atoms (ENAs)

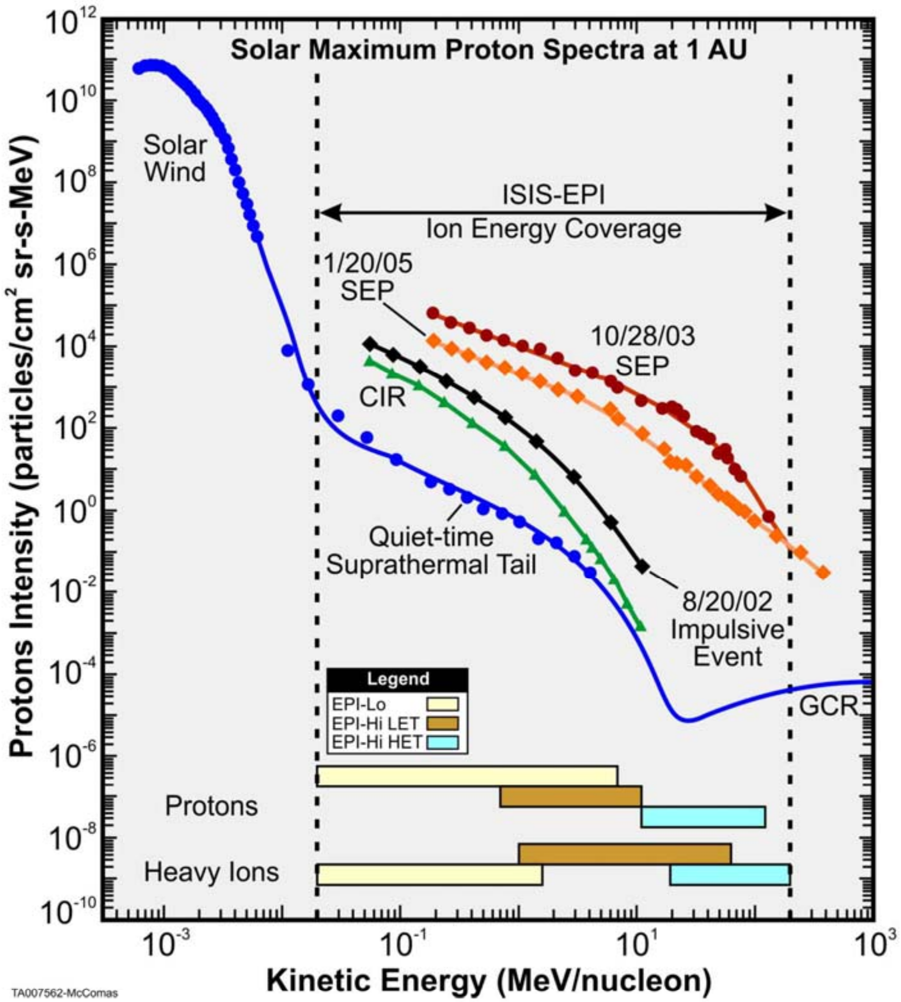
What can ENAs from solar eruptions tell us about how SEPs are accelerated and escape the Sun?





Calculated ENA emission profiles versus time as a shock moves from 2 to 20 Rs. (Mewaldt et al., 2009)

Measurement Summary



ISIS-EPI also provides electron measurements from ~0.025 to 6 MeV

- Determine in both gradual & impulsive Solar EP events:
  - Energy spectra
  - Composition (electrons, protons, major heavy elements)
  - Timing
  - Pitch angle distributions
- Measure ^{3}He as a key indicator of impulsive events
- Measurements of other populations (CIRs, ACRs, and GCRs) provide important new information on the radial dependences of these particles

Driving Requirements

- Energetic electron energy range: ≤0.05 to ≥3 MeV
- Energetic protons and heavy ions: ≤0.05 to ≥50 MeV/nuc
- Field of View: ≥π/2 sr in both sunward and anti-sunward hemispheres including coverage within 10° of the nominal Parker spiral field direction at perihelion
- Composition: at least H, He, ^{3}He, C, O, Ne, Mg, Si, Fe
- Maximum intensity <1MeV: ≥10^{6} particles/cm^{2}sr-s
- Maximum intensity >1MeV: ≥5×10^{5} particles/cm^{2}sr-s

Primary Measurement Requirements

MRD Req't	Parameter	Required	Comment/Heritage
MRD-96a MRD-97a	Energy range	e^-: ≤ 0.05 to ≥ 3 MeV p^+/i: ≤ 0.05 to ≥ 50 MeV	Combined energy range of all sensors; small gaps in energy coverage are acceptable
MRD-96b MRD-97b	Energy binning	≥ 6 bins/decade	ΔE/E≤16%
MRD-96c MRD-97c	Highest cadence	e^-: ≤ 1s for selected high-statistics electron rates p^+/i: ≤ 5s for selected high-statistics ion rates	Additional rates at lower cadences, as appropriate for expected statistics and bit rate allocation
MRD-96d MRD-97d	Field of view	≥ π/2 ster coverage in both sunward and anti-sunward hemispheres, including coverage within 10 degrees of the nominal Parker spiral field direction at perihelion	Combined sky coverage of all sensors, some regions densely sampled rather than 100% covered
MRD-96e MRD-97e	Angular sectoring	e^-: ≤ 45 degree sectors p^+/i: ≤ 30 degree sectors	
MRD-97e	Composition	at least H, He, ^{3}He, C, O, Ne, Mg, Si, Fe	Measured species; not all measured under all conditions
MRD-98a	Max. intensity <1 MeV	≥ 10^6 particles/cm^2-sr-s	
MRD-98b	Max. intensity >1 MeV	≥ 5×10^5 particles/cm^2-sr-s	Highest intensities measured over restricted fields of view

Summary

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- ISIS energetic particle measurements play key role in understanding origins, acceleration, and transport mechanisms
- Science goals have been mapped to measurement requirements
- These key requirements have been flowed down into the instrument design through the systems engineering process

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Systems Engineering

John Dickinson

ISIS SE (SwRI)

Outline

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- ISIS SE Approach
- SPP Requirements
- ISIS Requirements and Flowdown
- Interfaces and Accommodation
- Resources
- Instrument Command and Autonomy
- Environmental Design and Test Requirements
- Trade Studies
- Summary

ISIS Systems Engineering Approach

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- Distributed Systems Engineering
  - Both EPI-Hi and EPI-Lo engage fully in the SE process
- ISIS SE role is to:
  - Coordinate interactions with the project
  - Maximize use of shared resources
  - Provide oversight of technical tasks

- Requirements development process:
  - ISIS has actively worked with the Project to make sure the correct requirements are being developed at all levels
  - ISIS has ownership of its requirements at all levels

SPP Req's Doc. Architecture and Status

Solar Probe Plus
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Status Key:
- Started
- Draft: Key Driving
- Draft: Complete
- Preliminary
- Baseline

Level 1

L1 Requirements For The SPP Mission
Appendix E to Living With a Star Program Plan

Level 2

Solar Probe Plus (SPP) Level 2 Mission Requirements Document (MRD)

Level 3

SPP Level 3 Payload Requirements Document (PAY)

EDTRD | EMECP | CCP | MPCP | PCP

SPP-ISIS ICD | GI ICD | MOC/SOC ICD Due PDR+60

Level 4

SPP ISIS Level 4 Instrument Requirements Document (IRD)

Level Definitions

- L1 requirements are defined by NASA as advised by the SPP Science Working Group
  - This document belongs to **NASA**
  - "SPP mission shall"
  - **Program Level Requirements**
- L2s are APLs response to the L1s
  - This document belongs to **APL/Project Office**
  - "Mission shall"
  - **Mission Requirements Document**
- L3s are performance and functional requirements on individual mission elements
  - This document belongs to **APL/Project Office**
  - "Payload shall" or "ISIS suite shall"
  - **Payload Requirements Document**
- L4s are the payload response to L3s
  - This document belongs to **ISIS**
  - "EPI-Lo shall" or "EPI-Hi shall"
  - **Instrument Requirements Document**

Level\Owner	NASA HQ	APL	ISIS
Level 1 Program Level	SPP shall...		
Level 2 Mission Level		Mission shall...	
Level 3 Payload Level		Payload shall or ISIS shall...	
Level 4 Instrument / Subsystem Level			EPI-Lo shall or EPI-Hi shall...

SPP Requirements Documents

Project Requirements Document	Version	Date
NASA L1 Requirements For The SPP Mission Appendix E to Living With a Star Program Plan	Rev. -	9/6/2011
APL 7434-9047, Solar Probe Plus (SPP) Level 2 Mission Requirements Document (MRD)	Rev. C	8/30/2013
APL 7434-9051, SPP Level 3 Payload Requirements Document (PAY)	Rev. -	6/27/2013
APL 7434-9066, SPP General Instrument to Spacecraft ICD	Rev. -	10/3/2013
APL 7434-9058, SPP to ISIS ICD	Rev. -	10/30/2013
APL 7434-9078, SPP MOC to SOC ICD	Draft	PDR+60d
APL 7434-9039, SPP Environmental Design and Test Requirements Document	Rev. -	6/18/2013
APL 7434-9040, Electromagnetic Environment Control Plan (EMECP)	Rev. -	4/23/2013
APL 7434-9011, SPP Contamination Control Plan (CCP)	Rev. -	6/17/2013
APL 7434-9009, SPP Materials and Processes Control Plan (MPCP)	Rev -	6/11/2013
APL 7434-9001, SPP EEE Part Control Plan (PCP)	Rev. A	4/11/2013
JPL D-8545, JPL Derating guidelines	Rev. E	8/4/2006
Plus other Mission Assurance Documents		

ISIS Response Documentation

Number	Document	Released
16105-ISIS-IRD-01	ISIS Instrument Requirements Document	8/8/2013
16105-SPARES_PLAN-01	ISIS Spares Plan	10/15/2013
16105-EPI-Hi_SDP-01	EPI-Hi Software Development Plan	9/12/2013
16105-EPI-Lo_SDP-01	EPI-Lo Software Development Plan	9/6/2013
16105-SOC_SDP-01	SOC Software Development Plan	10/18/2013
16105-EPI-HI_SRD-01	EPI-Hi Software Requirements Document	8/8/2013
16105-EPI-Lo_SRD-01	EPI-Lo Software Requirements Document	8/8/2013
16105-ISIS_VVP-01	ISIS Verification and Validation Plan/Verification Matrix	10/8/2013
16105-ISIS_CMP-01	SwRI Configuration Management Plan	10/7/2013
16105-EPI-Hi_CMP-01	Caltech Configuration Management Plan	[In Review]
7464-9001	APL Configuration Management Plan (in PAIP)	10/3/2013
16105-ISIS_CRMP-01	ISIS Risk Management Plan	10/7/2013
16105-EPI-Hi_CCP-01	EPI-Hi Contamination Control Plan	[In Review]
7445-9023	EPI-Lo Contamination Control Plan	10/17/2013
16105-EPI-HI_FMEA-01	EPI-Hi Inputs to SC Interface FMEA	10/7/2013
16105-EPI-Lo_FMEA-01	EPI-Lo Inputs to SC Interface FMEA	9/6/2013

Reviewed Supporting Documents

Solar Probe Plus
A NASA Mission to Touch the Sun

- In addition to the Requirements documents, ISIS has provided feedback on the following documents/topics:

ISIS Input to Project
Limited Life Items List
Missile System Pre-Safety Package (MSPSP) Inputs
Materials and Processes List
Long Lead-Time Items List
Common Buy Item List
Instrument Thermal Model Supporting Information
Structural Analysis Documentation and Models
Instrument Mechanical Models
List of Planned Reviews
Comments on MOC-SOC Software ICD
Response on SPP Contamination Control
Reliability Plan Review

- ISIS has been responsive to inputs required by Project

Driving Requirements at L1/L2

- The Mission shall measure energetic protons and heavy ions, as follows:
  - Energy range: ≤ 0.05 to ≥ 50 MeV/nucleon
  - Highest cadence: ≤ 5s for selected rates
  - FOV: ≥ π/2 sr in sunward and anti-sunward hemispheres
  - Angular sectoring: ≤ 30 degree sectors
  - Composition: at least H, He, 3He, C, O, Ne, Mg, Si, Fe
- The Mission shall measure energetic electrons, as follows:
  - Energy range: ≤ 0.05 to ≥ 3 MeV
  - Highest cadence: ≤ 1s for selected rates
  - FOV: ≥ π/2 sr in sunward and anti-sunward hemispheres
  - Angular sectoring: ≤ 45 degree sectors
  - Composition: n/a

- Requirement above in blue is traced to lower levels in subsequent slides

Requirements Flowdown to L3

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- L2: The Mission shall measure energetic protons and heavy ions, as follows:
  - FOV: ≥ π/2 sr in sunward and anti-sunward hemispheres
- L3:

[PAY-270] Measurement: Energetic Protons/Heavy Ions Field-of-View (EPI-Lo)
EPI-Lo shall be capable of measuring protons and heavy ions over solar orbital distances of 9.86 R_S to 0.25 AU with a $\geq \pi/2$ steradians FOV in the sunward hemisphere and a $\geq \pi/2$ steradians FOV in the anti-sunward hemisphere including coverage within 10° of the Spacecraft-Sun line, subject to the constraints and FOV obstructions defined in the ISIS-to-Spacecraft ICD (7434-9058).

Rationale
-- This requirement meets Level 2 Mission Science Requirements. The FOV should cover as much as the sky as possible in order to allow accurate particle intensity measurements even when the angular distribution is highly anisotropic or the magnetic field deviates strongly from the nominal Parker spiral. The minimum FOV requirement allows measurement of particles with pitch angles out to ~40° from the nominal field direction in both the forward and backward directions and enables good determinations of first order anisotropies. Additional measurements closer to 90° pitch angle are important for investigating the time evolution of particle pitch angle distributions and for measuring higher order anisotropies.

Parent Traceability
-- **MRD-97** : The Mission shall measure energetic protons and heavy ions, as follows:
-- Energy range: ≤ 0.05 to ≥ 50 MeV/nucleon
-- Highest cadence: ≤ 5s for selected rates
-- FOV: $\geq \pi/2$ sr in sunward and anti-sunward hemispheres
-- Angular sectoring: ≤ 30 degree sectors
-- Composition: at least H, He, ^{3}He, C, O, Ne, Mg, Si, Fe

Requirement Allocation
ISIS

[PAY-271] Measurement: Energetic Protons/Heavy Ions Field-of-View (EPI-Hi)
EPI-Hi shall be capable of measuring protons and heavy ions over solar orbital distances of 9.86 R_S to 0.25 AU with a $\geq \pi/2$ steradians FOV in the sunward hemisphere and a $\geq \pi/2$ steradians FOV in the anti-sunward hemisphere including coverage within 10° of the Spacecraft-Sun line, subject to the constraints and FOV obstructions defined in the ISIS-to-Spacecraft ICD (7434-9058).

Rationale
-- This requirement meets Level 2 Mission Science Requirements. The FOV should cover as much as the sky as possible in order to allow accurate particle intensity measurements even when the angular distribution is highly anisotropic or the magnetic field deviates strongly from the nominal Parker spiral. The minimum FOV requirement allows measurement of particles with pitch angles out to ~40° from the nominal field direction in both the forward and backward directions and enables good determinations of first order anisotropies. Additional measurements closer to 90° pitch angle are important for investigating the time evolution of particle pitch angle distributions and for measuring higher order anisotropies.

Parent Traceability
-- **MRD-97** : The Mission shall measure energetic protons and heavy ions, as follows:
-- Energy range: ≤ 0.05 to ≥ 50 MeV/nucleon
-- Highest cadence: ≤ 5s for selected rates
-- FOV: $\geq \pi/2$ sr in sunward and anti-sunward hemispheres
-- Angular sectoring: ≤ 30 degree sectors
-- Composition: at least H, He, ^{3}He, C, O, Ne, Mg, Si, Fe

Requirement Allocation
ISIS

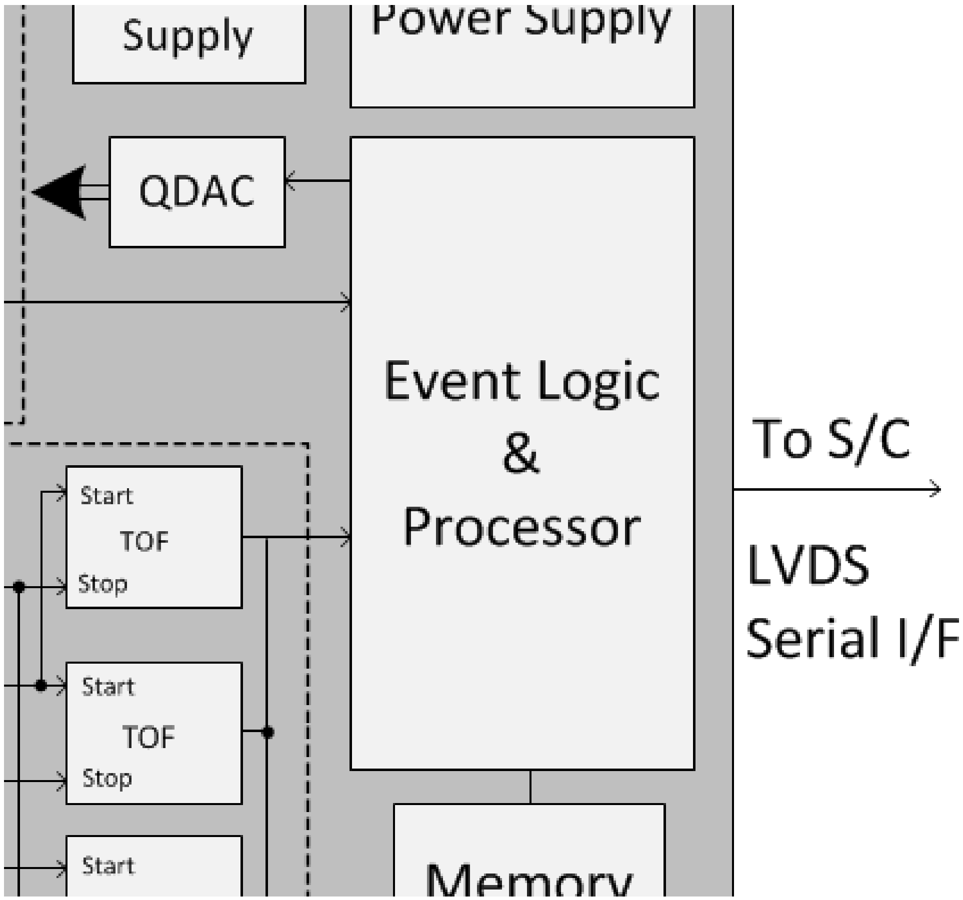
- Traceability to L2 as well as more detail captured at L3
  - Description/Clarification, Spacecraft Rationale, Parent Traceability, Requirement Allocation

Requirements Flowdown to L4

	Energetic Protons/Heavy Ions FOV	ISIS-118	EPI-Lo Instrument Protons/Heavy Ions Field of View
PAY-270	**EPI-Lo** EPI-Lo shall be capable of measuring protons and heavy ions over solar orbital distances of 9.86 Rs to 0.25 AU with a ≥ π/2 steradians FOV in the sunward hemisphere and a ≥ π/2 steradians FOV in the anti-sunward hemisphere including coverage within 10° of the Spacecraft-Sun line, subject to the constraints and FOV obstructions defined in the ISIS-to-Spacecraft ICD (7434-9058).		The EPI-Lo instrument shall have ≥π/2 unobstructed field of view (FOV) in both sunward and anti-sunward hemispheres for the measurement of energetic protons/heavy ions including coverage within 10° of the spacecraft-Sun line, subject to the constraints and FOV obstructions specified in the SPP to ISIS ICD, 7434-9058. **Rationale:** The FOV should cover as much as the sky as possible in order to allow accurate particle intensity measurements even when the angular distribution is highly anisotropic or the magnetic field deviates strongly from the nominal Parker spiral. The minimum FOV requirement allows measurement of particles with pitch angles out to ~40° from the nominal field direction in both the forward and backward directions and enables good determinations of first order anisotropies. Additional measurements closer to 90° pitch angle are important for investigating the time evolution of particle pitch angle distributions and for measuring higher order anisotropies. **Notes:** EPI-Lo views ~ half the sky by densely sampling with 80 apertures. The coverage is approximately 50% as there are gaps between apertures, but also overlap. The sunward quarter sky is ~1 π sr and EPI-Lo must view this down to <= 10 degrees from the sun. At 50% coverage, this means that EPI-Lo should have an unobstructed π/2 sr down to 10 deg. Similarly EPI-Lo must view the anti-sunward quarter-sky, which, at 50% coverage, is about π/2 sr. Reasonableness of this requirement depends on what the ICD says. It is important that the project provide us with accurate, up-to-date CAD models of the spacecraft including all of the potential obstructions so that this requirement can be checked. **Verification Method:** Analysis & Test **Verification Activity:** Analyze obstructions using CAD model and inspect mounting on the spacecraft after integration to verify the accuracy of that analysis. **Verification Result:**
PAY-271	**EPI-Hi** EPI-Hi shall be capable of measuring protons and heavy ions over solar orbital distances of 9.86 Rs to 0.25 AU with a ≥ π/2 steradians FOV in the sunward hemisphere and a ≥ π/2 steradians FOV in the anti-sunward hemisphere including coverage within 10° of the Spacecraft-Sun line, subject to the constraints and FOV obstructions defined in the ISIS-to-Spacecraft ICD (7434-9058).		

ISIS-218	EPI-Hi Instrument Protons/Heavy Ions Field of View
	The EPI-Hi instrument shall have ≥π/2 unobstructed field of view (FOV) in both sunward and anti-sunward hemispheres for the measurement of energetic protons/heavy ions including coverage within 10° of the spacecraft-Sun line, subject to the constraints and FOV obstructions specified in the SPP to ISIS ICD, 7434-9058. **Rationale:** The FOV should cover as much as the sky as possible in order to allow accurate particle intensity measurements even when the angular distribution is highly anisotropic or the magnetic field deviates strongly from the nominal Parker spiral. The minimum FOV requirement allows measurement of particles with pitch angles out to ~40° from the nominal field direction in both the forward and backward directions and enables good determinations of first order anisotropies. Additional measurements closer to 90° pitch angle are important for investigating the time evolution of particle pitch angle distributions and for measuring higher order anisotropies. **Notes:** A π/2 steradian solid angle cone has a half-angle of about 41.4 degrees. This is nearly as large as the 45 degree half angle viewing cone planned for each end of each telescope. Since the TBS will obstruct portions of the FOV of HET and LET1 in the sunward direction and since portions of the FOVs of these two telescopes overlap outside of this obstructed region, the portion of the LET2 FOV that is in the sunward hemisphere may be required to achieve the required π/2 steradian solid angle. This should be checked. Reasonableness of this requirement depends on what the ICD says. It is important that the project provide us with accurate, up-to-date CAD models of the spacecraft including all of the potential obstructions so that this requirement can be checked. **Verification Method:** Analysis & Inspection **Verification Activity:** Analyze obstructions using CAD model and inspect mounting on the spacecraft after integration to verify the accuracy of that analysis. **Verification Result:**

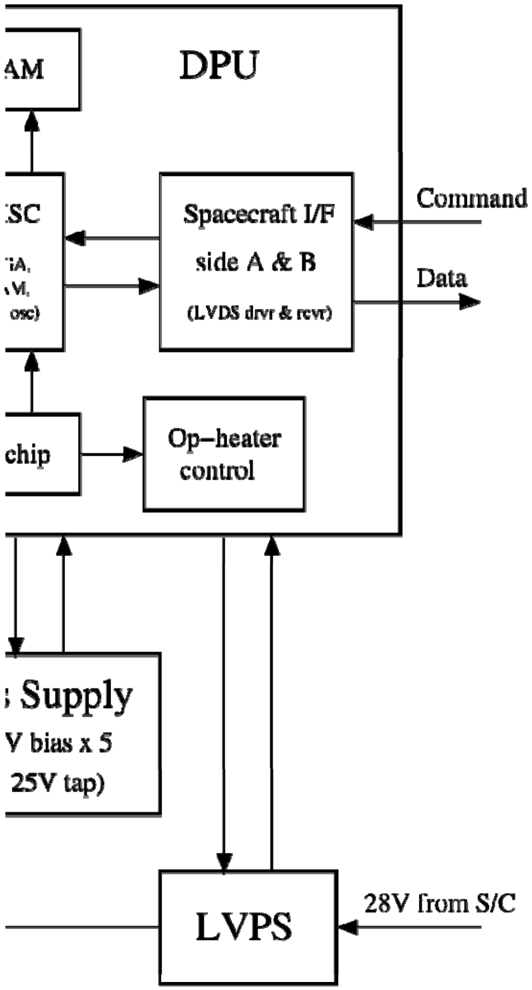
EPI-Lo Spacecraft Interfaces



- Unique EPI-Lo-to-spacecraft Interfaces include:
  - Spacecraft power
  - Command/Telemetry
  - Survival Heaters
  - Spacecraft Temperature Sensors

EPI-Lo mounted to shared ISIS Bracket

EPI-Hi Spacecraft Interfaces

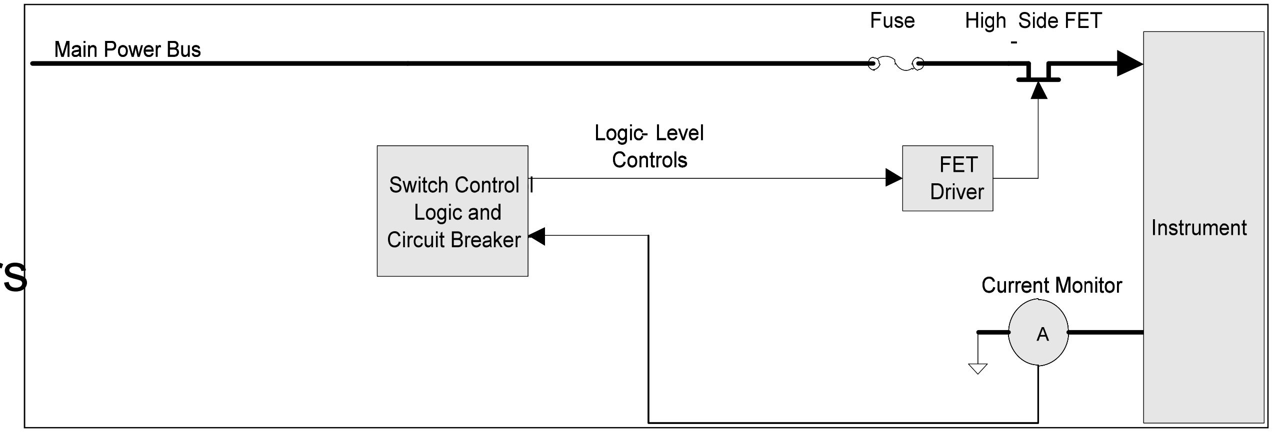


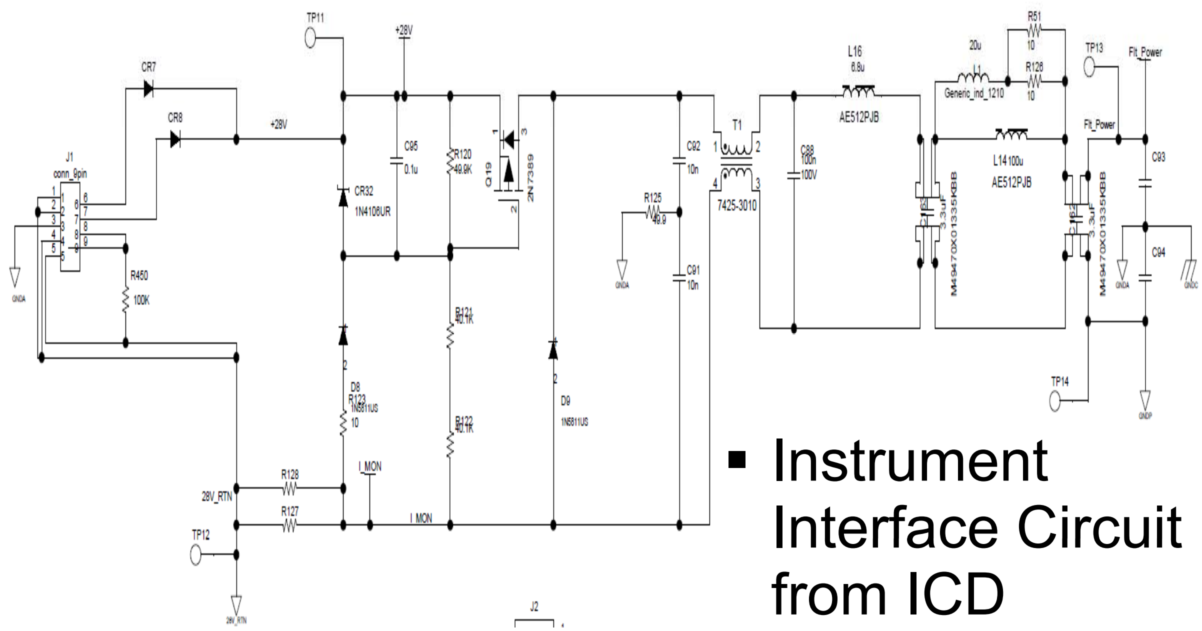
- Unique EPI-Hi-to-spacecraft Interfaces include:
  - Spacecraft power
  - Command/Telemetry
  - Survival Heaters
  - Spacecraft Temperature Sensors

EPI-Hi mounted to shared ISIS Bracket

Spacecraft Electrical Interfaces

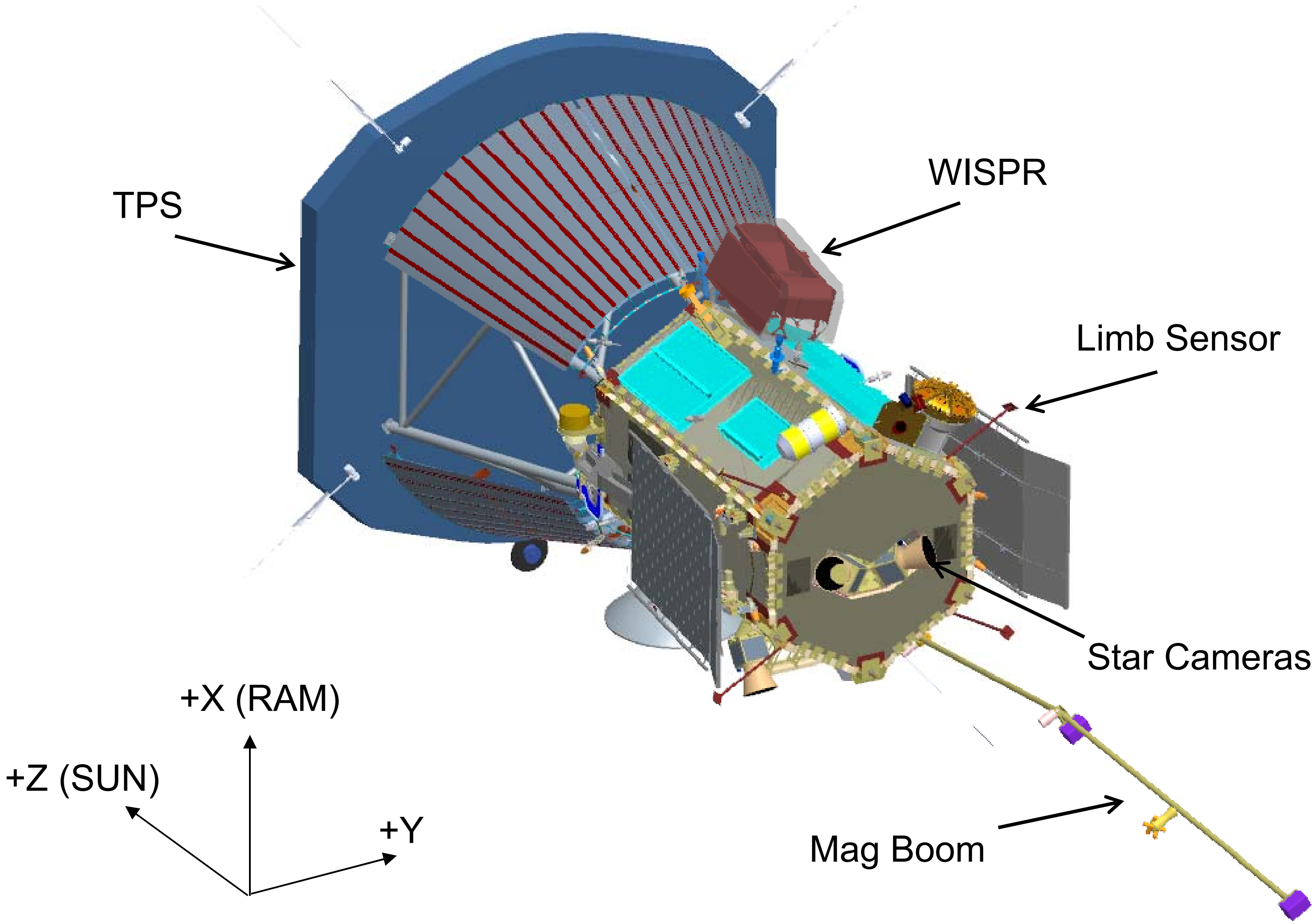
- Power
  - Main Instrument Power
  - Survival Heaters
  - Operational Heaters (EPI-Hi)
- Command & Telemetry
  - Side A/B LVDS UART
- Grounding
  - Chassis Ground to Bracket, thermally isolated
- Thermal
  - Heaters
  - Temperature Sensors
- Captured in GI and SPP-ISIS ICDs





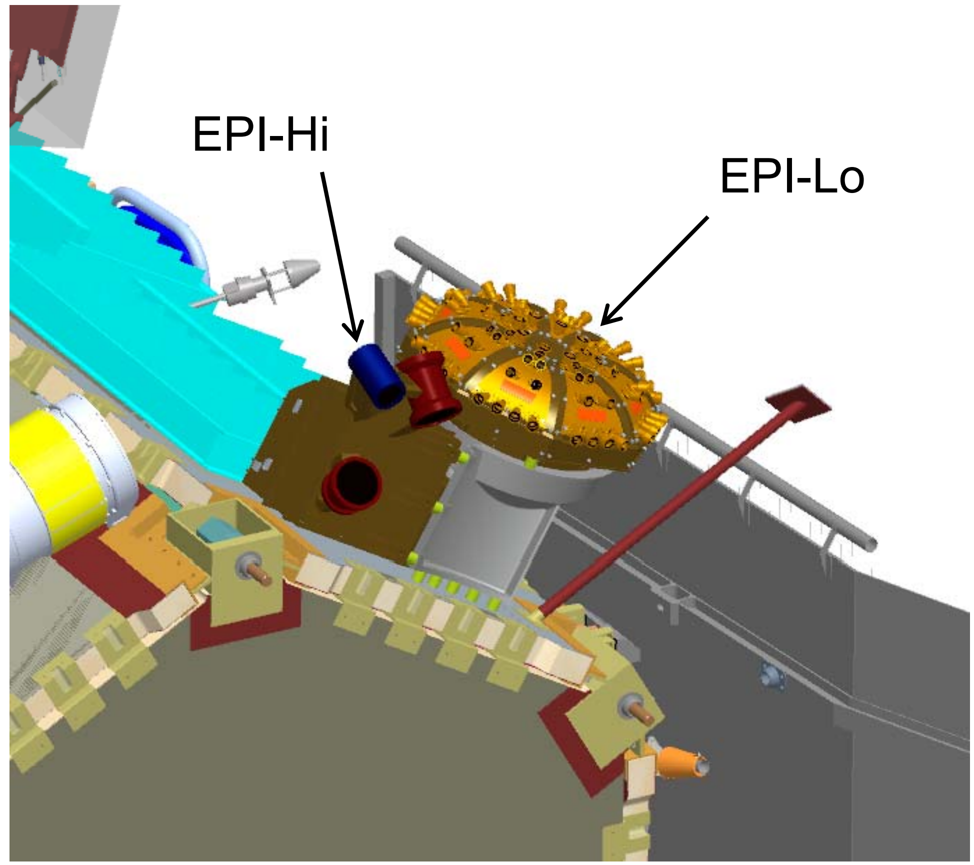
- Instrument Interface Circuit from ICD

ISIS Spacecraft Accommodations



Mechanical Interfaces

- ISIS suite mounted as a single unit on the spacecraft deck
- EPI-Hi & EPI-Lo are thermally isolated from ISIS bracket; ISIS bracket is thermally isolated from the spacecraft deck
- ISIS is mounted in order to keep both EPI-Hi and EPI-Lo adjacent to the umbra
- Harness, Purge, Grounding, MLI all still being developed, but can easily be accommodated into existing design



Spacecraft Sep Plane Keep Out Zone

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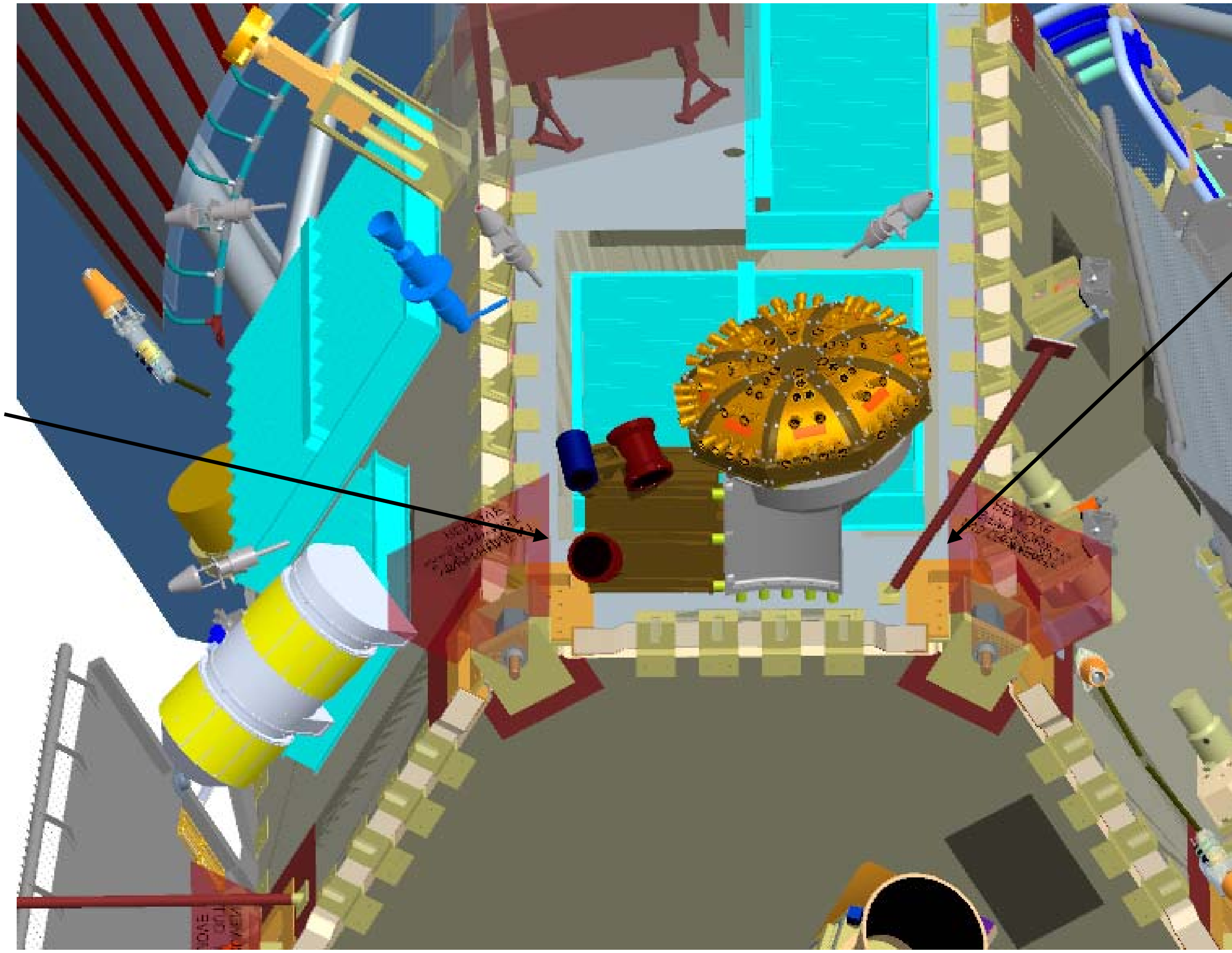
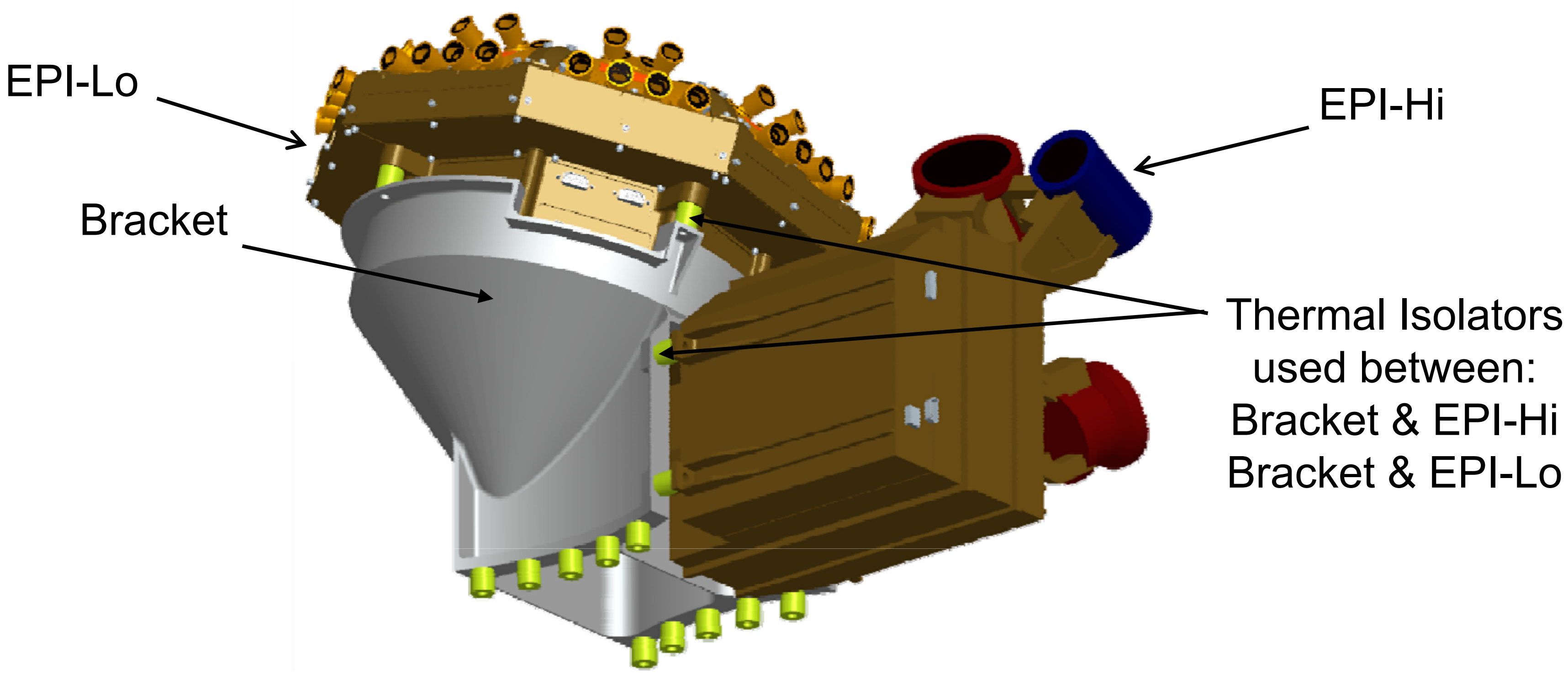
EPI-Hi to S/C Sep Conn. is ~2 cm



Ample clearance between EPI-Lo and S/C

ISIS Instrument Mounting to Bracket

- ISIS mounting bracket provides common mounting for both EPI-Hi and EPI-Lo
- Bracket keeps instruments close to umbra with a minimal footprint on the spacecraft deck
- EPI-Hi and EPI-Lo can each be attached independently to the bracket, in either order, before or after the bracket is mounted to the spacecraft deck



ISIS Mounting to Spacecraft Deck

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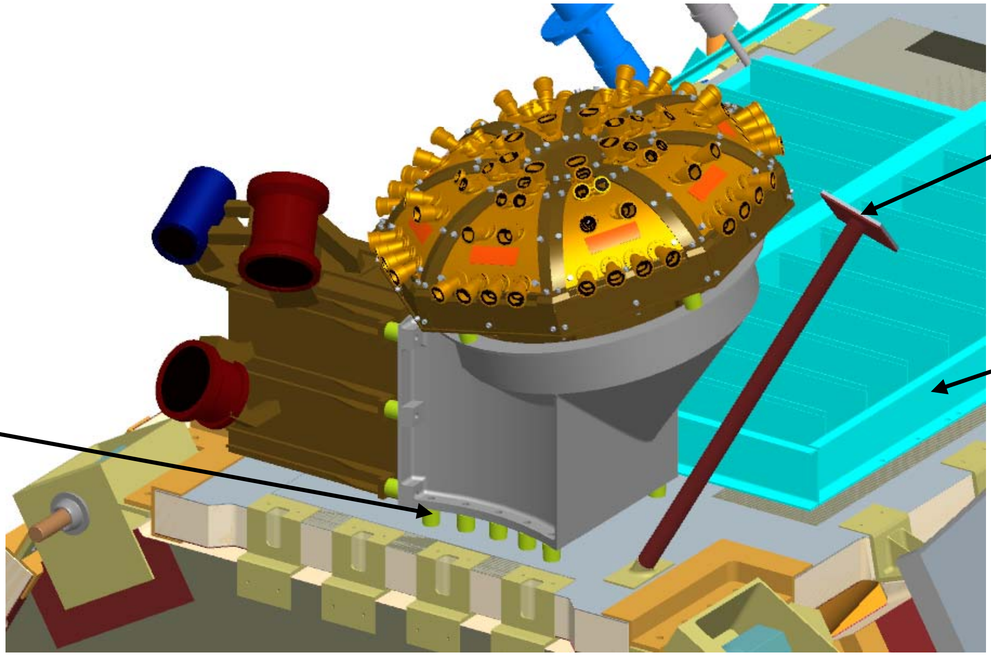
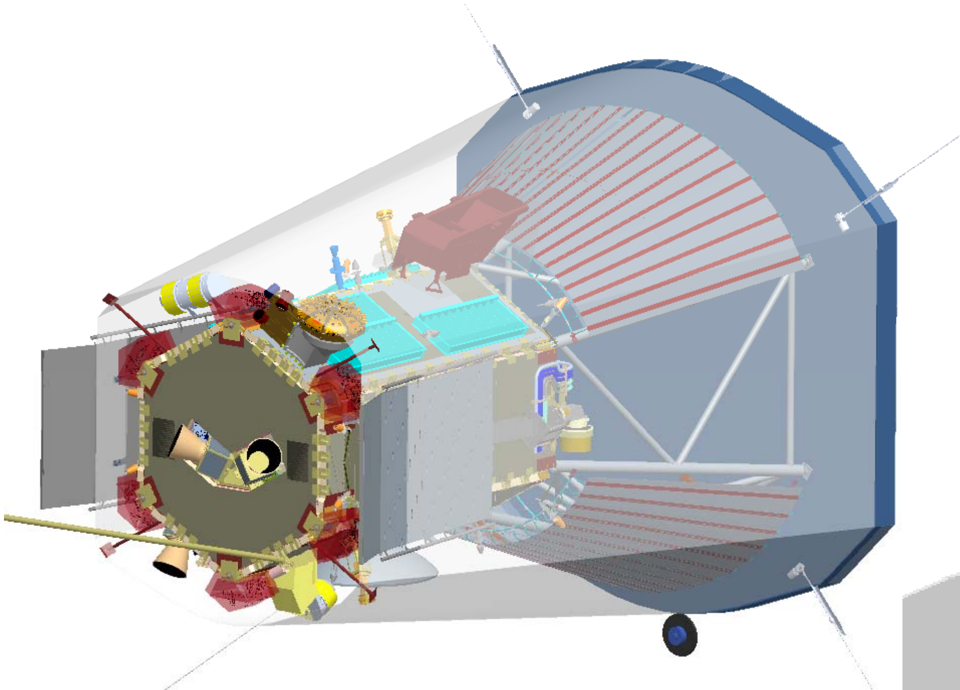
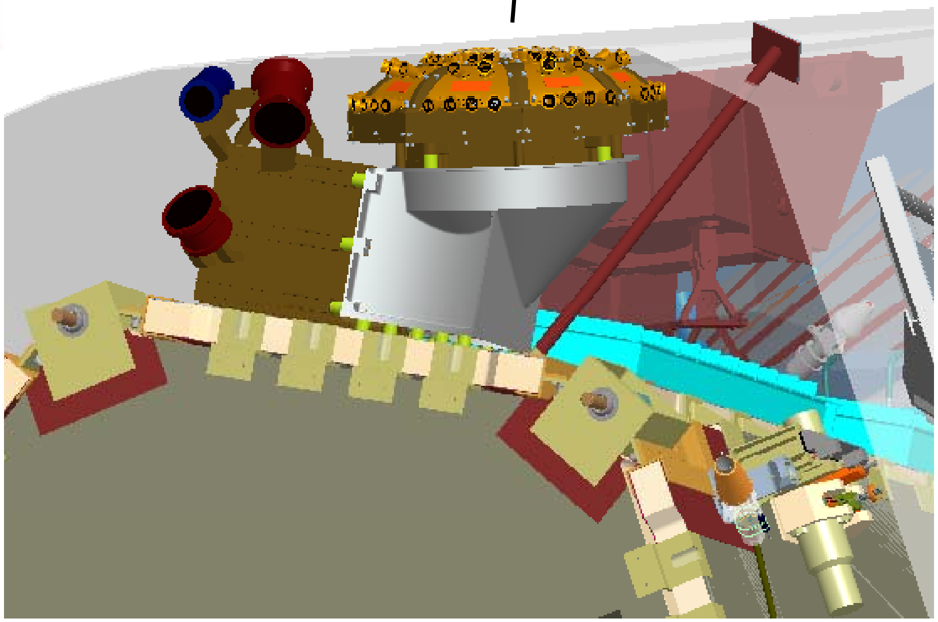
- ISIS bracket mounts on a very small footprint, keeping away from spacecraft structural elements and other deck-mounted components
- ISIS bracket allows for flexibility in mounting order of EPI-Hi and EPI-Lo, and accommodates easy access to EPI-Hi and EPI-Lo mounting interfaces and spacecraft interfaces (i.e. harnesses)
- Bracket can be easily moved to accommodate TPS growth to keep EPI-Hi and EPI-Lo close to the umbra



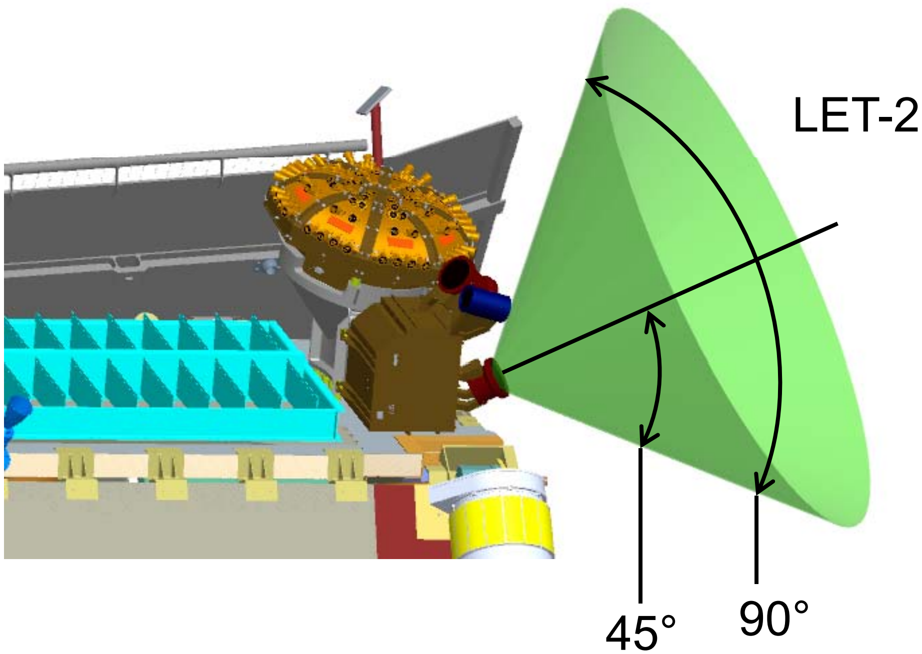
Relationship of ISIS to TPS Umbra

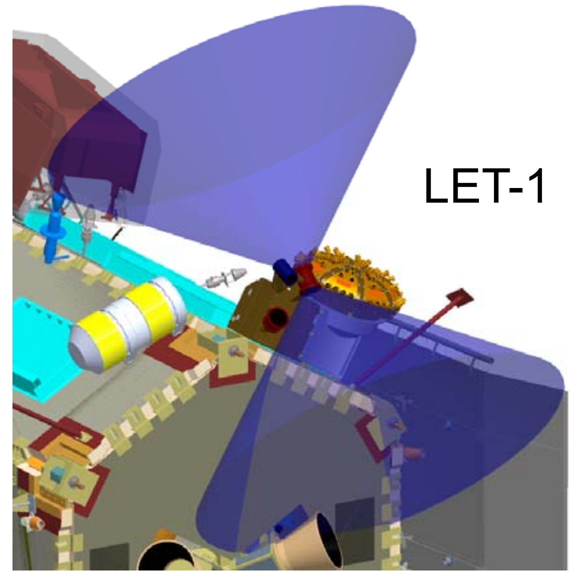


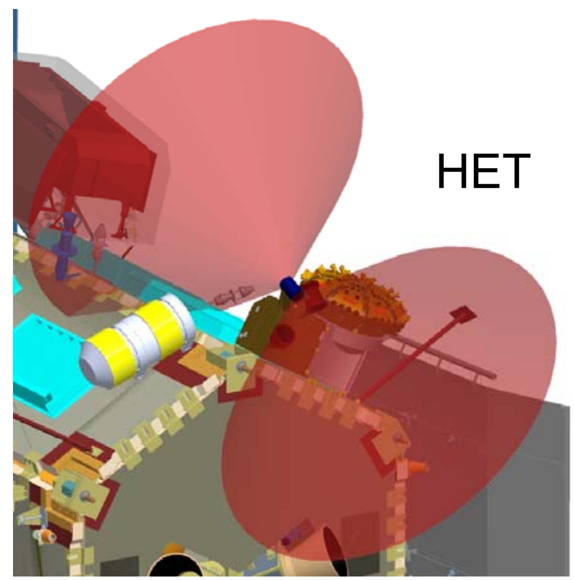
Bracket height can increase in the event of a late TPS shift (Direction of motion shown)



EPI-Hi Field Of View



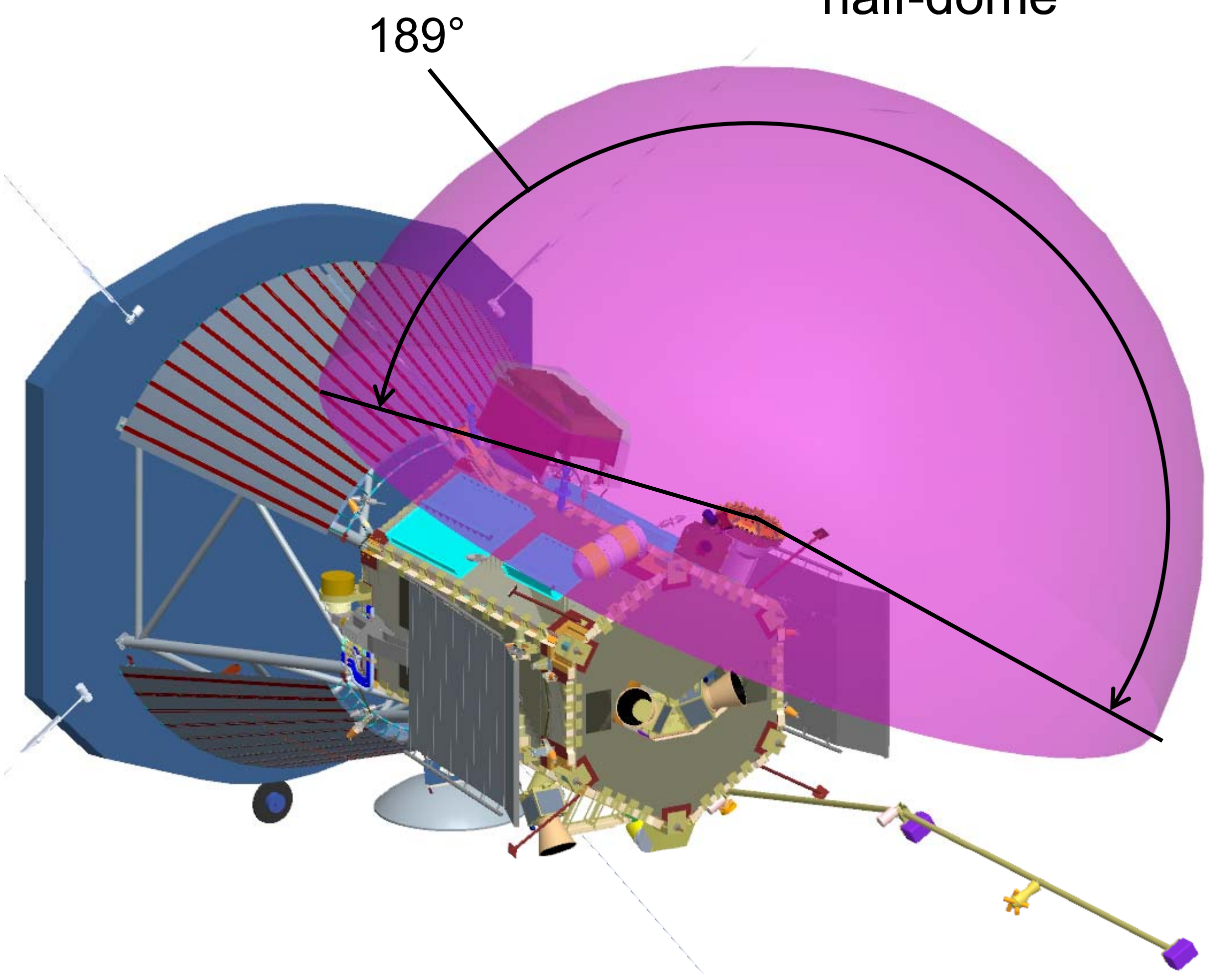


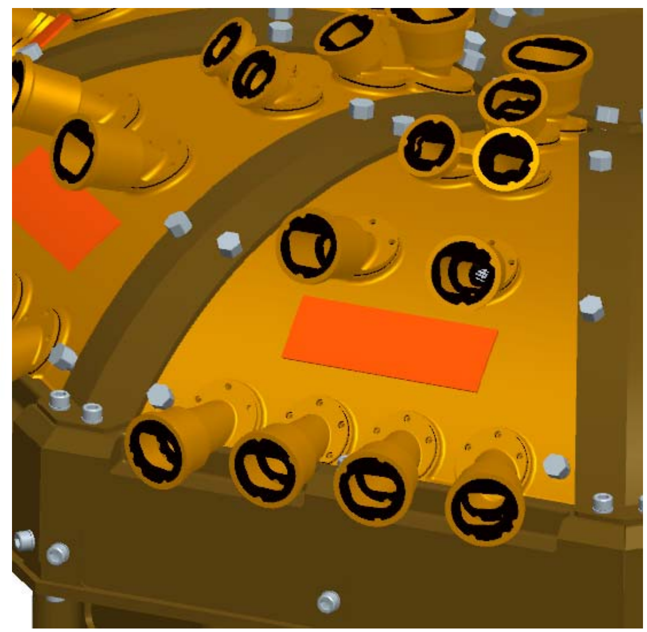


- All EPI-Hi telescopes have the same FOV shape as dimensioned in LET-2

EPI-Lo Field Of View

- EPI-Lo FOV is comprised of 80 individual apertures, which together approximate a half-dome





Thermal Interfaces

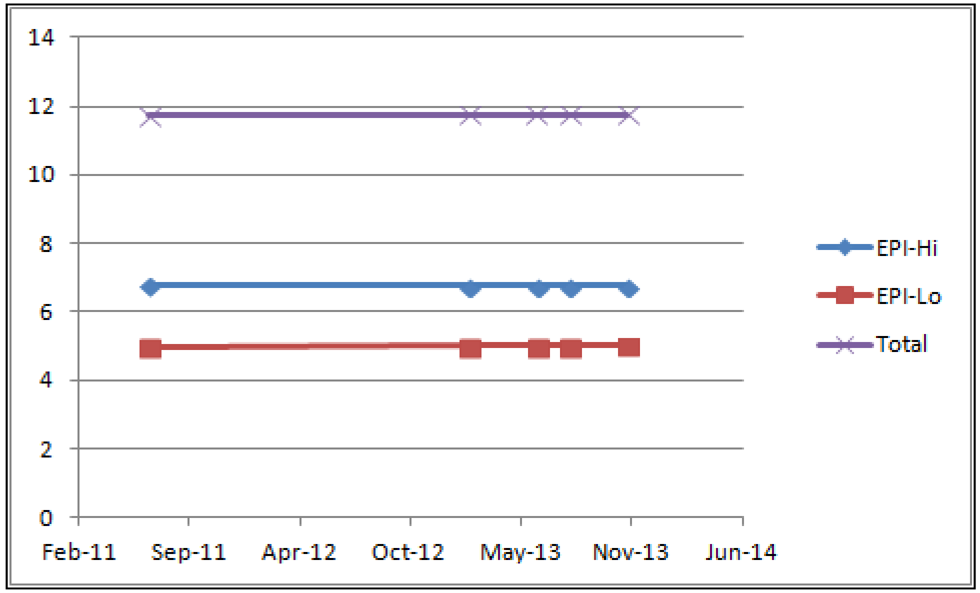
- EPI-Hi:
  - Both survival and operational heater services from the spacecraft
  - Instrument controls operational heater
  - Spacecraft controls survival heater
  - Has 5 temp sensors monitored by spacecraft
- EPI-Lo:
  - Has a dual use survival/operational heater, used during survival conditions, instrument pre-on warm-up, and in low power modes
  - EPI-Lo has 2 temp sensors
- Ground strap is thermally isolated

Instrument Subsystem	Design / Test Operating Temperture Range (C)	Non-op Survival Temperature Range (C)	Survival Heater Equivalent Resistance (Ohms)	Operational Heater Equivalent Resistance (Ohms)	Surival Heater Set Point Temperature Range (C)
EPI-Hi	-25 / +30	-40 / +50	87	1056	-35 to -32
EPI-Lo	-30 / +35	-45 / +50	121	---	-40 to -37

Resources - Power

ISIS	Hi CBE	Hi Uncty	Hi Total	Lo CBE	Lo Uncty	Lo Total	ISIS Total
Instrument Power (W)	5.81	0.96	**6.77**	4.17	0.83	**5.00**	**11.77**
Operational Heaters (W)	0.48	0.07	**0.55**	0.00	0.00	**0.00**	**3.47**
Survival Heaters (W)	3.81	0.57	**4.38**	2.45	0.37	**2.82**	**7.20**
Totals:	**10.10**	**1.60**		**6.62**	**1.20**		

- ISIS Current Best Estimates and Uncertainties
- During Survival, heater power is duty cycled to ensure instrument stays above survival temperature
- During Warm-up, heater has a 100% duty cycle to warm the instrument prior to normal operations (Encounter Mode)

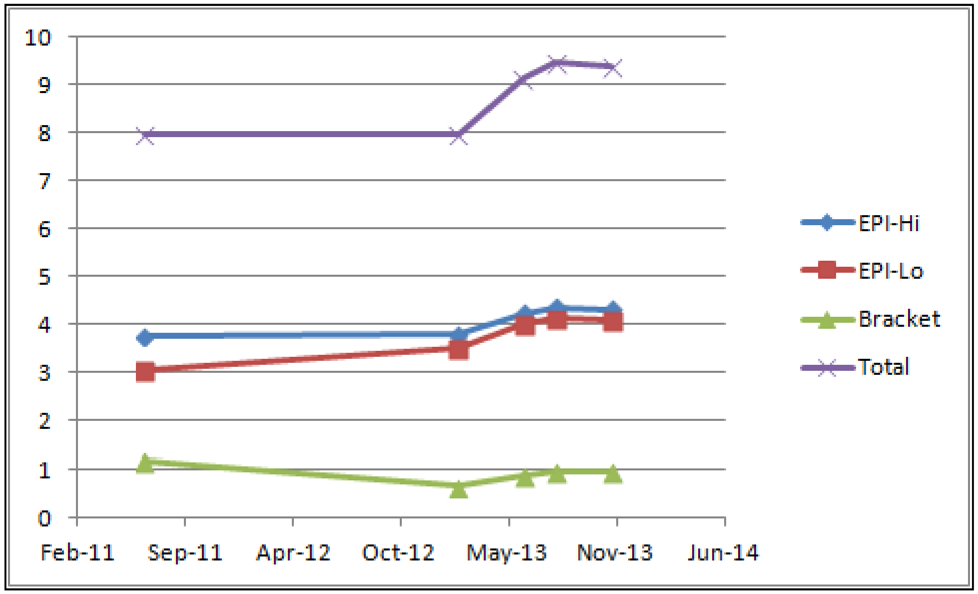


- Because all resources on SPP are tightly constrained, mass and power estimates have been rigorously maintained based on heritage instruments from the beginning
- As a result of this attention to rigorous estimation, there has been no change in instrument power allocation over time

Resources - Mass

	Hi CBE	Hi cont.	Lo CBE	Lo cont.	Bracket	cont.	Total
Mass (kg)	3.628	0.692	3.435	0.656	0.817	0.156	**9.384**

- ISIS Current Best Estimates and Uncertainties
- With the spacecraft orbit change, the Instruments were asked to propose key areas to increase mass to reduce risk (in June 2013)
- This increased instrument allocation by 1.5 kg.



Three Selected Requests	Risk Addressed
ISIS Bracket Change to Follow Umbra at TPS Shift	APL to hold additional 0.100 kg as lien.
Increase Size of Four EPI-HI Boards	Mitigate board area allocation risk.
Heavier Than Expected MCPs	Realized mass growth.
Total:	1.536 kg

Resource - Telemetry

		Total ISIS	12 Gbits	r < 0.25 AU and burst only, include compression, packetization, but not contingency				
			13.3253022	0.89894993				
		bps	# of secs	total raw bits	total (Gbits)	*0.75 comprss	*1.05 Packt	
EPI-Hi	r < 0.25 AU	3640.747218	902545.7301	3655310207	3.655310207	2.741482655	2.878556788	
	r > 0.25 AU						n/a	
EPI-Lo	r < 0.25 AU	11271.03423	902545.7301	11316118364	11.31611836	8.487088773	8.911443212	
	r > 0.25 AU						n/a	
	Burst					0.2	0.21	
							12	Gbits/orbit

- ISIS Telemetry request is unchanged since Phase A

Instrument	Gbit / orbit	+ 30%	Avg. Rate <0.25 AU 11 days	Continuous Data Rate	Peak Data Rates (3 Hours)
WISPR	23	30	30 kbps	260 kbps	350 kbps
					8 kbps
FIELDS 1 & 2	20	26	26 kbps		80 kbps
					80 kbps
SWEAP	20	26	26 kbps		80 kbps
ISIS	12	16	16 kbps		80 kbps
					80 kbps
Science campaign "data bank"	10	13	13 kbps		NA
	85 Gbit	111 Gbit	111 kbps	341 kbps	758 kbps

CCSDS APIDs

Allocation	APID Range (Hex) - Low	APID Range (Hex) - High	Assignment
64	0x490	0x4CF	EPI-Lo
64	0x440	0x47F	EPI-Hi

APID (Decimal)	APID (Hex)	Assignment
1180 TBR	0x49C TBR	EPI-Lo Critical Housekeeping Packet
1088 TBR	0x440 TBR	EPI-Hi Critical Housekeeping Packet

- CCSDS APIDs assigned in SPP-ISIS ICD
- EPI-Lo and EPI-Hi have each been allocated a contiguous range of 64 APIDs for CCSDS telecommand and telemetry packets.

Autonomy Summary

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The spacecraft will monitor and respond to:

- ISIS Power requests instrument critical housekeeping telemetry packet:
  - instrument power-down (response = power-down)
  - instrument power-cycle (response when < 0.25 AU = power-cycle; response when >= 0.25 AU = power-down)
- ISIS Stale aliveness status as determined from the sequence count in the ITF (response when < 0.25 AU = power-cycle; response when >= 0.25 AU = power-down)
- Excessive ISIS power levels as determined from spacecraft Power Distribution Unit (PDU) telemetry (response = power-down)
- Excessive ISIS temperature as determined from spacecraft Remote Interface Units (RIUs) (response = power-down)
- ISIS is still working with the Project to flesh out all operational scenarios to ensure a comprehensive and feasible approach to ISIS autonomy.

Environmental Requirements & Tests

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- Key Environmental Requirements set in EDTRD:
  - Duration: 7 years
  - Orbits: 24
  - Solar Illumination: 1 sun on any aperture
  - TID: 80 kRad behind 60 mils Al
  - SEL: >80 MeV-cm2/mg
  - Dust: Probability of no impact >95%
    - EPI-Lo: >124.3 um particle diameter
    - EPI-Hi: >68.5 um particle diameter
  - Stiffness: >80 Hz Res. Freq.
  - Shock: 40G @ 100 Hz at separation interface

Typical Test Flow for Components and Instruments (EDTRD)

Test	Subsystem / Instrument Requirement
Magnetic Field (test magnetic hardware)	X[b]
Hermeticity (tanks, cooling system)	*
Comprehensive Performance Test	X
EMI/EMC	X
Initial Optical Alignment	*
Mass Properties	X[a]
Pre Vibration Survey	X
Sinusoidal Vibration	X
Random Vibration	X
Pressure Profile	
Shock (self induced)**	*
Acoustic	*
Strength	X
Post Vibration Survey	X
Deployments	*
Performance Test	X
Thermal Vacuum Balance	*
Thermal Vacuum Cycle	X
Bake-out	X
Final Optical Alignment	*
Comprehensive Performance Test	X

X Test is required

* Test is conditionally required, see relevant sections

Not Performed on ISIS

Pointing Requirements

- ISIS Pointing Requirement: 1 deg accuracy, 0.25 deg knowledge
- ISIS is not driving spacecraft pointing requirements
- ISIS is working with the Project to define Pointing Budget

ISIS Control to Nominal Pointing — BIAS
REQ 0.548 deg — 0.100
CBE 0.387 deg — 0.100
ALLOWABLE OFFSET 0.400 deg
Note: Desire 1 degree requirement?
Total
REQ **0.96 deg**
CBE **0.80 deg**

ISIS Internal Calibration — BIAS
REQ 0.20 deg — 0.000
CBE 0.20 deg — 0.000
Note: TBD

- ISIS Angular Measurement Accuracy/Resolution
  REQ 0.200 deg
  CBE 0.200 deg
  UNVERIFIED
  Note: Provided by ISIS Team

Initial ISIS Control to SC Body Frame — BIAS
REQ 0.24 deg
CBE 0.24 deg
Note: TBD

- ISIS Csys knowledge to Mech Ref Features
  REQ 0.100 deg
  CBE 0.100 deg
  UNVERIFIED
  Note: Provided by ISIS Team
- ISIS Mech Ref Features to SC frame knowledge
  REQ 0.200 deg
  CBE 0.200 deg
  UNVERIFIED
  Note: Measurement Accuracy
- SC body frame knowledge
  REQ 0.100 deg
  CBE 0.100 deg
  UNVERIFIED
  Note: Measurement Accuracy of Csys
- Allowable offset from nominal pointing
  REQ deg
  CBE deg
  UNVERIFIED
  Note: 0.4 deg - see final summation box

ISIS Control Changes from initial sett — BIAS
REQ 0.20 deg — 0.100
CBE 0.20 deg — 0.100
Note:

- Shock & Vibe Shifts
  REQ 0.050 deg
  CBE 0.050 deg
  UNVERIFIED
  Note:
  ADD
- Shipping shift
  REQ 0.050 deg
  CBE 0.050 deg
  UNVERIFIED
  Note:
  ADD
- Shock & Vibe in flight
  REQ 0.100 deg
  CBE 0.100 deg
  UNVERIFIED
  Note: TBD
- Mech. Therm. Distortion — BIAS
  REQ deg — 0.100
  CBE deg — 0.100
  UNVERIFIED
  Note:

SC Pointing and Knowledge — BIAS
REQ 0.40 deg — 0.000
CBE 0.10 deg — 0.000
Note: TBD

- SC Attitude Control Error
  REQ 0.400 deg
  CBE 0.100 deg
  UNVERIFIED
  Note: SCRD-166 2 deg. for ISIS

Contamination Requirements

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- Contamination requirements are defined in the Instrument Contamination Control Plans
- The plans define the criteria for implementing contamination control during the manufacture, assembly, and test ISIS instruments
- EPI-Lo has MCPs that drive ISIS contamination control requirements

	Initial Cleanliness	Sensor Integration/Assembly	Delivery to APL	BOL	EOL
Solid State Detectors	VC2+UV	VC2+UV/400 A/20	N/A	N/A	N/A
Aperture Foils	VC2+UV	VC2+UV/400 A/20	N/A	N/A	N/A
Micro channel Plates	VC2+UV	VC2+UV/400 A/20	N/A	N/A	N/A
Instrument Interior Surfaces	VC2+UV	VC2+UV/400 A/20	N/A	500 A/20	750 A/10
Instrument hardware (fasteners, screws)	VC2+UV	VC2+UV	N/A	N/A	N/A
Instrument External Surfaces	N/A	N/A	VC2+UV/400 A/2	500 A/2	750 A
Harnesses and Cables	VC2+UV	VC2+UV	VC2+UV	N/A	N/A
Purge tubing/fittings	100/200 A/10 A/2	N/A	N/A	N/A	N/A
Shipping containers	VC2+UV	VC2+UV	VC2+UV	N/A	N/A
MLI Blanket materials	VC2+UV/400 A/2	N/A	VC2+UV/400 A/2	N/A	N/A
GSE Equipment	VC2	VC2	VC2	N/A	N/A
Bagging Material	VC2+UV	VC2+UV	VC2+UV	N/A	N/A
Storage Containers	VC2+UV	VC2+UV	VC2+UV	N/A	N/A

Table 2: Maximum particulate and molecular limits for the EPI-LO instrument.

Trade Studies

Trade	Description	Status	Closure Date
Hi: PHASIC Approach	Improve PHASIC TID: 1) Passive Shielding 2) RadHard respin of STEREO PHASIC by Aeroflex	EM Components fabricated, tested, and meet requirements	PDR (closed)
Hi: Thin Silicon Detectors	Process for making thin ion-implanted detectors that simultaneously meet all of the specifications for the EPI-Hi LET telescopes have not yet been demonstrated.	Thin detectors have been fabricated, tested, and meet requirements	PDR (closed)
Hi: Thin Windows	Because of the thin front detectors on the EPI-Hi LETs, it would be useful to make the windows at the LET apertures thinner than those used in heritage STEREO/LET instrument. (Note: Fall back to flight-proven 1/5 mil Kapton meets Level 1 Reqs)	Thin windows fabricated and tested at Heidelberg dust facility	PDR (closed)
Lo: RIO Chip	APL has developed an ASIC that performs housekeeping functions called the Remote IO (RIO) chip. Component may be useful as Housekeeping chip for ISIS (EPI-Hi and EPI-Lo).	EM Components fabricated, tested, and meet requirements	PDR (closed)
Lo: Wedge-to-TOF Chip Ratio	Time-of-Flight can be derived in several configurations of MCP wedges and TOF chips (start/stop inputs), i.e. 1 or 2 wedges with direct or daisy chained TOF chips. Minimizing mass without sacrificing measurement quality is the goal.	Quadrant approach implemented	MDR (closed)
Lo: ASIC Lot Selection	The use of new generation TOF/CFD timing chips and RIO housekeeping chips alleviates the availability concern due to depletion of existing flight stocks. However, new designs might not be available in time.	EM Components fabricated, tested, and meet requirements	PDR (closed)

Summary

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- ISIS takes a comprehensive and distributed approach to systems engineering
- ISIS requirements are approached with flowdown and verification in mind
  - ISIS has been involved at all levels of requirement generation
  - Requirements flowdown is easily traceable and well understood
  - ISIS design meets or exceeds all Level 3 requirements
- ISIS to Spacecraft electrical, mechanical, and thermal interfaces are well described in the ICDs
- ISIS Resource estimates are within spacecraft allocations
  - ISIS has cultivated a reputation as a good steward of mission resources
- Plans are in place for Environmental Testing and AI&T
- ISIS has demonstrated tremendous design and definition maturation throughout Phase B

Backup

Power by Mode

ISIS	Hi CBE	Hi Uncty	Hi Total	Lo CBE	Lo Uncty	Lo Total	ISIS Total
Instrument Power (W)	5.81	0.96	**6.77**	4.17	0.83	**5.00**	**11.77**
Operational Heaters (W)	0.48	0.07	**0.55**	0.00	0.00	**0.00**	**3.47**
Survival Heaters (W)	3.81	0.57	**4.38**	2.45	0.37	**2.82**	**7.20**
Totals:	**10.10**	**1.60**		**6.62**	**1.20**		

Function	Power Service	Peak Current	Max Load Dissipation (CBE+Uncertainty) by Mode				
		(A)	(W)				
		EPI-Lo Modes:	*Survival*	*WarmUp*	*Boot*	*Non-Encounter*	*Encounter*
EPI-Lo	Main Power	0.208 @ 24V	0.00	0.00	2.00	5.00	5.00
	Survival Heater Power, 121 Ω eq. res.	0.271 @ 33V	2.82	5.56	3.00	0.00	0.00
		EPI-Hi Modes:	*Survival*	*WarmUp*		*Non-Encounter*	*Encounter*
EPI-Hi	Main Power	0.282 @ 24V	0.00	0.00		6.77	6.77
	Survival Heater Power, 87 Ω eq. res.	0.378 @ 33V	4.38	7.74		0.00	0.00
	Operational Heater Power, 1056 Ω eq. res.	0.031 @ 33V	0.00	0.00		0.55	0.55

- ISIS Current Best Estimates and Uncertainties
- ISIS Power by Mode and service
- EPI-Lo has a low-power Boot safe-hold mode in which survival heaters are used as operational heaters to maintain instrument above Cold Op. temps
- EPI-Hi is either on or off
- During Survival, heater power is duty cycled to ensure instrument stays above survival temperature
- During Warm-up, heater has a 100% duty cycle to warm the instrument prior to normal operations (Encounter Mode)

Solar Probe Plus

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Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

EPI-Lo Sensor Design

Ralph McNutt

EPI-Lo Lead Co-I (JHU/APL)

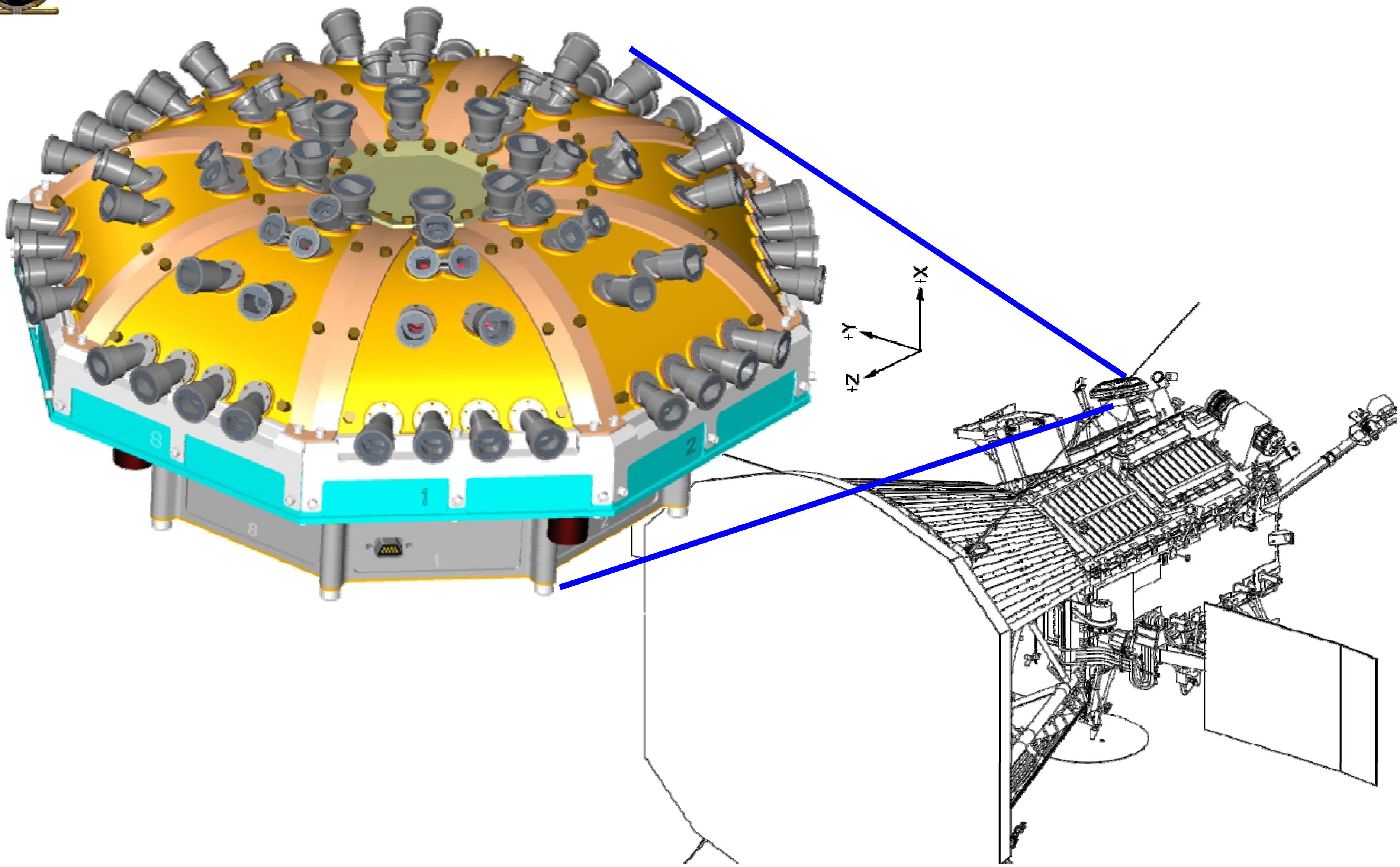
Outline

- Requirements
- Placement
- Cross-Section
- Fields of View
- Ions
- Electrons
- Energy Distribution
- Microchannel Plate (MCP)
- Block Diagram
- Collimators and Start Foils
- Anti-Coincidence System
- Light and Dust Mitigation
- Follow-up from Peer Reviews
- Summary

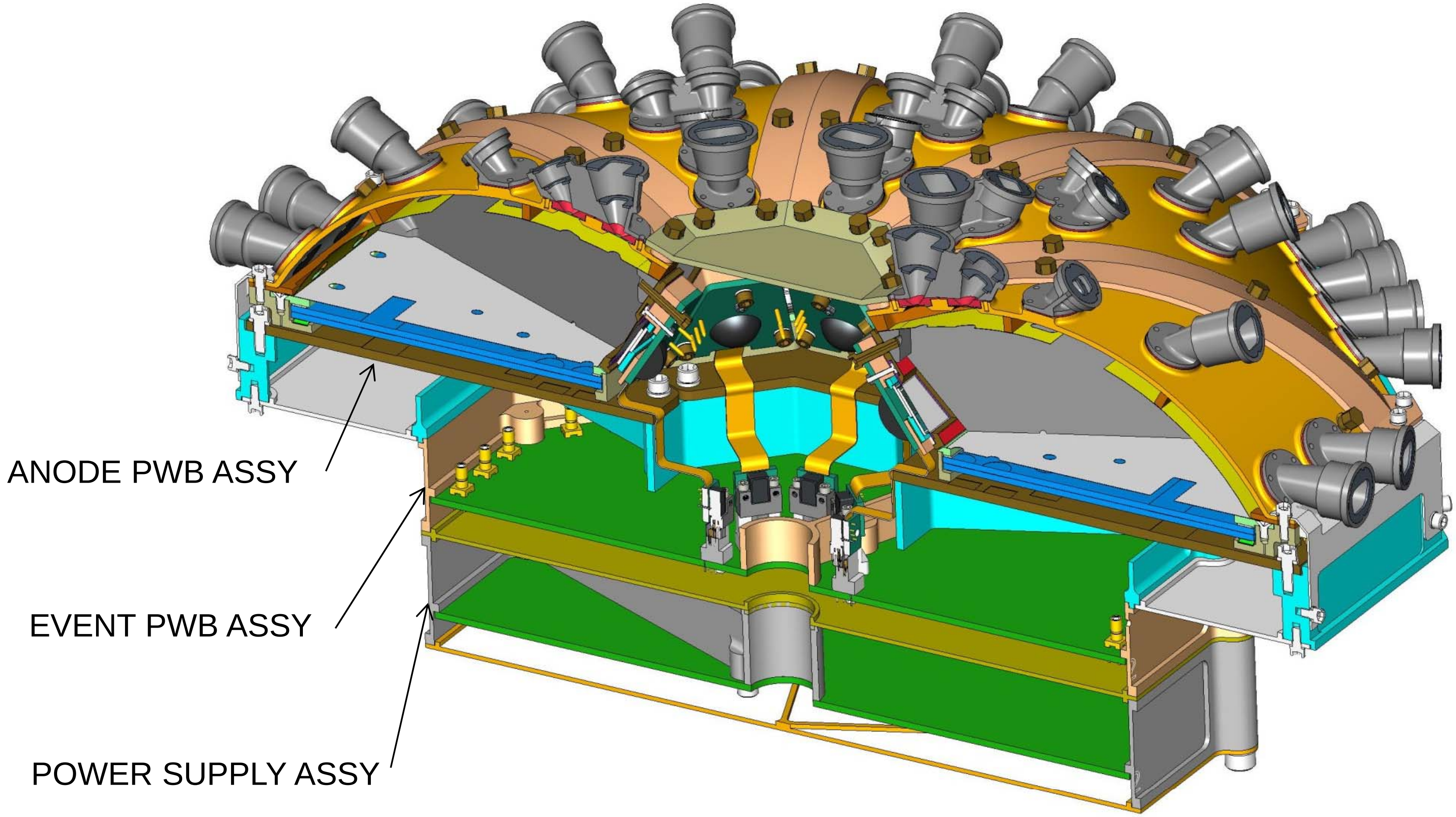
The EPI-Lo Instrument Requirements

Parameter	Required	Goal (Capability)	Comment/Heritage
Electron Energies	50 – 500 keV	25 - 1000 keV	Electron capability from JEDI, RBSPICE
Ion Energies	50 keV/nucleon – 15,000 keV Total E	50 keV/nucleon – 15,000 keV Total E	Capability based on that of RBSPICE. Maximum energy ~250keV/nuc for Fe
Energy Resolution	45% for required energy range	40% for required energy range	Telemetry limited
Time sampling	5 sec	1 sec	Telemetry and/or statistics limited
Angle resolution	<30° x <30°	Ions, ~15° x 12° to <30° x <30° e-, 45°	Varies with elevation
Pitch Angle (PA) Coverage	0° -90° or 90° -180° , some samples in both hemispheres	0° -90° or 90° -180° , some samples in both hemispheres	
Time for Full PA	1 – 5 sec	1 – 5 sec	Telemetry limited
Ion Composition	H, ^{3}He, ^{4}H4, C, O, Ne, Mg, Si, Fe	H, ^{3}He, ^{4}He, C, O, Ne, Mg, Si, Fe	^{3}He / ^{4}He ~50 to 1000 keV/nuc
Electron Sensitivity	j = 10-10^{6} / cm^{2}-s-sr	Sensor-G:0.144 (cm^{2}.sr) Pixel-G: ~0.02 (cm^{2}.sr) Up to 6x10^{6} 1/s counting	j=Intensity (1 / cm^{2}-s-sr) G=Geometric factor (cm^{2}-sr) 8 pixels/sensor
Ion Sensitivity	j = 10-10^{6} / cm^{2}-s-sr	Sensor-G:0.16 (cm^{2}.sr) Pixel-G: ~0.002 (cm^{2}.sr) Up to 3.5x10^{6}/s rate (TOF x E)	80 pixels/sensor

EPI-Lo Instrument Placement

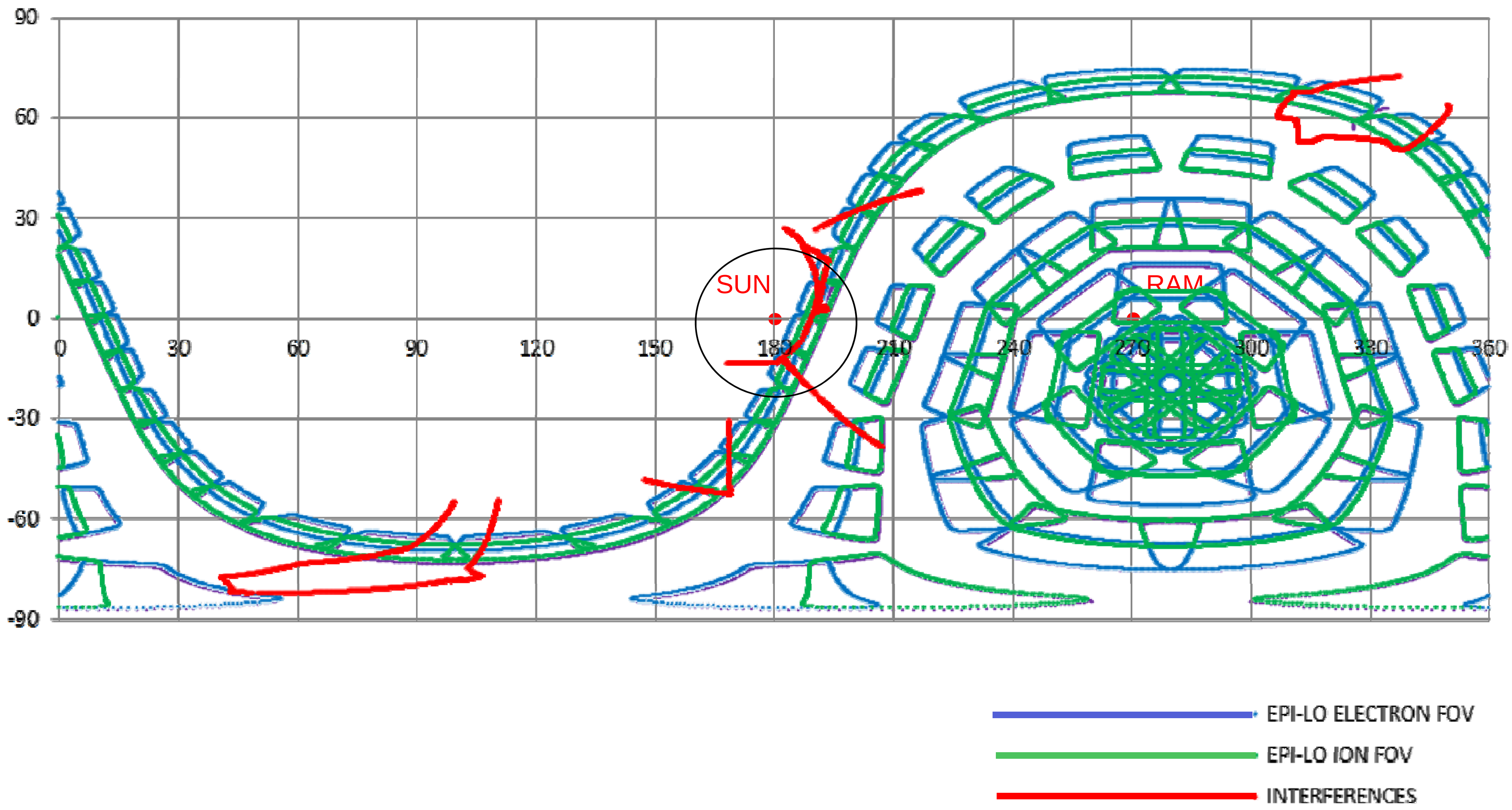


EPI-Lo Instrument Cross Section

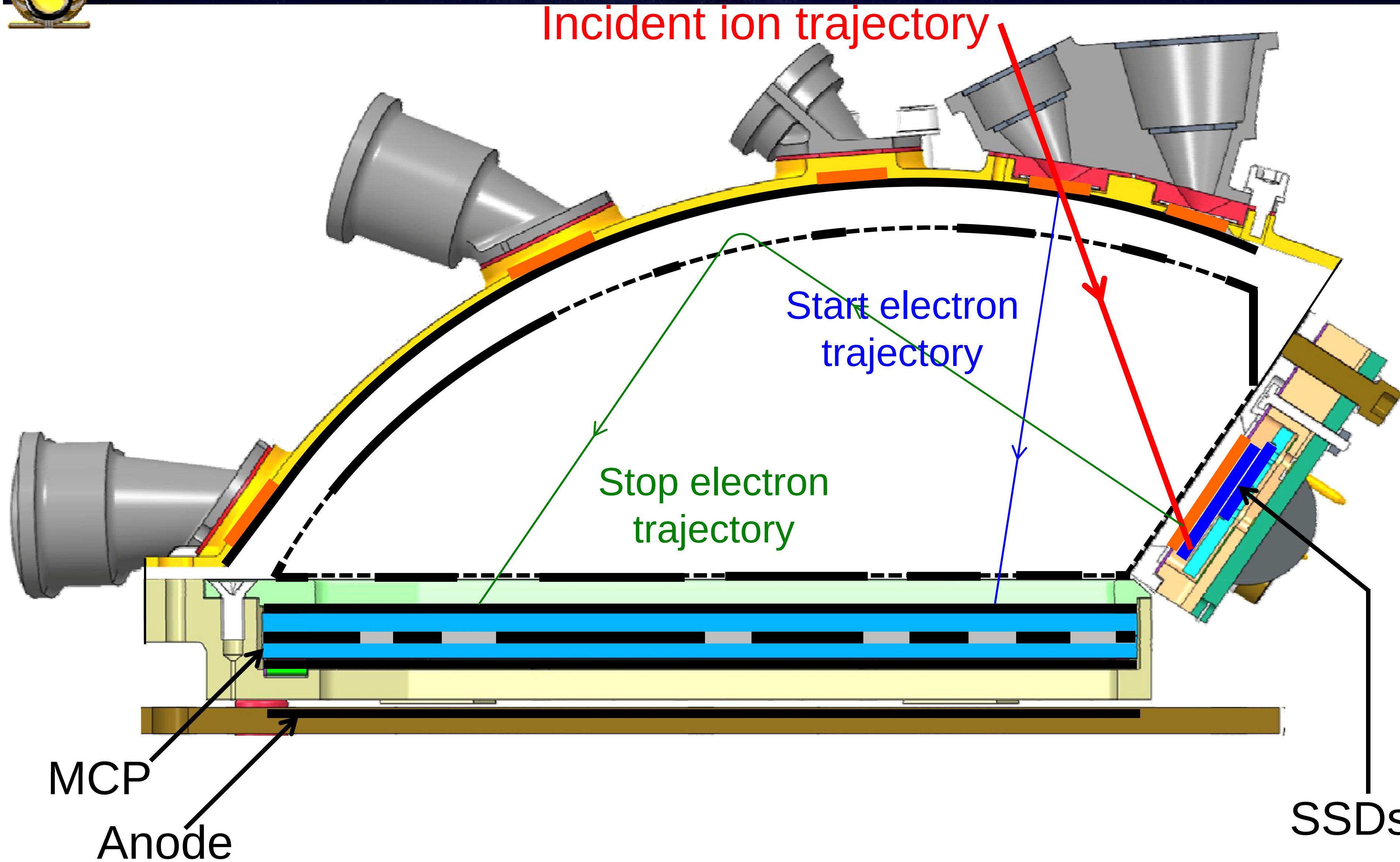


EPI-Lo Cross-Section View Isometric

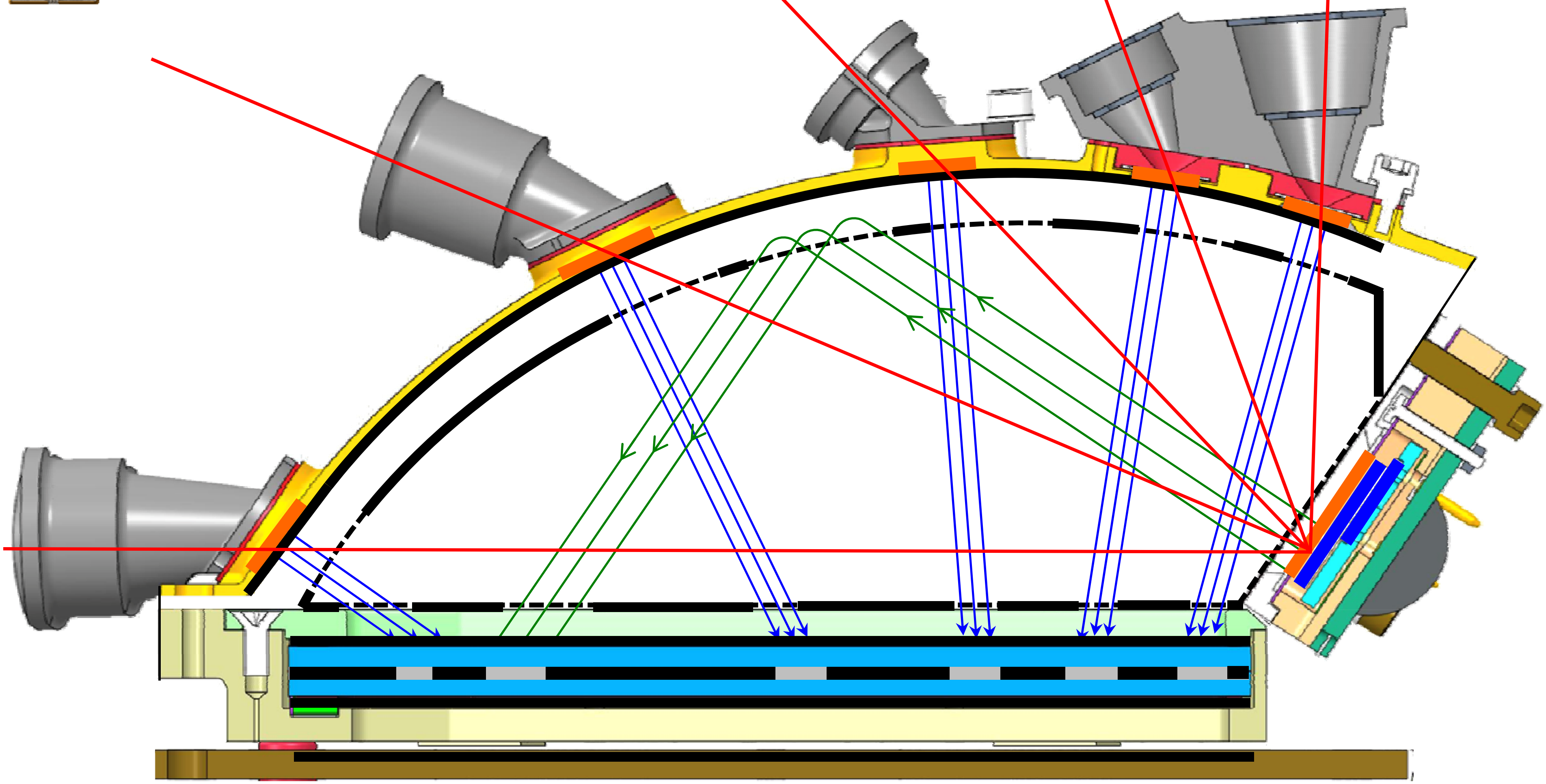
EPI-Lo Field(s) of View



Ions (Energy, TOF, and Position)

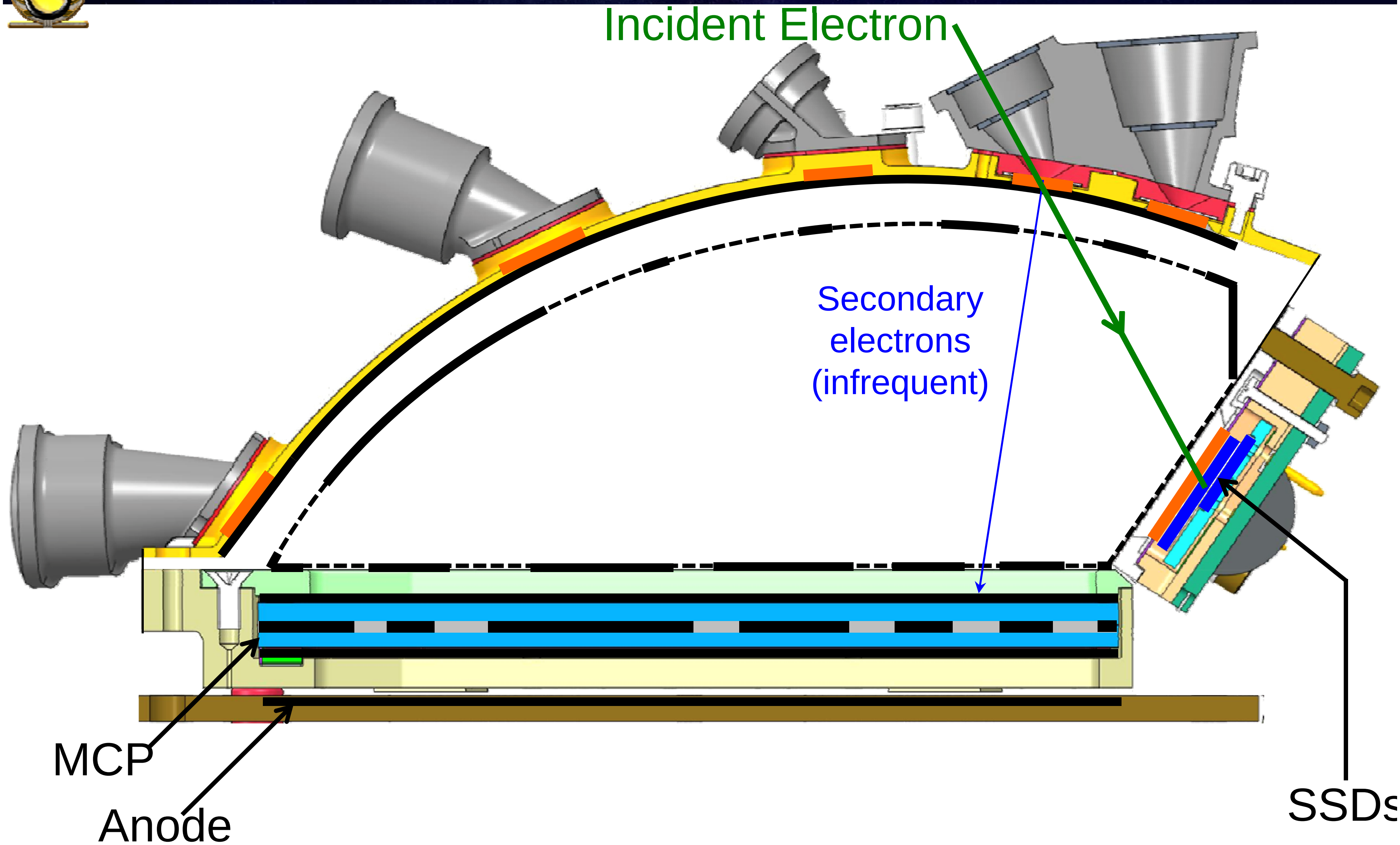


Energetic Ion Measurements

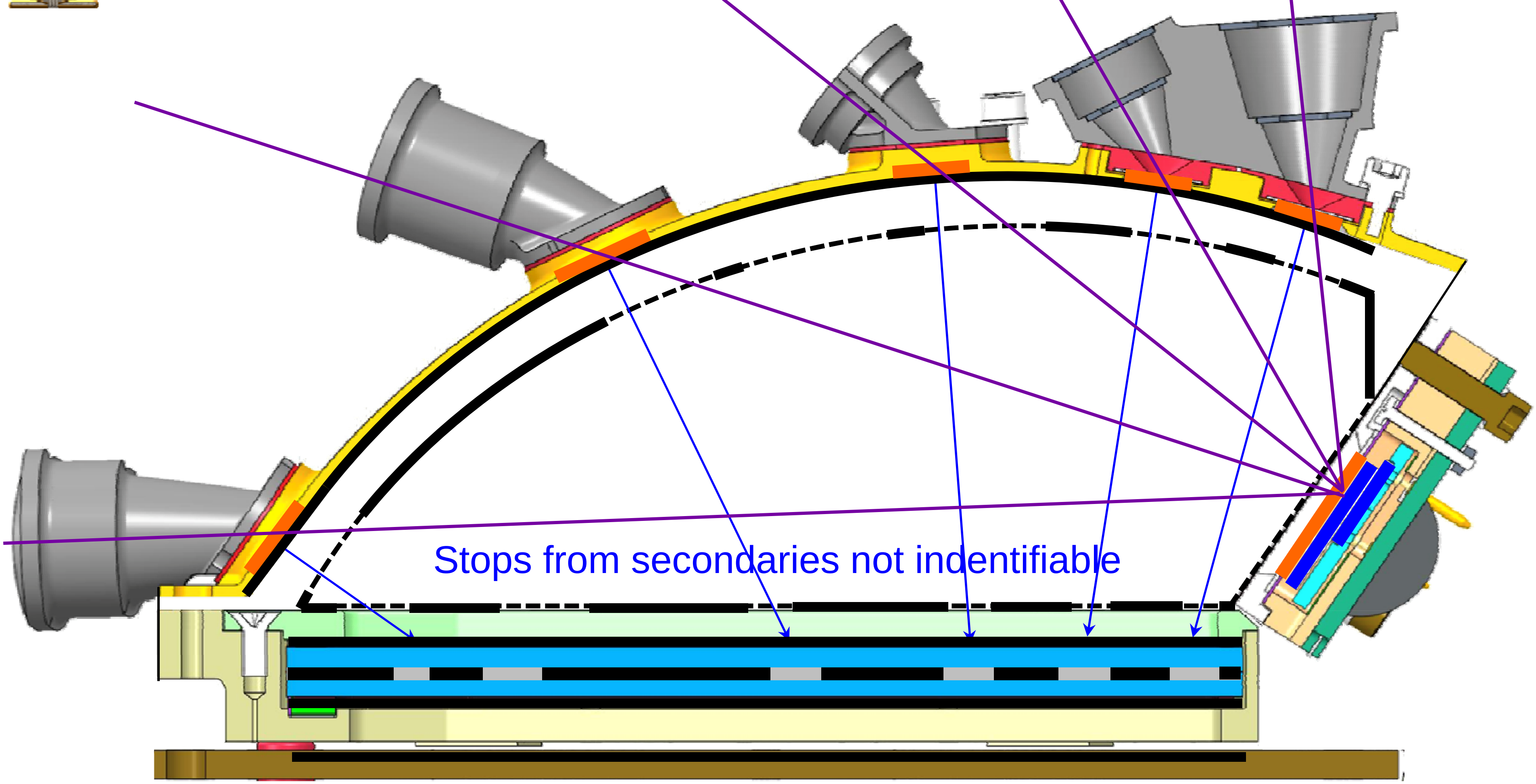


Ion Measurement Logic can toggle TOF, but no TOF ➔ no species identification

Electrons: Energy (& Position)

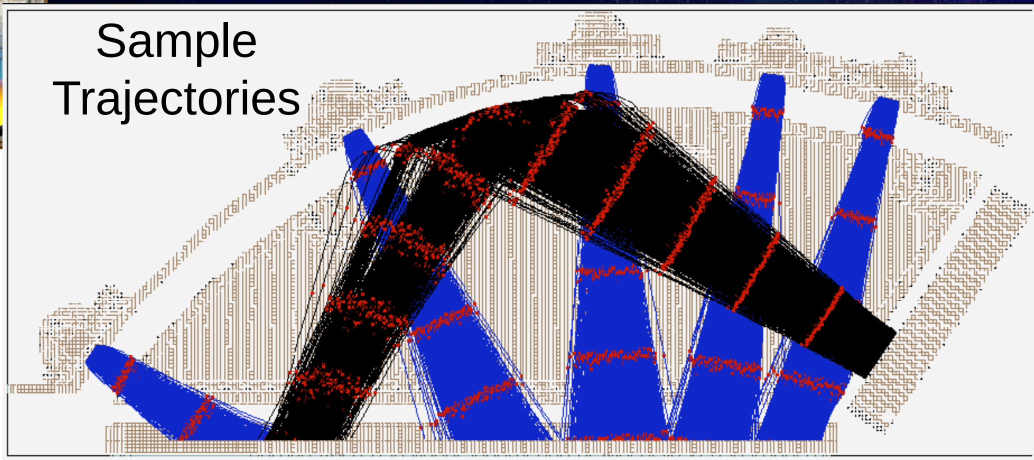


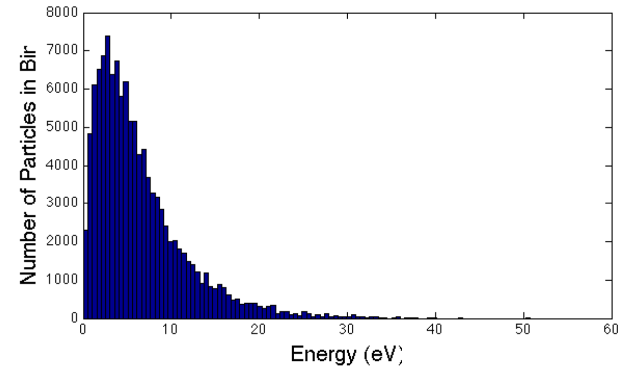
Energetic Electron Measurements

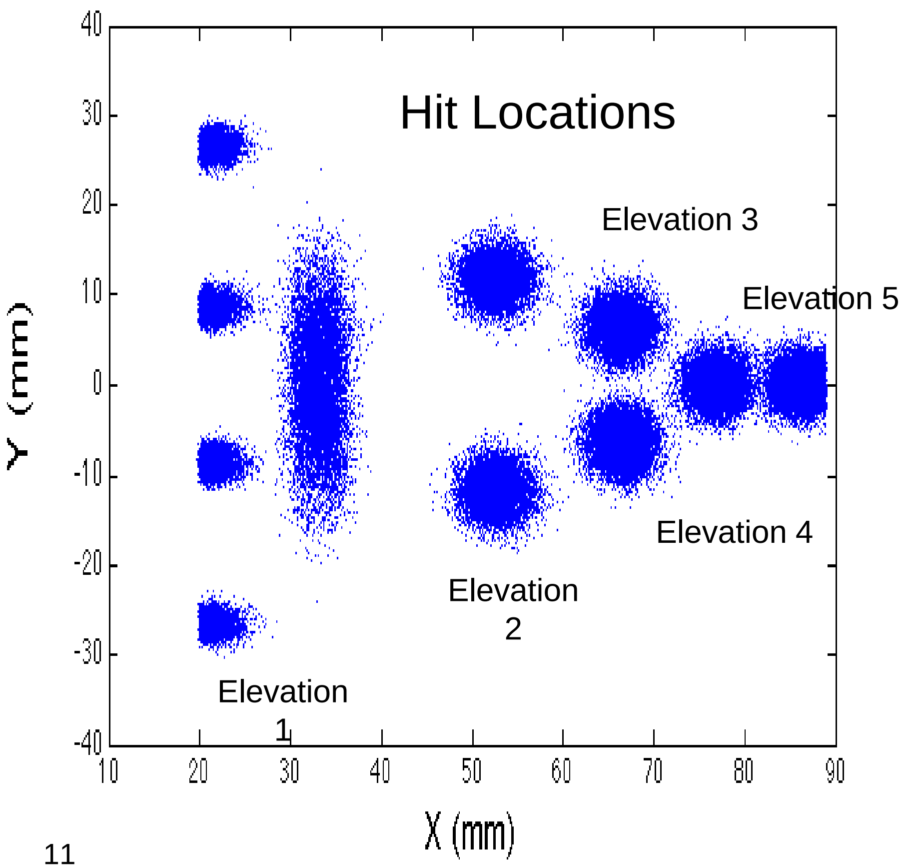


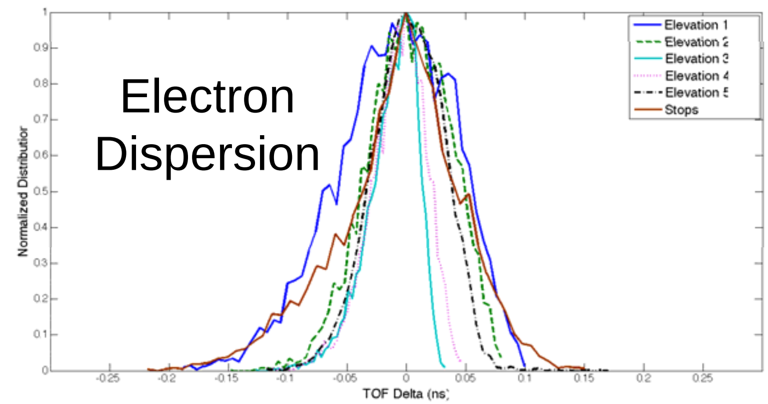
Secondary Electrons from Start Foils possible, but Low Probability;
Start Electron only identifies entrance aperture

SIMION, Allegrini Energy Distribution



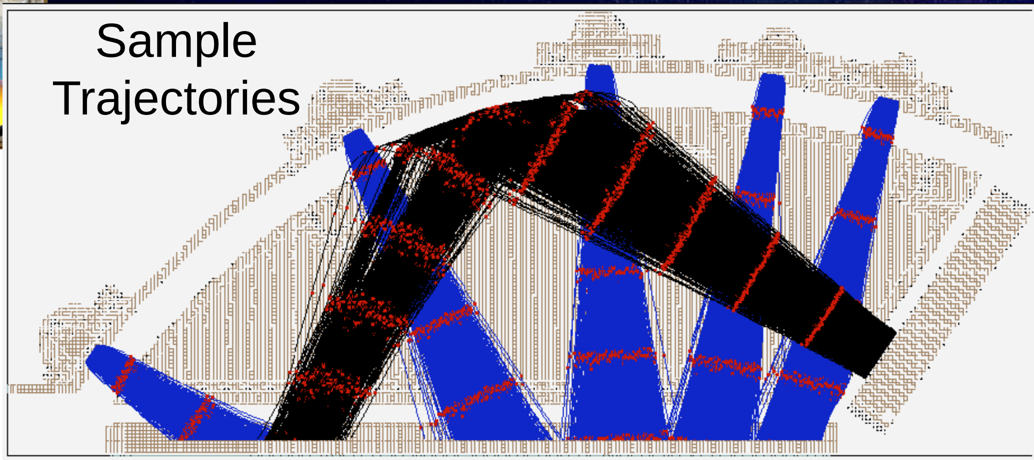


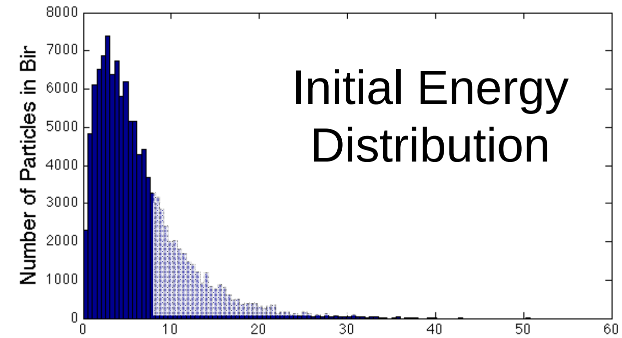


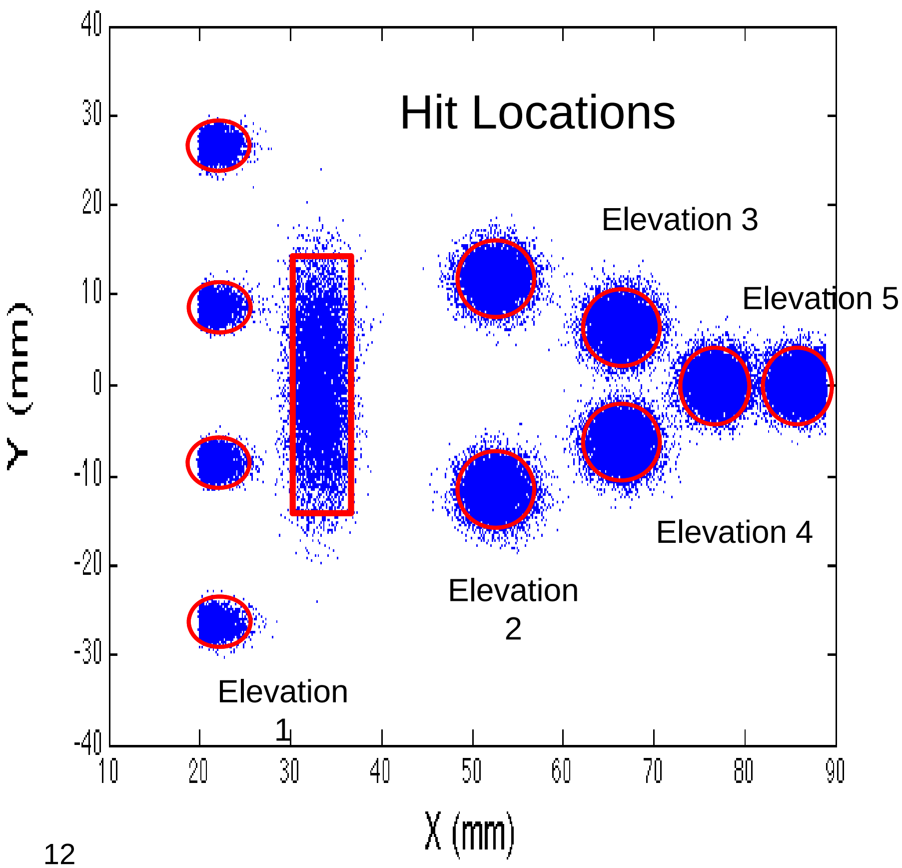


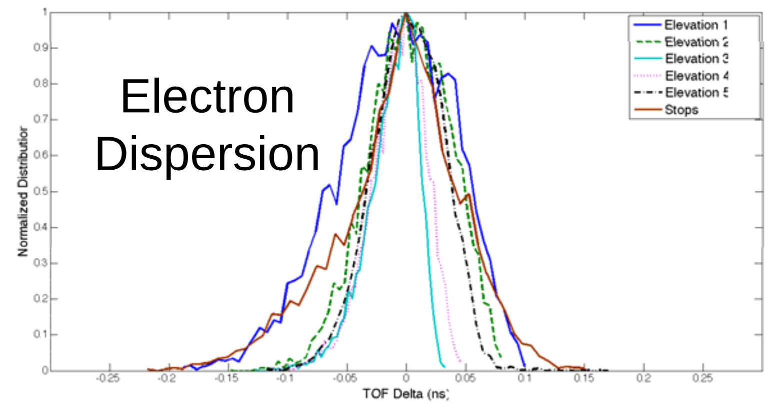
Name	Mean TOF (ns)	FWHM (ns)
Elevation 1	0.93	0.12
Elevation 2	2.12	0.08
Elevation 3	2.35	0.04
Elevation 4	2.32	0.05
Elevation 5	2.26	0.08
Stops	5.23	0.09

SIMION, Allegrini Energy Distribution









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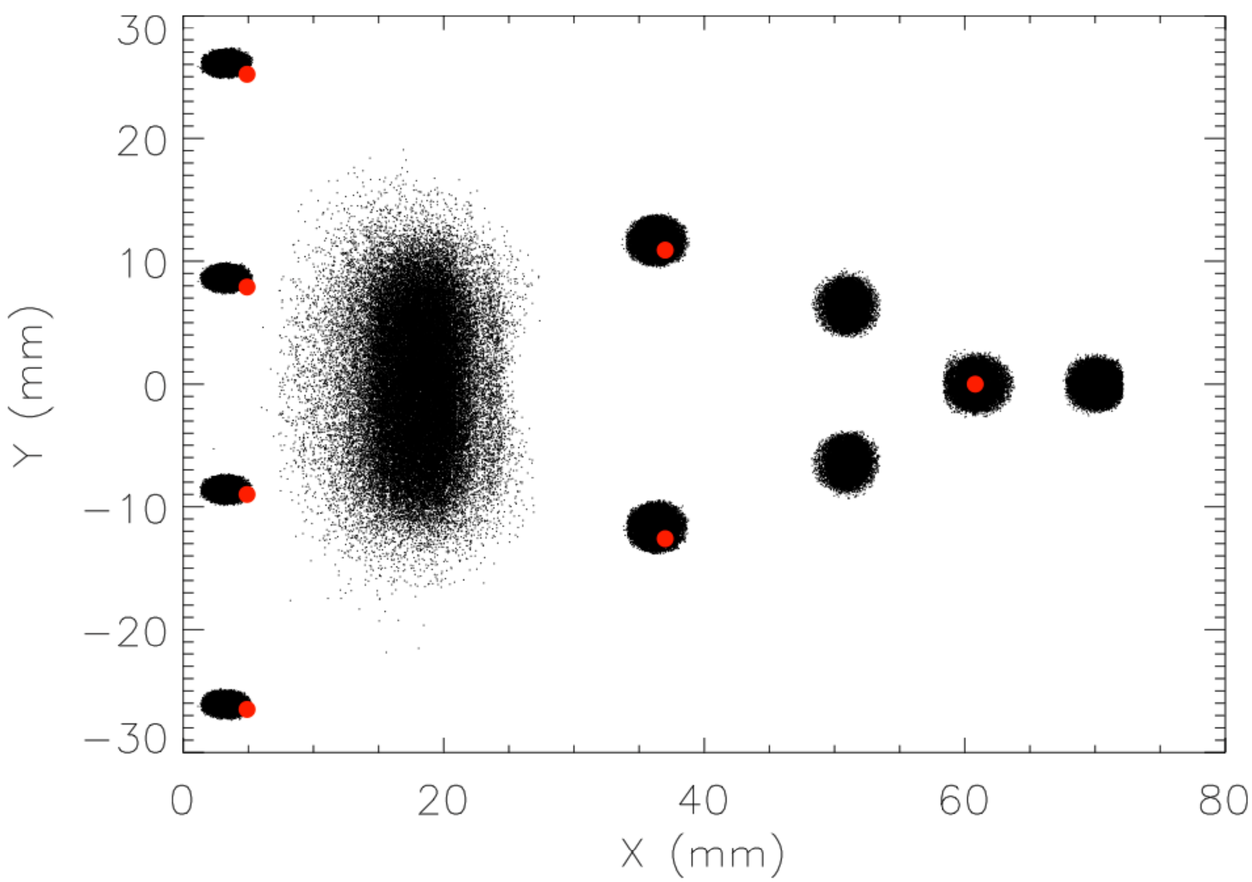
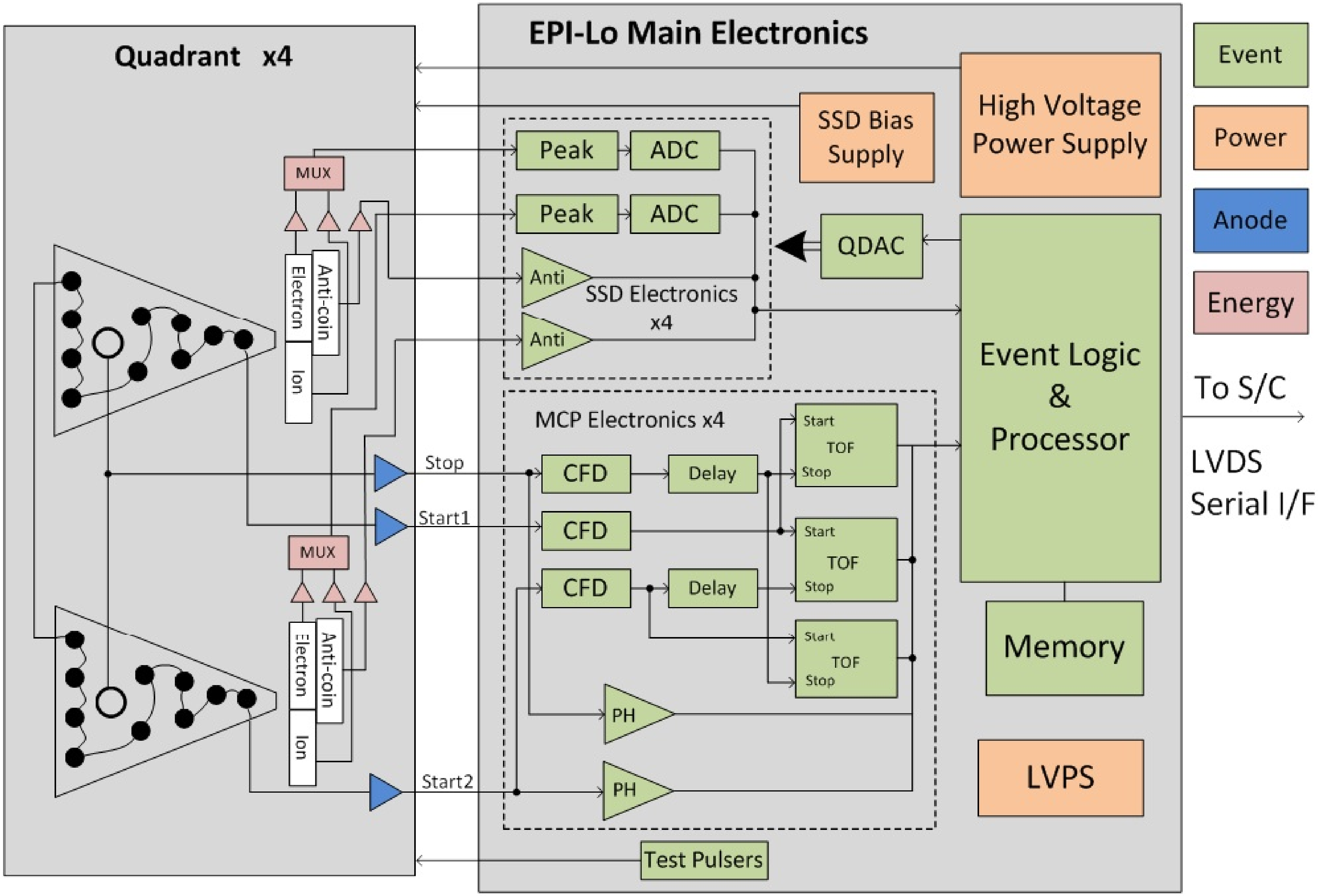
Stops	5.23	0.09

Microchannel Plate (MCP)

- Simulation (black) versus measured centroids (red)
- The misalignment in Y-direction was due to a registration offset in the setup
- The offset in the X direction for the left-most data was caused by an obstruction at the edge of the MCP mount that has since been eliminated



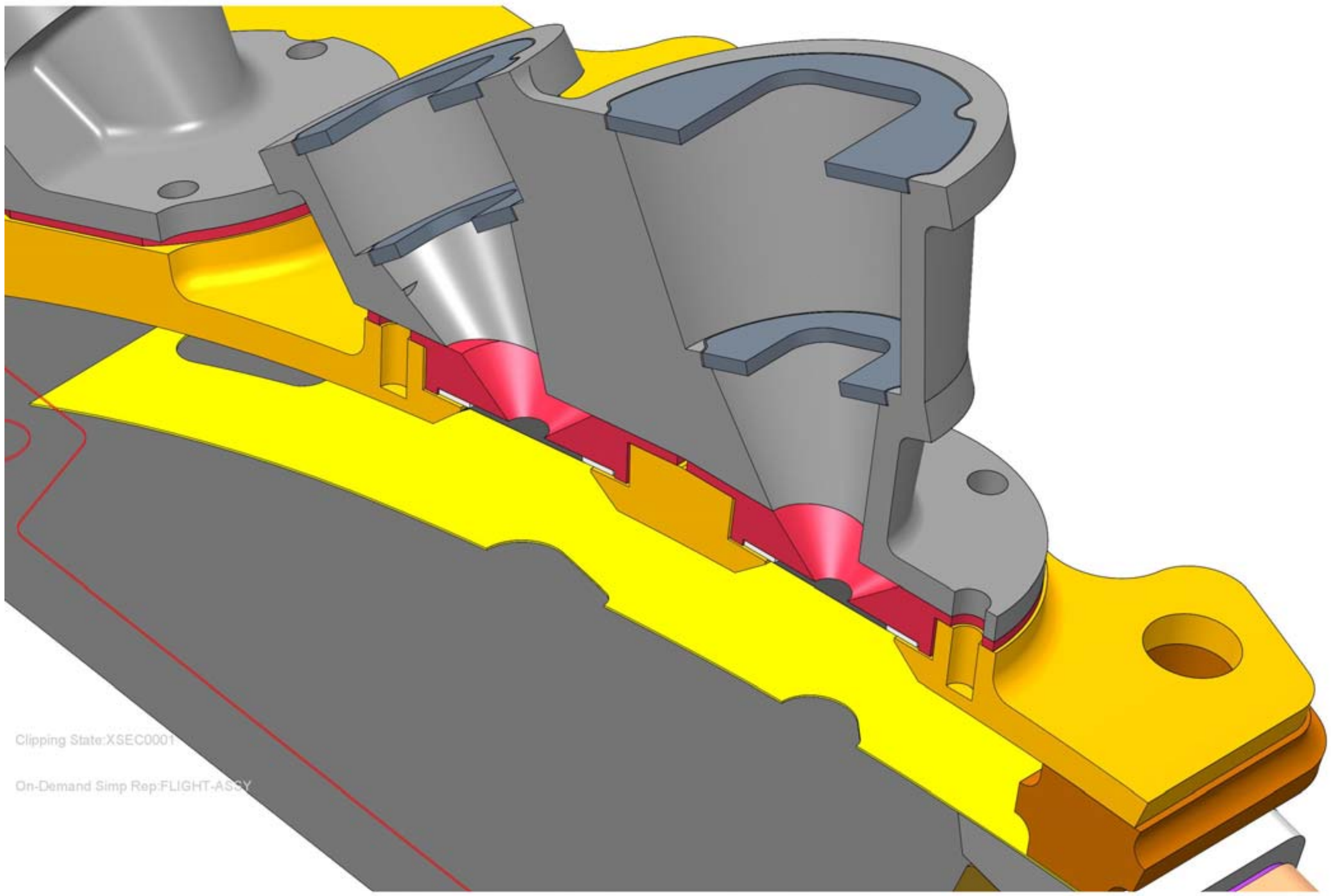
EPI-Lo Block Diagram



Collimators and Start Foils

- Foils Mount on Apertures (red)
  - Each elevation tailored for equal geometric factors
  - Second foil at intermediate baffle (vented)

- Collimators screw-mount to outer cover, capture foils
  - Each elevation and azimuth is unique



Anti-coincidence System

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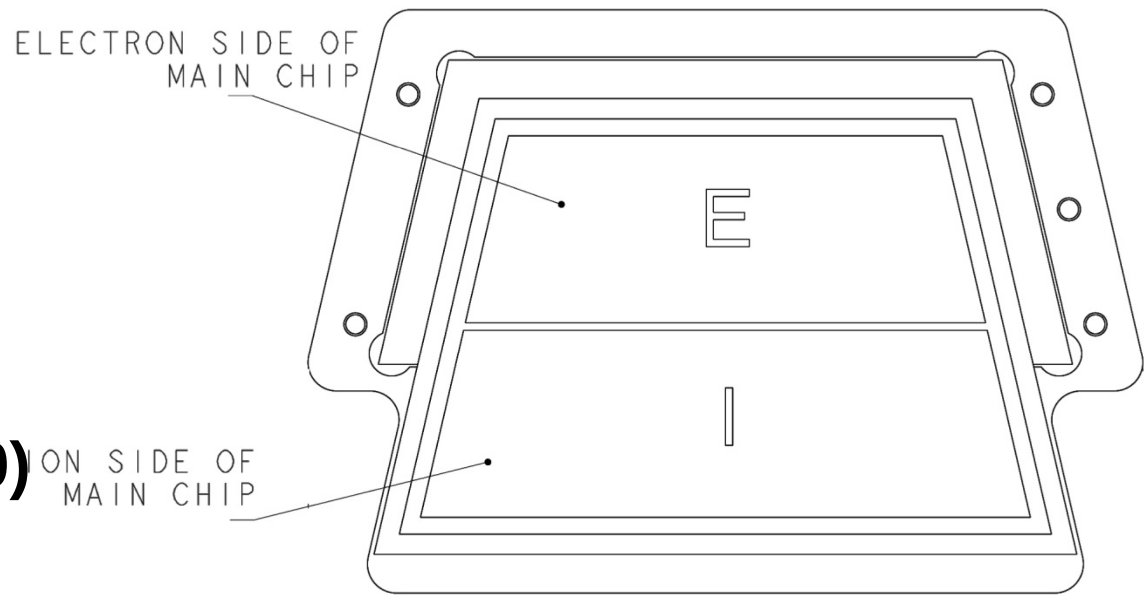
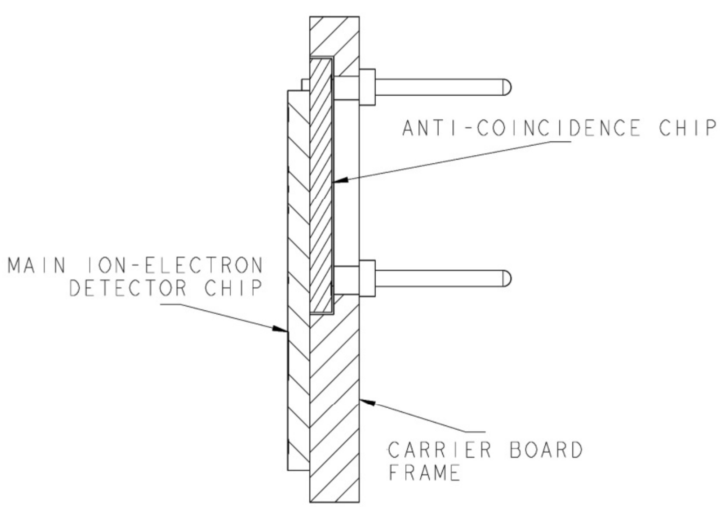
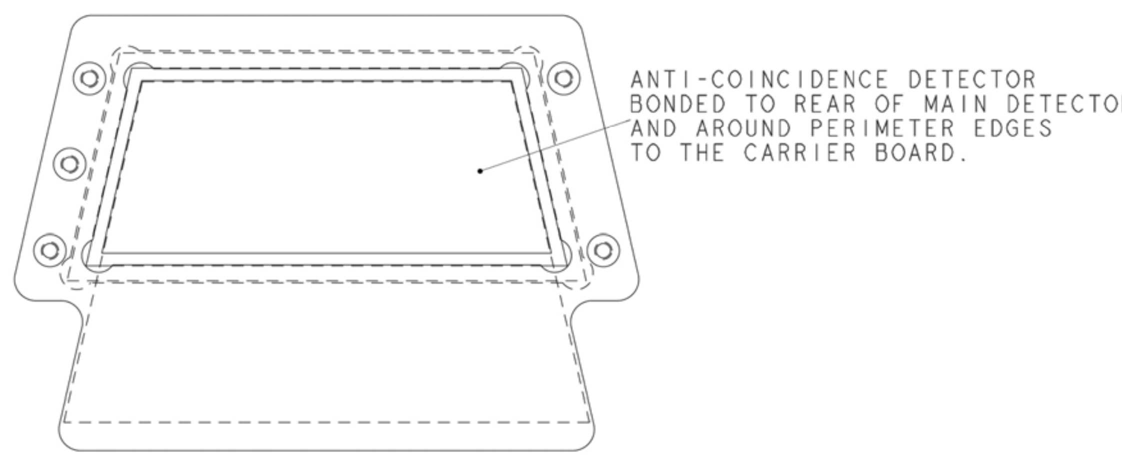
- **Electron SSD is backed by an anti-coincidence SSD**
- **Improves S/N for electrons by a factor ~25 (from ~0.4 to ~10)**







Anti-coincidence System: GEANT Setup

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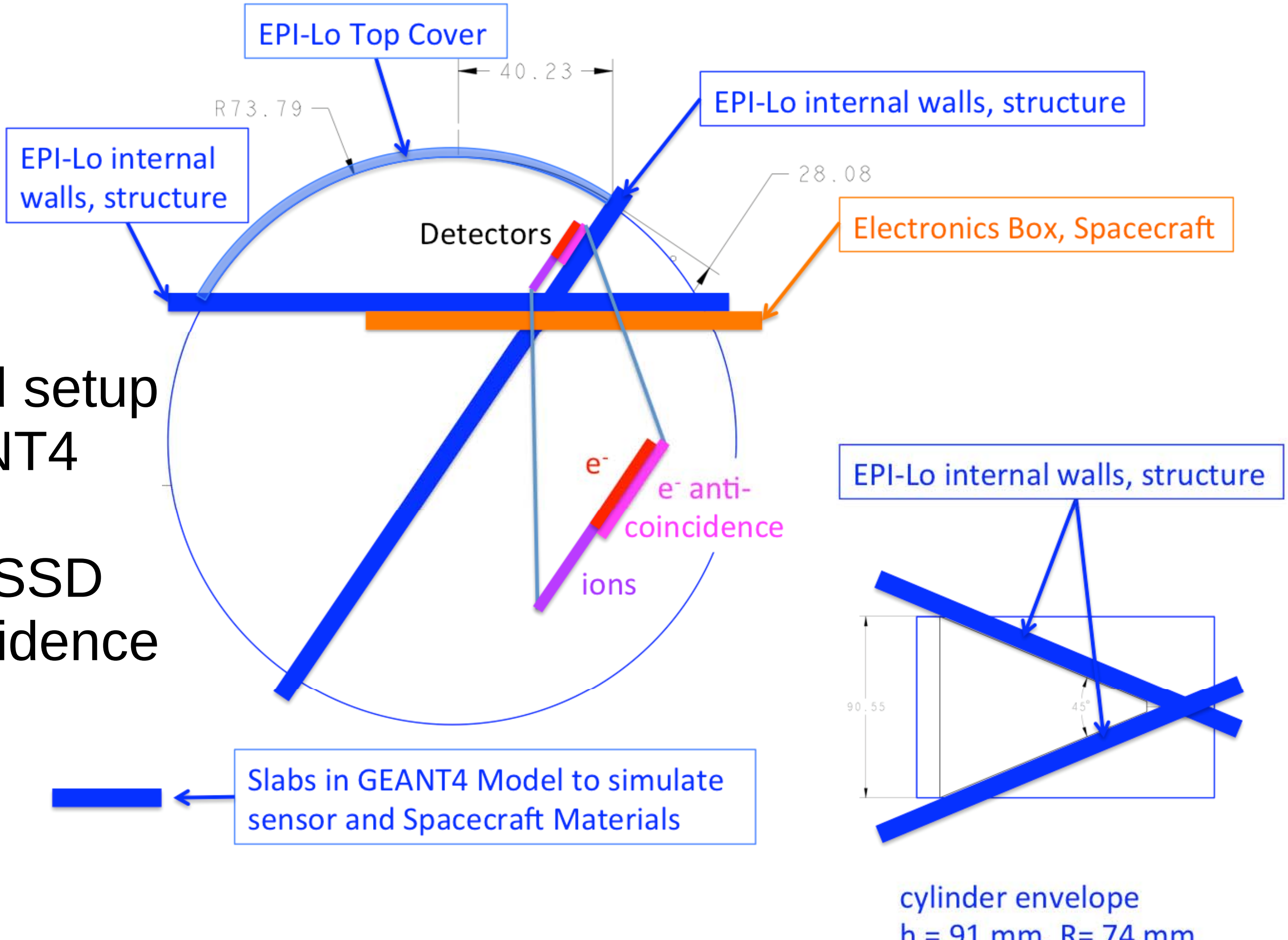
- Improved setup for GEANT4 model of electron SSD anticoincidence



EPI-Lo Simplified Wedge Cover

Anti-coincidence System: GEANT Results

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Assumed electron flux of j(E) ~ $E^{-2.65}$ from ~10 keV to ~5 MeV

Penetrator rejection efficiency range from 83% to 95% from 1 MeV up to 10 MeV incident electron energy

Following peer review result of S/N of ~3 for foreground electrons with anti-coincidence, higher fidelity sensor model yields S/N ~10

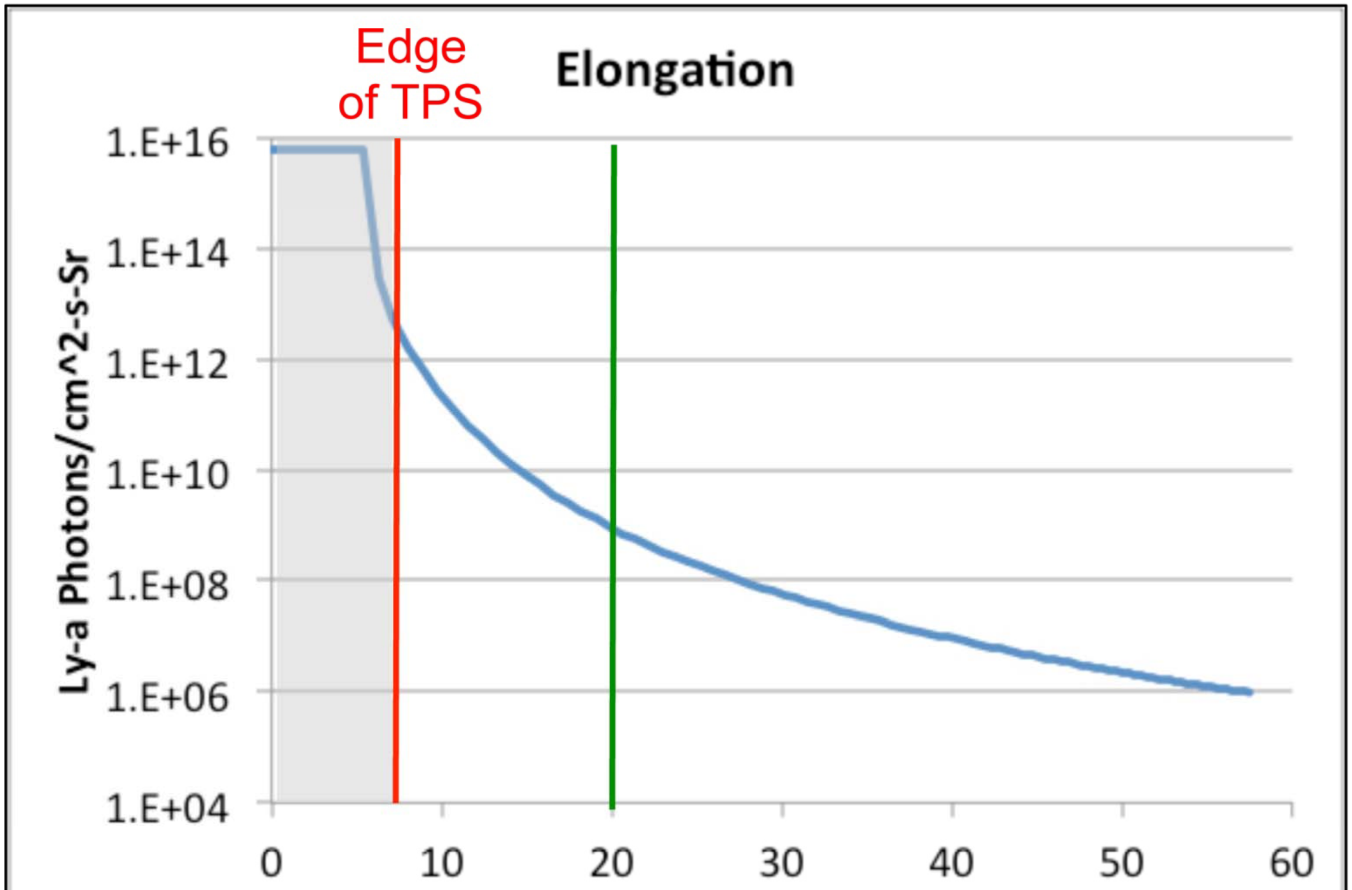
New GEANT model accounts for more realistic geometry and extra shielding by structure

Only ~1% of electrons below 2 MeV penetrate to detectors in this model

Light and Dust Mitigation (1/2)

- Dust may produce pinholes in the Start and collimator foils.
- Foils are designed to reduce UV by ~3 orders of magnitude.
- Pinholes may account for as much as ~0.4% of a foil area.

- For the 4 foils closest to the TPS edge, the suppression factor must be ~4 orders of magnitude. For these, pinholes are important to UV suppression.



- Intensity of Ly-α EUV vs elongation. Most EPI-Lo entrances at >20 degrees elongation
- 4 apertures near the TPS 8-20 degrees, max UV ~10^{12}, average ~10^{10}.

Light and Dust Mitigation (2/2)

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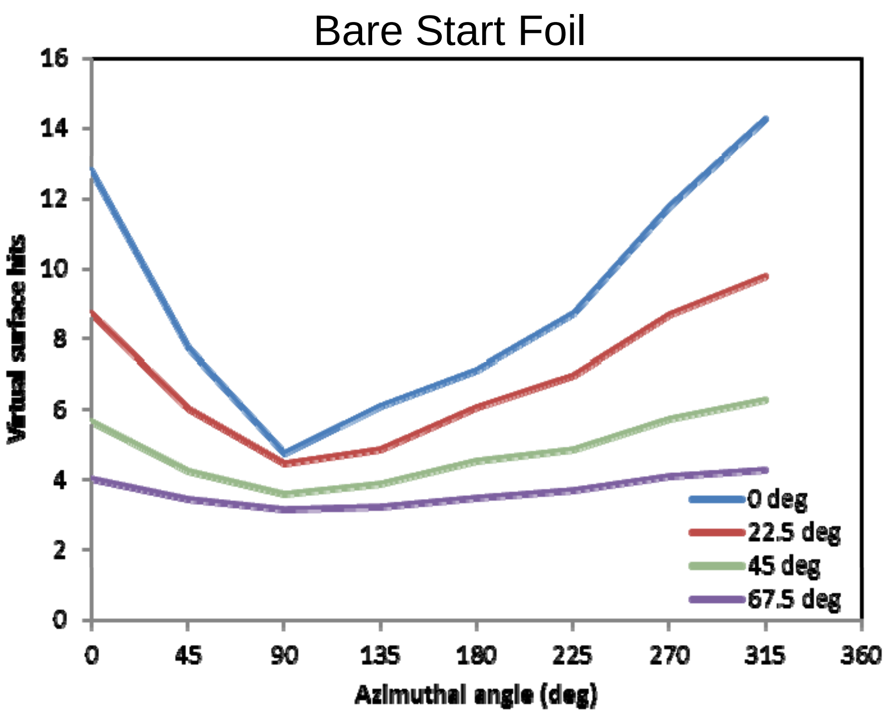
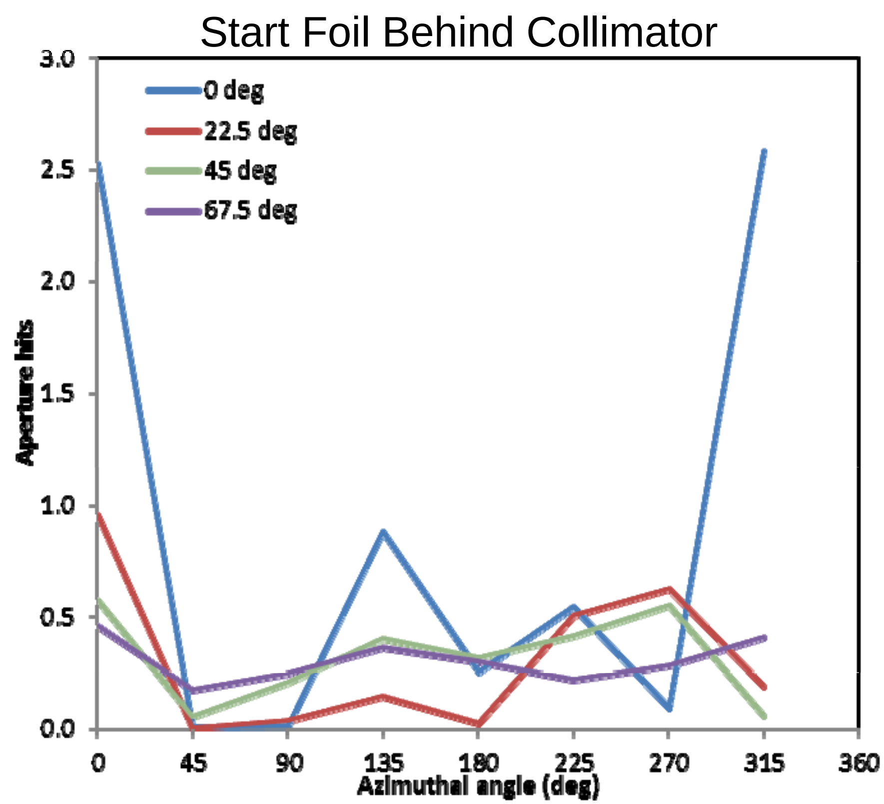
- Dust may produce pairs of pinholes in the Start and collimator foils
  - Foils are designed to stop solar-wind-energy electrons
  - Pinhole pairs allow will still allow access to solar-wind electrons
- Solar wind electrons have an energy of ~100 eV or less
- Electrons that “leak in” through apertures are indistinguishable from Start secondary electrons
- Solar wind electron flux ~2 x 10^{12}/cm^2-s-sr
- Estimate foil pinhole as size of a support grid element is ~4.9 x 10^{-5} cm^2
- Geometric factor of a pair of pinholes separated by ~0.5cm is ~1.3 x 10^{-8}
  - The flux through a pinhole pair can be estimated as ~2.6 x 10^4/s
  - If every aperture had 1 grid-element pinhole, the total for a quadrant would be ~5.0 x 10^5/s
  - This rate would be well tolerated by the electronics processing
- Such a pinhole pair would result in UV induced counting rates ~10/s

Dust: Simulating the Environment

- Expect ~10 damage-inducing hits on each unprotected foil during entire mission
- Reduced to ~1 hit per mission with collimator
- Can lower further with pairs of pinholes





Follow Up from Peer Review

Area of Concern/Action	Resolution/Comment	Status
1. Photoelectron flux false starts.	Second start foil reduces flux of e- accelerated.	Closed
2. MCP count rate density > 1 MHz/cm2	Simulations show density below this.	Closed
3. Rates, S/N, efficiency compilation.	Draft closure memorandum complete 10/25/2013	Closed
4. Electron measurement poor S/N.	Higher resolution GEANT runs completed	Closed
5. Incorrect plug power co-ax.	Use labeling and/or color-coding.	Closed
6. Alternate internal e- noise sources.	In equipotential 100 V retarding potential rejects e-	Closed
7. Reject false signals w/ redundant info.	Consistency checks will be done b/w 3 TOF chains.	Closed
8. In-flight pulser for rate correction.	Mewaldt et al, Space Sci Rev (2008) 136:285-362.	Closed
9. HV discharge secondary effects.	Addressed by design and testing	Closed
10. Fasteners w/o locking features.	Locking inserts, Bellville washers, etc. added.	Closed
11. Wishbone webbing field deformation.	Webs removed, extra 0-1kV surface length added.	Closed
12. Bonded external baffles allowed?	Preliminary answer is yes; final requires thermal specs	Closed
13. EPI-Lo/Hi electron energy gap.	Additional GEANT simulations complete	Closed
14. Thicker foil effect on lookup tables.	Not a problem on board, just science interpretation.	Closed
15. Dual foils near sun handle pinholes.	Second foil is under consideration.	Closed
16. Neutrals/photoelectrons/plasma bkg.	Solar wind electron fluxes cut-down by dual foil.	Closed
17. Auto use of extra data allocation.	Too complicated to implement.	Closed
18. Spare MCP assembly plans.	Spares plan held at ISIS level.	Closed
19. Vent back cover of SSD assembly.	Vent is added.	Closed
20. Mounting structure for tags/handling.	Plan is in place.	Closed
21. How are foils marked/serialized?	Labels laser etched prior to assembly.	Closed
22. Sensor purging plan.	Purge IN in center and vent OUT in each octant.	Closed

Summary

- EPI-Lo Sensor development is on schedule and on budget
- Peer review held and action items have been responded to
  - 22 items
  - All closed
  - Sensor design and approach are matured through Technical Readiness Level 6:
    - **System/subsystem model or prototyping demonstration in a relevant end-to-end environment (ground or space):** Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.

- Ready to proceed to Phase C

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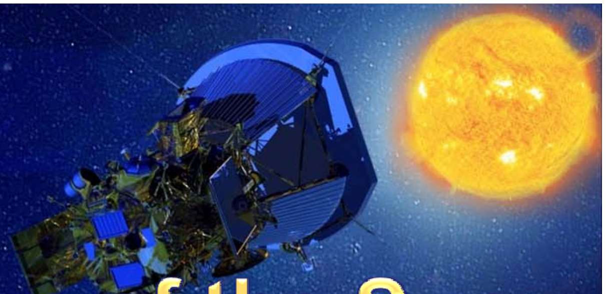

Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

EPI-Lo Technology Development

Reid Gurnee

EPI-Lo SE (JHU/APL)

Outline

Solar Probe Plus
A NASA Mission to Touch the Sun

- EPI-Lo Technology Developments to TRL6
- Performance Requirements and Derivation
- Energy System Development
  - Fidelity of Test Article
  - Test and Analysis Results
- Sensor / Timing System Development
  - Fidelity of Test Article
  - Test and Analysis Results
- TOF-D/CFD-D ASIC Development
  - Fidelity of Test Article
  - Test and Analysis Results
- Transition to Flight

EPI-Lo Technology Developments to TRL6

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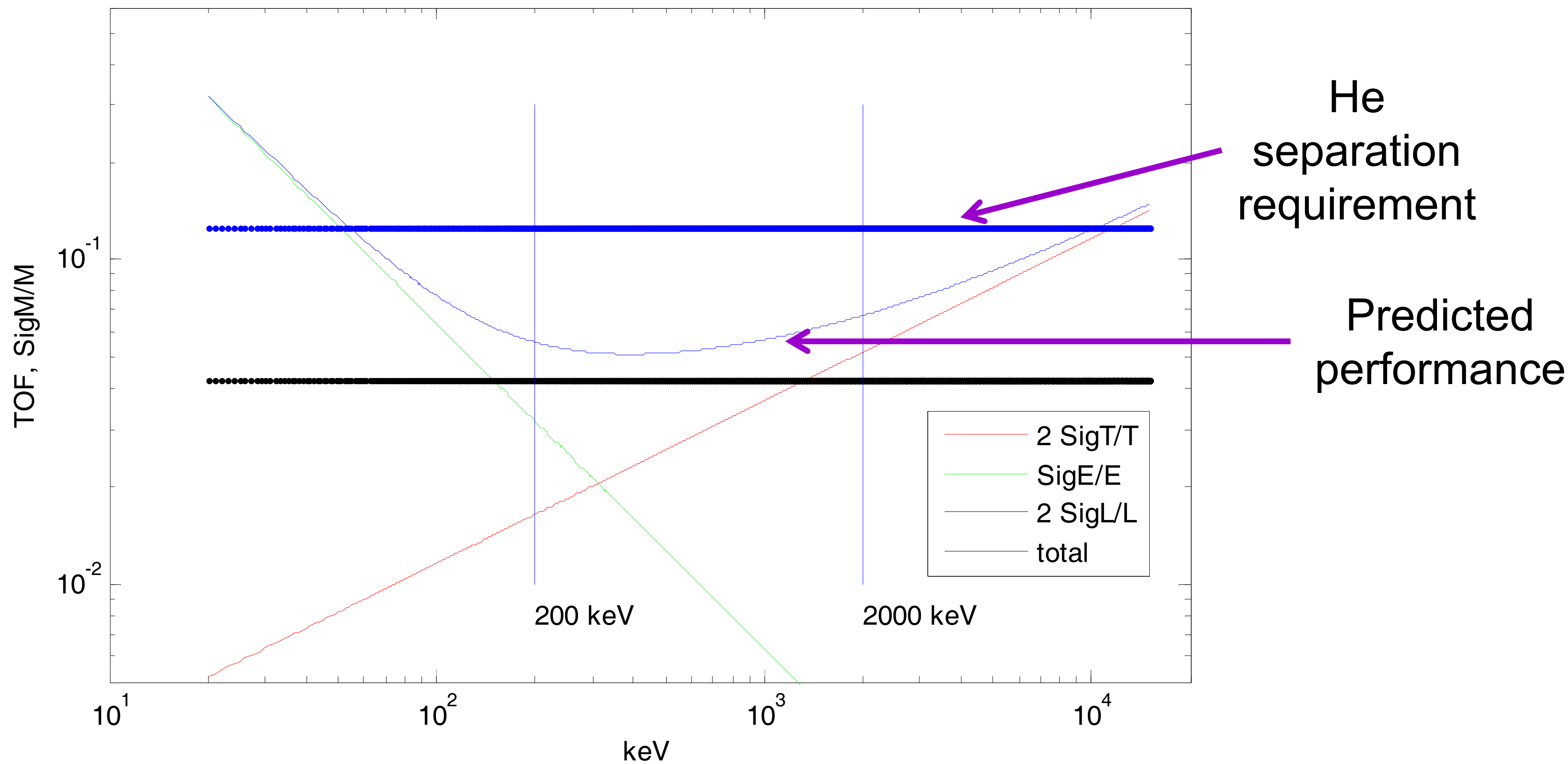
- Species composition driven by two systems: energy system and timing system
- Energy and TOF performance to meet 3He / 4He separation
  - 3He, 4He: 0.5 FWHM AMU
    for incoming energies between ≤0.2 MeV and ≥2.0MeV
  - Validate that one anode covering two sensors has adequate timing performance – quadrant anode design uses significantly less readout electronics than an octant design
  - Validate that SSD has adequate energy performance
- TOF-D and CFD-D ASIC development

EPI-Lo Performance Modeling

- Two independent models used
  - Monte-Carlo
    - Inputs are timing noise, SSD noise, and path length variation
    - Inputs can by any distribution (not limited to Gaussian)
  - Analytical
    - Inputs are timing noise, SSD noise, and path length variation
    - All inputs are Gaussian
  - The two models have been compared and shown to give identical results
  - Does not include foil losses (not significant for >200 keV He)
- **Modeling shows 400 ps FWHM, 15 keV FWHM performance comfortably meets requirements**

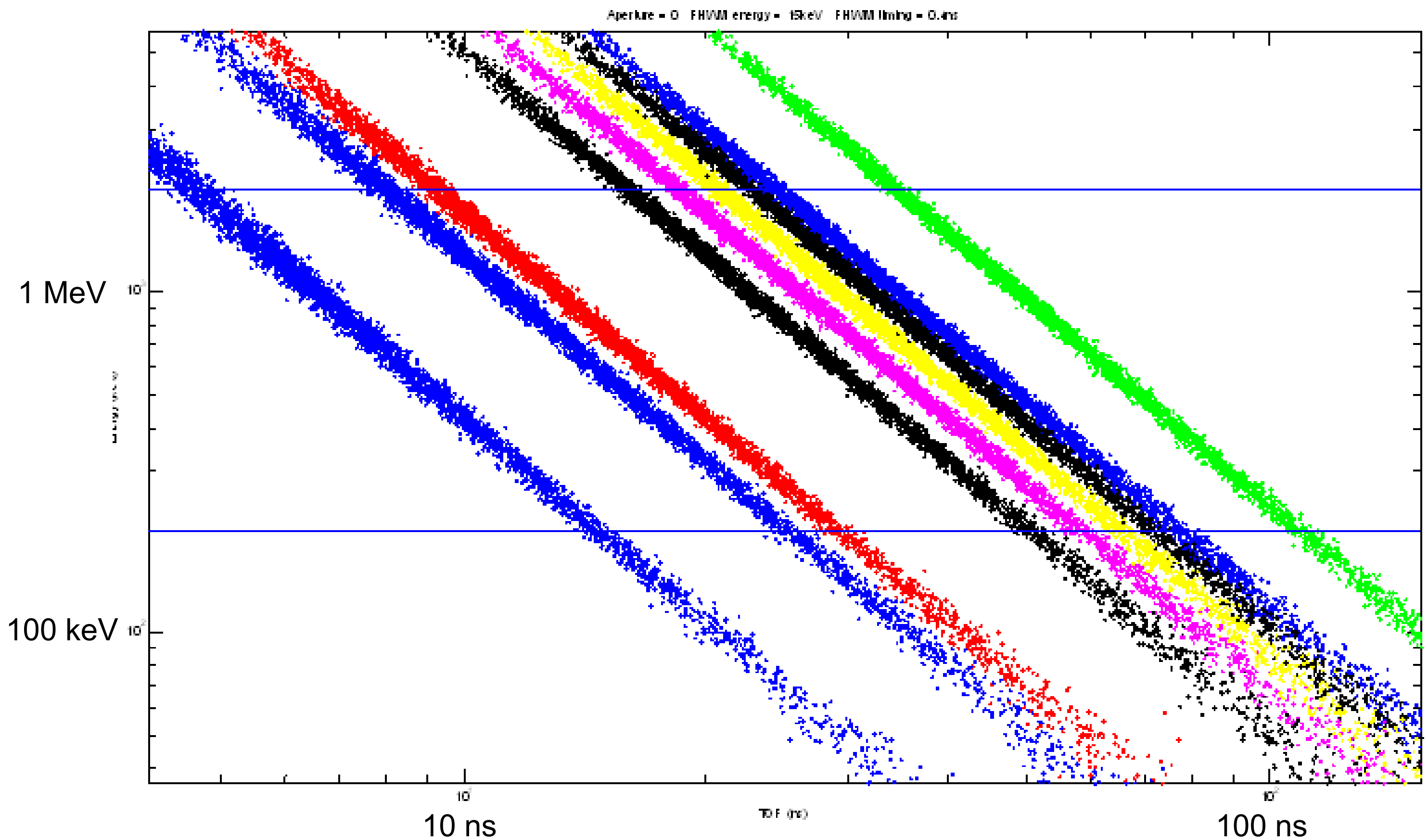
He Separation Requirements

- At low energies the energy resolution dominates performance
- At high energies the timing resolution dominates performance
- Predicted performance has ample margin from requirement



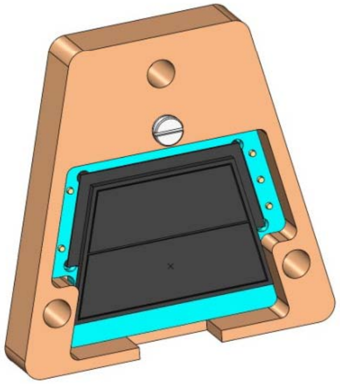
Track Simulations

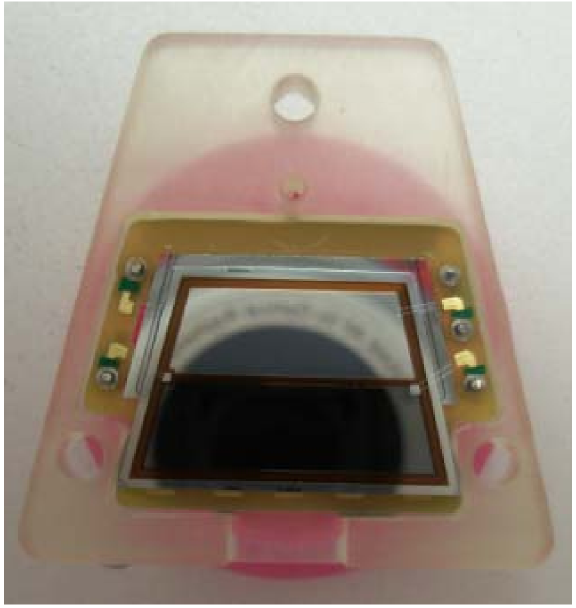
- Monte-Carlo model for all species with 400 ps FWHM timing and 15 keV FWHM energy resolutions

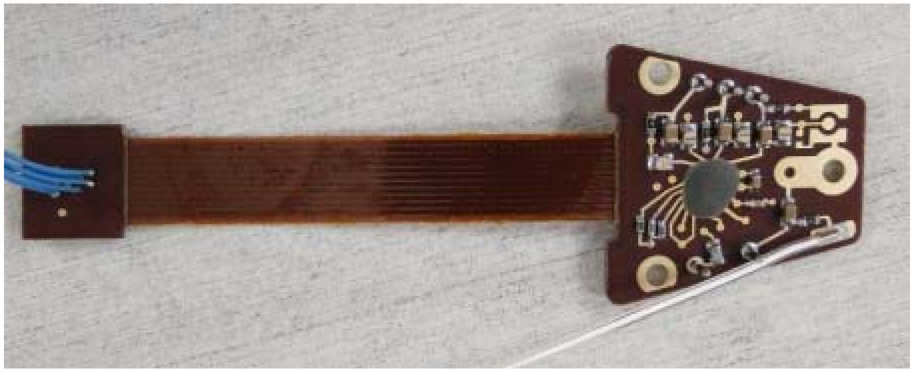


Energy System Development

- Solid-State Detector is fabricated and mounted to carrier board
- Energy board is fabricated and populated
- All components nearly identical to flight – no design changes expected







RBSPICE DATA with 60keV X-ray Source

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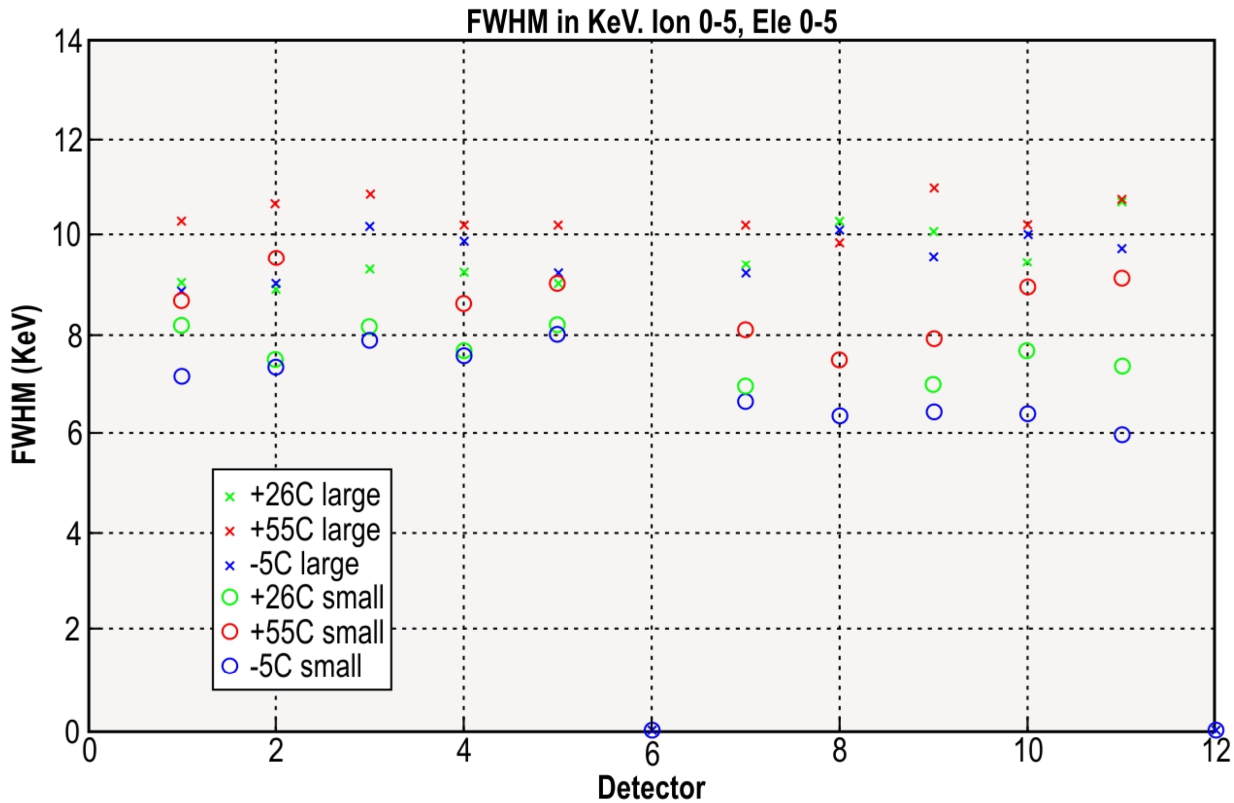
- SSD performance base-lined on RBSPICE instrument tested with 60 keV X-ray
- Performance is ~11 keV FWHM over a wide temperature range
- EPI-Lo SSD in testing now – preliminary results show <15 keV FWHM at 60 keV

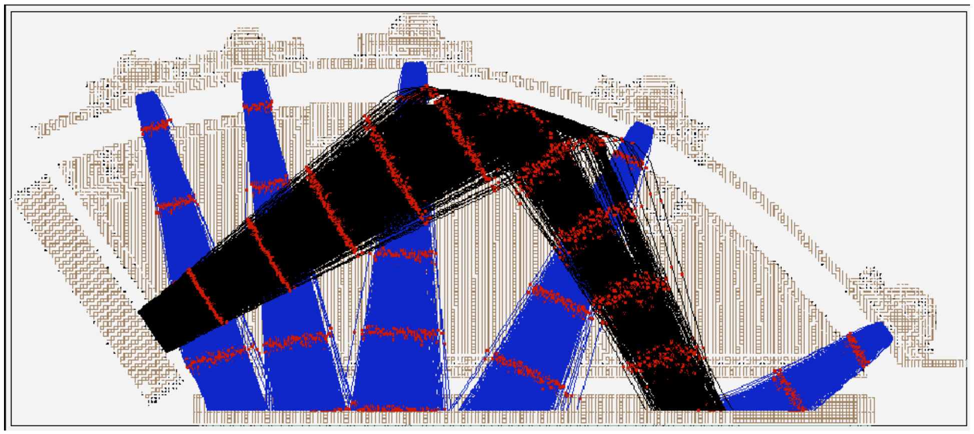


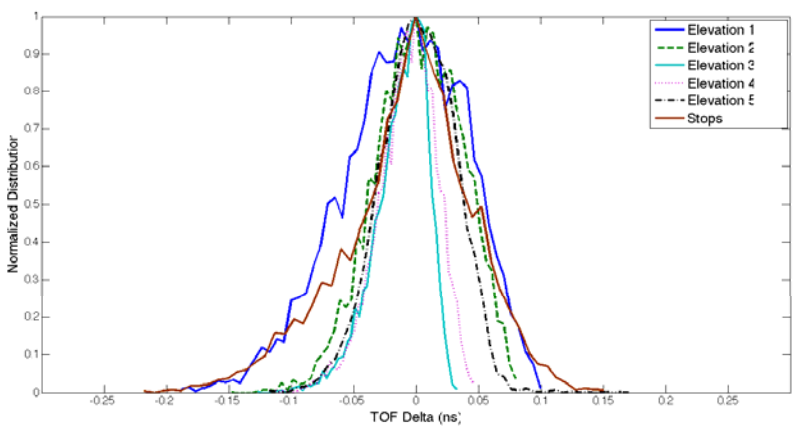
Timing Performance: Timing Budget

- Electron Dispersion: 200 ps
- TOF-D ASIC: 200 ps
- CFD-D ASIC: 200 ps
- Total: 350 ps (requirement is 400 ps)

Timing budget – Secondary Electron Dispersion Simulations

- 250 ps Time Markers
- Electron dispersion (start and stop combined) for worse case elevation 1 is 150 ps

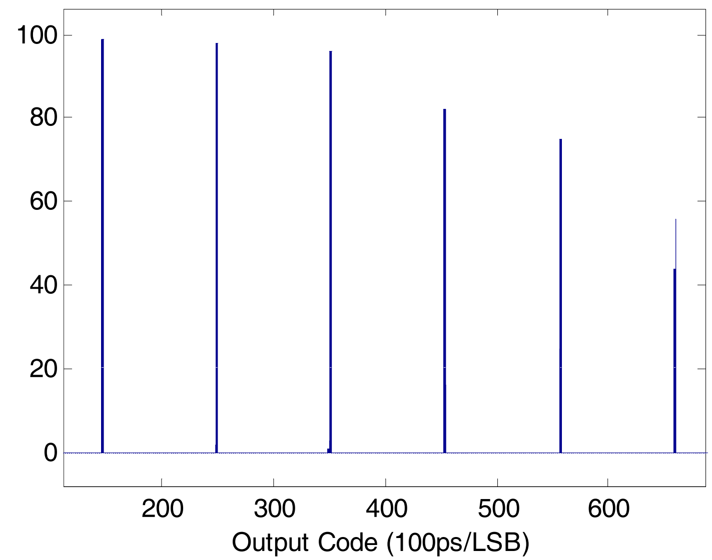


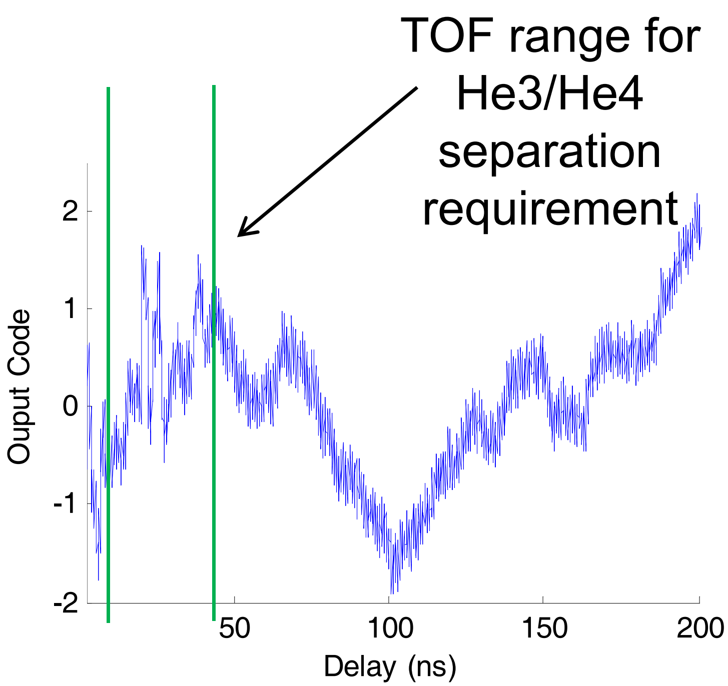


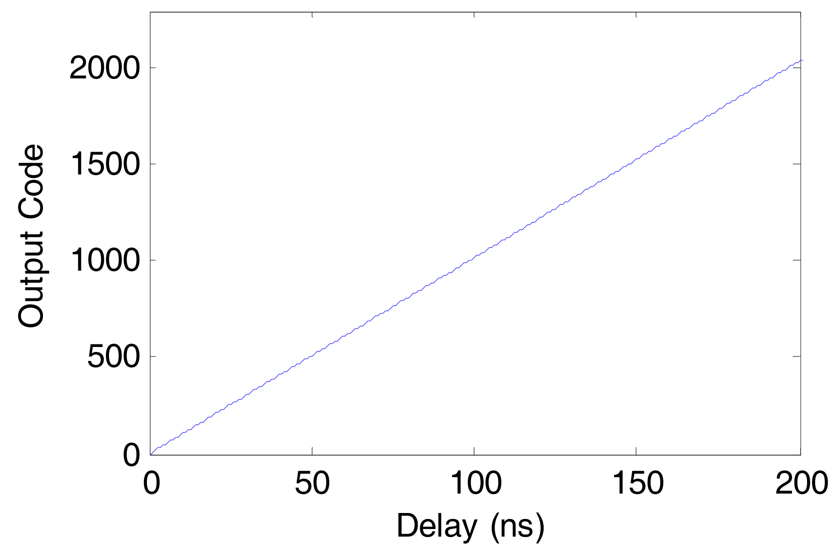
Name	Mean TOF (ns)	FWHM (ns)
Elevation 1	0.93	0.12
Elevation 2	2.12	0.08
Elevation 3	2.35	0.04
Elevation 4	2.32	0.05
Elevation 5	2.26	0.08
Stops	5.23	0.09

TOF-D Test Results

- TOF-D performance meets requirement
- INL variations compensated for with look-up tables
  - Same LUTs used to normalize path length for different apertures
- Jitter is less than 1 LSB FWHM

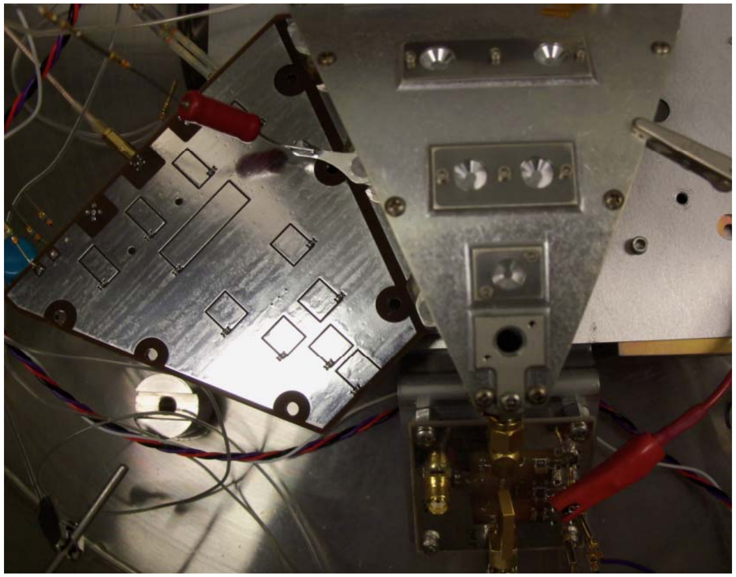


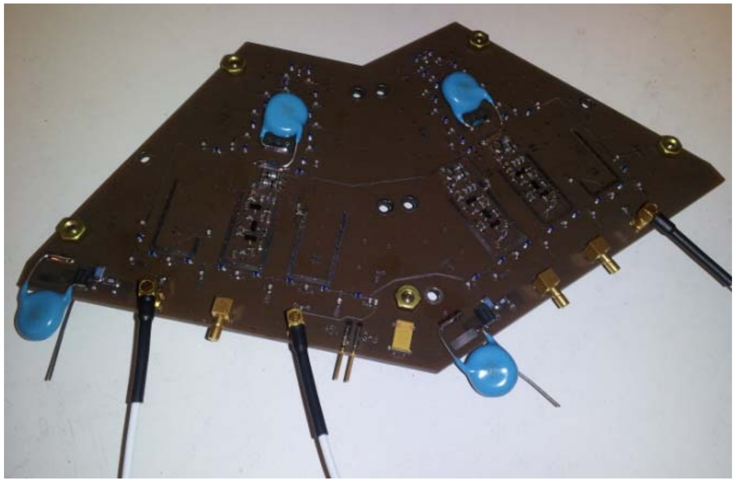




Prototype Quadrant Sensor Testing (1/2)

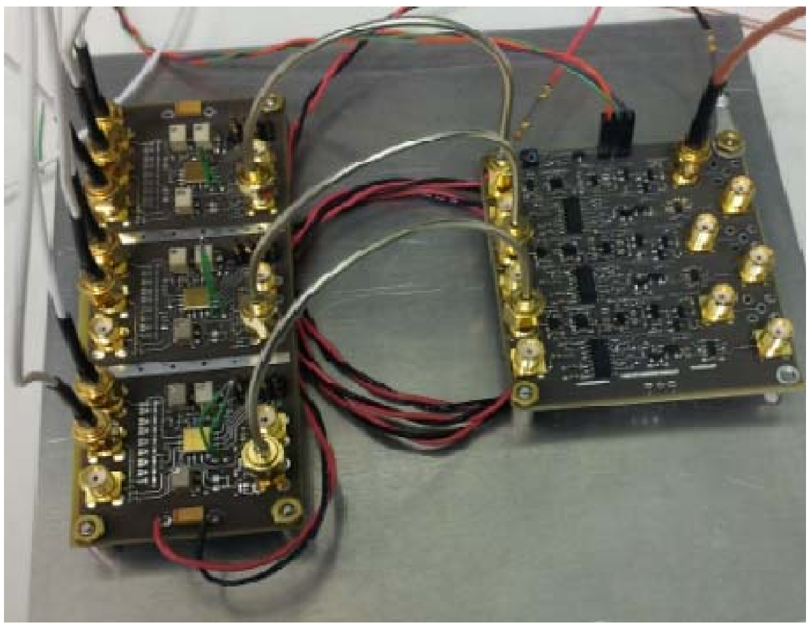
- Timing performance testing completed on prototype sensor
- End-to-end test includes variations due to electron dispersion, anode board performance, and CFD-D V0 performance
  - Does not include TOF-D ASIC
- Prototype anode board is close to flight configuration
  - HV isolation in imbedded capacitance
  - Start delay line covers two sensors
  - Does not mechanically fit flight design
- Prototype sensor is similar to flight sensor – key sensor geometries are the same

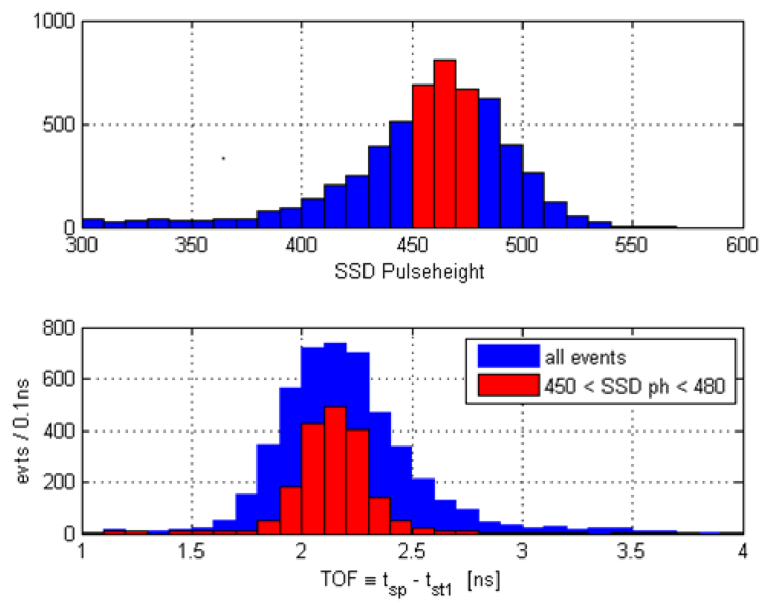




Prototype Quadrant Sensor Testing (2/2)

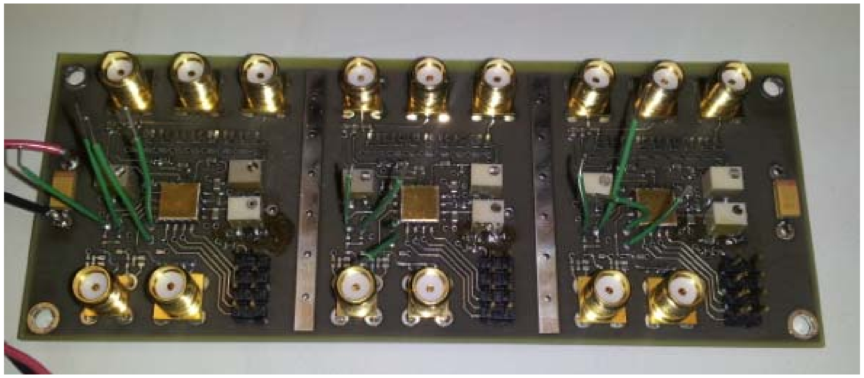
- Initial results show about 300 ps FWHM timing performance (CFD-D and electron optics contributions), which meets our requirements
- The final version of the CFD-D has lower jitter at low thresholds and reduced walk, which we expect will improve performance

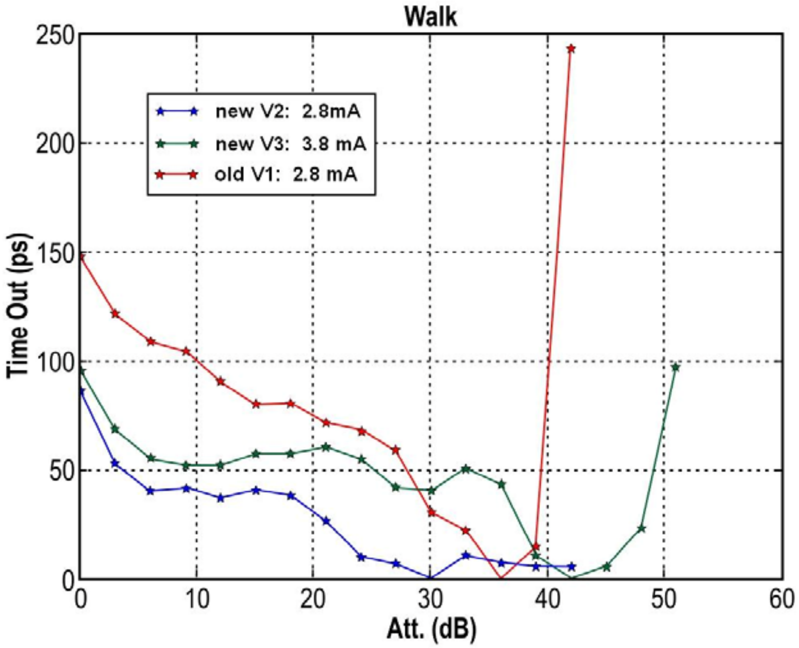


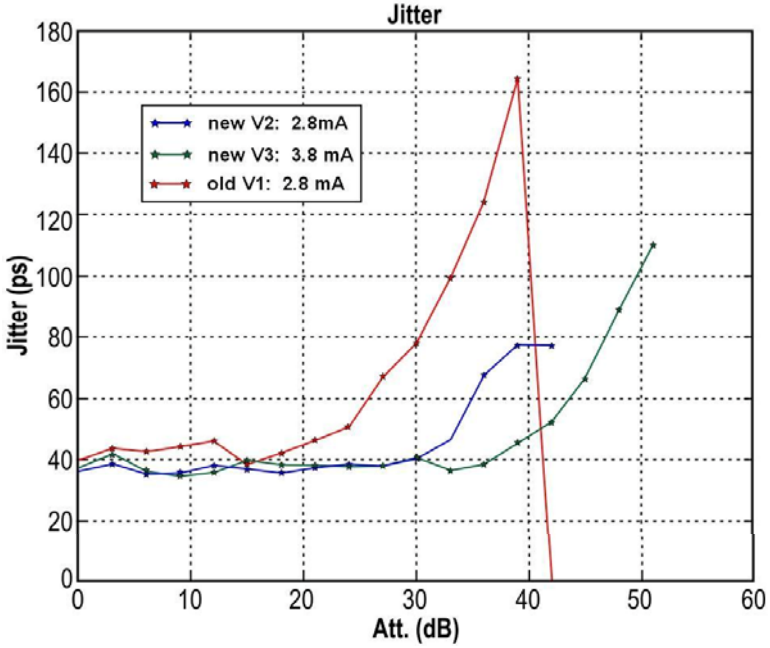


CFD-D Test Results

- CFD-D extensively tested using the CFD-D test board
- CFD-D V3 has improved performance

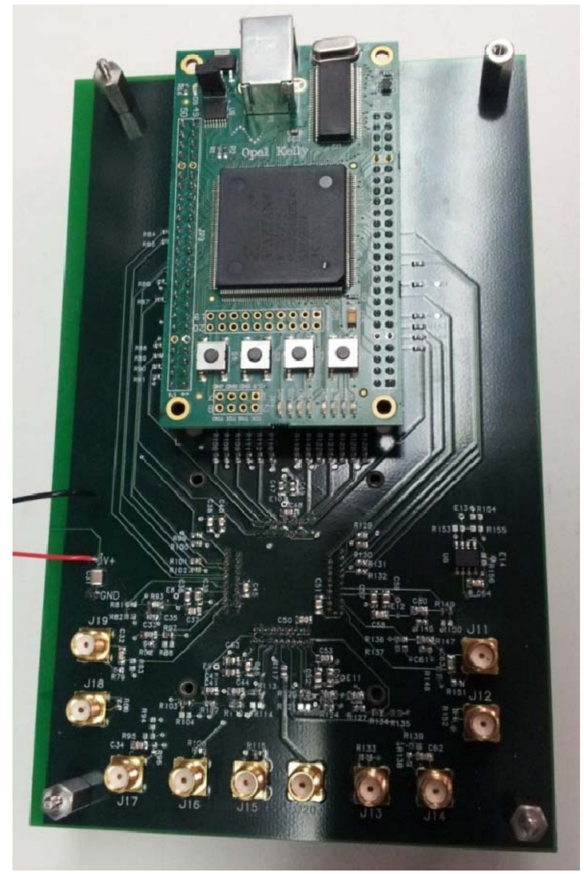






Technical Development: ASIC Progress

- First version of TOF-D chip fabricated and tested
  - Temperature testing from -40°C to 70°C
  - Supply tested from 3.0 V to 3.6 V
  - Functionality verified over 10 ps to 2 ns LSB
  - Successfully completed SEE testing at Texas A&M
  - Completed total dose testing
- Second version of TOF-D chip and first version of CFD-D chip fabricated and tested
- Flight Fabrication - third version of TOF-D chip and second version of CFD-D chip fabricated and tested
  - Temperature testing from -40°C to 70°C
  - Supply tested from 3.0 V to 3.6 V
  - TOF-D functionality verified over 10 ps to 2 ns LSB
  - Working with vendor for final qualification of both ASICs



Transition to Flight

- TOF-D, CFD-D ASICs
  - Complete qualification with external test house
  - Parts are needed in early 2014 for SIS instrument – EPI-Lo not the driver
  - Complete radiation testing on flight parts (prototype parts passed all radiation testing)
- Sensor Development
  - Build and test EM sensor
  - Integrate sensor with SSD
- SSD
  - EM design complete
  - Finish testing EM SSD
  - Flight design will be identical

- **All critical performance metrics for quadrant anode design have been verified with prototype testing**

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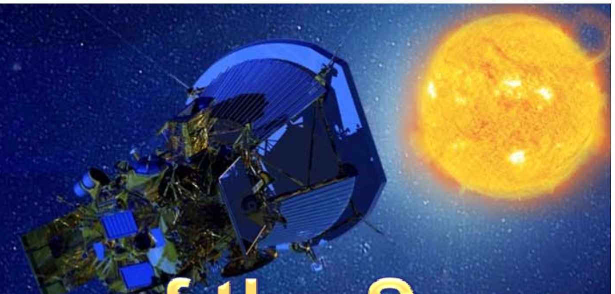


Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

EPI-Lo Mechanical

Scott Cooper

EPI-Lo Lead ME (JHU/APL)

Outline

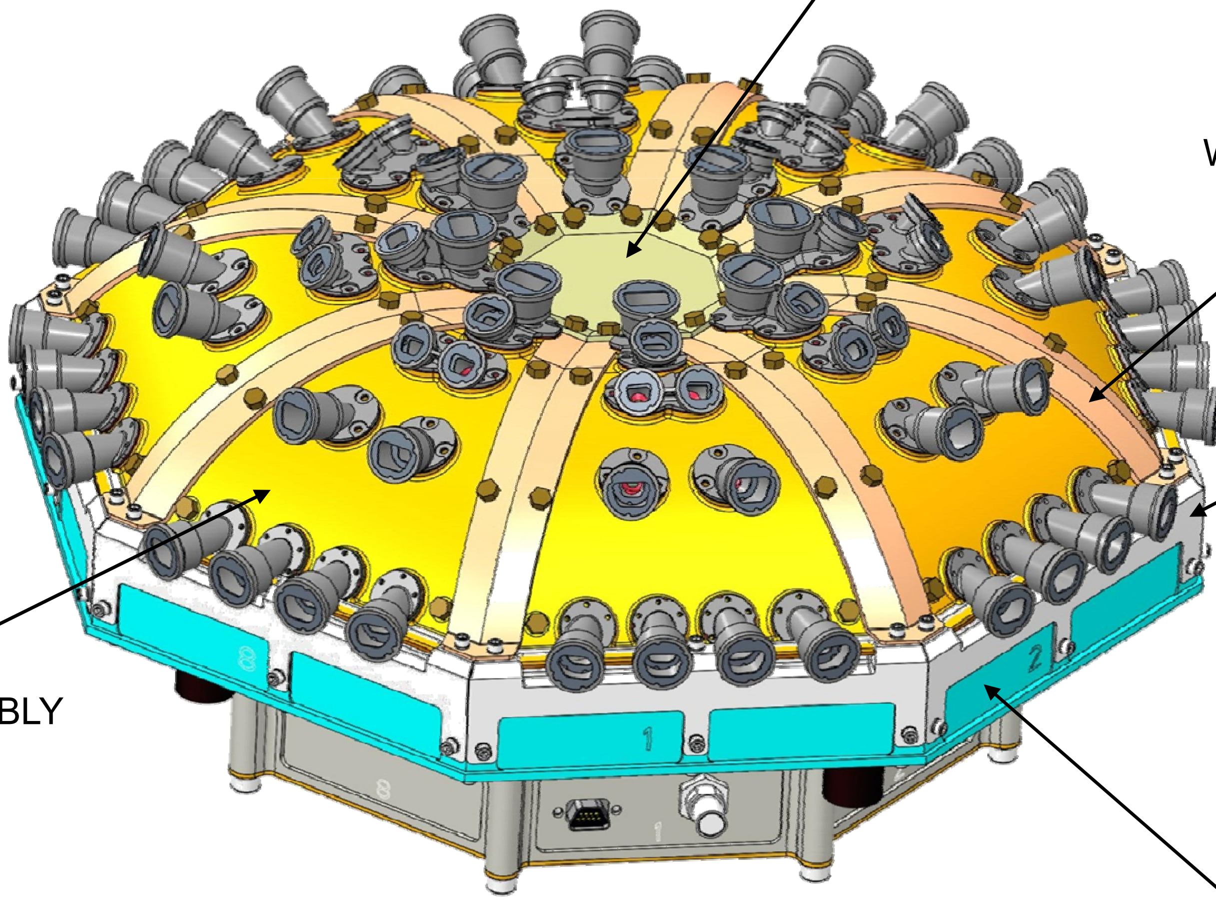
- Summary of mechanical design requirements
- Overview of mechanical design
- Detailed description of the instrument mechanical design
  - Wedge Assembly
  - MCP Assembly
  - SSD Assembly
- Assembly process
- Mechanical development status
- Summary of analyses
- Summary of Peer Review results

Mechanical Design Requirements

- 7434-9039, SPP Environmental Design and Test Requirements Document
  - Subsystem to have min frequency >80 Hz
  - PWAs to have min frequency >150 Hz
  - Quasi-static load factor: 40 g (Figure 4-11 & Table 4-19)
  - Factors of safety: Table 4-5, Unpressurized Factors of Safety
  - Random vibration levels: Table 4-8 and Table 4-9

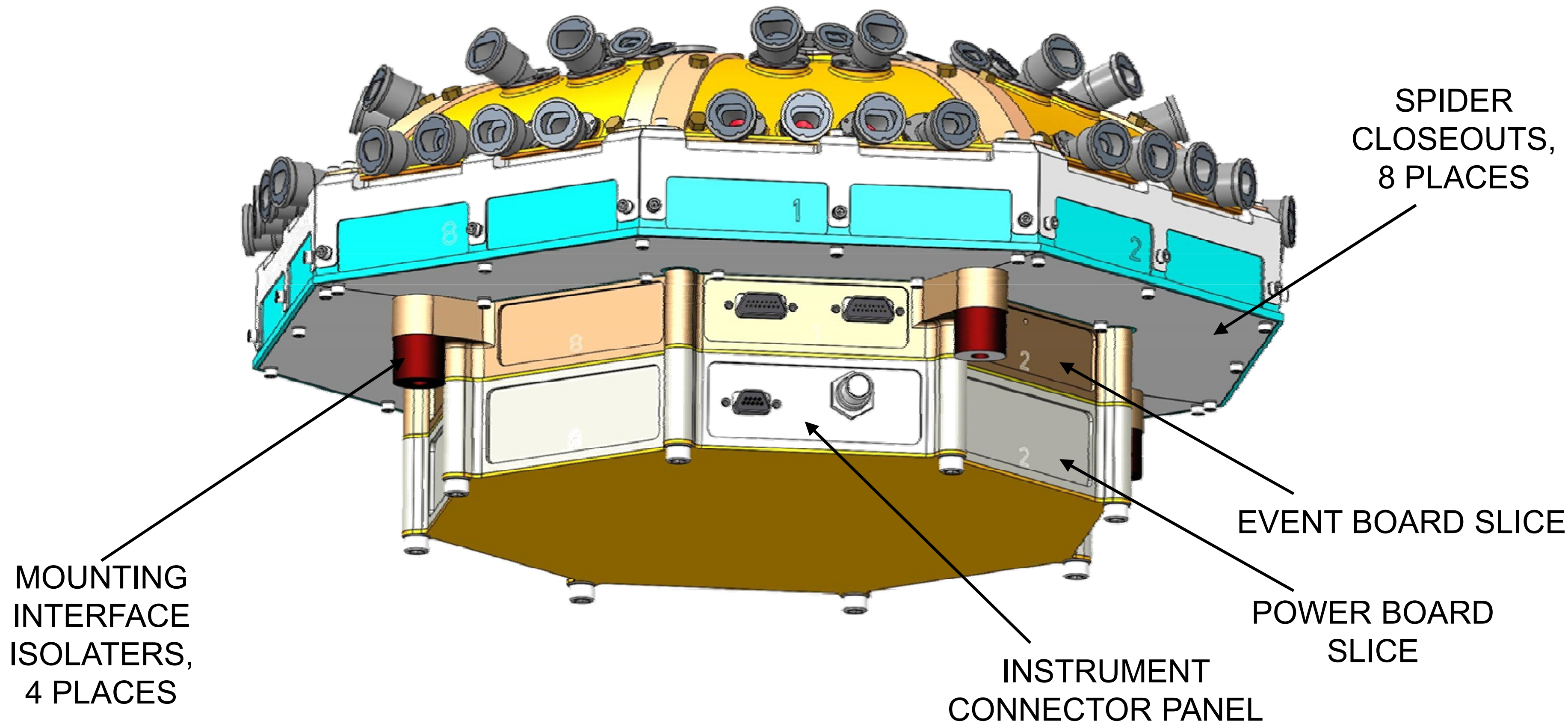
- 7464-0008 EPI-Lo-S/C Mechanical ICD
  - Generated by EPI-Lo to document placement and orientation of instrument on spacecraft

Instrument Overview (1/2)



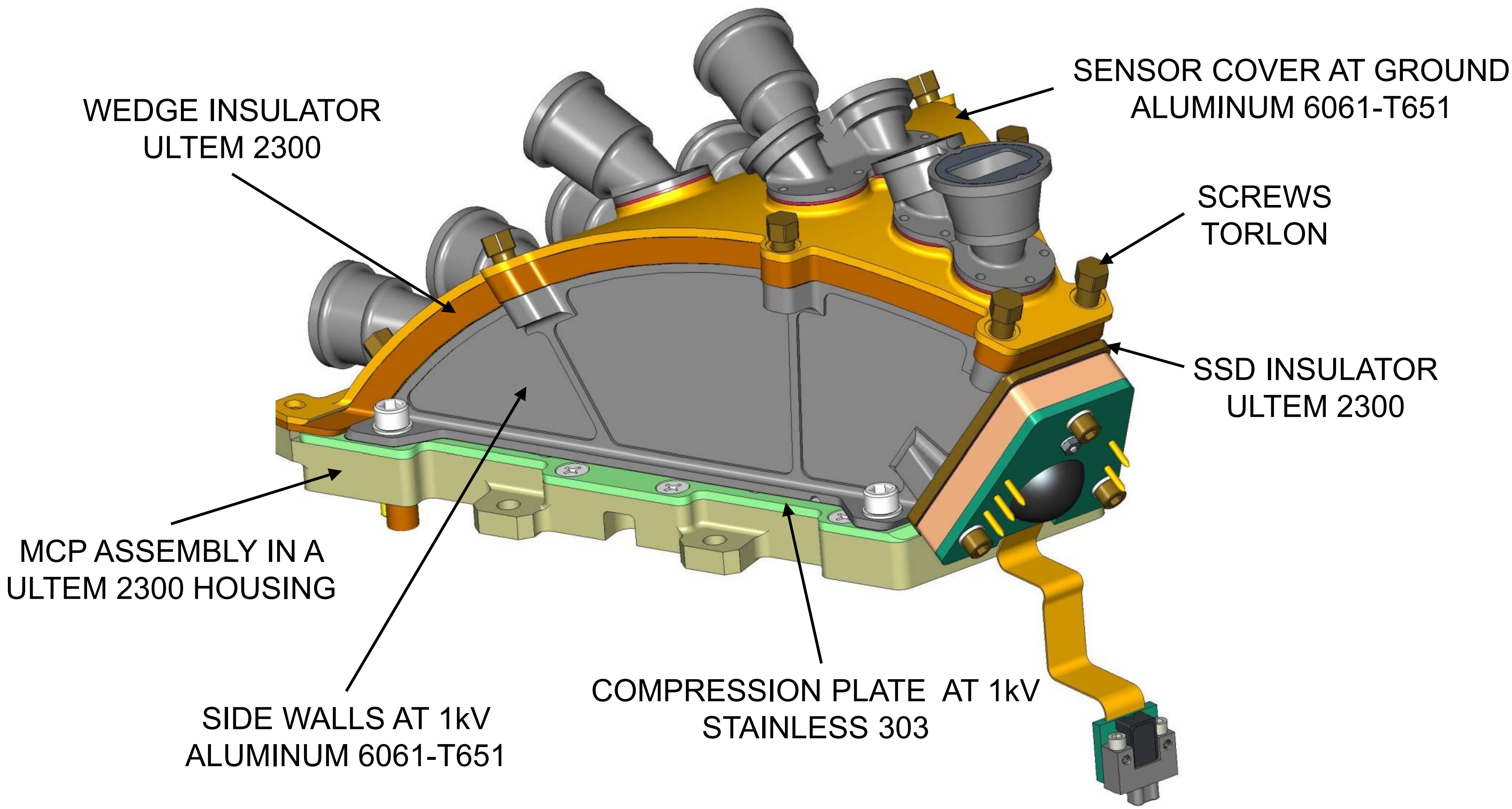
EPI-Lo Instrument Isometric View

Instrument Overview (2/2)



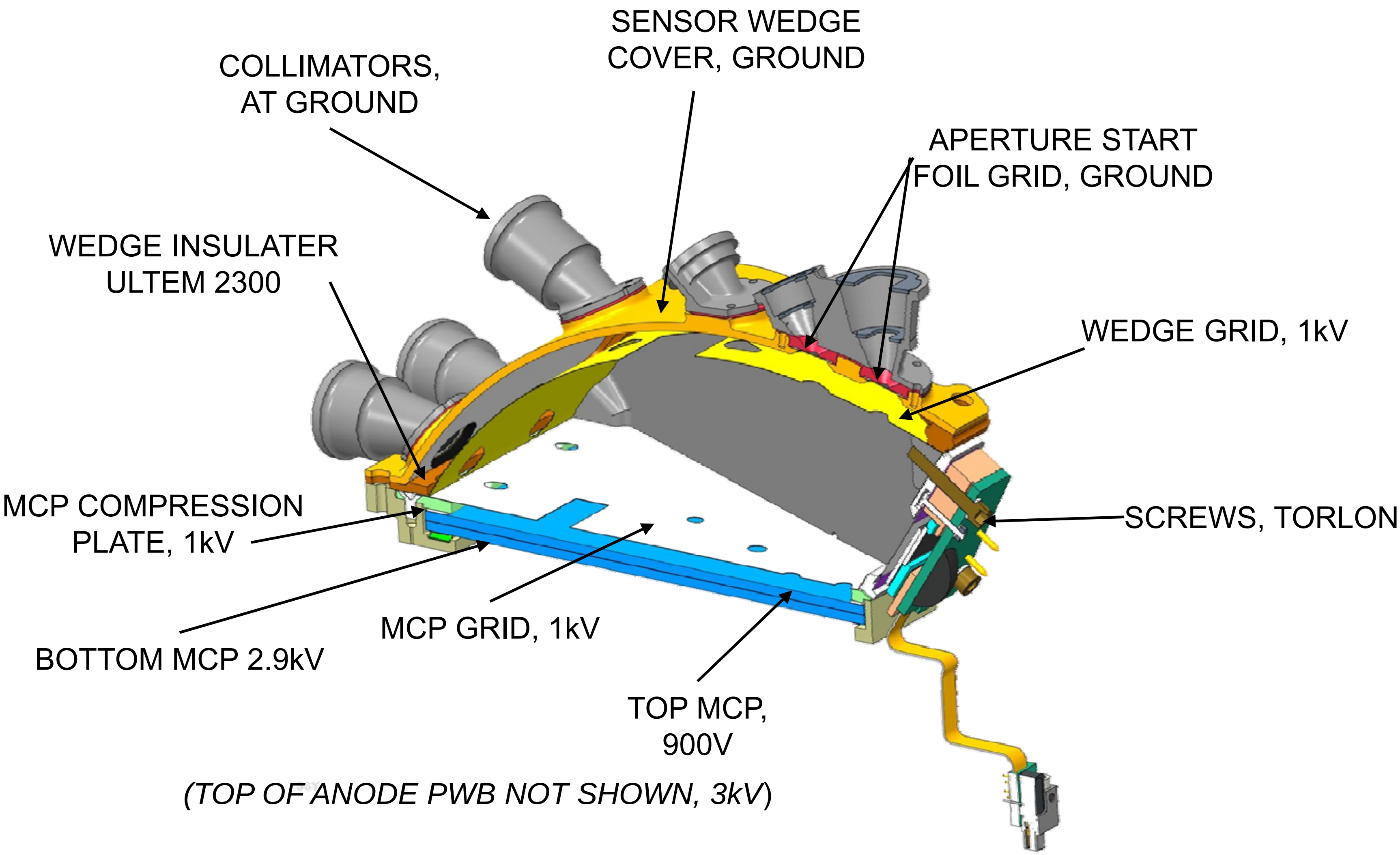
EPI-Lo Instrument Side Isometric View

Wedge Design (1/2)



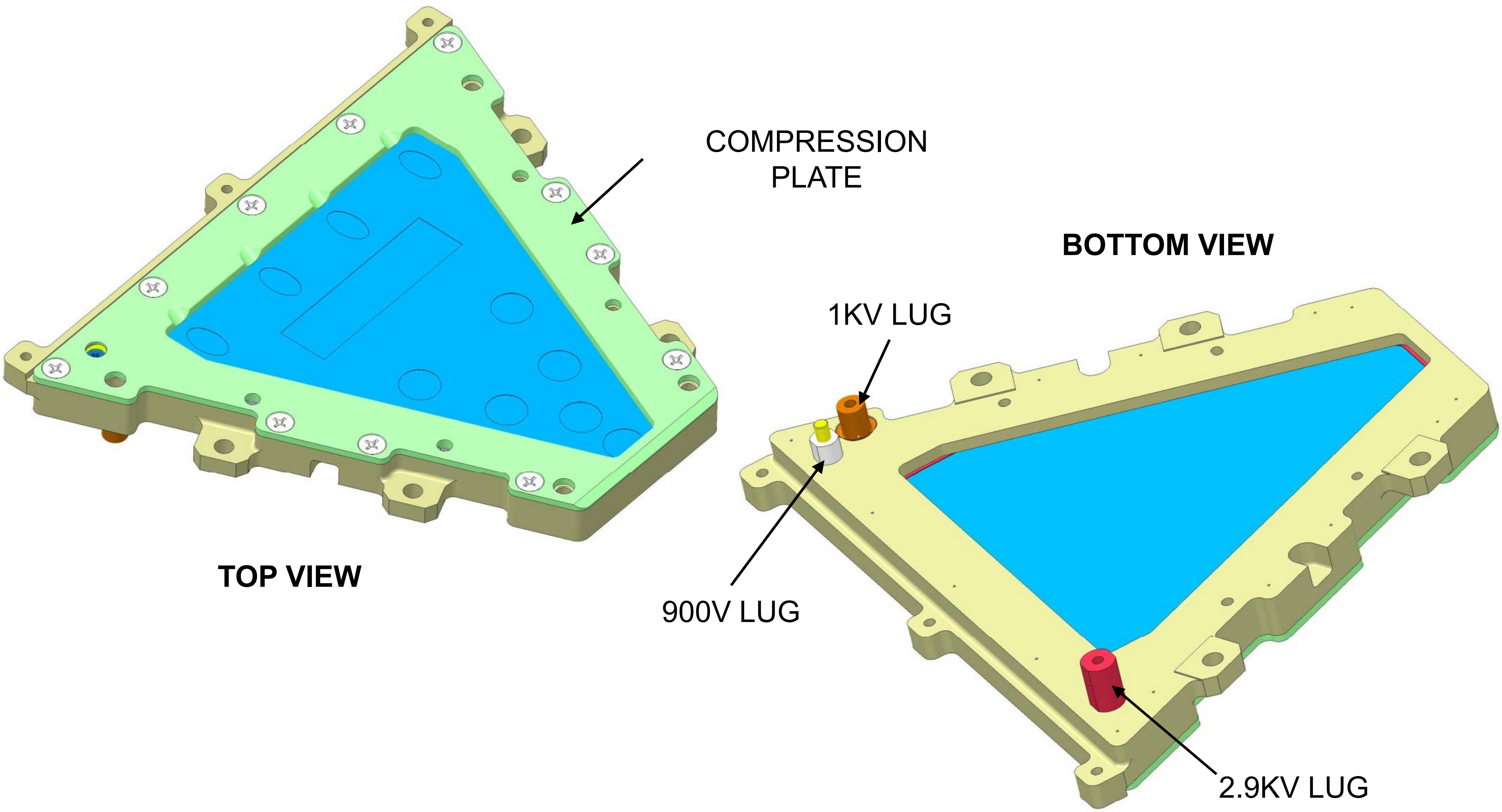
EPI-Lo Sensor Wedge Assembly

Wedge Design (2/2)



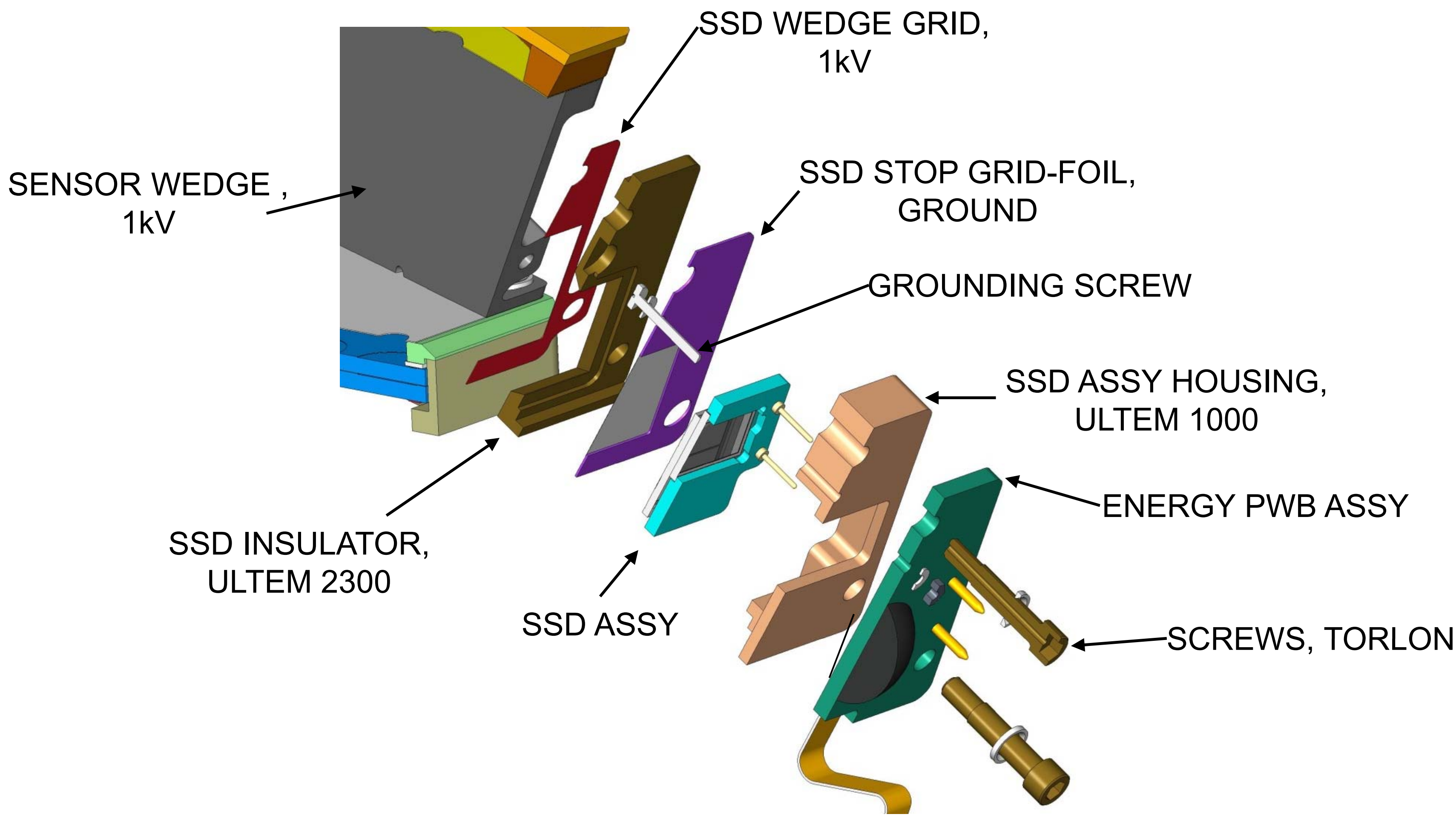
EPI-Lo Sensor Wedge Assembly Cross-Section View

MCP Assembly Design



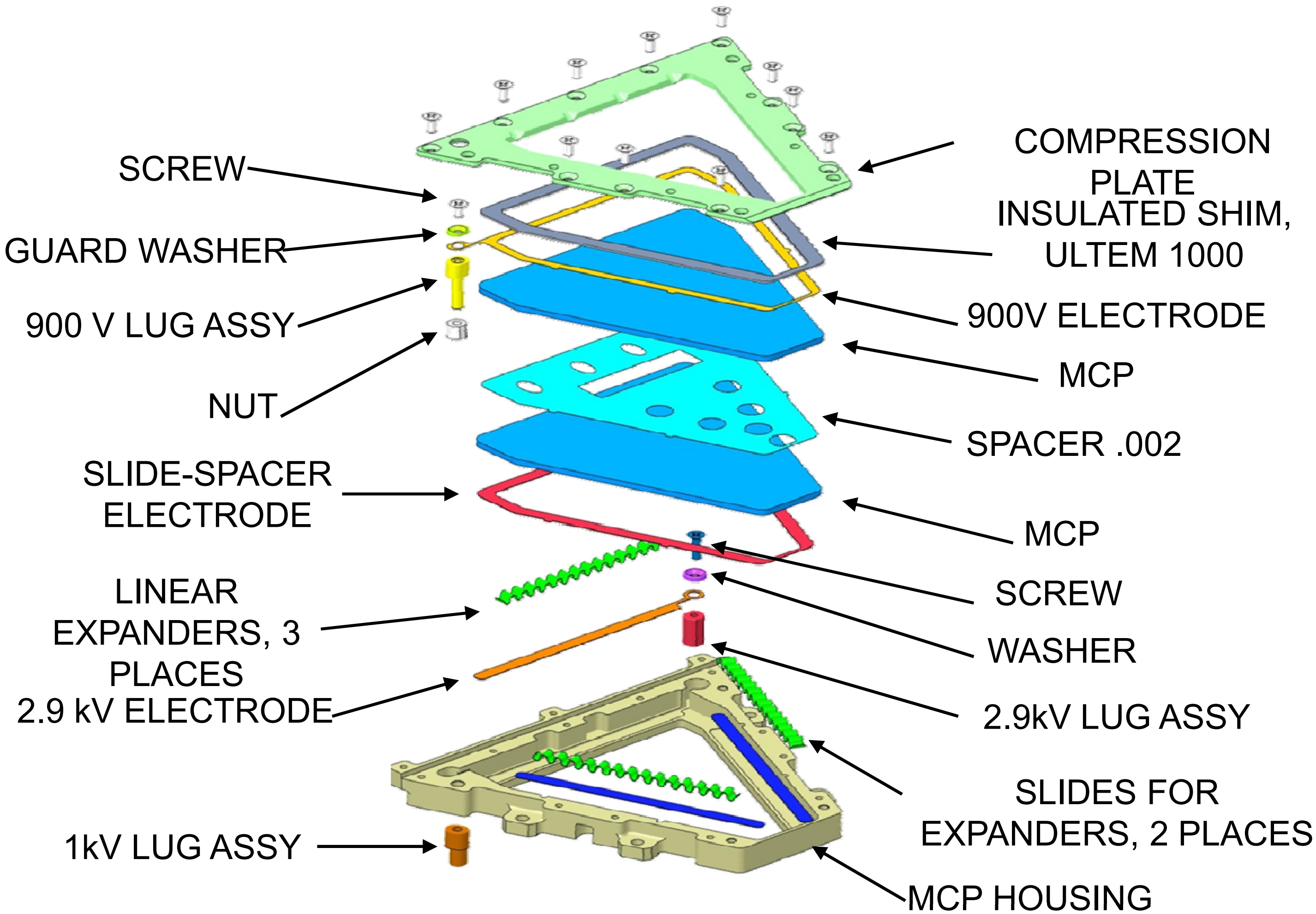
MCP Assembly

SSD Assembly Design



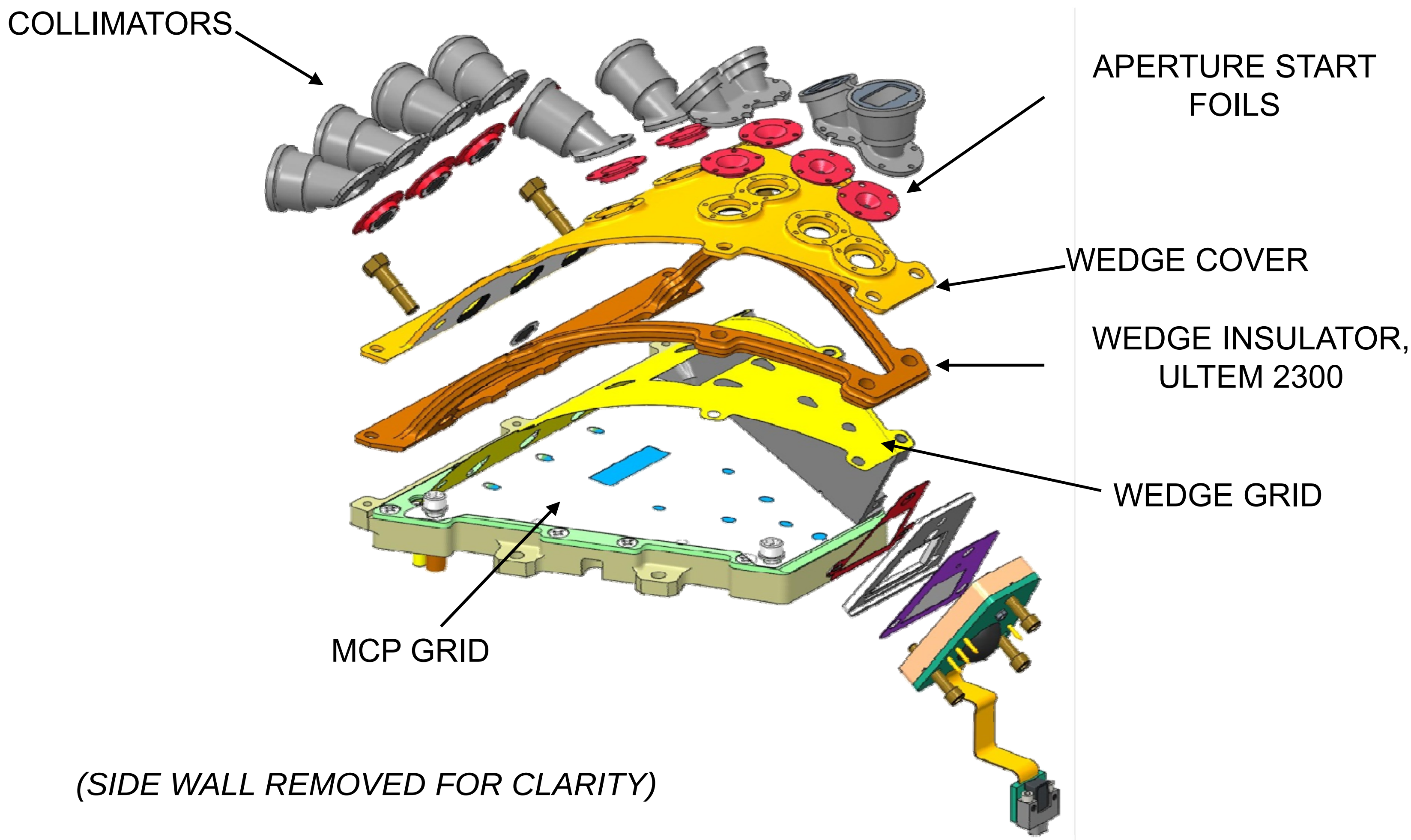
SSD Assembly Exploded Cross-Section View

MCP Assembly Process



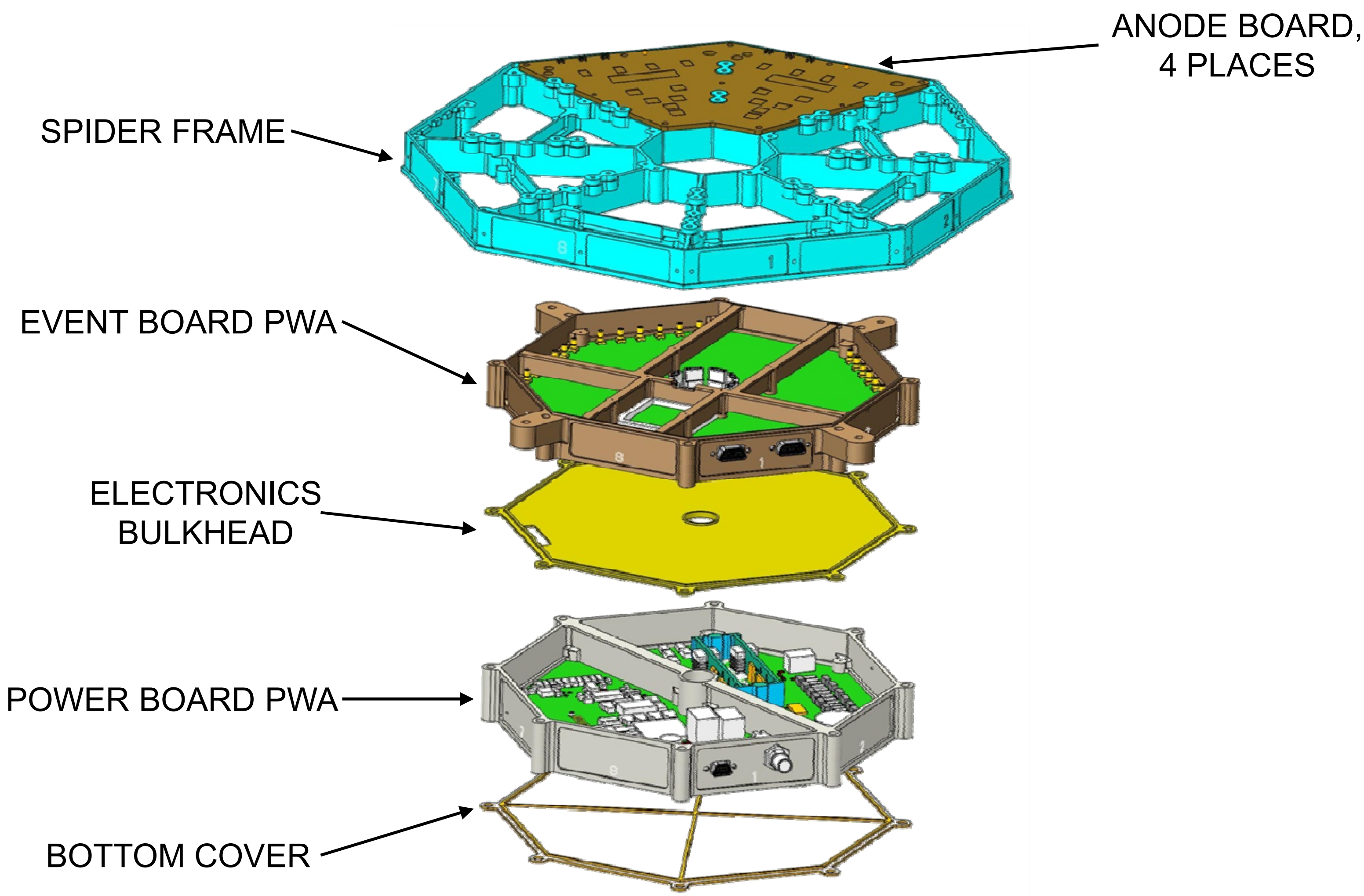
MCP Assembly Exploded View

Wedge Assembly Process



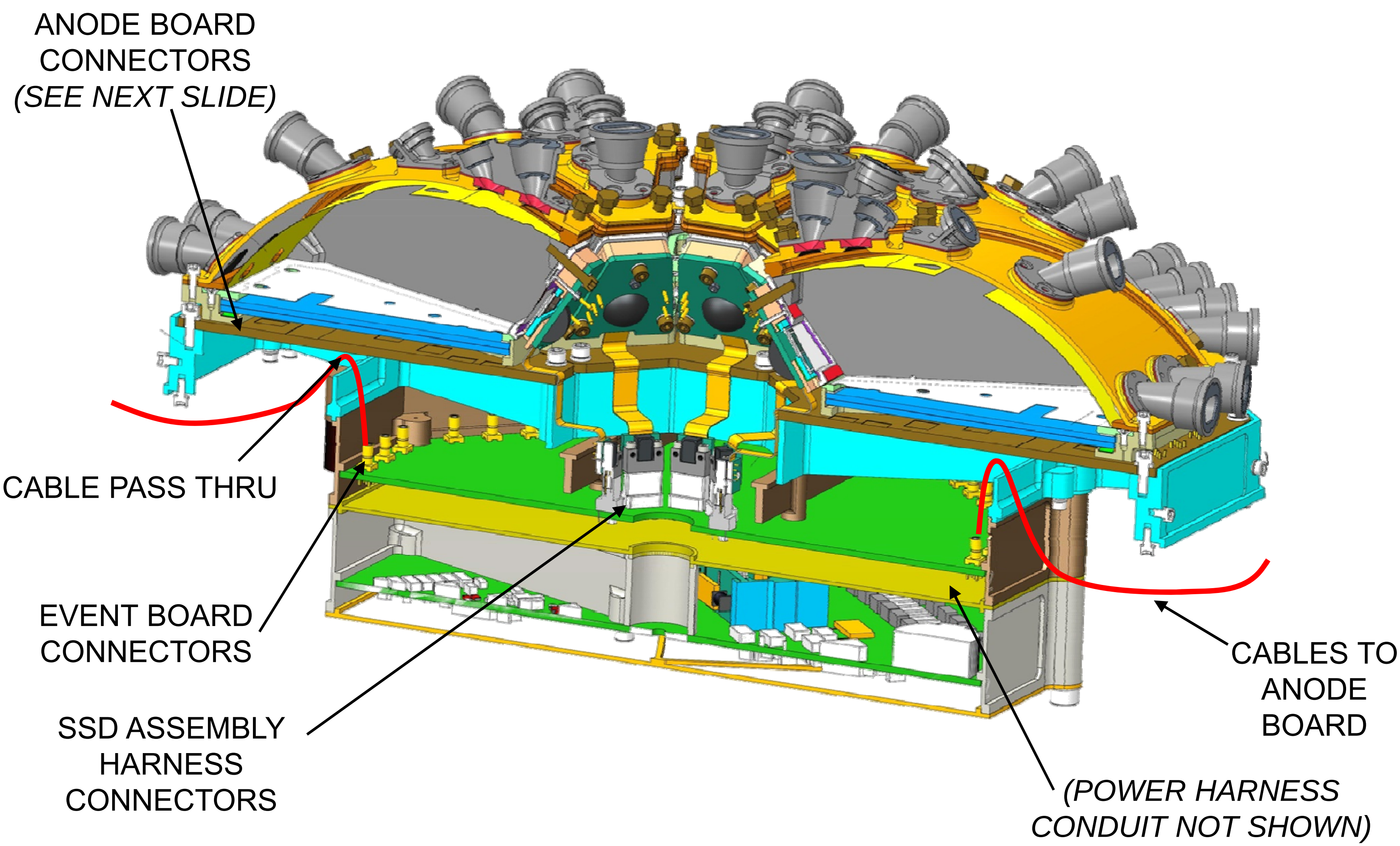
EPI-Lo Sensor Wedge Assembly Exploded View

Spider and Electronics Integration



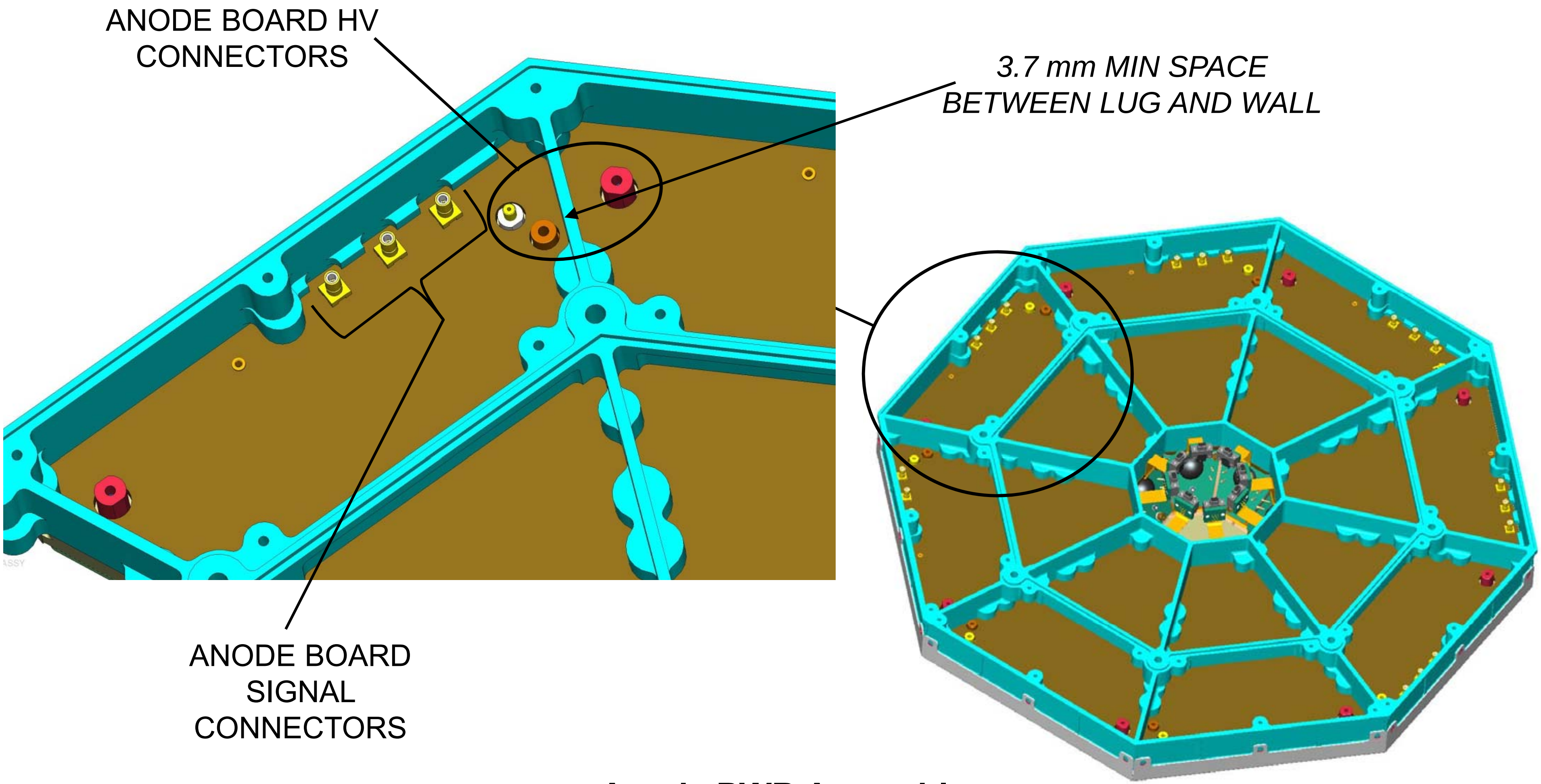
EPI-Lo Electronics Frames Exploded View

Wedge Integration and Cable Routing



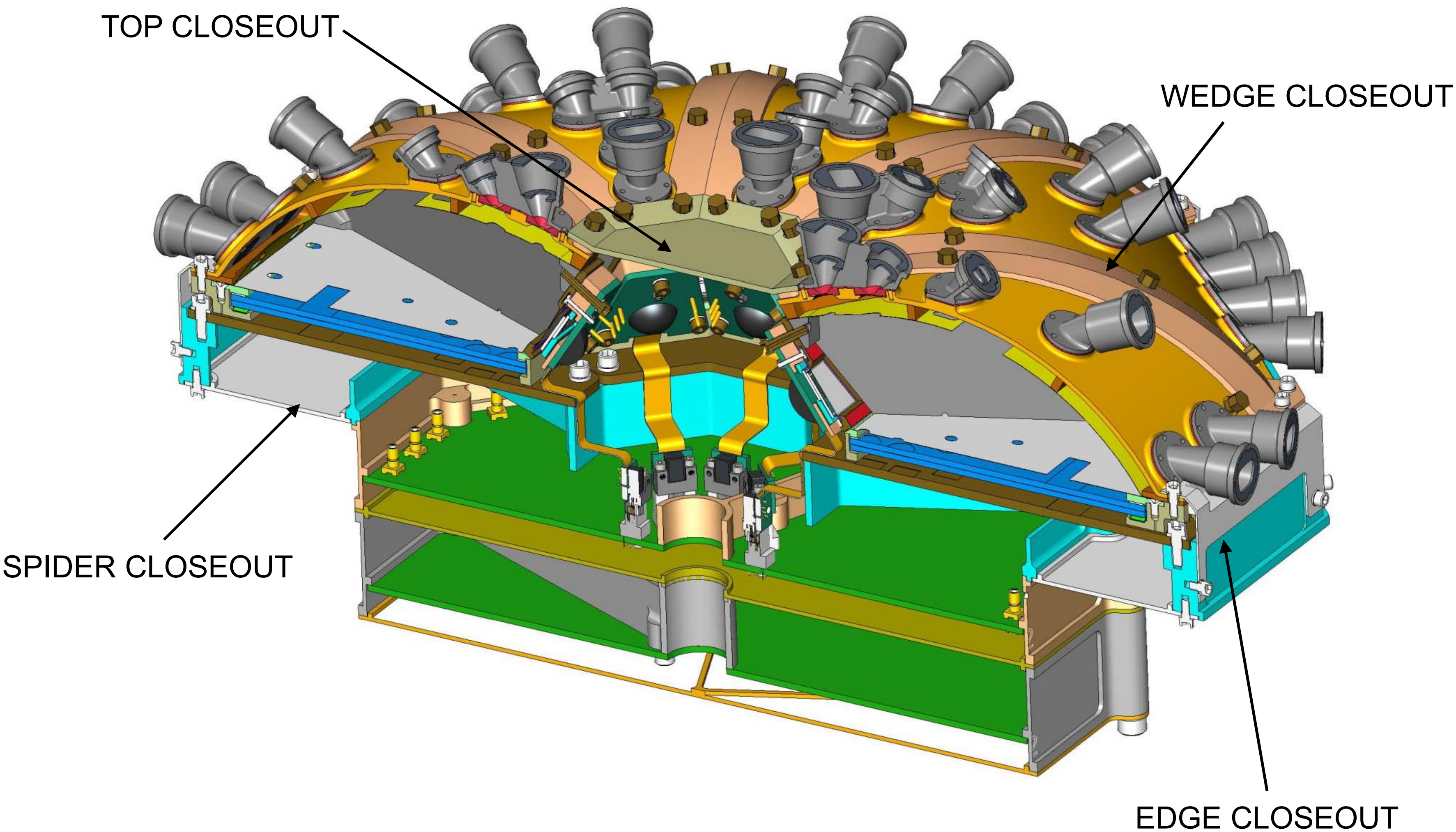
EPI-Lo Cross-Section Isometric View

Cable Connections



Anode PWB Assembly, Bottom Side Shown Mounted To Spider Frame

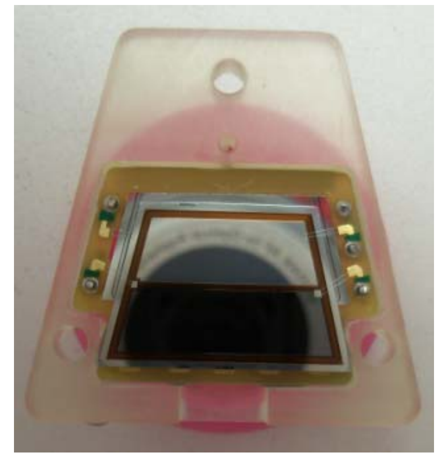
Instrument Closeout Installation

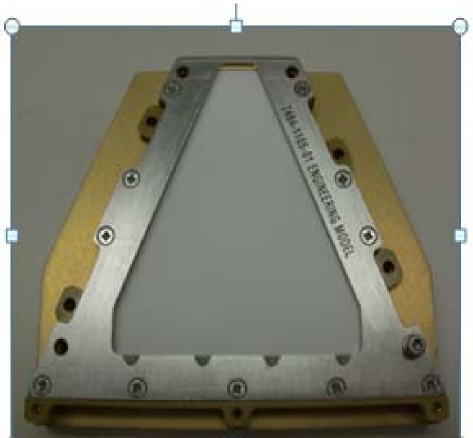


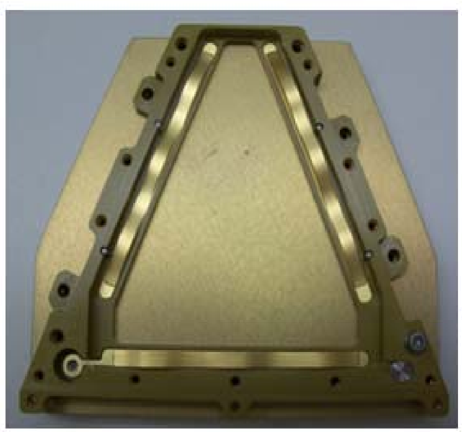
EPI-Lo Cross-Section Isometric View

Development Status

- Prototype sensor fully assembled and tested
- EM sensor
  - EM MCPs in house
  - EM SSDs in house and mounted to carrier
  - MCP holder with all electrodes assembled and tested at HV with ceramic plates
  - All EM grids and foils procured and in-house
  - Upper sensor parts in fabrication
    - Side walls, top cover, collimators







Mechanical – Path Forward

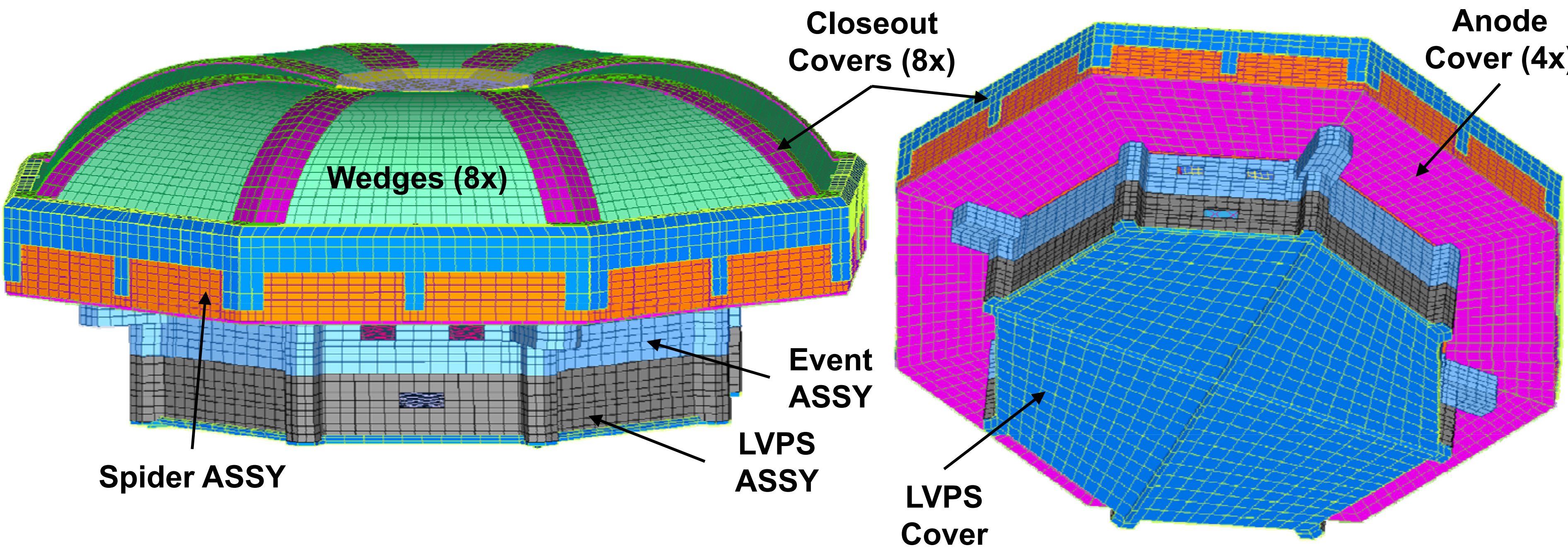
- Sensor EM testing
  - Test MCP assembly with MCPs and EM anode board
  - Assemble upper sensor parts
  - Test sensor wedge
    - Start and stop secondary electron locations
    - Timing performance
  - Integrate SSD to sensor wedge
  - Full performance testing with source and in APL accelerator
- Instrument-level EM testing
  - Fabricate chassis and e-box frames
  - Vibration testing with bracket, EPI-Hi mass model, two sensor wedges and other wedges as mass models
  - Acoustics testing with bracket, EPI-Hi mass model, two sensor wedges and other wedges as mass models
  - Thermal testing (simplified model representing outer surface)

Preliminary Analysis Results

- SPP EPI-Lo instrument analyzed
  - Created from EPI-Lo CAD model as of 6/19/2013 SPP configuration
  - Instrument orientation to S/C panel taken from ISIS bracket CAD model: 4/19/2013
  - Instrument mass estimated at 2.99 kg (6.58 lbm)
- Structural model analyzed based on 7434-9039 SPP EDTRD requirements
  - Modal frequencies of assembly
  - Quasi-static design limit load per EDTRD Section 4.4.2.1 and 4.4.7.1
  - Random vibration analysis per EDTRD Section 4.4.3
    - Grms acceleration response for various components of the assembly
    - Peak 3-σ stress and displacement results

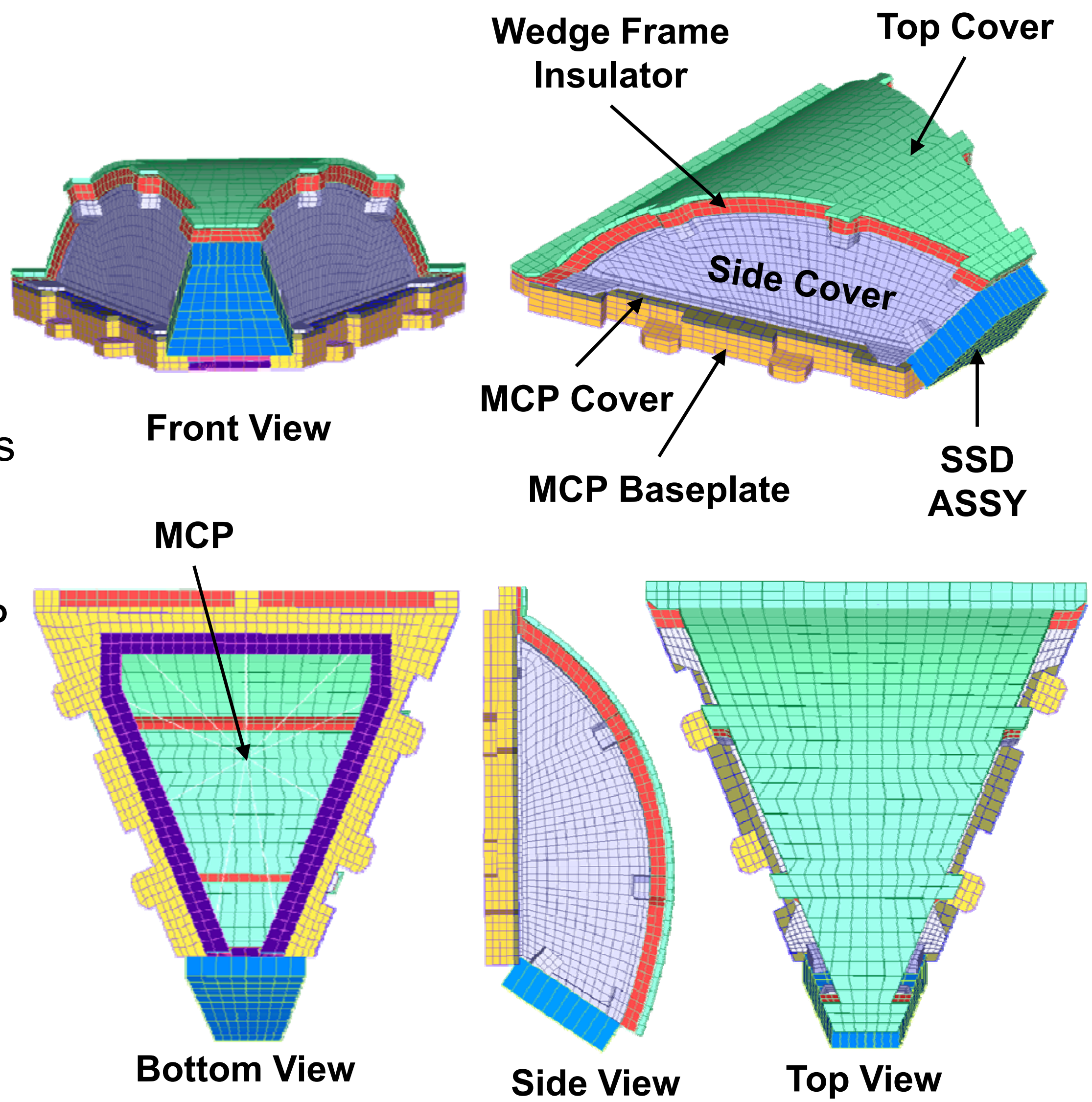
FEM Overview - Instrument Level

- Modeling Strategy
  - Plate elements where applicable: PWAs, frames, covers
  - Solid elements where necessary: frame bosses, bookbolt bosses, small aspect ratios
  - Beam elements: chassis ribs, LVPS bottom cover ribs
  - PWA: EEE part mass smeared over total board area
  - Rigid elements (RBE2s): bookbolts, mounting hardware, Connectors
- Model size: nodes = 89,077, elements = 70,645



FEM Overview - Wedge Assembly

- EPI-Lo has 8 identical wedges
- Top cover: plate elements, Al-6061 properties & collimator mass smear
- Wedge Frame Insulator: plate and solid elements, Ultem1000 material properties
- Side cover: beam, plate and solid elements, Al-6061 material properties
- MCP Cover: plate elements, SS 304 properties
- MCP: mass element & RBE3 to MCP cover and baseplate
- MCP Baseplate: plate and solid elements, Ultem100 material properties
- SSD Assembly: plate elements, Ultem100 material properties
- Wedge assembly connected using RBE2s at all bolted interfaces



FEM Overview - Spider & Anode PWAs

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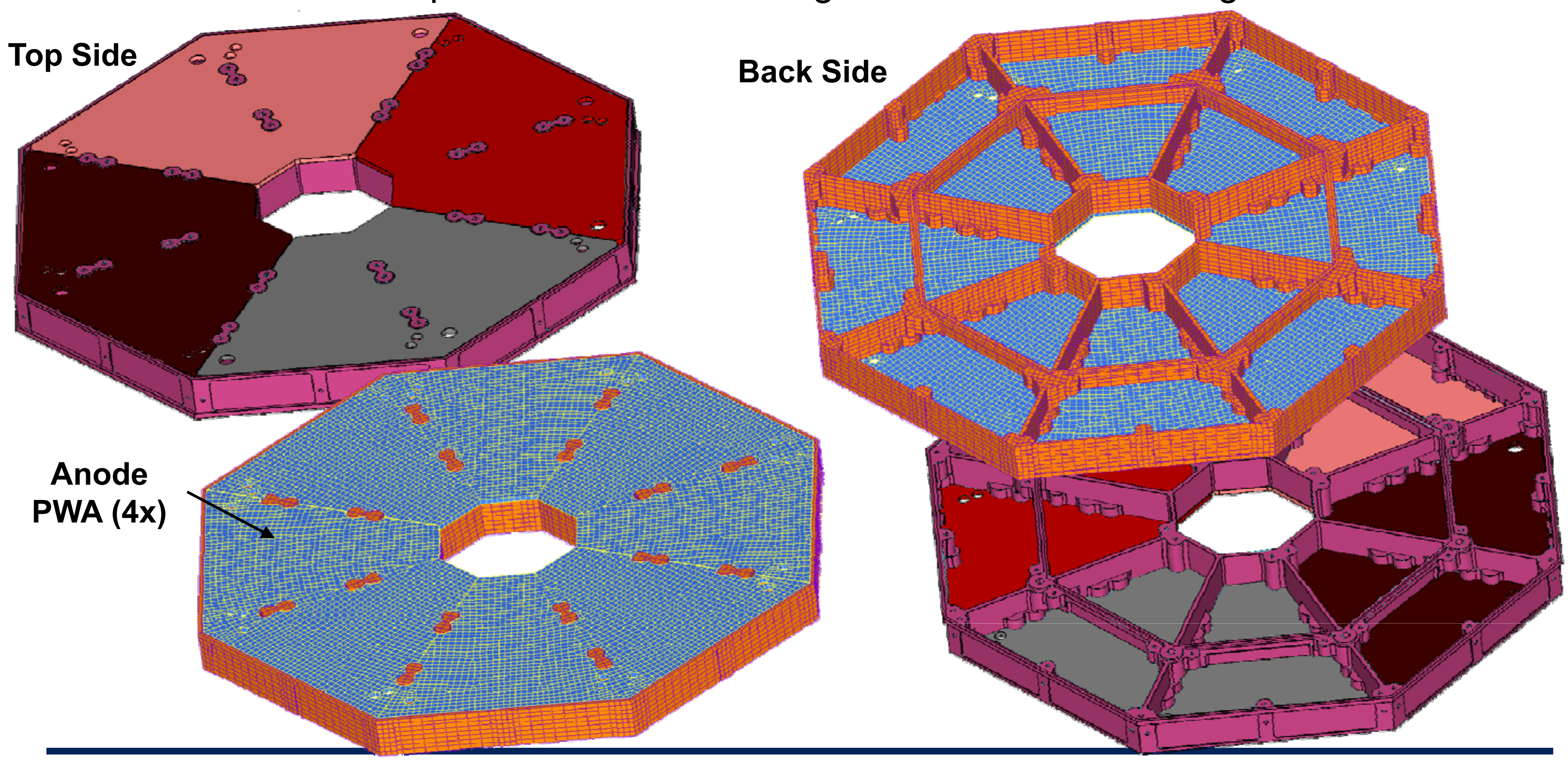
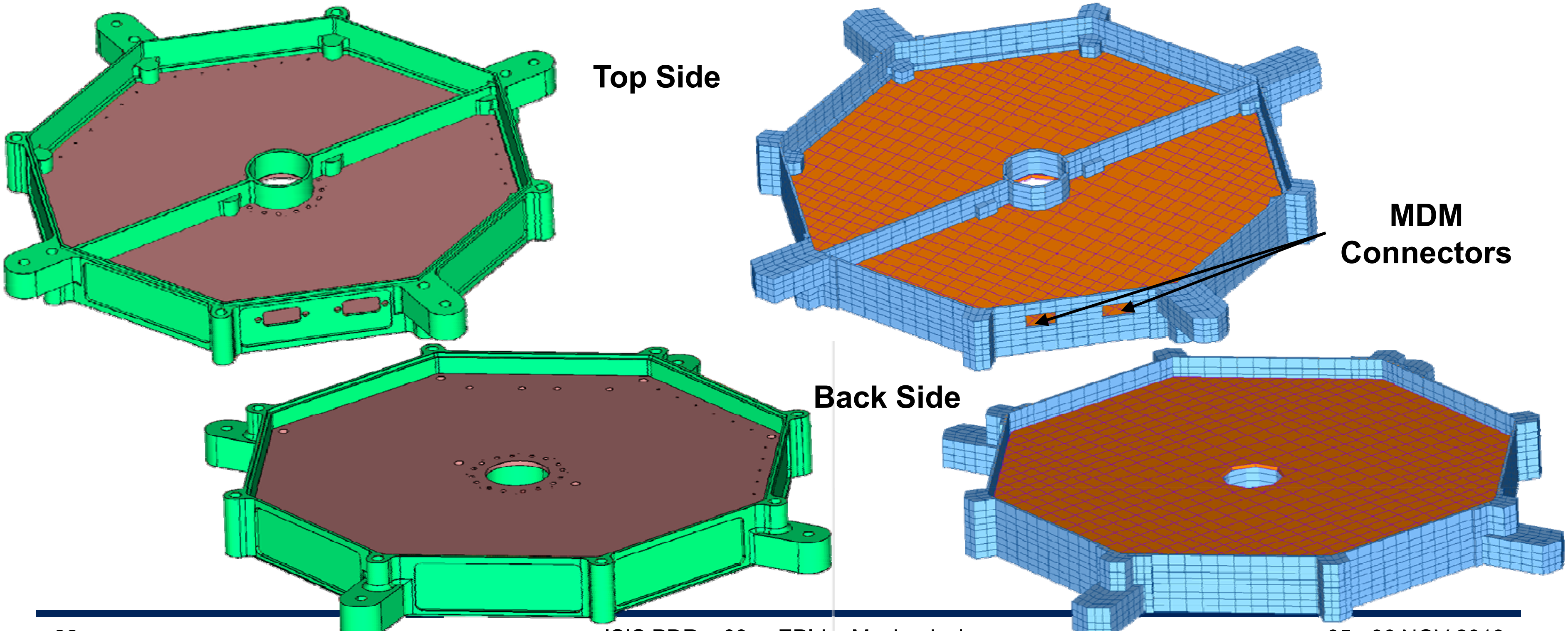
- Spider frame modeled in detail using plate and solid elements with Al 6061 material properties
- Anode PWAs (4x) modeled using plate elements and PWA material properties with estimated board mass smeared across PWA
- PWAs connected to Spider frame at mounting hardware bosses using RBE2 elements



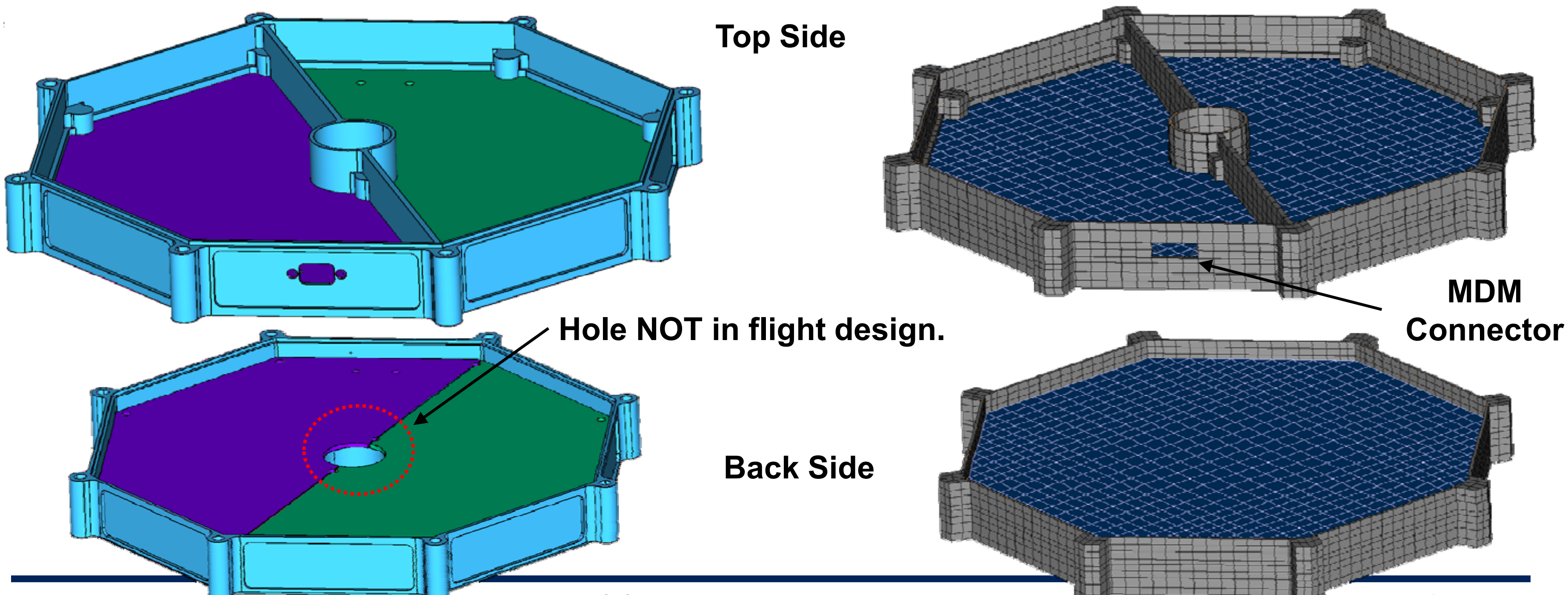
FEM Overview - Event Slice Assembly

- Event housing: plate and solid elements, Al 6061 material properties
- Event housing thickness .040” at minimum, thicker at bosses
- Event PWA: plate elements, PWA material properties and EEE part mass smeared across board
- PWA: diameter = 7.0”, thickness = 0.093”
- Right-angle MDM connectors modeled with RBE2s from frame to board
- PWA connected to housing with RBE2s at mounting bosses



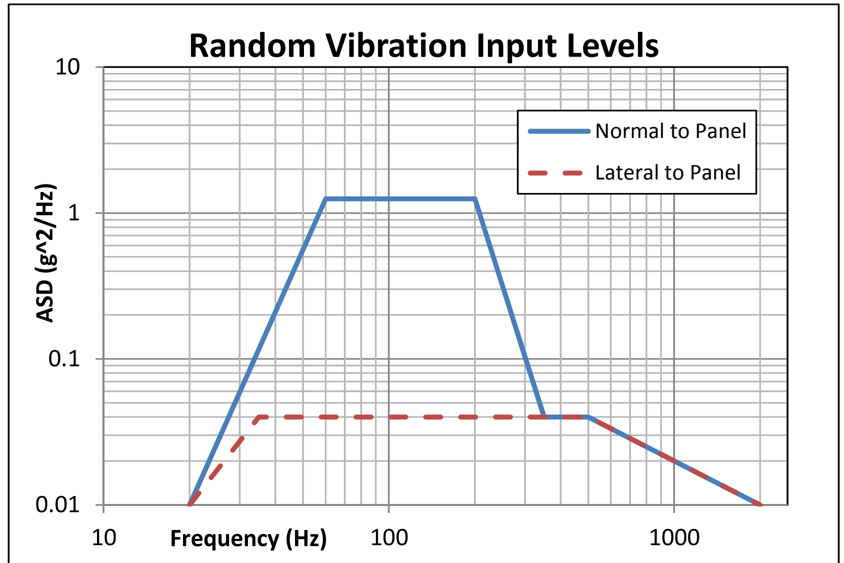
FEM Overview - LVPS Slice Assembly

- LVPS housing: plate and solid elements, Al 6061 material properties
- LVPS housing thickness .040” at minimum, thicker at bosses
- LVPS PWA: plate elements, PWA material properties and EEE part mass smeared across board
- PWA: diameter = 7.0”, thickness = 0.093”
- Right-angle MDM connector modeled with RBE2 from frame to board
- PWA connected to housing with RBE2s at mounting bosses
- CAD PWA model does not capture flight design, FEM representative of flight config.



Forced Response Analysis

- All relevant structural environmental inputs per 7434-9039 SPP EDTRD
- Assume critical damping = 2.5% across full frequency range
- Sine sweep spec per Section 4.4.4 is TBD, therefore not analyzed
- Random vibration levels per Section 4.4.3
  - Table 4-8, Side panel mounted components & subsystems parallel to panel
  - Table 4-9, Side panel mounted components & subsystems lateral to panel
- Items of interest for random response analysis:
  - Grms acceleration response of instrument and PWAs
  - Peak 3-σ displacement response
  - Peak 3-σ stress & margins of safety
- Random vibration analysis results envelope Static 40 g load (per Section 4.4.2.1)
- 40 g static load results not presented in this analysis



Normal to Panel		Parallel to Panel	
Freq (Hz)	ASD Level (g^2/Hz)	Freq (Hz)	ASD Level (g^2/Hz)
20	0.01	20	0.01
60	1.25	35	0.04
200	1.25	500	0.04
350	0.04	2000	0.01
500	0.04		
2000	0.01		
Overall Amplitude: 16.4 grms		Overall Amplitude: 6.8 grms	

Forced Response Analysis Random Vibration Grms Results

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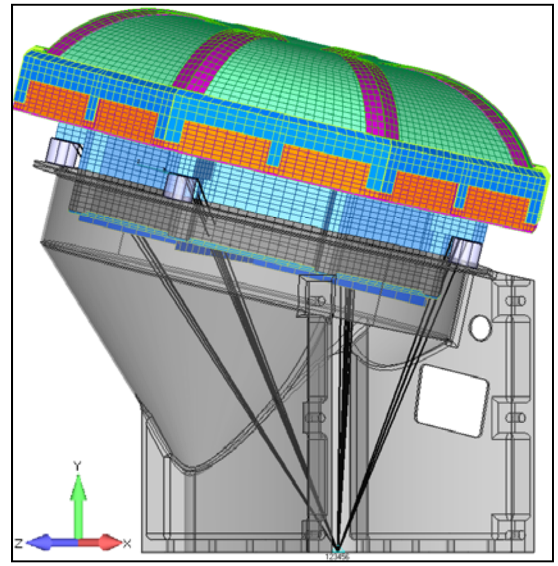
- Random vibration inputs simulated at B.C. node
  - B.C. node "spidered" to nodes at instrument mounting interface to ISIS bracket
  - ISIS bracket and G-10 standoffs NOT part of EPI-Lo FEM, assume instrument "hard-mounted"
  - Inputs simulated one axis at a time for all three orthogonal axes
- Acceleration spectral density (ASD) response for various nodes
  - Nodes represent worst case response per subassembly
  - Across full range (20-2,000 Hz) of interest
- Due to EPI-Lo's mounting configuration in relation to the input load, there are significant cross-axes responses



Y-axis Input 3-σ grms Response

ID	X-Axis	Y-axis	Z-Axis
Input	0.0	16.4	0.0
C.G.	7.8	67.9	8.1
Event PWA	**31.2**	**193.0**	**30.1**
LVPS PWA	26.4	158.1	25.1
LVPS Cover	26.9	153.5	26.2
Top Cover	16.0	112.1	17.0
Anode PWA	9.4	76.5	10.2
Anode Cover	12.2	92.3	12.8
Spider Frame	5.5	66.1	9.5

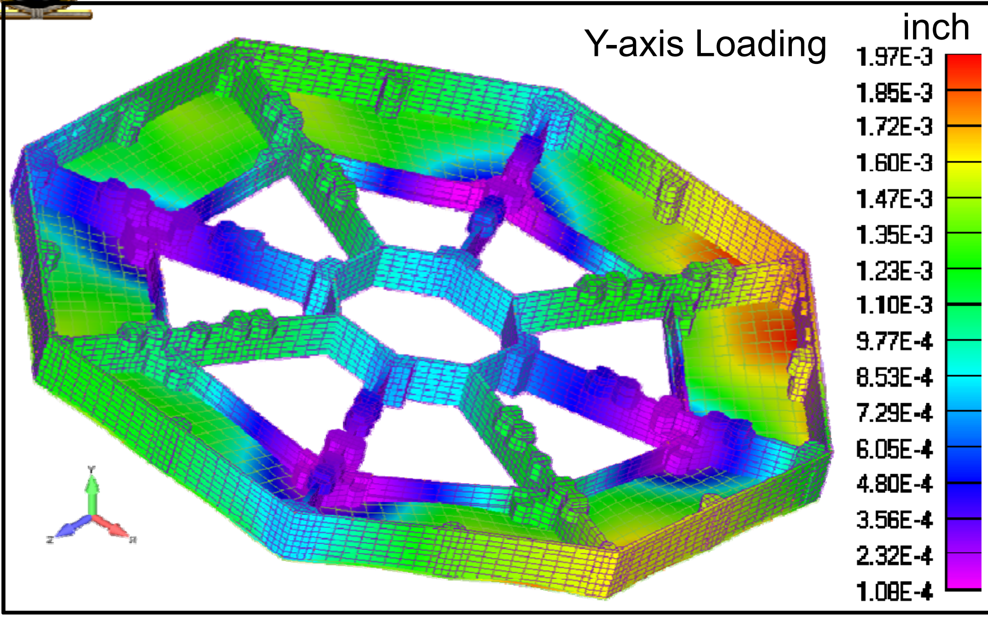
X-axis Input 3-σ grms Response

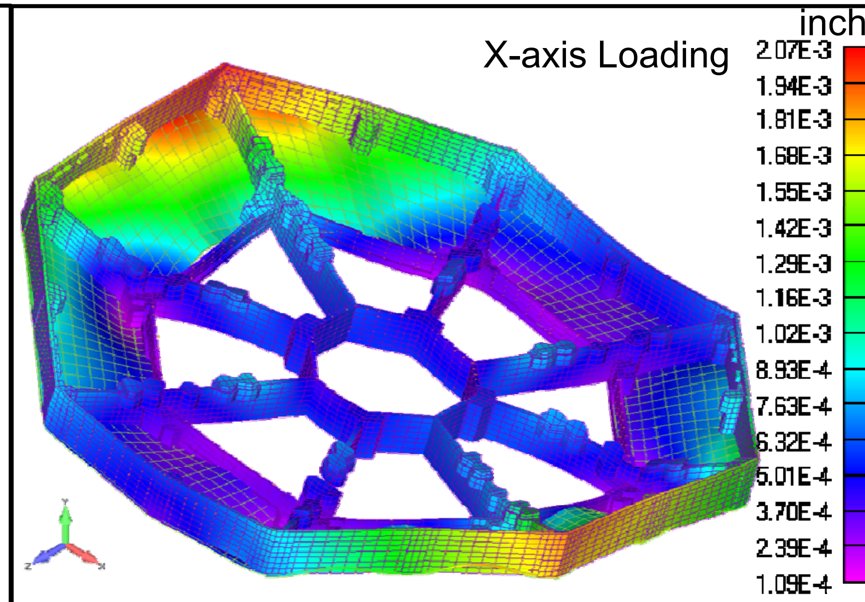
ID	X-Axis	Y-axis	Z-Axis
Input	6.8	0.0	0.0
C.G.	30.9	7.8	3.4
Event PWA	26.2	41.4	8.0
LVPS PWA	**48.9**	**97.9**	**27.4**
LVPS Cover	45.7	30.5	14.8
Top Cover	58.0	16.3	5.6
Anode PWA	30.8	61.5	10.3
Anode Cover	35.7	161.1	27.0
Spider Frame	29.9	64.0	12.1

Z-axis Input 3-σ grms Response

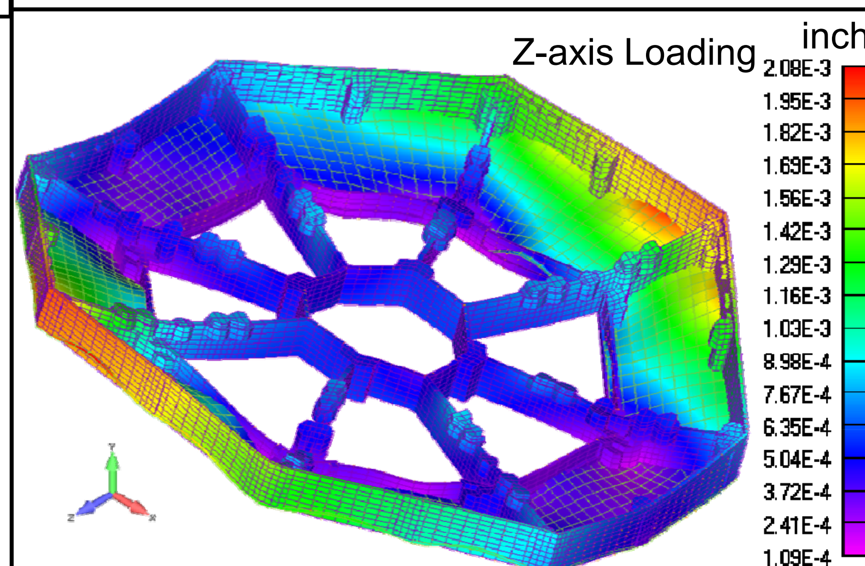
ID	X-Axis	Y-axis	Z-Axis
Input	0.0	0.0	6.8
C.G.	3.4	8.2	31.3
Event PWA	13.6	64.7	29.4
LVPS PWA	**24.1**	**71.9**	**46.5**
LVPS Cover	14.2	27.7	50.9
Top Cover	5.6	17.0	57.9
Anode PWA	11.8	65.4	33.9
Anode Cover	13.1	67.3	26.8
Spider Frame	8.7	28.1	31.4

Forced Response Analysis
Random Vibration Results: Displacement





- Spider frame and Anode cover total displacement results for the 3 individual loading conditions
- Max displacement ~2 mil for all 3 loading conditions
- Spider frame rigid out-of-plane due to hexagonal rib design
- Anode covers stiff due to 9 mounting holes, all corners and mid-span



Forced Response Analysis
Random Vibration Results: von Mises Stress

- Model analyzed for von Mises stress under random vibration loading using MAYA structural analysis toolkit
- 3-σ stress results output for complete model
- Interested mainly in PWA and Frame stress
- Fastener analysis not done at this time
- Factors of safety (FoS) taken from 7434-9039 SPP EDTRD Rev E, Table 4-5.
  - Additional 1.28 factor for random analysis per Section 4.4.2.2
  - Metallic structures: FoSu = 2.68, FoSy = 2.53
  - Composite (PWA + Ultem1000): FoSu = 2.78, FoSy = N/A
- Margins of safety (MoS) calculations performed,
  - MoS formula -> $MoS = \frac{Strength}{FoS * \sigma} - 1$
- All margin of safety results are positive for the current design iteration

Analysis Summary

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- Preliminary structural analysis of the baseline SPP EPI-Lo Instrument performed
- MSC.Nastran, MAYA SATK, and Femap used for analysis
  - Model simplified wherever possible to aid solution time
  - PWAs modeled as plate elements with uniform stiffness, thickness and density
  - Instrument model oriented to ISIS bracket configuration in relation to S/C panel
- Modal analysis performed, 1st mode = 304 Hz (Event PWA); Instrument mode 1 = 553 Hz
- Analysis environmental input levels per 7434-9039 SPP EDTRD Rev -
  - Analysis performed for all three orthogonal axes relative to S/C panel
  - Sine vibration analysis not performed (TBD in EDTRD)
  - EPI-Lo 3-σ acceleration random response enveloped static load requirement
  - Random vibration analysis 3-σ response desired for EPI-Lo instrument displacements, stresses and forces
- Random vibration PWA displacement response may be relatively high for EEE part solder/lead wire fatigue resistance, further analysis needed after EEE parts placement finalized
- All margin of safety positive for model configuration as of 6/19/13 under EDTRD Rev - inputs
- Detailed analysis needed for the flight configuration to confirm that flight design will have positive margins and meet minimum frequency requirement

Instrument Peer Review

- EPI-Lo Sensor Peer Review
  - Held May 22, 2013 at APL
  - Review yielded 12 action items, all are now closed

- EPI-Lo Instrument Peer Review
  - Held August 19, 2013 at APL
  - Review yielded 8 mechanical action items, all are now closed

Solar Probe Plus

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Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

EPI-Lo Electronics

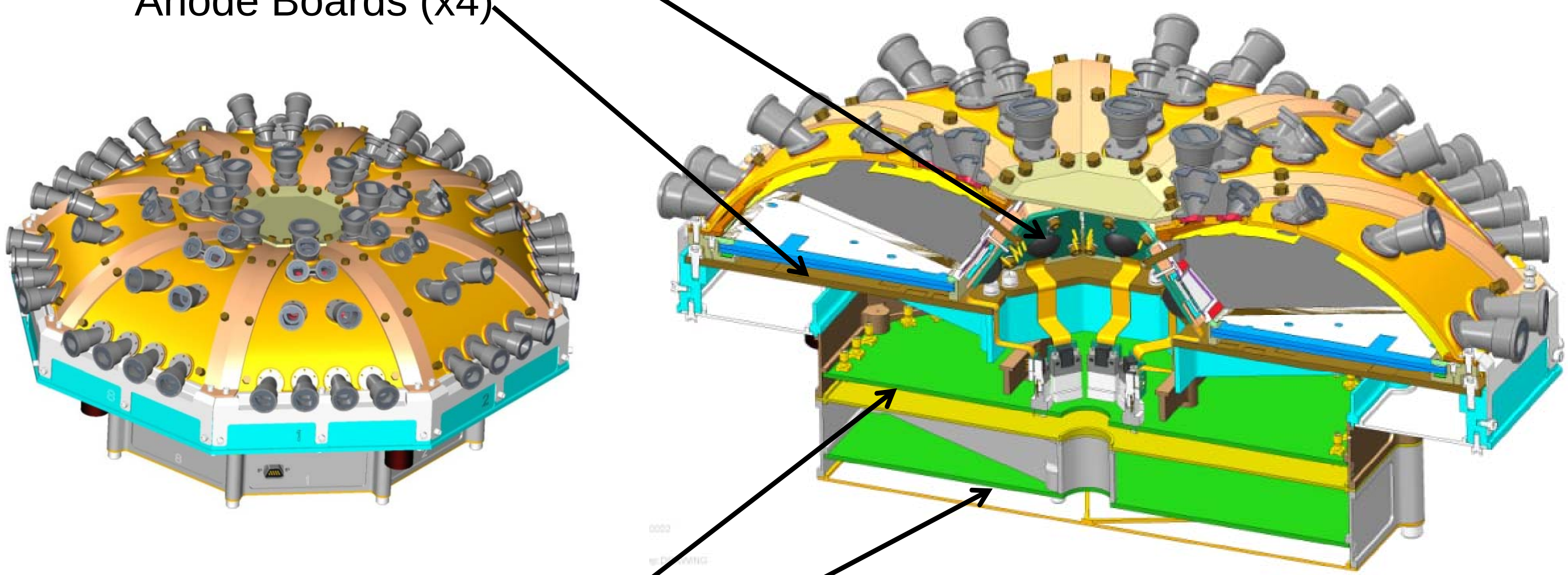
Reid Gurnee

EPI-Lo SE (JHU/APL)

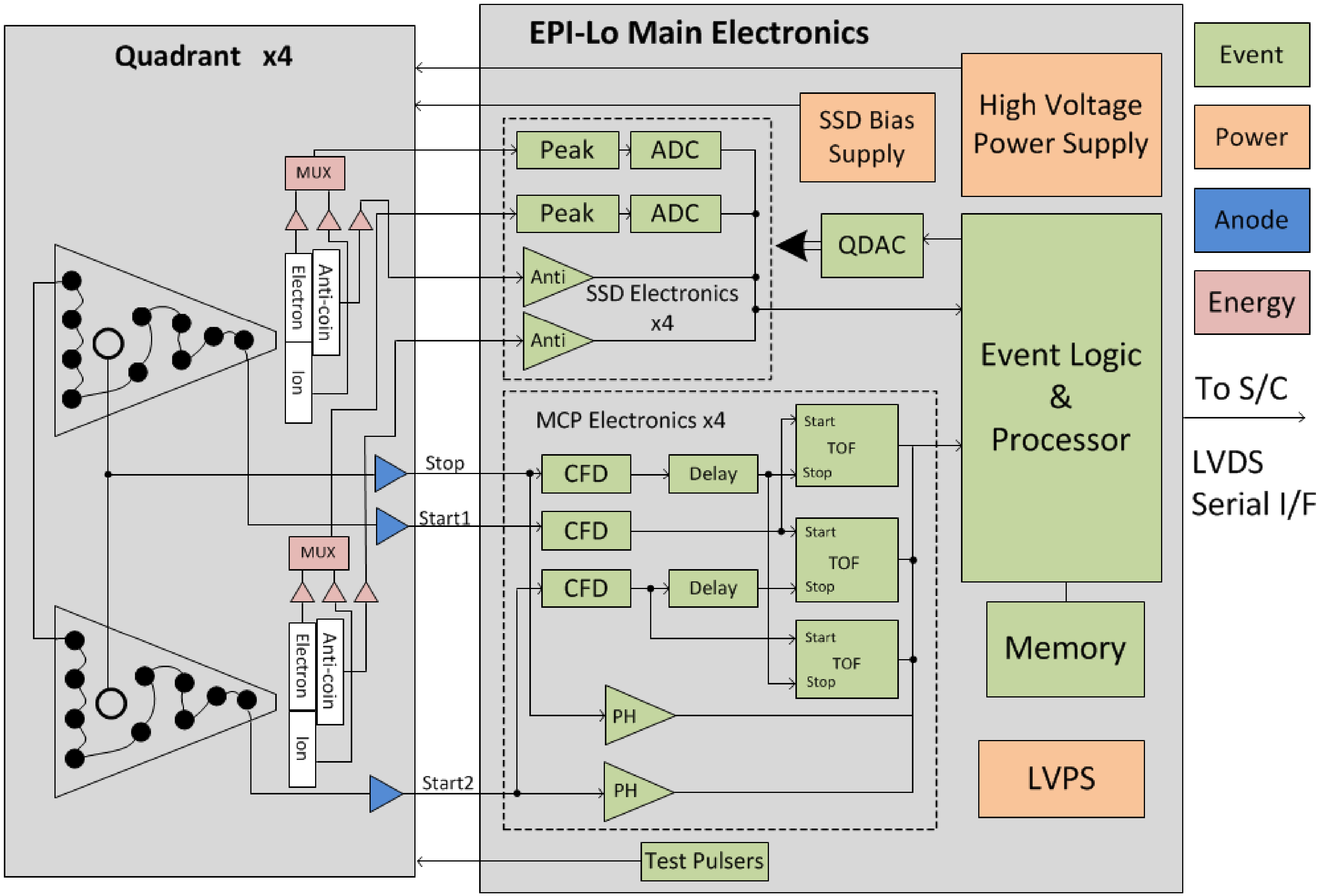
Outline

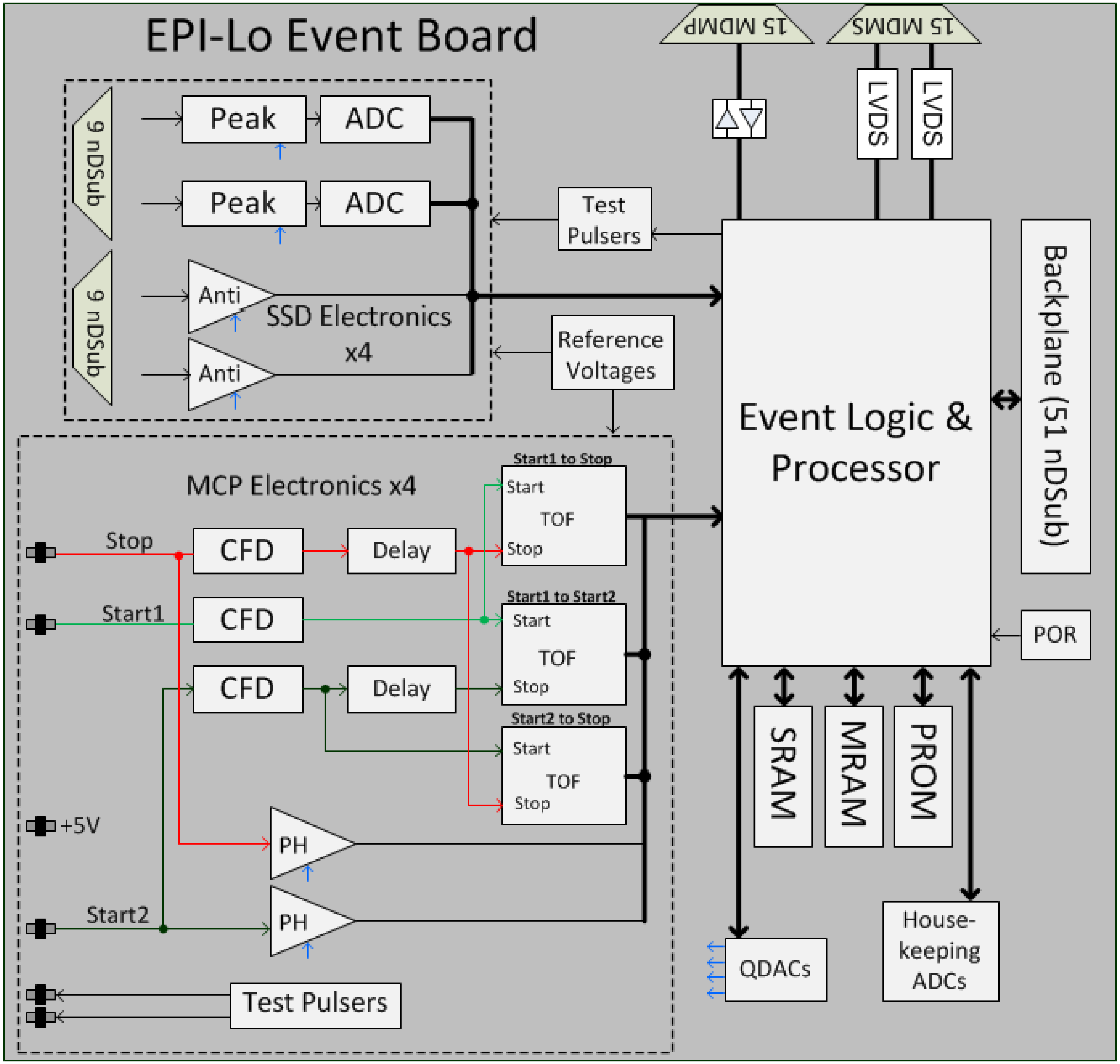
- Electronics Overview
- Block Diagrams
- Driving Requirements
- Event Board
  - Functionality, Interfaces, prototyping, FPGA, layout
- Anode Board
  - Functionality, Interfaces, prototyping, layout
- Energy Board
  - Functionality, Interfaces, prototyping, layout
- Packaging and Thermal Considerations
- Radiation Analysis
- Plans for Testing
- Preliminary Parts List and Special Screening Considerations
- Status Summary
- Plan Forward
- Peer Review Status

EPI-Lo – Electronics Overview



EPI-Lo Block Diagram




EPI-Lo Event Board
15 MDMP
15 MDMS
LVDS
LVDS
9 nDSub
9 nDSub
Peak
ADC
Peak
ADC
Anti
Anti
SSD Electronics x4
Test Pulsers
Reference Voltages
Event Logic & Processor
Backplane (51 nDSub)
MCP Electronics x4
Start1 to Stop
Start
TOF
Stop
Stop
CFD
Delay
Start1
CFD
Start1 to Start2
Start
TOF
Stop
CFD
Delay
Start2 to Stop
Start
TOF
Stop
+5V
PH
PH
Start2
Test Pulsers
POR
SRAM
MRAM
PROM
QDACs
House-keeping ADCs

Electronics Driving Requirements

- Analog Performance
  - Timing resolution < 400 ps FWHM
  - Energy resolution < 15 KeV FWHM
- MCP timing system dynamic range of 500 k to 25 M electrons
- Energy system dynamic range of 50 keV to 15 MeV
  - Higher energies (>1 MeV) use pulse width mode
- Temperature
  - Survival: -55°C to +85°C
  - Operational: -35°C to +65°C
- Radiation
  - TID: 25 kRad (based on FASTRad analysis)
  - SEL: 80 MeV-cm^2/mg
- Event board very similar to previous programs (RBSPICE, JEDI, EIS). All major changes have been prototyped.

Event Board Functionality (1/2)

- Instrument Processor
  - Embedded processor in RTAX2000
    - Execute flight code, accumulating and formatting telemetry, commanding, and alarm detection and action
  - Spacecraft Communication
  - Boot code in PROM, classification tables and application code in MRAM
  - Accumulate data into classification tables
- Event Processing
  - Communicate and handle timing with ADCs, TOF-Ds
  - Pre-process and accumulate event data
  - Accumulate rates
- HVPS Control
  - Control four opto-coupler generated HVPS outputs
  - Provide high speed safing of HVPS in response to over current

Event Board Functionality (2/2)

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- Time-of-flight based on APL TOF-D and CFD-D ASICs
  - New ASICs developed for future programs
  - Improved size and performance from previous ASICs
  - 12 CFD-Ds and 4 TOF-Ds for timing system
- Solid-State Detector Energy Measurements
  - 8 Peak detect ASICs and A/D converters for energy system
  - Peak detect chips are APL ASICs flown on previous missions (PEPSSI, Jedi, RBSPICE)
- MCP pulse height comparators
- Pulsers
  - Independent pulsers for start and stop signals on each anode board
  - 2 pulsers for Energy system

Event Board Interfaces

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- Solid-State Detector Interface
  - 8, 9-pin ndsub connectors to energy boards
  - ~10 mV to over 1 V unipolar-shaped pulses
  - Control, pulser, and power lines
- Anode Board Interface
  - 12 Time-of-Flight Coax connectors
    - ~10 mV to over 1 V fast-shaped pulses
  - 4 power and 8 pulser Coax connectors
- Test Port Connector
  - 2 test inputs (to aid in end-to-end timing tests)
  - 5 test outputs
- Spacecraft Data Connector
  - Redundant LVDS interface (2 drivers, 2 receivers)
- Power Board Connector
  - 51 pin ndsub connector for power and communication

Energy System Updates

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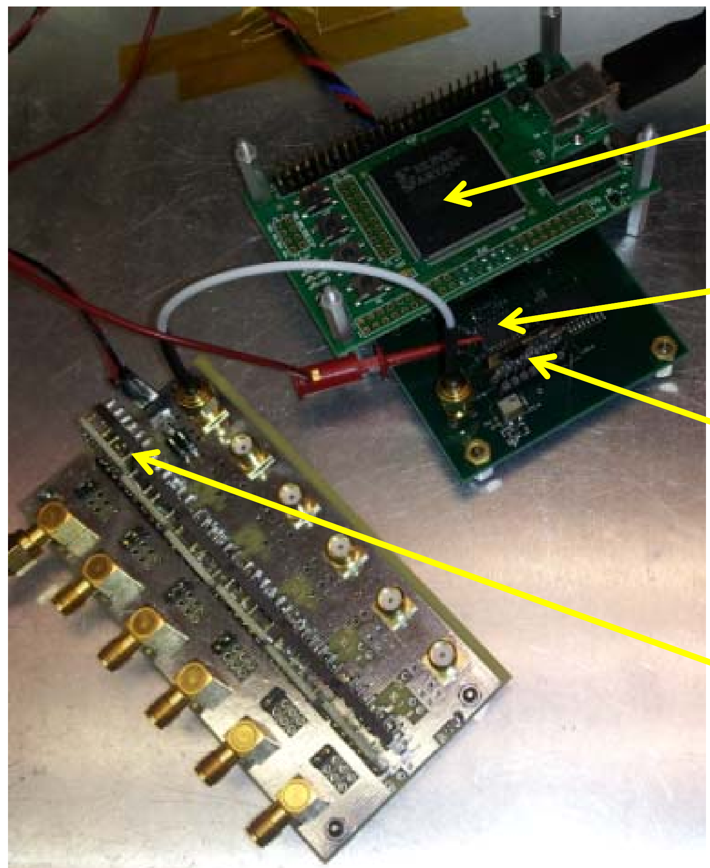
- Energy system re-designed from previous instruments
  - 8 ADC121s read out the 8 peak detect chips
  - Prior designs used MUX and one fast ADC
  - New design allows de-coupling of quadrants – each quadrant has completely independent readout electronics and can be operated as an individual instrument
  - Event logic will be identical for each quadrant, and then the data will be combined
  - New approach significantly simplifies event logic design and increases data processing rates and redundancy

Energy System Prototype

- Fully tested interface of energy chip to peak–detect SIP to ADC using flight-like components
- Energy resolution of test setup far exceeds requirement (15keV)

atten. DB	KeV	FWHM (KeV)
-6	912.161	8.78712
-7	812.964	6.26275
-8	724.555	6.08932
-9	645.760	5.81954
-10	575.535	5.5883
-15	323.647	4.91385
-20	182.000	4.64407
-25	102.346	4.50918
-30	57.553	4.29721
-35	32.365	4.14305
-40	18.200	4.54772



FPGA Functionality

- FPGA contains all event logic and event processing
  - SCIP: 16-bit 10 MIPS processor (reused custom embedded processor based on Harris RTX2010 and APL's FRISC)
  - Processor memory interface to PROM, MRAM, SRAM
  - Support I/O
    - Provide voltage supply clocks, read safing status, set thresholds, monitor housekeeping, etc.
    - LVDS spacecraft communication interface
    - Processor test port interface
  - Event Logic
    - Count sensor basic rates and diagnostic rates
    - Provide pulser stimulus
    - Collect and process TOF values to generate start direction and particle time-of-flight
    - Select appropriate SSD channel and record energy deposited
    - Detect anti-coincidence (electron only) and pulse-height over-threshold (start and stop)
    - Send selected valid events based on commanded event criteria to processor event buffer
    - Event logic test port for ground testing

FPGA Resources

- Actel RTAX2000SL -1 speed CCGA-624 (common buy part)
  - Estimate ~40% resource utilization based on RBSPICE design
  - Internal RAM for event FIFO only
    - No minimum size required and soft memory is fine (parity check)
  - 418 user I/O total, 18 spares
    - 3 spares to power board + 7 spares through Schmitt triggers to test connector + 8 true spares = 18 spares
    - Note: At the FPGA requirement review, moderate reuse designs are green for at least 17 uncommitted I/O pins
  - 1.5 V Core Voltage, 3.3 V I/O supply voltage
    - +/-5% voltage tolerance
    - Supplies can be powered up or powered down in any sequence as long as some app note details are considered
    - I/O are tri-stated during power-up

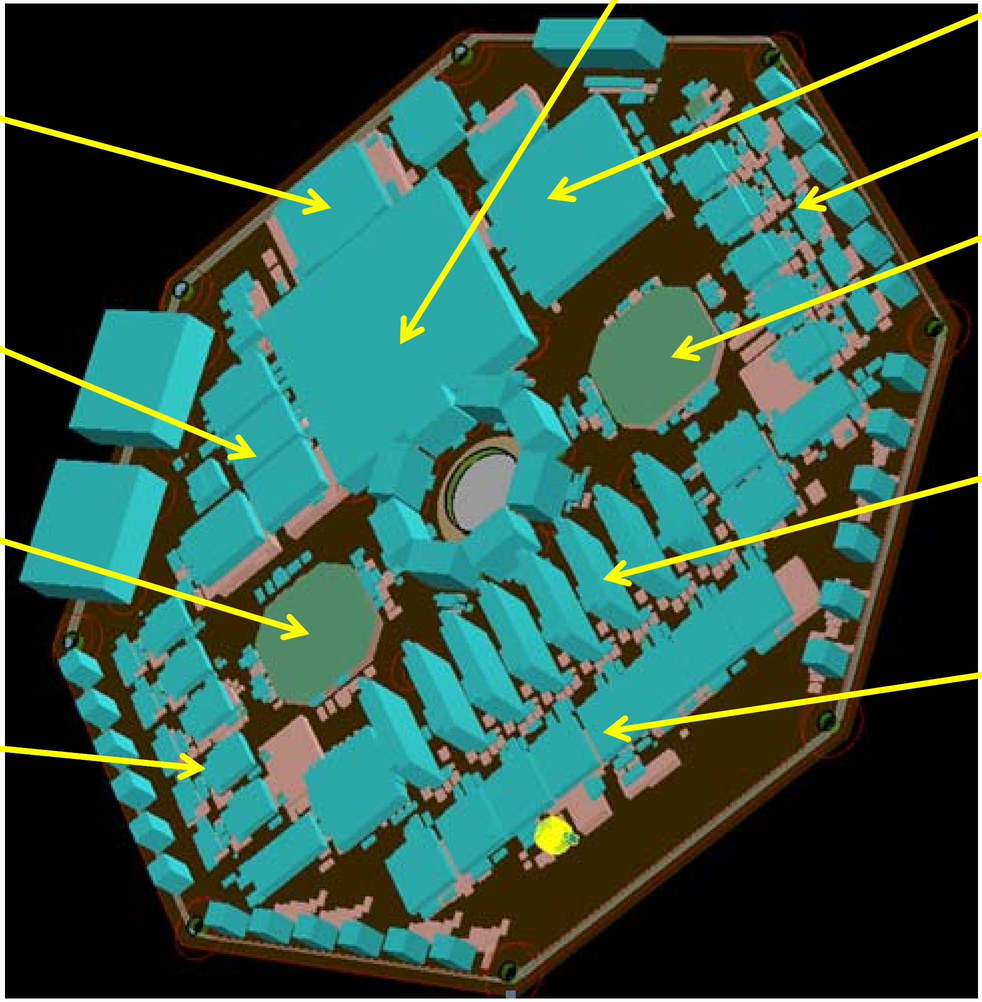
FPGA Development

- Part prototyping
  - Reprogrammable Aldec/Actel system for EM
  - Board layout also accommodates commercial socket if needed
- Design prototyping/reuse
  - SCIP is identical to RBSPICE
  - Similar approach to RBSPICE for many interfaces: S/C communication, power supplies, QDACs, test port, memories, peak detects, pulsers
  - New interfaces prototyped prior to EM: TOF-D rather than TOF-C, new ADC for HK and energy readout
  - Significant previous experience with all design tools: VHDL (with tcl scripts, pdc files etc.), Synplify Pro, Actel Libero, ModelSim
- No expected areas of concern
  - No timing closure challenges expected (most of design at 10 MHz, some at 40 MHz)
  - Primarily synchronous design techniques with standard clock domain crossing techniques and no gated clocks
  - Straightforward reset filtering and routing network
  - Sufficient clock nets available for clocks and reset

Event Board Layout

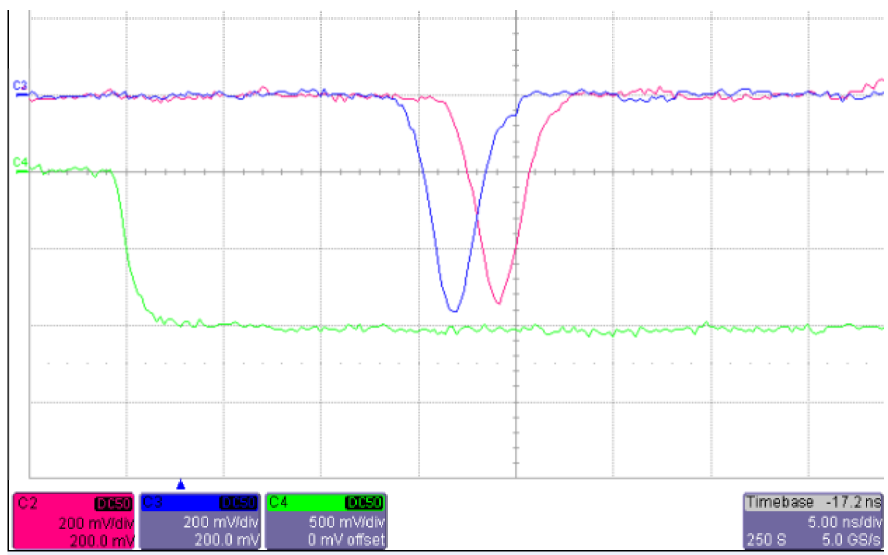
- Sensitive analog is separated from digital
  - FPGA, S/C communication, SRAM, PROM, MRAM, and oscillator on top of board
  - TOF electronics on left and right of board
  - Peak detect and ADC electronics on bottom of board
  - All critical routing isolated by ground planes from digital routing
- 12 layers, 2 ground planes, 2 power planes, 8 routing planes
- Actel located with SRAM directly adjacent
  - Reduce track-length to SRAM to reduce noise
  - Actel on Primary side, to allow the Development Tool access to the program pins

Event Board Layout



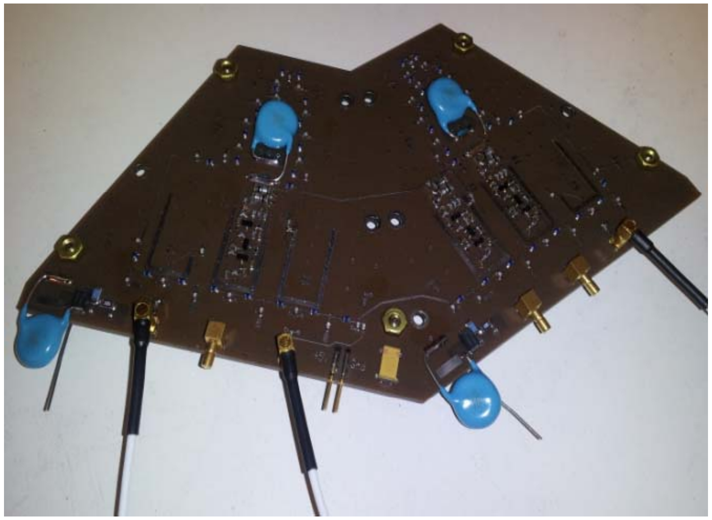
Anode Board Description

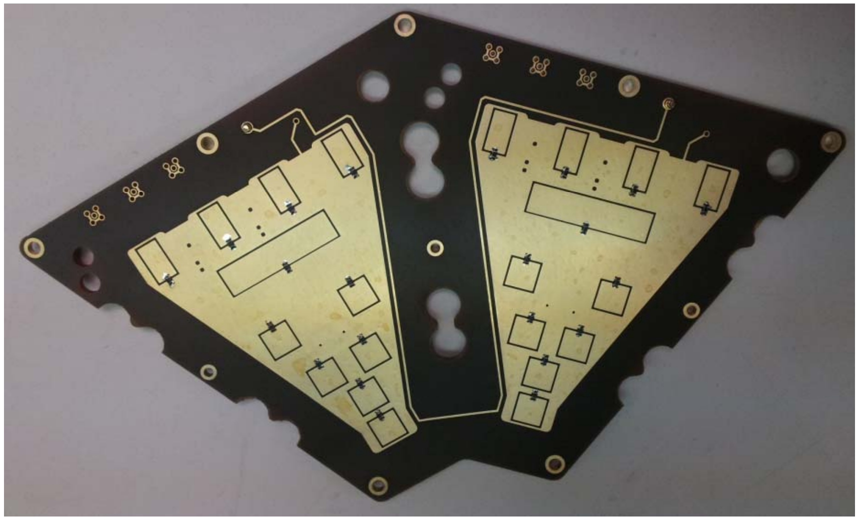
- Functionality
  - 3 fast discrete amplifiers
    - Stop anode and each end of the start delay line
    - 50 ohm impedance matched, designed to drive 50 ohms
  - Anode is at 3kV, PCB embedded capacitors isolate HV from LV
  - 1 start pulser and 1 stop pulser
    - Start pulser location in imaginary anode between sensor wedges
- Interfaces
  - 6 coax SSMB connectors
  - Power, 3 outputs, 2 pulsers
  - HV connection for anode



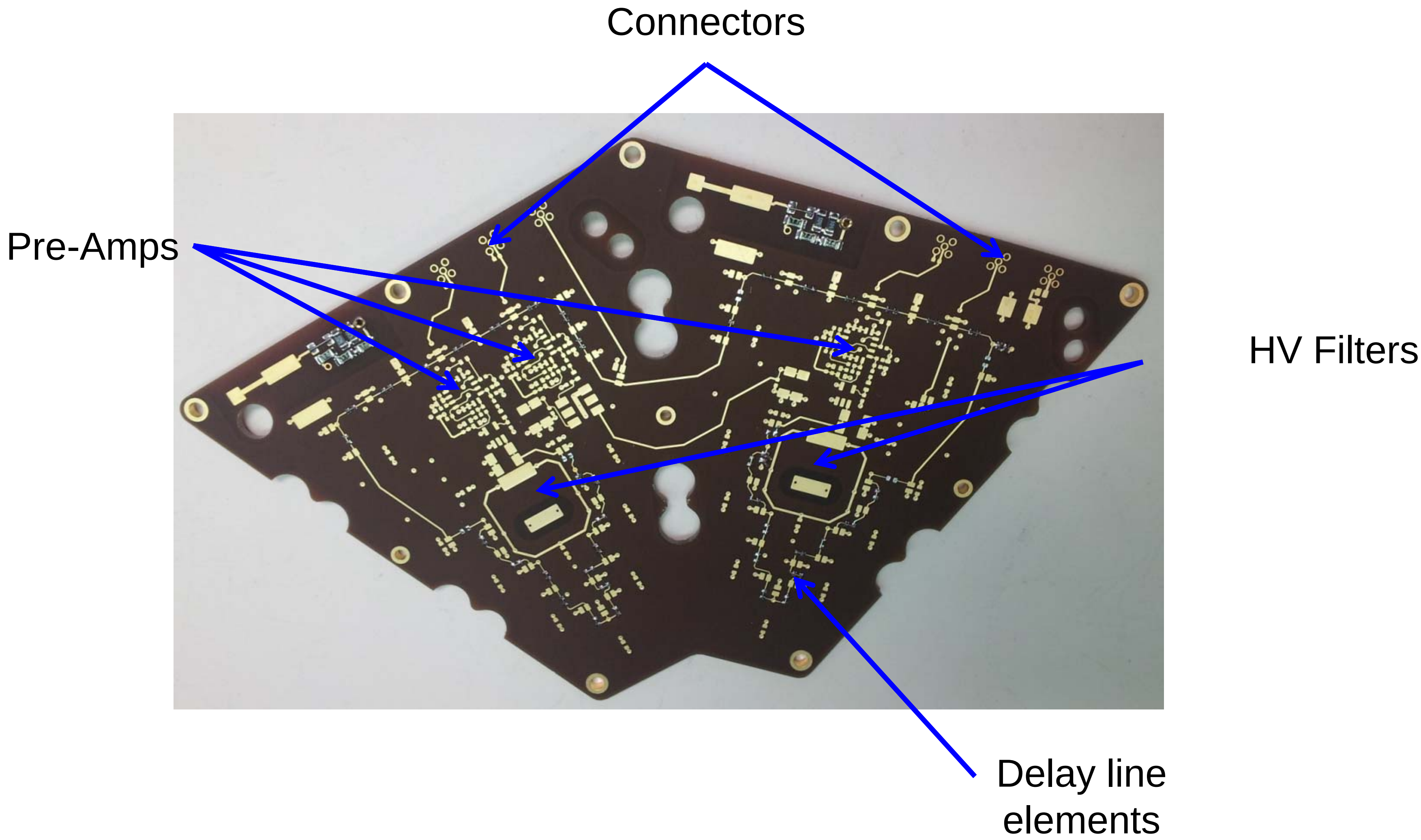
Anode Board Prototyping

- Initial prototype board fabricated, assembled, and tested
  - First implementation of embedded capacitors for HV anode
  - Verified quadrant design
- EM anode board fabricated, assembled, and in testing
  - Electrical and mechanical interfaces well defined
  - Position mapping on prototype verified simulations for start pad locations
  - Kapton layer provides dielectric strength of ~20kV for embedded capacitors
    - Passed 10 day, 2x HV standoff test (recommended by Steve Battel)
  - APL packaged transistor array



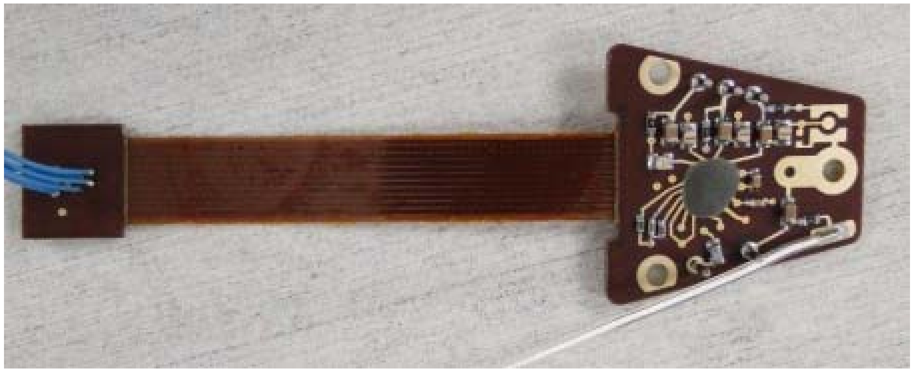


Anode Board Layout

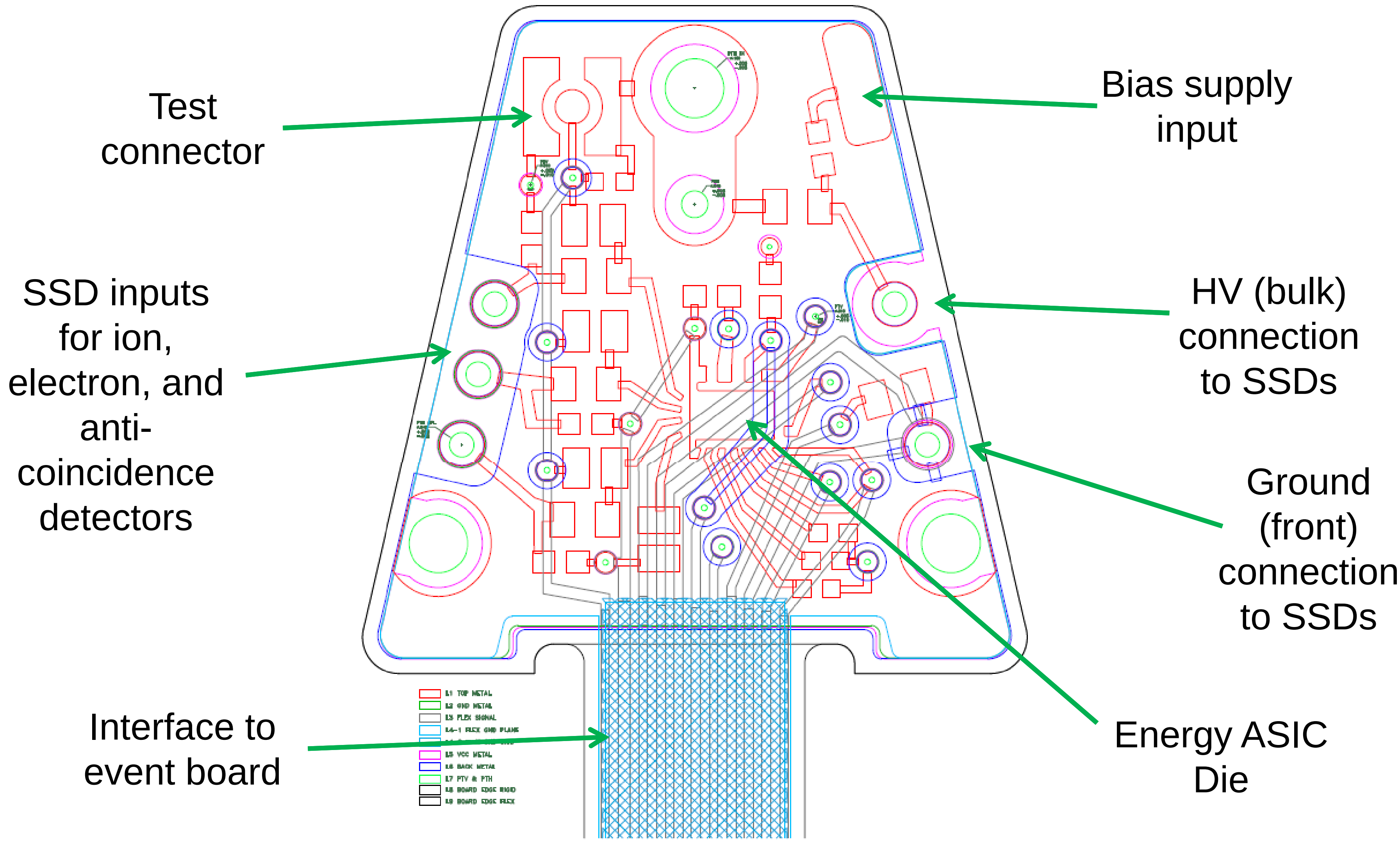


Energy Board

- Functionality
  - SSD Pre-amplifier and shaper
  - Energy ASIC supports 3 pre-amplifiers and MUX
    - Ion channel, electron channel, anti-coincidence channel
    - Select between ion channel or electron and anti-coincidence channels
  - Thermistor for temperature measurements
  - Test connector for pulser inputs
- Interfaces
  - 9 pin ndsub connector for power, signals, pulser, and temperature monitor
  - Bias voltage from separate HV wire (<200V)
  - Test connector (MMCX)
  - SSD connections (Mill-Max Socket)
- EM energy board fabricated and in testing

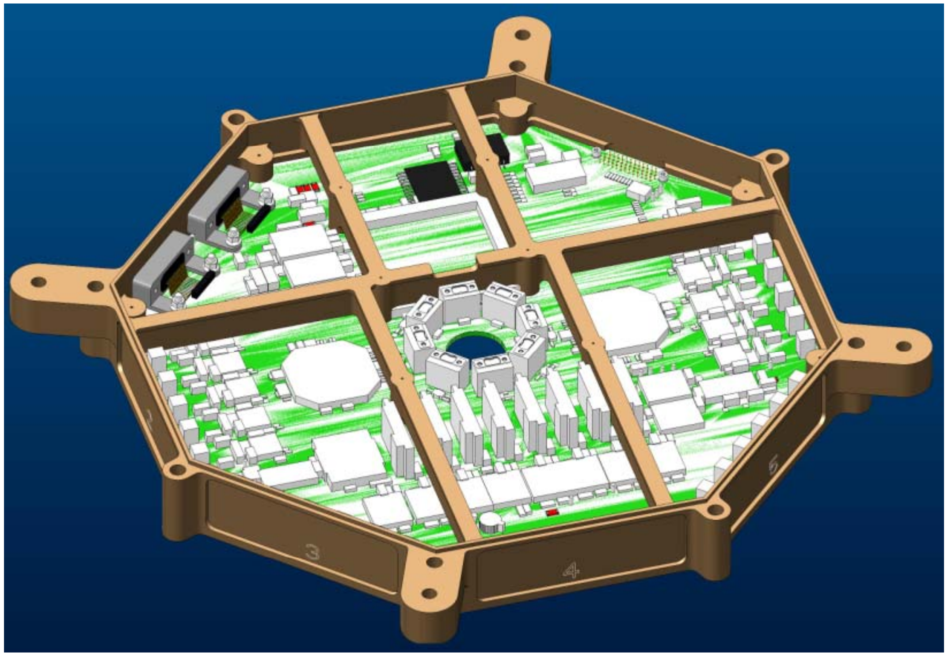


Energy Board Layout



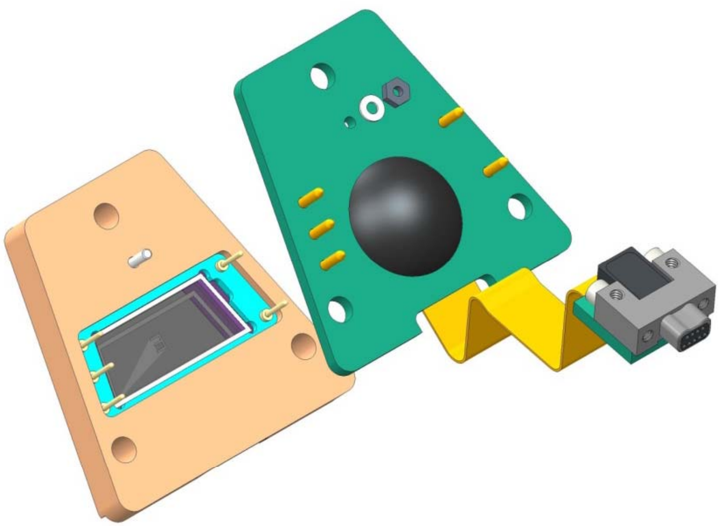
Event Board Packaging

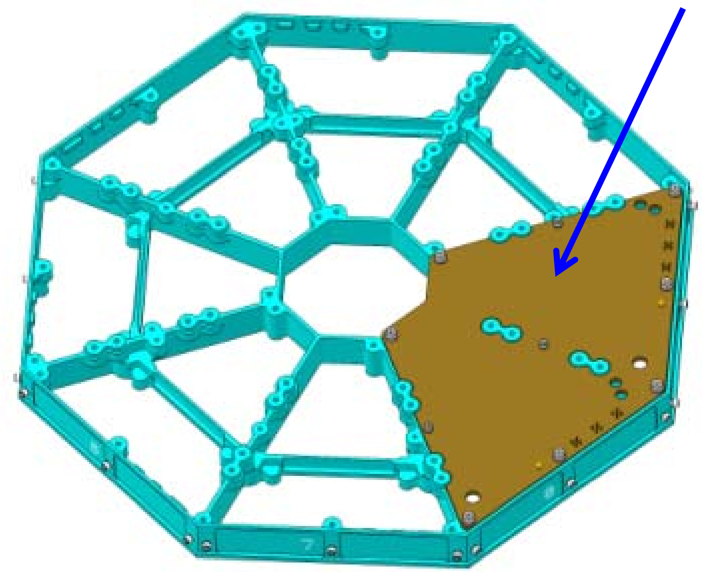
- Packaged in octagon frame “slice”
  - Board is loaded from the bottom and has six center mounting supports and full contact around the perimeter
  - FPGA is supported on four corners
- Large number of thermal vias under the higher power parts
  - Actel, RAM, and MRAM to dissipate power into the board planes and out to the frame.
  - Total board power is ~1 watt. No thermal issues expected.



Anode and Energy Board Packaging

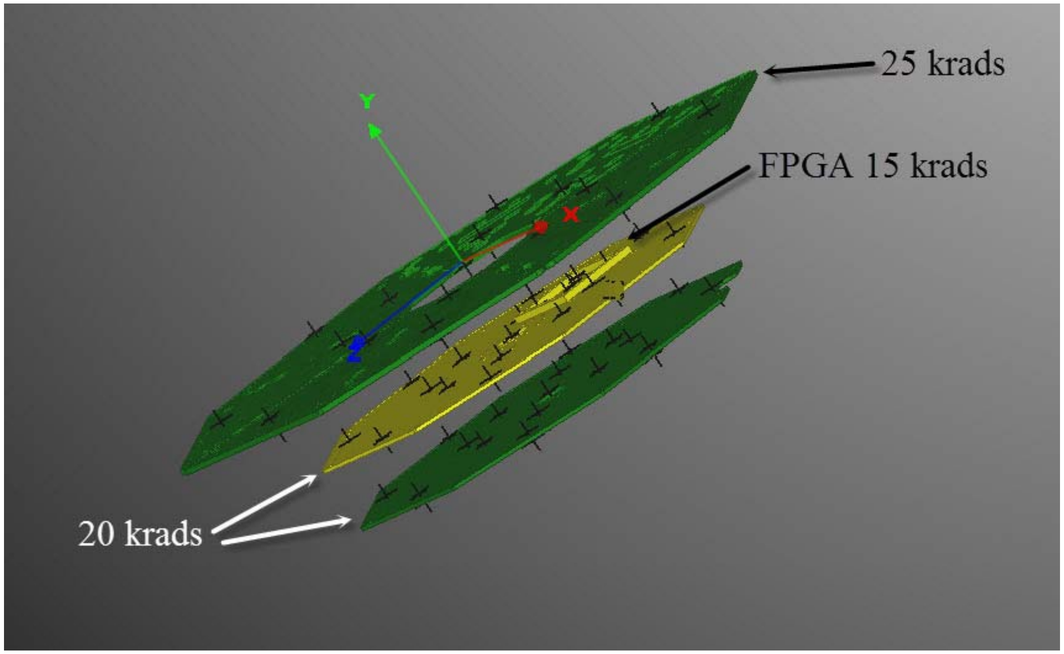
- Anode Board
  - Mounted to instrument main support structure
  - Total board power is 90 mW, no thermal concerns
- Energy board is mounted directly behind SSD
  - Total board power is 25 mW, no thermal concerns





Radiation Analysis

- FASTRad analysis performed on instrument in S/C model to predict doses seen at electronics (bracket, instrument, and S/C modeled)
- Electronics boards: <25 krad
- Detectors: <40 krad



Plans for Testing

- Follows APL Manufacturing Flow, these are significant highlights
  - Populate Passive Components
  - Execute Test Procedure to Verify Passive Components
  - Populate First-level Active Components
    - Voltage References, Power-on Reset, Oscillator, applicable Tailor Flags
  - Execute Test Procedure to Tailor and Verify First-level Active Components
  - Populate Actives and Install Known Tailors or Tailor Flags
  - Install into Flight Frame
  - Execute Test Procedure to Test and Tailor Entire Board
  - ESS Testing
  - Execute Functional Test Procedure
  - Photograph and Conformal Coat
  - Execute Test Procedure to Calibrate and Characterize Board (over temperature)
  - Release to Next Assembly

Preliminary Parts List

- Investigating ADC for single event transients
- ADCMP600 being qualified by project
- Transistor array die being packaged by APL into ceramic 16 pin LCC

Function	Preliminary Part Number	Manufacturer
Event Board		
RTAX2000	RTAX2000SL-CGS624E	Actel
RAM	HLXSR01632	Honeywell
MRAM	UT8MR2M8-40YPC	Aeroflex
PROM	UT28F256LVQLE-65UPC	Aeroflex
Oscillator	1103D40M00000BX	Vectron
LVDS	UT54LVDS032LV-UPC	Aeroflex
LVDS	UT54LVDS031LV-UPC	Aeroflex
Schmitt Trigger	UT54ACS14E	Aeroflex
Comparator	ADCMP600BKSZ	Analog Devices
Op-amp	RH1078MW	Linear Technology
MDM connector (test)	MWDM2L-15PSMRTN	Glenair
MDM connector (data)	MWDM2L-15SSMRTN	Glenair
ndsub for SSDs	891-007-9S-__-BST-_-T	Glenair
ndsub for inter-board	891-006-51P-__-BST-_-T	Glenair
coax for anode board	050-451-0000-220	ITT Canon
Reference	RH1009MH	Linear Technology
ADC	ADC128S102WGMPR	TI
POR IC	ISL706ARHF	Intersil
Level Shifter	UT54ACS164245S-UPC	Aeroflex
CFD ASIC	10946-CFD-D-03	APL ASIC
TOF ASIC	10946-TOF-D-03	APL ASIC
DAC ASIC	10946-QDAC2B-01	APL ASIC
Energy Board		
Energy Chip	7425-5214-01	APL ASIC
Anode Board		
Transistor Array	ISL73096	Intersil

Status Summary

- Event Board
  - EM parts placement complete
  - Routing in process
  - EM PCB expected in December
  - All critical circuits have been prototyped
- Anode Board
  - Prototype anode board fabricated, assembled and tested
  - EM anode board fabricated, assembled and testing in process
  - 10 day, 2x HV standoff test successfully completed on EM
- Energy Board
  - EM board fabricated, assembled, and testing in process

Plan Forward

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- Anode Board
  - Complete testing on anode board
  - Fabricate flight anode board
- Energy Board
  - Complete testing on energy board
  - Fabricate flight energy board
- Event Board
  - Fabricate EM board
  - Complete testing on EM board
  - Fabricate flight Event board
- Finalize all documentation and procedures for flight build
- Build, tailor, calibrate, and qualify flight units

Peer Review Status

- Event and Power Board Peer Review
  - August 21, 2013
  - Summarized with action items in memo SRI-13-029
  - 11 action items generated / 11 action items closed (6 for event board)
- Anode Board Peer Review
  - June 21, 2013
  - Summarized with action items in memo SRI-13-025
  - 6 action items generated / 6 action items closed
- Energy Board Peer Review
  - August 26, 2013
  - Summarized with action items in memo SRI-13-030
  - 4 action items generated / 4 action items are closed
- Parts Stress Analysis
  - No issues expected
- WCA
  - No issues expected

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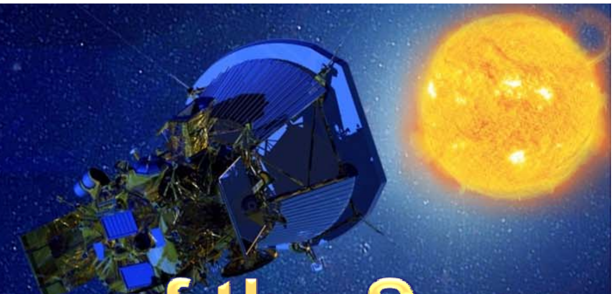


Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

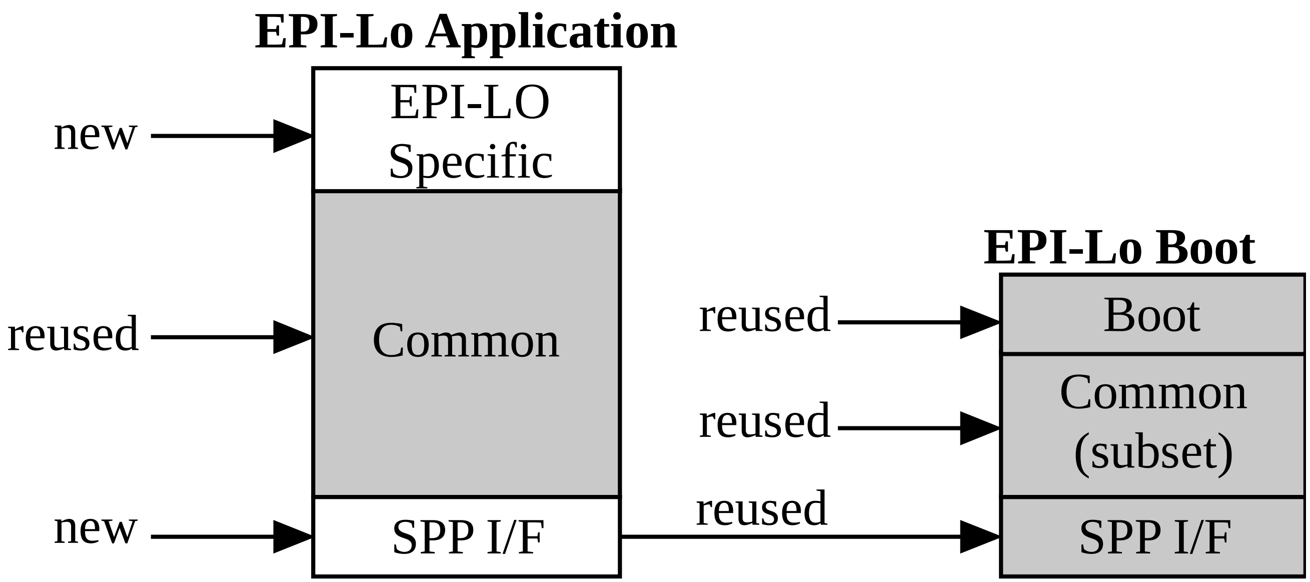
EPI-Lo Software

John Hayes

EPI-Lo FSW Lead (JHU/APL)

Outline

- Common Software
- SPP Host Software
- EPI-Lo Application Software
- EPI-Lo Boot Software
- Software Development Environment
- Summary



Common Software

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- Packet telemetry
- Command handling
- Macros (stored command sequences)
- Memory management
- Monitoring and alarm generation
- Status reporting

Common Software Reuse

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- Common software reuse estimates for EPI-Lo
  - ~50% of application
  - >90% of boot
- Common software currently (or soon to be) in flight:
  - MESSENGER: EPPS, GRS, MAG, MASCS, MDIS, NS, and XRS
  - MRO: CRISM
  - New Horizons: LORRI and PEPSSI
  - Pucks: Juno/JEDI, RBSP/RBSPICE, MMS/EIS (2014)
  - BepiColombo/Strofio (2015)
  - Solar Orbiter/SIS (2017)
- Automated regression test for common software (and for boot software)

SPP Spacecraft Interface Software

- Command and telemetry use 115200 baud UART protocol, 8 data bits plus odd parity
- Virtual 1PPS, i.e. falling edge of start bit of first byte in command ITF
- Redundant interface, side A vs. side B
  - Command arrival determines active side; telemetry sent only to that side
  - Dynamic side switching supported
- Interrupt driven: per-byte interrupt for command and telemetry, and side A and B 1PPS interrupts

SPP Host S/W – EPI-Lo to S/C

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- Telemetry ITF
  - Variable length up to 8196 bytes (EPI-Lo limits to 2060 bytes)
  - Multiple telemetry ITFs can be sent but cannot straddle 1PPS (EPI-Lo sends one per second)
  - Frame header includes sync pattern, length, etc.; checksum at end of frame
  - Frame transmission synchronized to 1PPS
- CCSDS telemetry packets
  - Variable length, up to 4096 bytes (including headers)
  - Zero to many packets per frame
  - Packets can straddle frames
  - 64 APIDs available
  - Critical housekeeping packet

SPP Host S/W – Critical Housekeeping

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- Critical housekeeping packet sent once per second
  - May optionally be sent to the SSR
  - If so, it counts against telemetry volume allocation
- Contains 32 bits of TBD data to share with other instruments
- Contains 8 bytes of housekeeping data
  - Data is included in spacecraft-generated combined instrument critical housekeeping packet
  - Data is NOT monitored by spacecraft autonomy
- Contains bits to request power off or power cycle, set via EPI-Lo command:
  - EPILO_SAF_OFF: Request power off
  - EPILO_SAF_CYCLE: Request power cycle

SPP Host S/W – S/C to EPI-Lo

- Command ITF
  - Variable length up to 512 bytes
  - S/C sends one command ITF per second
  - Frame header includes sync pattern, length, etc.; checksum at end of frame
  - Frame transmission synchronized to 1PPS
- CCSDS telecommand packets
  - Variable length, up to 362 (TBD) bytes (including headers)
  - One to many packets per frame
    - S/C time and status (telemetry) packet sent every second, always first
    - Zero or more command packets
  - Packets cannot straddle frames
  - Secondary header is optional (EPI-Lo does not use)
  - 64 APIDs available (EPI-Lo uses one)
- If command ITF is not received for a commandable number of seconds, EPI-Lo runs its safing macro

SPP Host S/W – Time Keeping

- Time is set by spacecraft
  - 32-bit MET (seconds)
  - Time arrives every second (as part of time and status)
  - Virtual 1PPS from S/C generates interrupt; interrupt routine sets time, converted to milliseconds
- Time is updated by EPI-Lo
  - 1000 Hz interrupt routine updates time
  - Common software telemetry and command processes run at 1PPS, use coarse (1 s. resolution) time tags
  - Science can be tagged with TBD finer resolution

EPI-Lo Application Software

- Subsystems
  - MCP HV
  - SSD bias
  - Time-of-flight and angle/position measurement (in backup)
  - Energy measurement (in backup)
  - Event analysis (in backup)
- Data Collection
  - Science products
  - Ancillary products
  - Integration control
- Miscellaneous
  - DACs and ADCs (in backup)
  - Autonomous operation

EPI-Lo Application S/W – MCP HV

- EPI-Lo software controls MCPs' High Voltage (HV) common supply (bulk) and four individual HVs (opto-isolator controlled)
- EPI-Lo software slowly ramps voltages to commanded levels
- At least two commands are required to turn on HV
- There are also commands to control current monitors implemented in hardware
- Commands:
  - EPILO_HV_COM_LEVEL: Set Common High Voltage Supply Level
  - EPILO_HV_COM_LIMIT: Set Common High Voltage Supply Limit
  - EPILO_HV_MCP_LEVEL: Set MCP High Voltage Supply Level
  - EPILO_HV_MCP_LIMIT: Set MCP High Voltage Supply Limit
  - EPILO_HV_MCP_STEP: Step MCP High Voltage Supply Level
  - EPILO_HV_CUR_ENB: Enable/Disable MCP HV Current Monitoring
  - EPILO_HV_CUR_LIMIT: Set MCP HV Current Monitoring Limit

EPI-Lo Application S/W – SSD Bias

- EPI-Lo software controls SSDs' Bias Voltage (BV) supply
- EPI-Lo software slowly ramps the supply voltage to commanded level
- At least two commands are required to turn on bias supply
- Commands:
  - EPILO_BV_LEVEL: Set SSD Bias Supply Level
  - EPILO_BV_LIMIT: Set SSD Bias Supply Limit
  - EPILO_BV_STEP: Step SSD Bias Supply Level

EPI-Lo Application S/W – Science Products

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- Ions are collected with different energy resolution, angular (position) resolution, and cadence
  - Ions - Fast: 8 angles, 8 energies
  - Ions - Slow: 80 angles, 69 energies (29 H, 12 He, 14 Heavy group 1, and 14 Heavy group 2)
- Electrons are collected with different resolution and cadence
  - Electrons - Fast: 8 angles, 6 energies
  - Electrons - Slow - Regular: 8 angles, 32 energies
  - Electrons - Slow - Hi-Angle: 80 angles, 16 energies

EPI-Lo Application S/W – Ancillary Products

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- Basic rates (i.e. singles) are collected
  - Hardware counters, e.g. SSD, Start1, Start2, Stop, Events queued, etc.,
    - 24-bit hardware counters accumulated in 32-bit software counters
    - Collected per-quadrant or octant
  - Software counters, e.g. Events processed
- Single events
  - Software reads events from hardware FIFO
  - A commandable number collected in raw event product

EPI-Lo Application S/W - Integration Control

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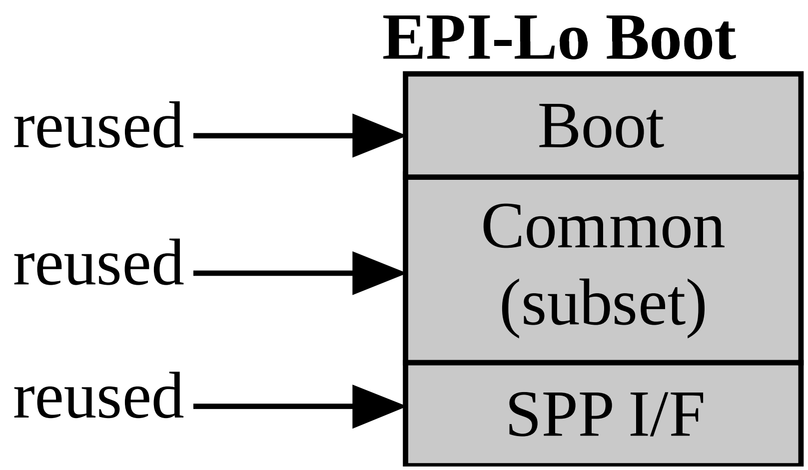
- EPI-Lo software defines data products as fast or slow
- The time to integrate fast and slow data is commandable
- Each data product can be individually enabled or disabled
- Commands
  - EPILO_DAT_COLLECT - Set Data Collection Pattern
  - EPILO_DAT_ENB - Enable/Disable Data Products
  - EPILO_DAT_RAW - Control Amount of Raw Event Data
  - EPILO_DAT_TIME - Control Data Integration Time

EPI-Lo Application S/W – Autonomous Operations

- Common-code macro capability support definition, execution, and save/restore of command sequences
  - Macros can pause until a given MET or delay a given number of seconds
  - Macros can contain do-loops, calls and “forks” to other macros
- Time and status from spacecraft includes
  - Startup Mode: selects manual vs. autonomous operation
  - Solar Distance: current distance to the Sun and in vs. outbound
- If autonomous operation is selected, EPI-Lo software will:
  - Automatically load macros from MRAM
  - Run startup macro; this ramps up HVs, etc.
  - Monitor solar distance against a set of commandable thresholds
    - Different threshold crossings trigger different macros to run
    - Macros configure science collection, e.g. integration times, etc.
- If autonomous operation is not selected, EPI-Lo software will wait for commands

EPI-Lo Boot S/W

- Commands: memory load, copy, execute, dump, check, plus boot from MRAM
- Telemetry: status/housekeeping, memory dump, etc.
- High (>95%) code reuse:
  - SPP I/F from application
  - Common software (subset)
  - Boot software (boot programs from MRAM)
- New: wrapper, startup, etc.
  - If autonomous operation is selected, EPI-Lo boot software will automatically try to boot a series of programs from MRAM
  - If autonomous operation is not selected, EPI-Lo boot software will wait for commands



Software Development Environment

- Flight software and development tools are on Space Department's Unix system
  - /project/spp-instr
  - Backed up nightly
  - Tools are C-based and have been used on Sun OS, Linux, & Mac OS X
  - Only single developer can modify software
- Software versions
  - Numbered with integers, i.e. 1, 2, 3, etc.
  - Each version is in a subdirectory; name of subdirectory includes version number
  - Version number reported in telemetry
  - Each delivered version includes snapshot of libraries
  - Archived in Product Lifecycle Management (PLM) system
- Testing
  - Unit and integration testing done on Xilinx prototype board (no sensor); concocted events are in RAM
  - Further testing on EM with pulsers simulating events
  - Acceptance testing is done as part of Instrument Test Procedure

Summary

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- EPI-Lo application software
  - EPI-Lo-specific software - new code
  - Common software - reused code, ~50% of application
  - SPP spacecraft interface software - new code, but derived from RBSP interface code
- EPI-Lo boot software, >95% reused code

Backup

Common S/W - Packet Telemetry

- Provides standard API to application
  - Delivers variable-length packets
  - Numeric ID identifies packet type/contents
  - Time tag of data collection time
- API also used within common code to deliver standard products:
  - Memory dump, memory checksum, etc.
  - Command echo
  - Alarm
  - Status/housekeeping

Common S/W - Commands

- Standard API for “clients” to register commands:
  - Numeric “opcode” and expected number of arguments
  - Pointer to code that implements command
- API also used within common code to register standard commands:
  - EPILO_CMD_NULL: do nothing; tests uplink and downlink paths
  - EPILO_STAT_CLR: reset counters
- Command process executes commands
  - Echoes opcode, up to ten argument bytes, and a result code
  - Also executes stored command sequences, macros …

Common S/W – Macros (1/2)

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- Macros are stored sequences of commands
- 256 different macros can be defined
- 64 Kbyte of RAM is available for macro storage
- Macros can nest 16 deep; up to 64 macros can execute concurrently
- Real-time uplink commands take precedence over macro commands
- Commands from a macro are echoed; the echo includes a flag indicating that the command is from a macro

Common S/W - Macros (2/2)

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- Macros are “learned” by the instrument
  - EPILO_MAC_DEF starts a macro definition; any command uplinked with its “macro” arg set will be appended to the macro
  - EPILO_MAC_ENDDEF ends the definition
  - While a macro is being compiled, any real-time command, i.e., one without a set “macro” arg will be executed.
  - There is no need for macro compiler or macro memory management by ground software
- Other macro commands:
  - EPILO_MAC_DELAY and EPILO_MAC_PAUSE delay by a give number of seconds or until a given time, respectively
  - EPILO_MAC_NEST and EPILO_MAC_RUN nest a macro and starts a concurrently executing macro, respectively
  - EPILO_MAC_LOOP_BEGIN and EPILO_MAC_LOOP_END delimit a definite loop
  - EPILO_MAC_HALT kills a running macro

Common S/W - Memory Management

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- Commands:
  - EPILO_MEM_LOAD: loads RAM
  - EPILO_MEM_COPY: copy memory; source and/or destination can be RAM or non-volatile MRAM
  - EPILO_MEM_READ: produce memory dump packets
  - EPILO_MEM_READ_ABRT: stop memory dump
  - EPILO_MEM_CHECK: produce a checksum packet summarizing given region
  - EPILO_MEM_RUN: jump to program at given address
- Note: these commands are the core of the boot software

Common S/W - Monitoring and Alarms

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- Alarm packet is generated in response to a software problem or to a monitored value going out of limits
- Alarms from monitors can be transient or persistent
  - If a monitored value is out-of-limits just once, a transient alarm is reported
  - If a monitored value is consecutively out-of-limits twice, a persistent alarm is reported and the software may take corrective action
  - If a monitored value is consecutively out-of-limits more than twice, either corrective action is taken again, the shutdown macro is run, or nothing is done, depending on the thing being monitored
- Commands:
  - EPILO_MON_CNTRL enables or disables corrective action

Common S/W - Monitoring Algorithm

- High response (low response is similar):

```
high once:
      issue transient high alarm

high twice:
      issue persistent high alarm
      if enabled (via EPILO_MON_CNTRL command)
                execute high response macro for this alarm

high more than twice:
      case of monitor class
                current/voltage:
                          if enabled (via EPILO_MON_CNTRL command)
                                    run shutdown macro
                temperature:
                          nop
                count rate:
                          if enabled (via EPILO_MON_CNTRL command)
                                    re-execute high response macro
```

Common S/W - Status Reporting

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- Status packet
  - Command and macro execution counters
  - Analogs: voltages, currents, and temperatures
  - Commanded instrument state
- Commands:
  - EPILO_STAT_INT: how often should status be reported

EPI-Lo Application S/W – Time-Of-Flight Subsystem

- Measures particle time-of-flight (TOF), angle (i.e. position) on the sensor, and pulse height
- EPI-Lo software controls discriminator thresholds
- Commands:
  - EPILO_TOF_CFD: Set TOF Constant Fraction Discriminator Threshold
  - EPILO_TOF_THRESH: Set TOF Pulse Height Discriminator Threshold

EPI-Lo Application S/W – Energy Subsystem

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- Measures particle energy
- EPI-Lo software time-multiplexes hardware between electron and ion detectors
- EPI-Lo software controls thresholds, one set per detector
- Commands:
  - EPILO_EGY_THRESH: Set Energy Discriminator Threshold
  - EPILO_EGY_ANTI: Set Energy Anti-Coincidence Threshold

EPI-Lo Application S/W – Event Subsystem

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- Analyzes data from TOF and energy subsystems to identify an "event"
- EPI-Lo software configures hardware to define a valid event
- Commands:
  - EPILO_EVT_MULTI: Enable/Disable Multiple Hit Reject
  - EPILO_EVT_WINDOW: Set Event Coincidence Window

EPI-Lo Application S/W – DACs and ADCs

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- 1 Hz activity schedule
- Control QuadDACs over I2C bus
  - Set power supply levels, e.g. MCP HV
  - Set thresholds, e.g. MCP HV current
- Read ADCs over SPI bus
  - Read analogs (read three times and use median value)
  - Save in housekeeping
  - Monitor and report/respond to out-of-limit conditions

EPI-Lo Application S/W – Test Support

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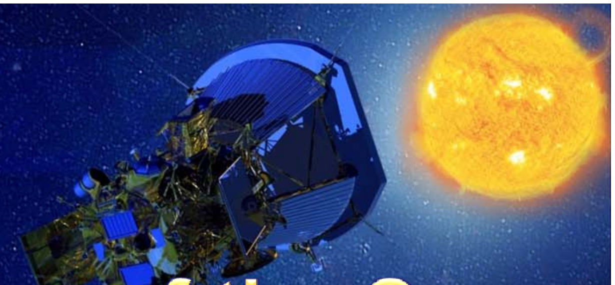
- EPI-Lo software provides commands to control an on-board pulser
- EPI-Lo software provides commands to select internal test points to bring out on the test port
- Commands:
  - EPILO_TST_PUL_CFG: Configure Pulser
  - EPILO_TST_PUL_ENB: Enable/Disable Pulser
  - EPILO_TST_POINT: Select Test Point Signals

Reference Documents

- 7434-9066, “Solar Probe Plus (SPP) General Instrument (GI) ICD”
- 16105-ISIS-IRD-01, “PRELIMINARY INSTRUMENT REQUIREMENTS DOCUMENT SOLAR PROBE PLUS PROJECT ISIS INSTRUMENT”
- 7464-9005, “EPI-Lo Flight Software Specification”
- 7464-9003, “EPI-Lo Software Development Plan”



Solar Probe Plus

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Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

EPI-Hi Sensor Design

Mark Wiedenbeck

EPI-Hi Lead Co-I (JPL)

Outline

EPI-Hi Measurement Requirements

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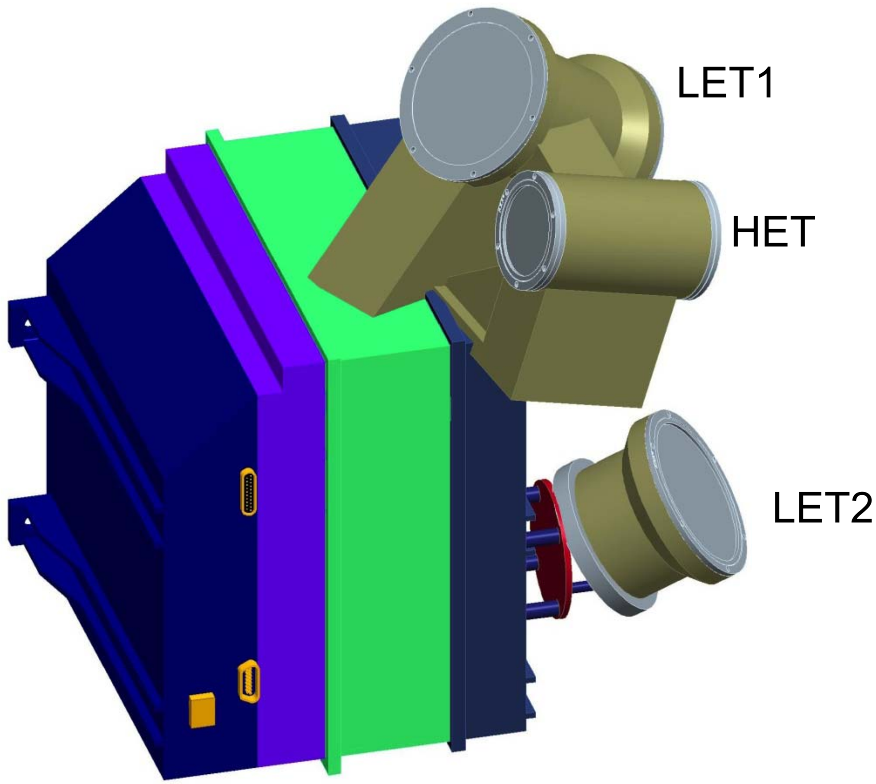
- Protons and Heavy Ions
  - Energy range: 1 MeV/nuc (TBR) to ≥50 MeV/nuc
  - Energy binning: ≥6 bins per decade
  - Cadence: at least one energy bin with time resolution of 5 s or better
  - FoV: ≥π/2 sr in sunward and anti-sunward hemispheres (incl. 10° from S/C-Sun line)
  - Angular sectoring: ≤30° sector width
  - Composition: at least H, He, C, O, Ne, Mg, Si, Fe, ^{3}He
  - Species resolution: FWHM ≤ 0.5 (TBR) × separation from nearest abundant neighbor
  - Max intensity: up to 10% (TBR) of upper limit proton spectrum from EDTRD
- Electrons
  - Energy range: 0.5 MeV (TBR) to ≥3 MeV
  - Energy binning: ≥6 bins per decade
  - Cadence: at least one energy bin with time resolution of 1 s or better
  - FoV: ≥π/2 sr in sunward and anti-sunward hemispheres (incl. 10° from S/C-Sun line)
  - Angular sectoring: ≤45° sector width
  - Max intensity: up to 10% (TBR) of upper limit electron spectrum from EDTRD*

*Note: upper limit electron spectrum not yet specified in EDTRD

EPI-Hi Sensor System Overview (1/2)

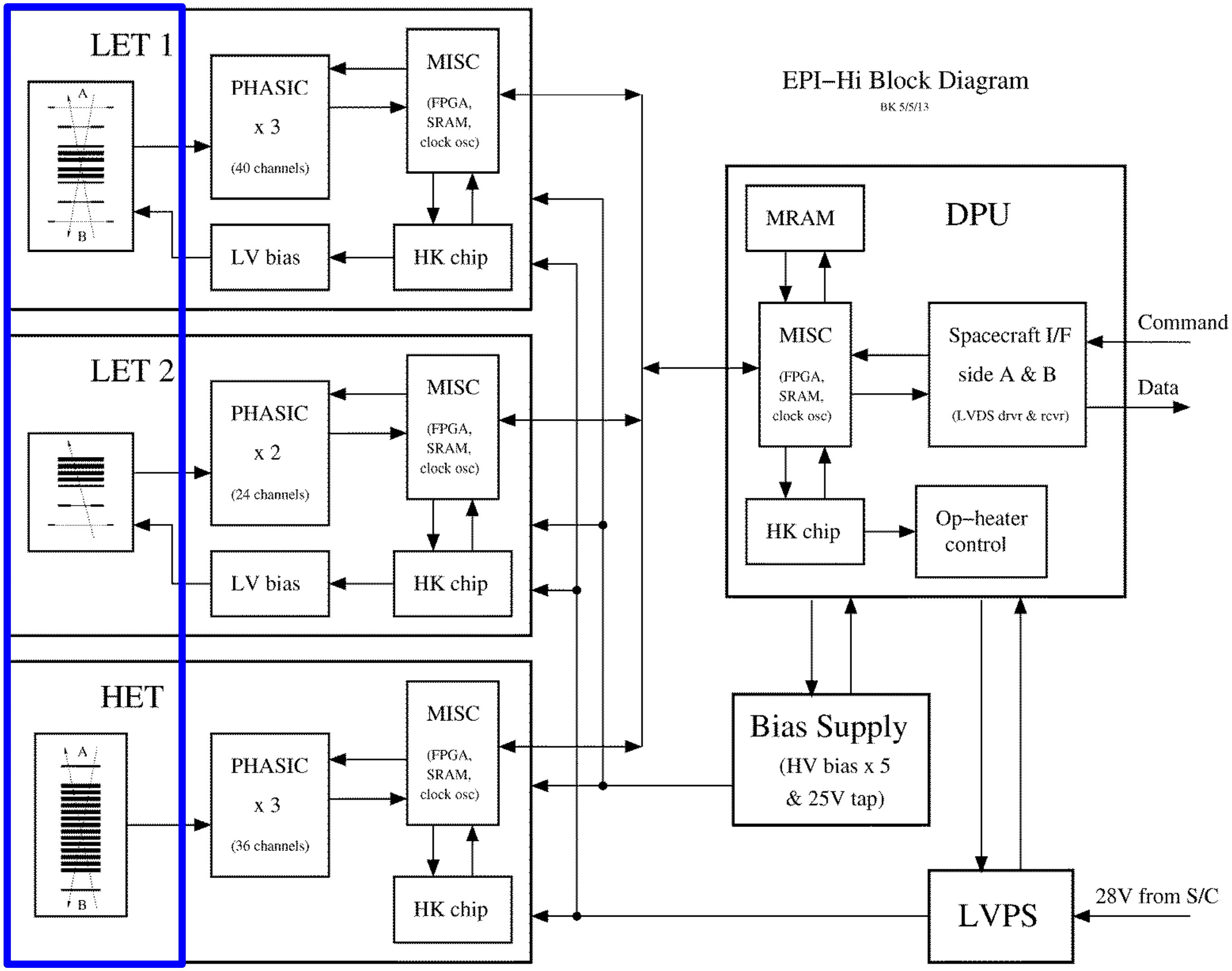
- Sensor Approach
  - All sensor elements are silicon solid-state detectors
  - Multiple detector telescopes to provide large energy range and sky coverage
  - Some telescopes double-ended to increase sky coverage
  - Detector segmentation to provide angular sectoring and adjustable geometrical factor
- Heritage
  - Numerous energetic particle instruments over the past 40 years
  - Direct predecessor: STEREO/LET & HET
- Key Differences
  - Thinner detectors and windows to reduce energy threshold
  - Compact telescope designs to reduce saturation at high particle intensities and backgrounds at low intensities



EPI-Hi Sensor System Overview (2/2)

3 detector telescopes:

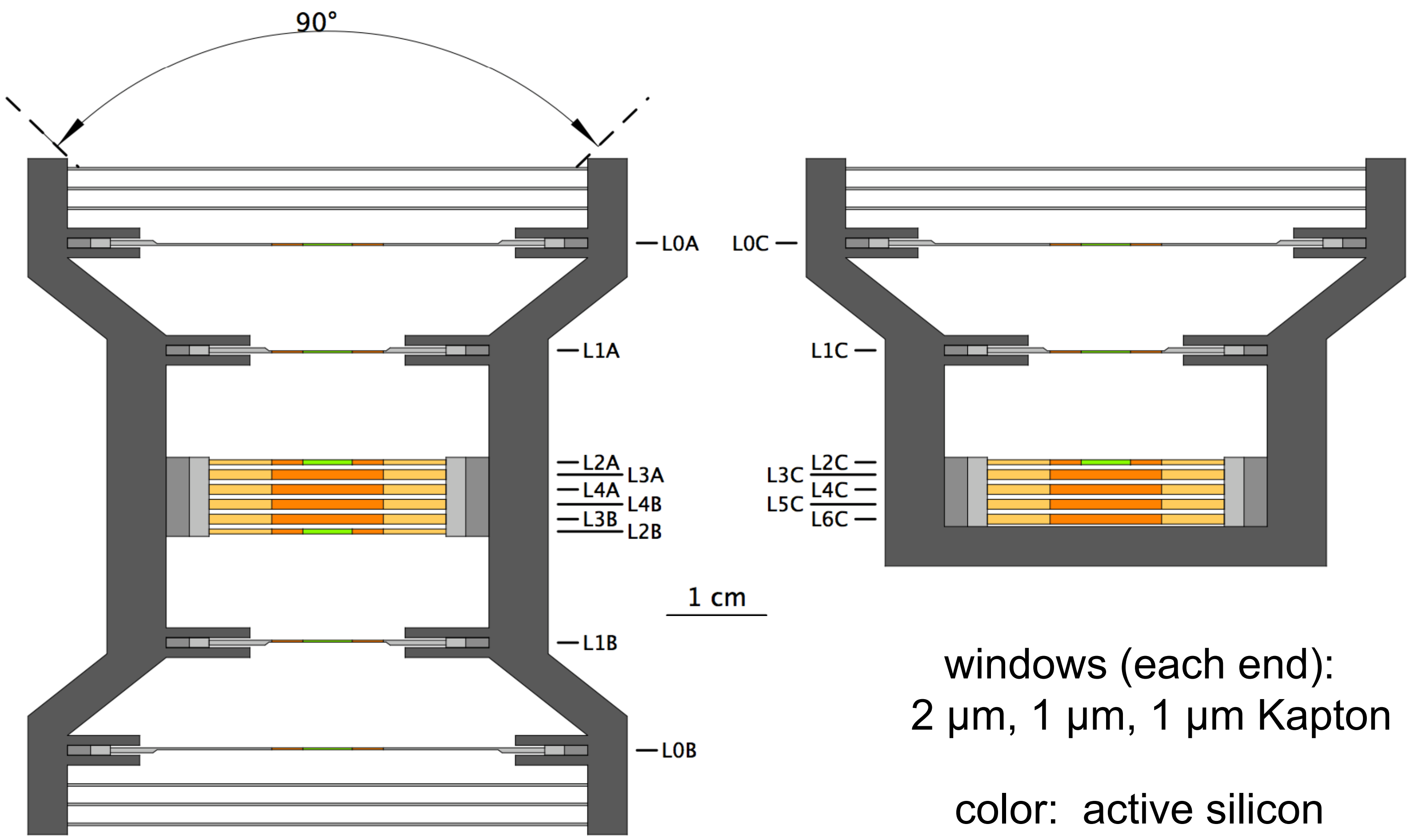
- 1 double-ended low-energy telescope (LET1)
- 1 single-ended low-energy telescope (LET2)
- 1 double-ended high-energy telescope (HET)
- All sensor elements are ion-implanted silicon solid-state detectors
- Signals from each telescope processed by an individual electronics board



Low-Energy Telescopes

LET1 (double ended)

LET2 (single ended)



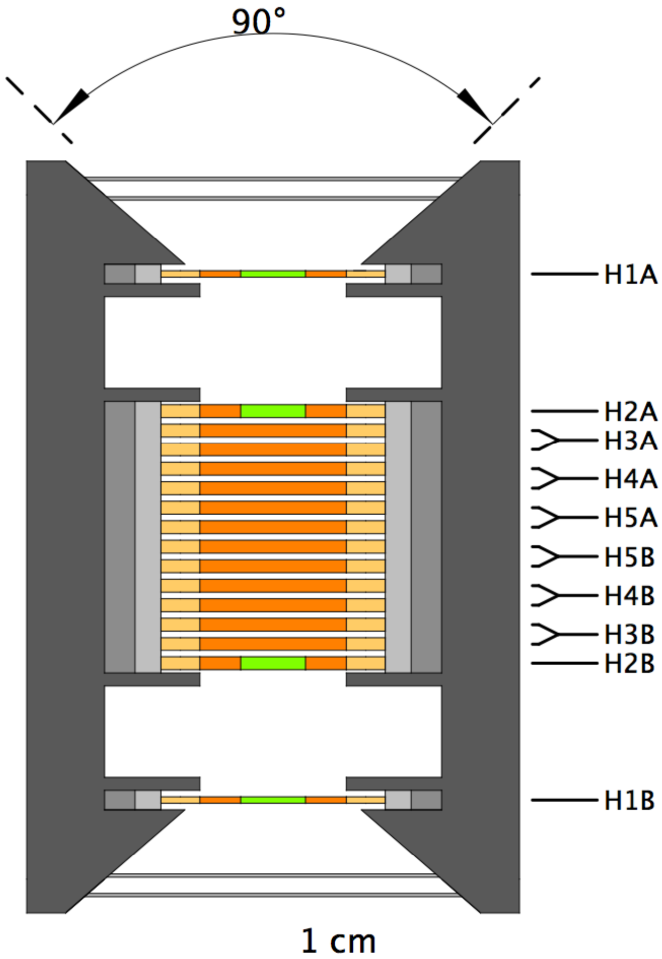
windows (each end):
2 µm, 1 µm, 1 µm Kapton

color: active silicon
grey: inactive material

High-Energy Telescope

Conceptual Cross Section

HET (double ended)



windows (each end):
2 × 127 μm Kapton

color: active silicon
grey: inactive material

Solid-State Detectors

EPI-Hi Silicon Solid-State Detector Designs

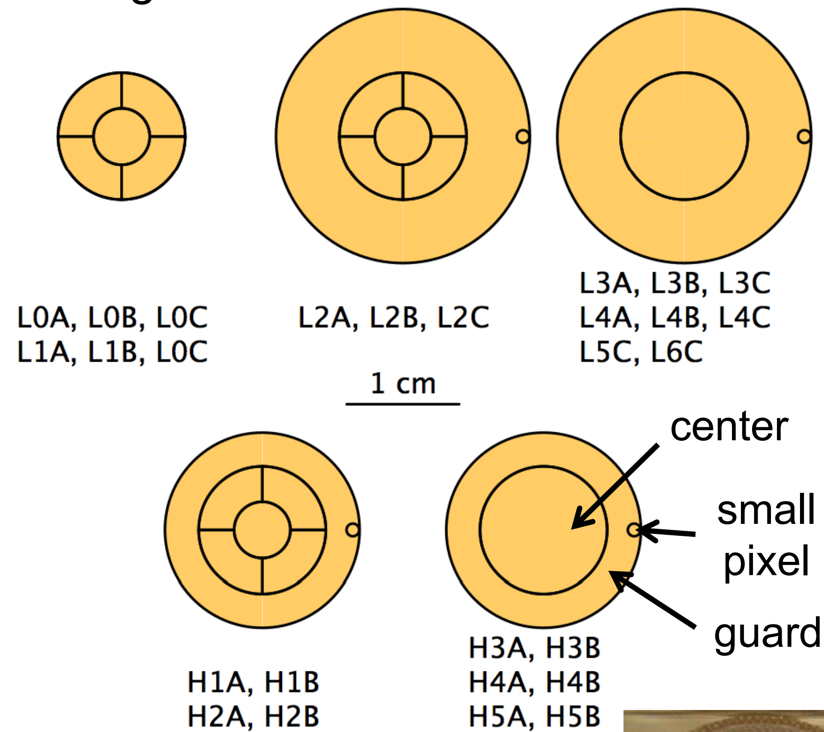
Detector Telescope	Detector Designations	Thickness	Number of Central / Guard / Small Pixel Segments	Central Active Area	Guard Active Area	Notes
LET1	L0A, L0B	12 µm	5 / 0 /0	1.0 cm^2	N/A	[1]
	L1A, L1B	25 µm	5 / 0 / 0	1.0 cm^2	N/A	[1]
	L2A, L2B	500 µm	5 / 1 / 1	1.0 cm^2	3.0 cm^2	[2]
	L3A, L3B	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
	L4A, L4B	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
LET2	L0C	12 µm	5 / 0 / 0	1.0 cm^2	N/A	[1]
	L1C	25 µm	5 / 0 / 0	1.0 cm^2	N/A	[1]
	L2C	500 µm	5 / 1 / 1	1.0 cm^2	3.0 cm^2	[2]
	L3C	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
	L4C	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
	L5C	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
	L6C	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
HET	H1A, H1B	500 µm	5 / 1 / 1	1.0 cm^2	1.73 cm^2	[2]
	H2A, H2B	1000 µm	5 / 1 / 1	1.0 cm^2	1.73 cm^2	[2]
	H3A, H3B	2 × 1000 µm	1 / 1 / 1	1.0 cm^2	1.73 cm^2	[2]
	H4A, H4B	2 × 1000 µm	1 / 1 / 1	1.0 cm^2	1.73 cm^2	[2]
	H5A, H5B	2 × 1000 µm	1 / 1 / 1	1.0 cm^2	1.73 cm^2	[2]

Notes:

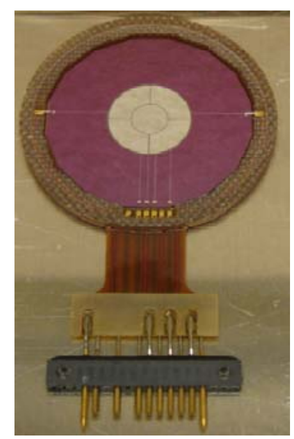
[1] new technology development

[2] small pixel at edge for rate monitoring on some detectors; area: 1 mm^2

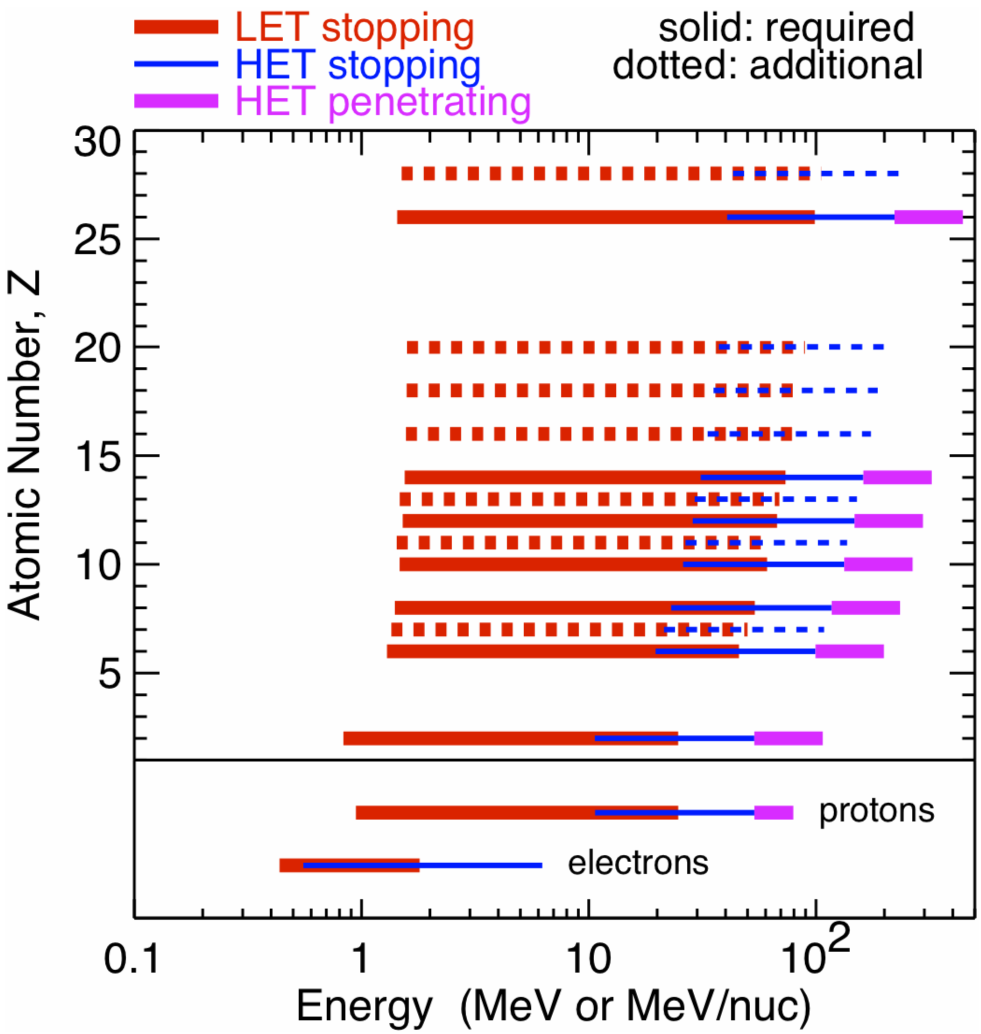
Segmentation of Active Areas:



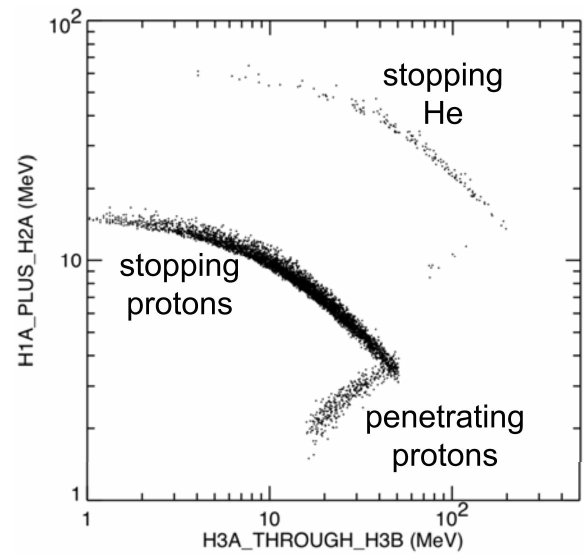
prototype L1 detector



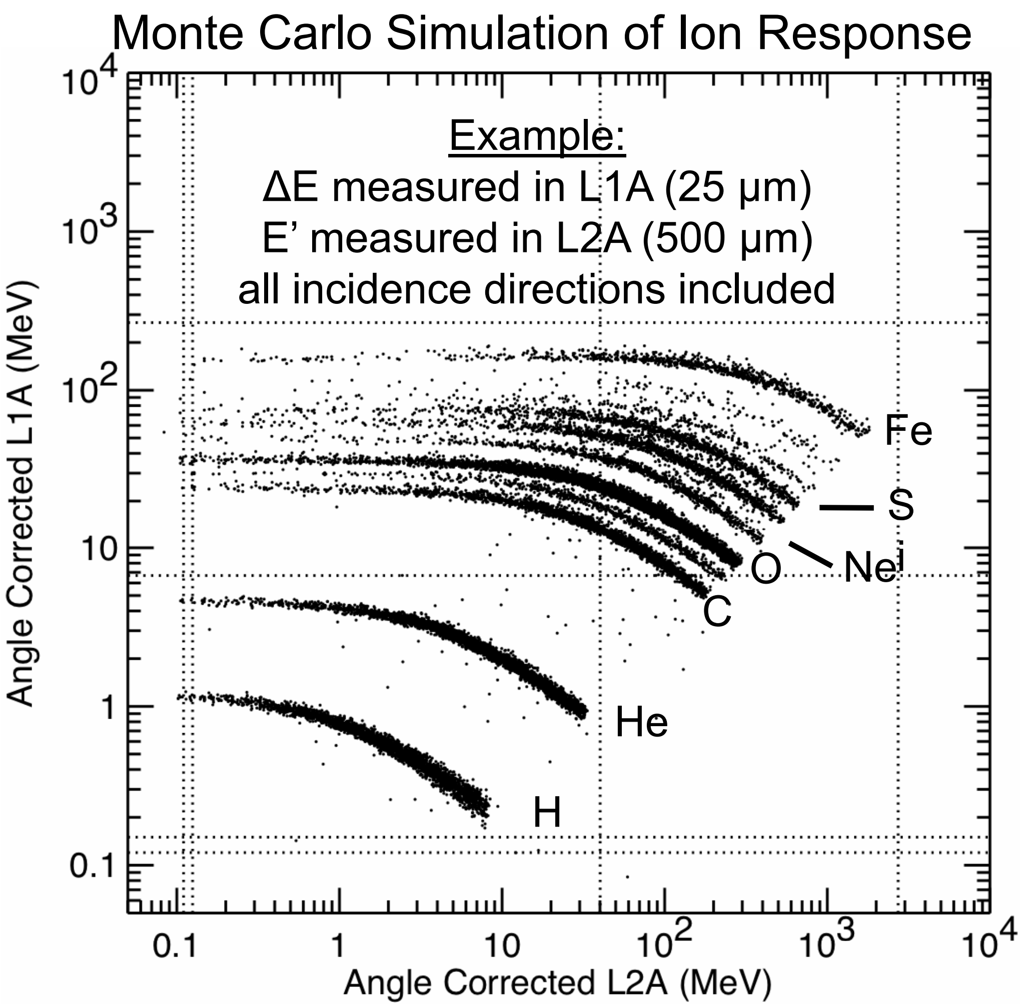
Species and Energy Coverage and Energy Binning



- Rates are accumulated on-board in logarithmically spaced energy bins of width of a factor of 2^½ or 2^¼
- Bin width of 2^½ corresponds to ~6.6 bins per decade
- Larger bins are used for some rates accumulated at the highest cadence (1 second) in order to increase statistical accuracy



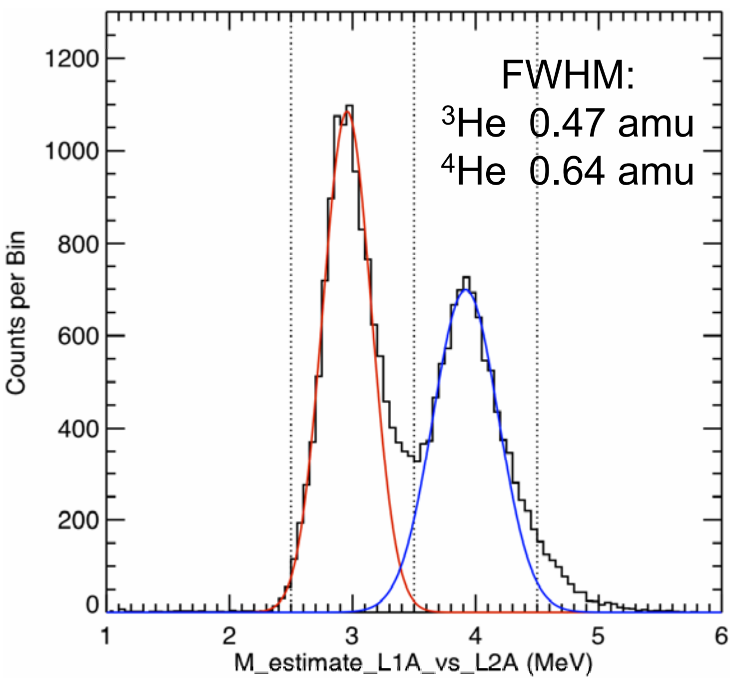
Element Resolution



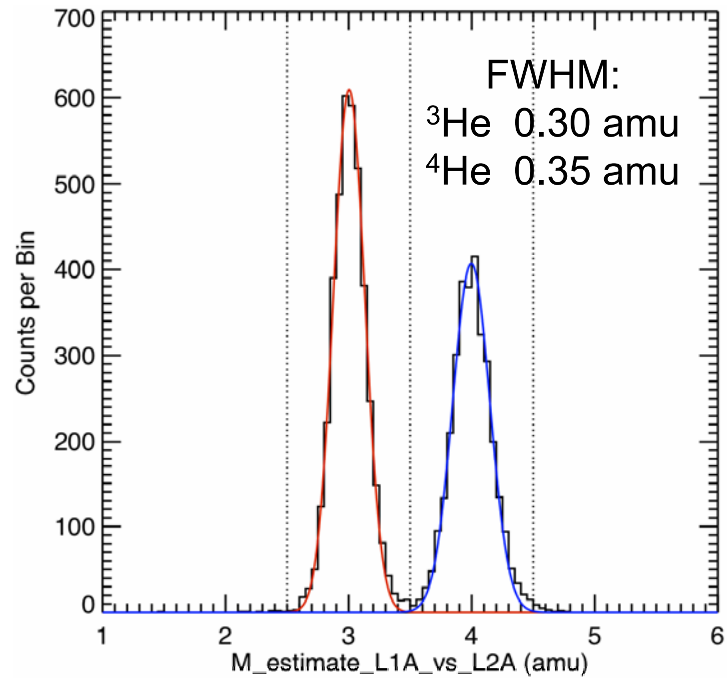
- Energy loss measurements from the detector in which a particle stops (E') and the preceding detector (ΔE) organize the data into distinct tracks for the various elements.
- Sector information is used to obtain mean thickness penetrated in the ΔE detector and make an on-board correction to the measured energies to optimize species resolution.
- Energy assigned on-board includes energies measured in overlying detectors and calculated energy loss in windows.

Helium Isotope Identification

Full Geometry Defined by
L1•L2 Coincidence



Geometry Defined by
L0•L1•L2 Coincidence
(~1/4 of L1•L2 geometry)



- Monte Carlo simulation of He isotope resolution: example based on L1A vs. L2A
- Resolution dominated by effect of incidence angle uncertainty on ΔE thickness penetrated
- Restricting analysis to narrow-angle sectors gives higher resolution dataset
- Other effects (e.g., channeling) limit measurable $^3He/^4He$ ratio at energies of a few MeV/nuc to >~5%

Electron Identification

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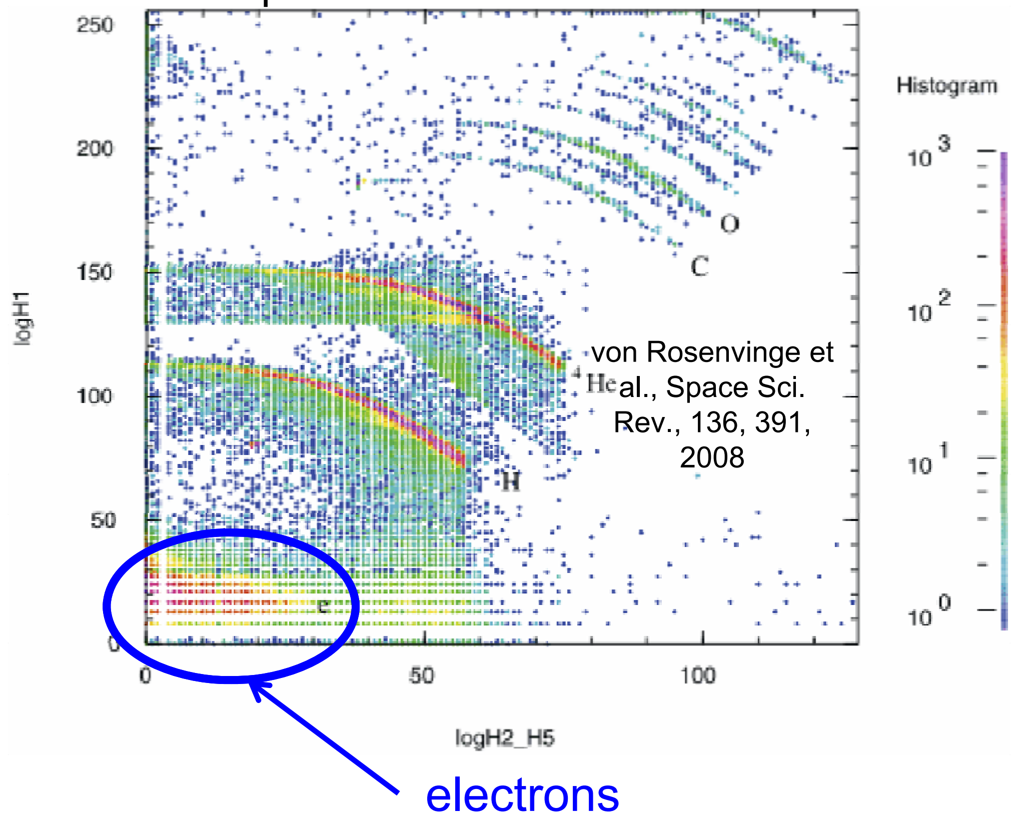
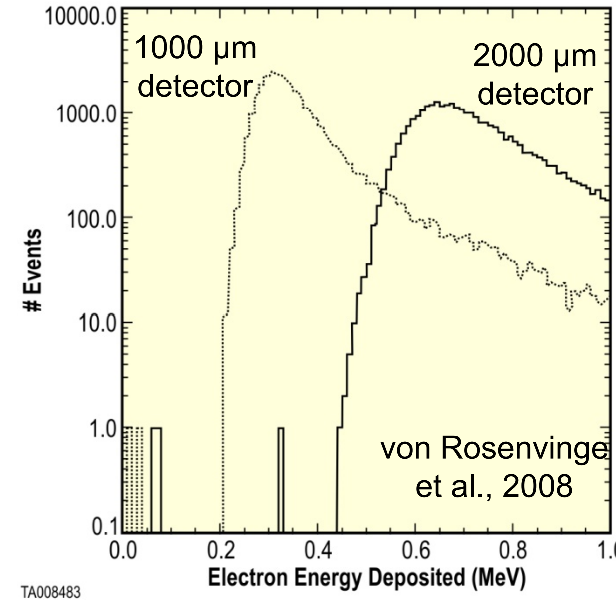
Example: measurements from the STEREO/HET telescope in the 13 Dec 2013 SEP event

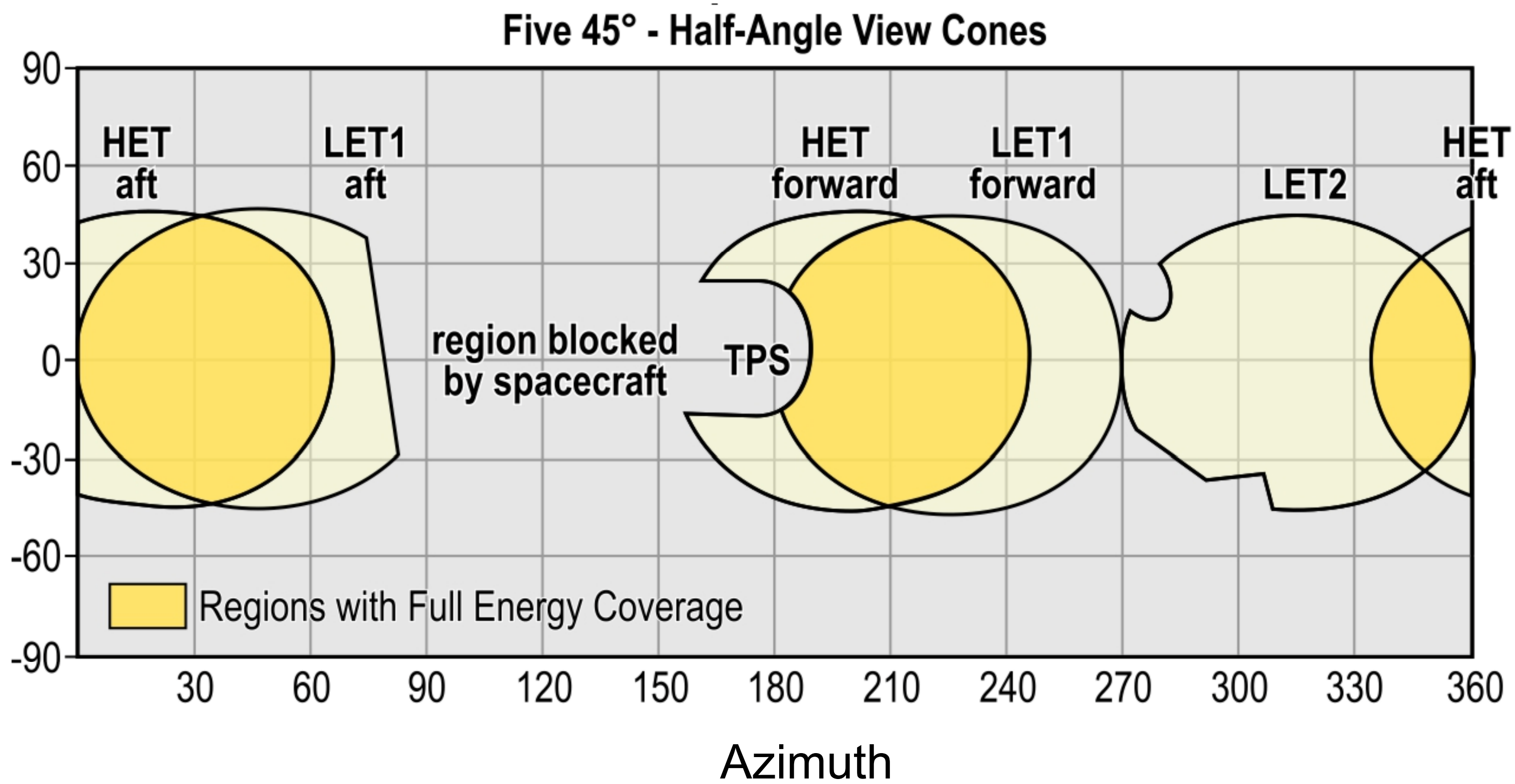


STEREO/HET Electron Threshold: GEANT4



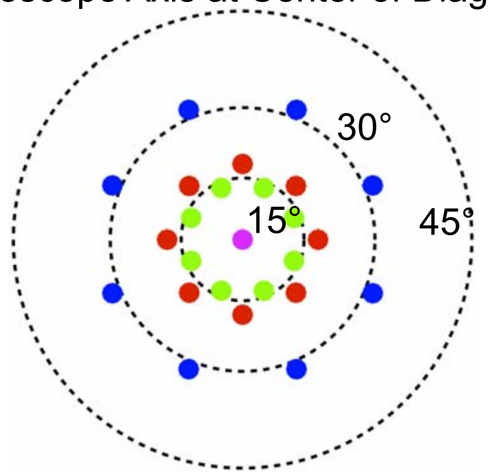
- EPI-Hi HET uses a 500 µm front detector vs. 1000 µm in STEREO/HET
- High-energy electrons should deposit ~0.17 MeV in H1 and be detectable using the modeled 0.11 MeV threshold
- Once electronic noise level has been measured in a realistic setup, we will assess whether a modest increase in the H1 thickness is desirable

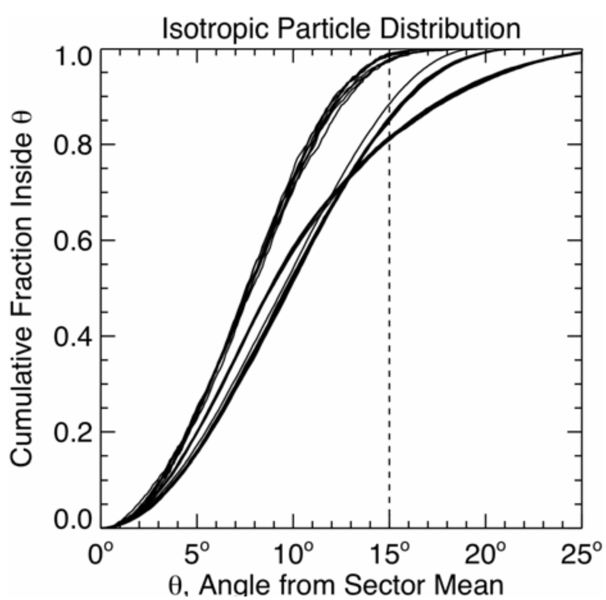
Fields of View



Angular Sectoring

Locations of Centers of Angular Sectors, Telescope Axis at Center of Diagram





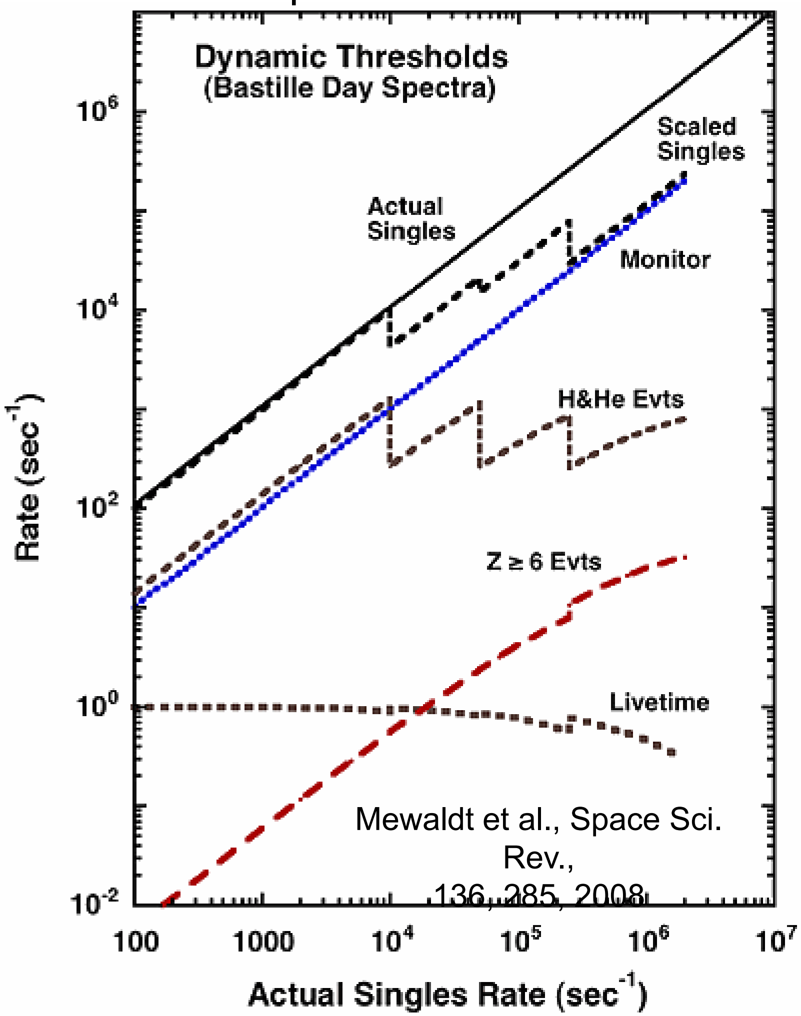
- Particle directions of incidence are determined based on active elements hit in two position-sensitive Si detectors (L0 and L1, L1 and L2, or H1 and H2)
- Each of these detectors has central bull's eye surrounded by 4 quadrants
- Area of each active element is 0.2 cm^2
- Quadrants in the second detector rotated 45° about the telescope axis relative to those in the first detector
- 25 combinations of hit elements in the two detectors are used to assign event to a viewing sector
- For an isotropic distribution of particles, ≥80% of the particles detected in a sector have directions of incidence within 15° of the mean viewing direction of the sector
- Significant overlap among sectors allows measurements of particle distributions with angular resolution smaller than the size of a sector
- HET provides sectored electron data, LET1 provides only front-back direction information for electrons

Measurement Cadences

- Highest cadence: 1 second
  - Used for one electron bin below and one above 1 MeV
  - Used for 4 proton bins above 1 MeV
- Intermediate cadence: 10 sec
  - Used for narrow energy bins for e, H, He, ^{3}He
  - Used for intermediate-width energy bins for element groups CNO, NeMgSi, Fe
- Normal cadence: 60 sec
  - Used for narrow energy bins for ^{3}He, and major elements from C through Ni
  - Used for wide energy bins for groups of ultraheavy elements
- Low cadence: 300 sec
  - Used for angular distribution of e, p, He, ^{3}He, CNO, NeMgSi, and Fe in intermediate energy bins
- Very low cadence: 1 hr
  - All rates accumulated at cadences of 60 sec and 300 sec are also accumulated over 1 hr

Dynamic Range in Particle Intensities (1/2)

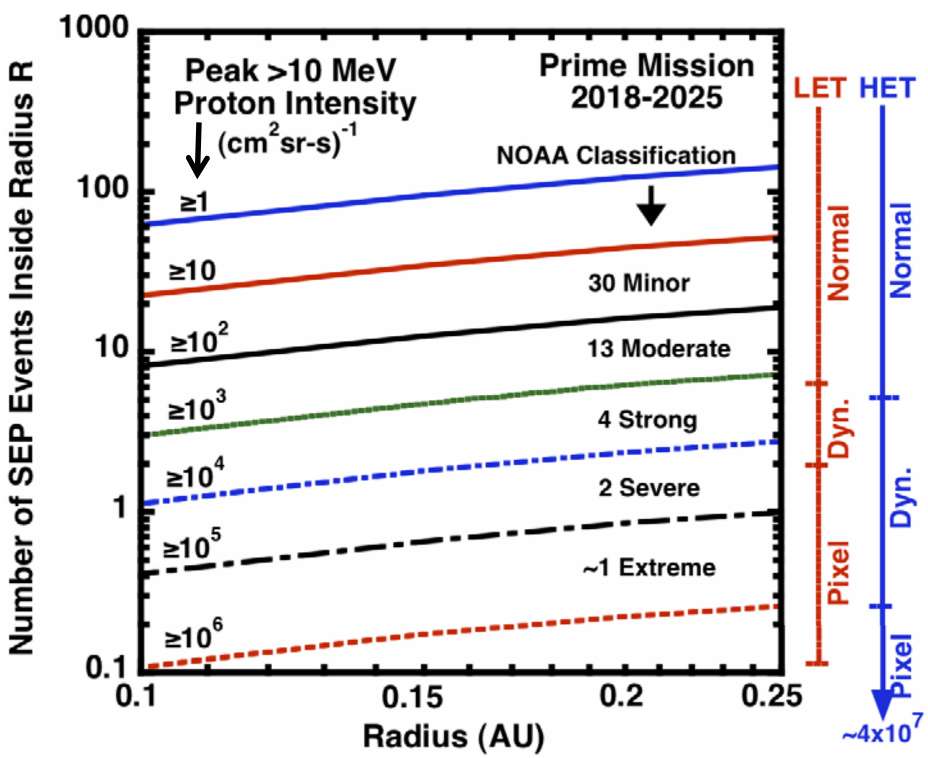
Example from STEREO/LET



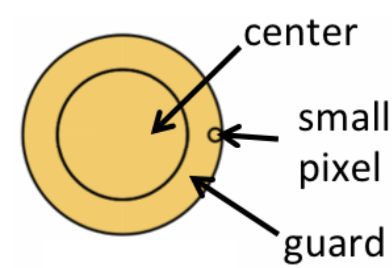
- Protons and He dominate the EPI-Hi count rates and the associated dead-time
- A "dynamic threshold" system, successfully used in the LET and HET instruments on STEREO, allows the adjustment of the geometrical factor for protons and He while maintaining the full geometrical factor for Z≥6 elements
- In several stages, thresholds are raised on all but one active element in detectors progressively deeper in the stack to suppress protons and He over a portion of the instrument geometrical factor
- A detector element that remains sensitive to protons and He is used to monitor the actual rate so that thresholds can be returned to the lower values (with some hysteresis) when particle intensities have decreased
- Count rates at which thresholds are dynamically raised and lowered are controlled by entries in the command table

Dynamic Range in Particle Intensities (2/2)

- An estimate of the distribution of SEP event sizes was obtained by combining: 1) an extensive database of SEP observations at 1 AU, 2) the radial dependence of peak intensities derived from Lario et al. (2007), and 3) the SPP orbit
- ~50 events are expected inside 0.25 AU over the 7-year mission, including ~2 “severe” events and possibly an “extreme” event
- Both HET and LET use dynamic thresholds when intensities exceed ~2000 /cm^{2}sr-s



- There is significant uncertainty in the radial dependence of SEP intensities close to the Sun
- The EDTRD includes a worst-case spectrum having a >10 MeV intensity of 3×10^7/cm^{2}sr-s (95% confidence)
- In order to measure proton intensities in extreme events up to this level, singles count rates from several small (1 mm^2) pixels are used with thresholds raised on all other detector elements



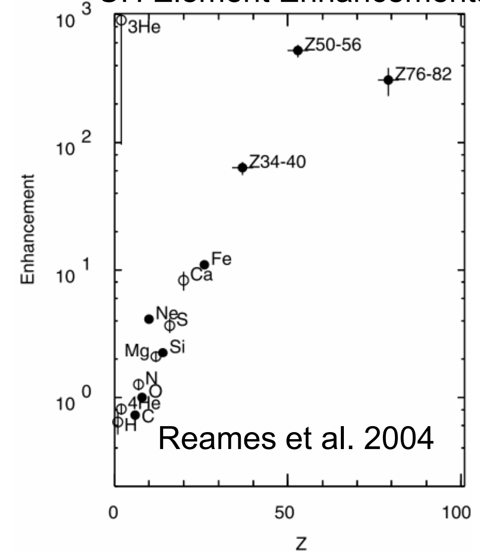
Redundancies: Design for Graceful Degradation

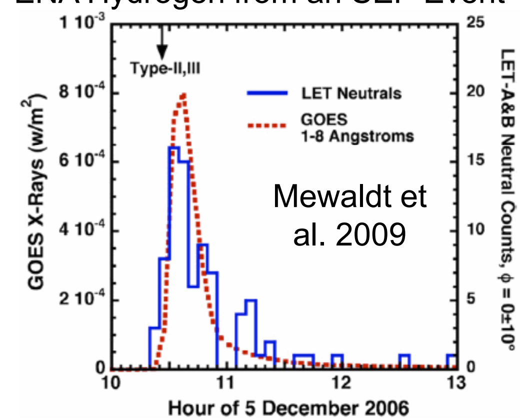
- The radiation and dust environments close to the Sun are poorly known and may be severe.
- The front detectors, particularly in the LETs, have minimal shielding in order to achieve a low energy threshold and are thus particularly vulnerable to damage by radiation and dust.
- The normal instrument coincidence logic defines some categories of events that do not require a signal from an L0 detector, so failure of an L0 detector would increase the LET telescope threshold but otherwise not interfere with instrument operation.
- The coincidence equations can be redefined in order to optimize performance in the event of other detector failures. For example, if an H1 detector were to fail, the HET coincidence could be redefined to accept events based on detectors deeper in the stack and allow measurements with poorer angular and energy resolution.
- The double-ended telescopes have separate bias supplies for the two ends to preserve functionality in the event of a bias failure.
- Resistors in series with detectors allow a limited number of shorted detectors without compromising the operation of an entire telescope end.

Additional Capabilities: Bonus Science Opportunities

EPI-Hi lends itself to several measurements without requiring modifications of the hardware design:

- Ultraheavy (UH) elements: PHASIC dynamic range allows measurements of groups of elements with atomic numbers Z≥30. Large enhancements of UH elements are sometimes observed in impulsive SEP events.
- $^{22}Ne/^{20}Ne$ isotope ratio measurements: this isotope ratio has been observed to be enhanced by factors ~5 in some impulsive events.
- Neutral particles including gamma-rays, neutrons, and energetic neutral atoms (ENAs): HET should be capable of measuring gammas and neutrons in some large SEP events. LET should be able to identify ENA hydrogen originating from charge exchange between SEP protons and ambient H atoms in the corona.





Peer Review Results

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A combined peer review of the sensor system and front-end electronics (PHASIC) design was held on 1 March 2013 to address the suitability of this combination for making the required measurements. External (non-EPI-Hi) reviewers: Rick Leske (Caltech), Matt Hill (APL), Mihir Desai (SwRI).

Significant Issues Raised and Responses or Actions Taken:

1) If the instrument experiences large temperature variations, electronic thresholds, gains, and offsets could change enough to require updating parameters used for the on-board analysis during a solar encounter. Response/Action: Temperature variation over the SPP orbit has been evaluated and found to be less than the ~10°C that would require adjusting on-board analysis parameters.

2) Large dynamic range could lead to significant cross-talk and possibly retriggering, as experienced on STEREO/LET. Response/Action: Design improvements going from the STEREO PHASIC to the SPP PHASIC had already been implemented to reduce retriggering and to flag crosstalk. Details are given in the presentation on the EPI-Hi electronics.

Summary

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- EPI-Hi builds on heritage from the STEREO/LET and HET instruments to provide a combination of sensor system and electronics capable of meeting the requirements of Solar Probe Plus
- Significant new features include:
  - The development of thin silicon detectors to reduce the EPI-Hi energy threshold and achieve some overlap with EPI-Lo
  - Compact packaging of detector stacks to reduce backgrounds and improve performance under conditions of high particle intensities
  - Addition of small detector segments (“small pixels”) that can be used to provide a measure of proton intensities under extreme conditions
  - Enhancement of capabilities for on-board analysis including He isotope identification and multiple measurement cadences to optimize the use of available telemetry

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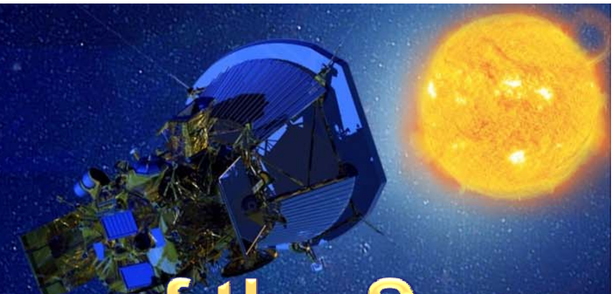

Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

EPI-Hi Technology Development

Mark Wiedenbeck

EPI-Hi Lead Co-I

Outline

- Objective
- Thin Silicon Detector Fabrication Process Summary
- Development Strategy and Status
- Prototype Thin Detectors
- Fidelity of the Test Article
- Tests Required to Achieve TRL6
- Tests Performed
- Electrical Characteristics
- Thermal-Vacuum Stability Test
- Accelerator Test Using Heavy-Ion Beams
- Tests with a Radioactive Source of Alpha Particles
- Radiation Tolerance Testing
- Mechanical Robustness
- Transition to Flight
- Summary

Objective

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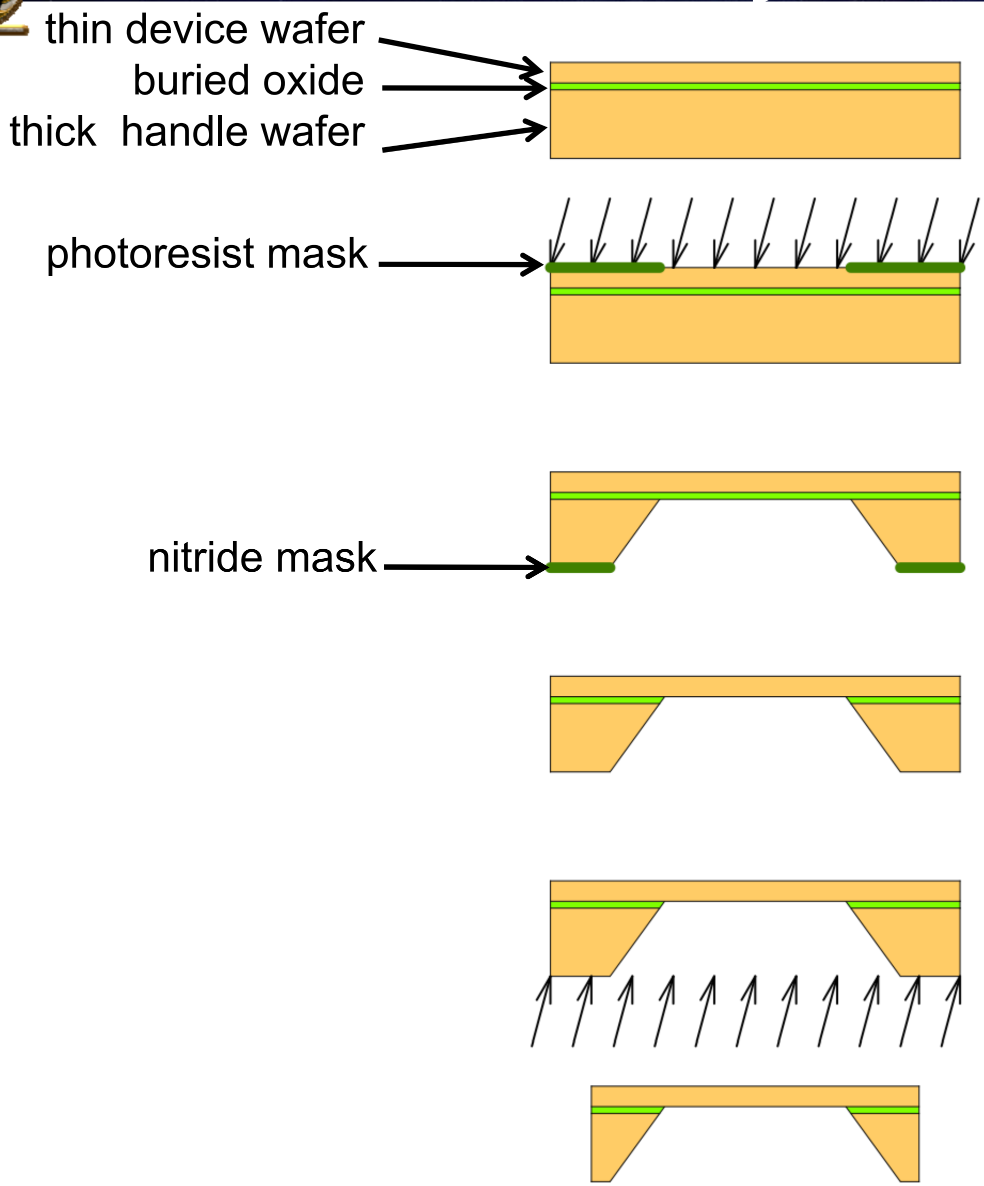
Develop a new approach to fabricating multi-element ion-implanted silicon solid-state detectors thinner than ~30 μm with the following features:

- Thicknesses in the range ~10 to 30 μm
- Good control of absolute thickness and detector-to-detector variation (±1 μm)
- Good thickness uniformity (~0.2% or better rms variation) to allow good species resolution (e.g., He isotope separation)
- Mechanical robustness to provide good manufacturing yield and to survive launch environment without breaking

Thin Silicon Detector Fabrication Process Summary



silicon-on-insulator (SOI) wafer is a commercial product with excellent device layer uniformity and control

ion implant to produce diode pn junctions on device layer

wet etch to remove handle layer under active area—oxide acts as etch stop and preserves the thickness uniformity of the device layer

etch away oxide from underneath the active area using HF, which has negligible effect on the silicon

ion implant from back to produce detector's ohmic contact

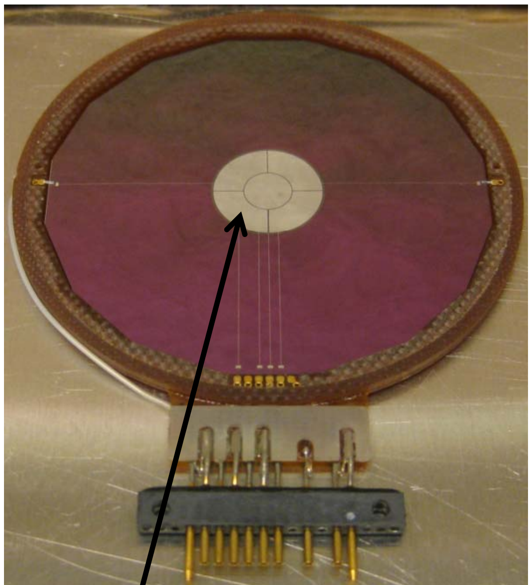
dice wafer into individual thin detectors with thick supporting frames

Development Strategy and Status

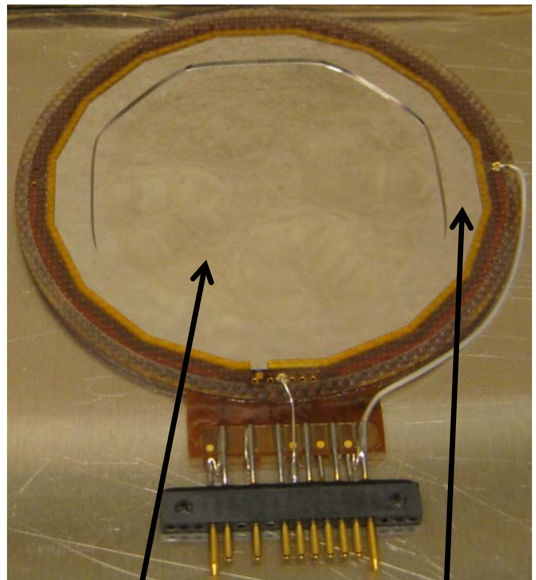
- Background
  - Prototyping studies carried out by a collaboration between LBNL (diode fabrication) and Caltech/JPL since 2003
  - Prior Caltech/JPL collaboration with Micron Semiconductor (Lancing, Sussex, England) allowed them to develop the capability for making thin, supported detectors from conventional silicon wafers; thickness control and uniformity did not meet specifications
- Phase B Activity
  - Efforts to prototype EPI-Hi thin detectors from SOI wafers have been funded during phase B both at Micron and LBNL
  - Testing and evaluation being carried out by the manufacturers and by Caltech/JPL and GSFC
- Flight Detectors
  - Plan to down-select to a single source for flight detectors based on test results

Prototype Thin Detectors

L0 Detector from Micron Semiconductor



front



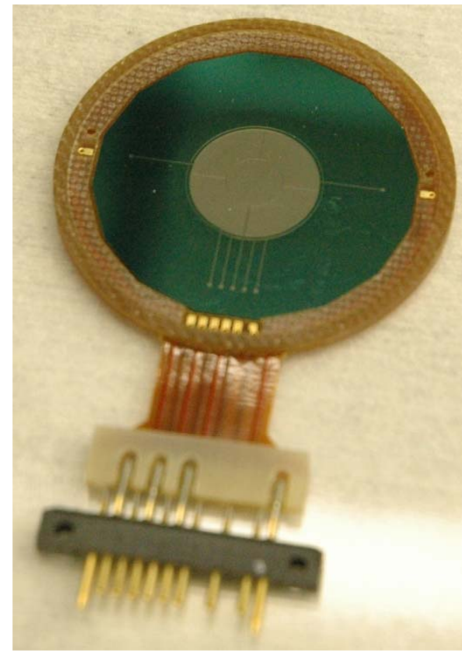
back

active area (1 cm^2)

12 µm membrane

thick frame

L1 Detector from LBNL



Note: thick frames on L1 detectors extend inward nearly to the edge of the active area.

Fidelity of the Test Article

- Flight detectors are expected to be identical to the prototypes
  - The same photolithography masks will be used
  - No changes are anticipated in process parameters (ion implantation energy, annealing temperature and time, etc.)
  - It presently appears that a sufficient supply of SOI wafers may be left over from the phase B work to allow fabrication of all of the flight detectors and spares
  - No changes are anticipated in the detector mounts (provided by GSFC to both LBNL and Micron)
- Possible exceptions
  - If LBNL is selected to make flight detectors, adhesive used for gluing detectors into mounts may be changed to that conventionally used by Micron

Tests Required to Achieve TRL6

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Determining that this technology for fabricating thin silicon detectors has achieved TRL6 (prototype demonstration in a relevant environment) requires demonstration that:

- The detectors yield the expected charge signals proportional to deposited energy that is characteristic of conventional silicon solid-state detectors when exposed to energetic ions
- A detector telescope using the detectors for measuring dE/dx can resolve elements and He isotopes
- The detectors have depletion and breakdown voltages acceptable for use in a solid-state detector telescope
- The detector characteristics are stable over an extended period (weeks) in vacuum at a nominal maximum temperature of 40°C
- The detectors can survive high radiation doses without degradation beyond that expected from displacement damage in conventional silicon detectors
- The detectors are mechanically robust enough to survive the acoustic loads expected at launch

Tests Performed

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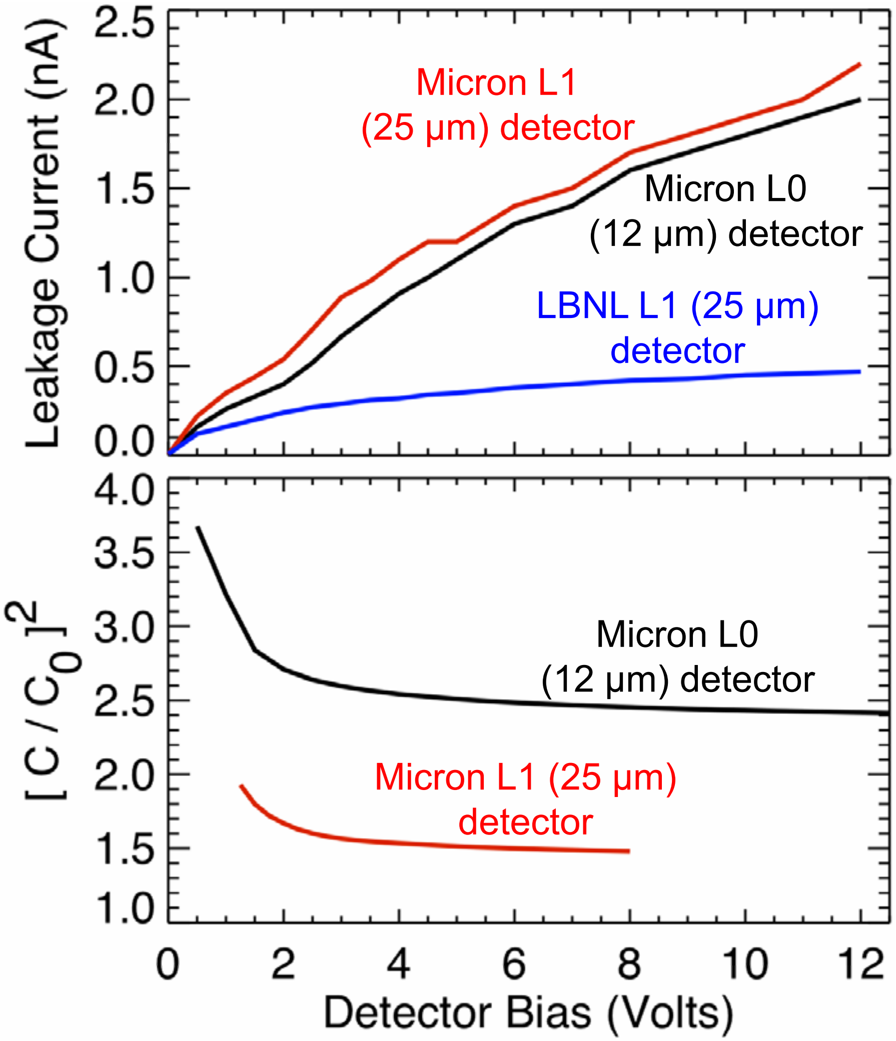
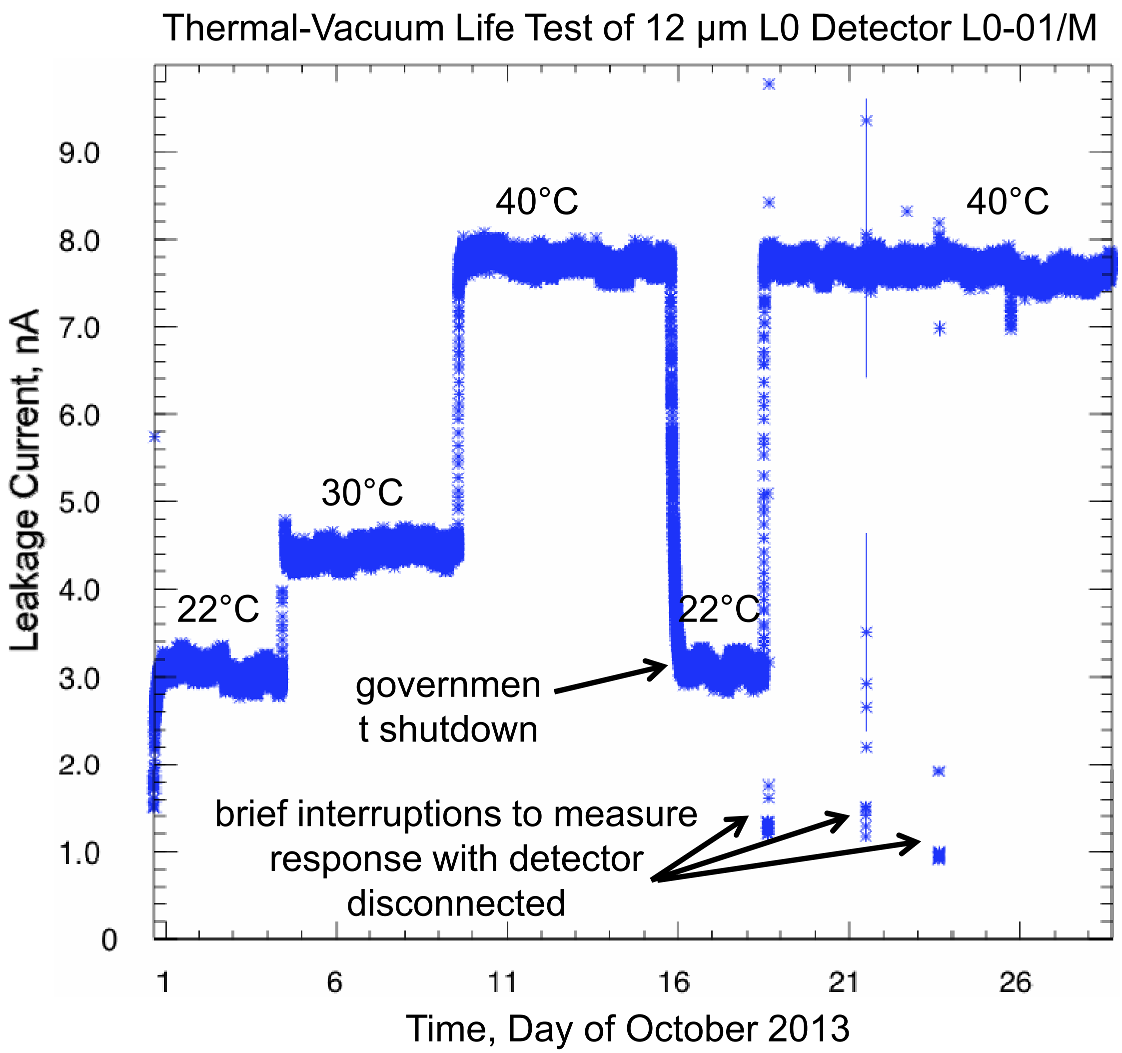
- Electrical characteristics
  - Leakage current versus bias (IV) ↔ maximum operating voltage
  - Capacitance versus bias (CV) ↔ bias required for full depletion
- Particle response
  - Alpha particles from ^{244}Cm source (5.8 MeV ↔ 1.45 MeV/nuc)
  - Accelerator beams of heavy ions
  - Thickness characteristics inferred from particle data
- Stability in expected environment
  - Thermal-vacuum life test at GSFC—our standard test for flight qualification of all silicon detectors
  - Total dose testing using ^{60}Co gamma-ray source at JPL
- Mechanical robustness
  - Acoustic test of mechanical model made from thinned SOI

Electrical Characteristics



- Measurements of leakage current versus applied bias (IV curves) are used to determine the highest allowed bias voltage before onset of electrical breakdown
- breakdown voltages are found to be >25V for both the L0 and L1 detectors
- Measurements of detector capacitance versus applied bias (CV curves) are used to determine the minimum bias required to totally deplete the detector
- Depletion voltages are found to be ~2V for L0 detectors and ~3V for L1 detectors
- Capacitances at full depletion exceed those obtained from a simple parallel plate capacitor calculation (C_0) due to dead layers and to the capacitance of traces connecting active elements to wirebond pads
- CV measurements have not yet been made for the LBNL detectors, but particle data indicate that depletion voltages are similar to those obtained for the Micron detectors

Thermal-Vacuum Stability Test

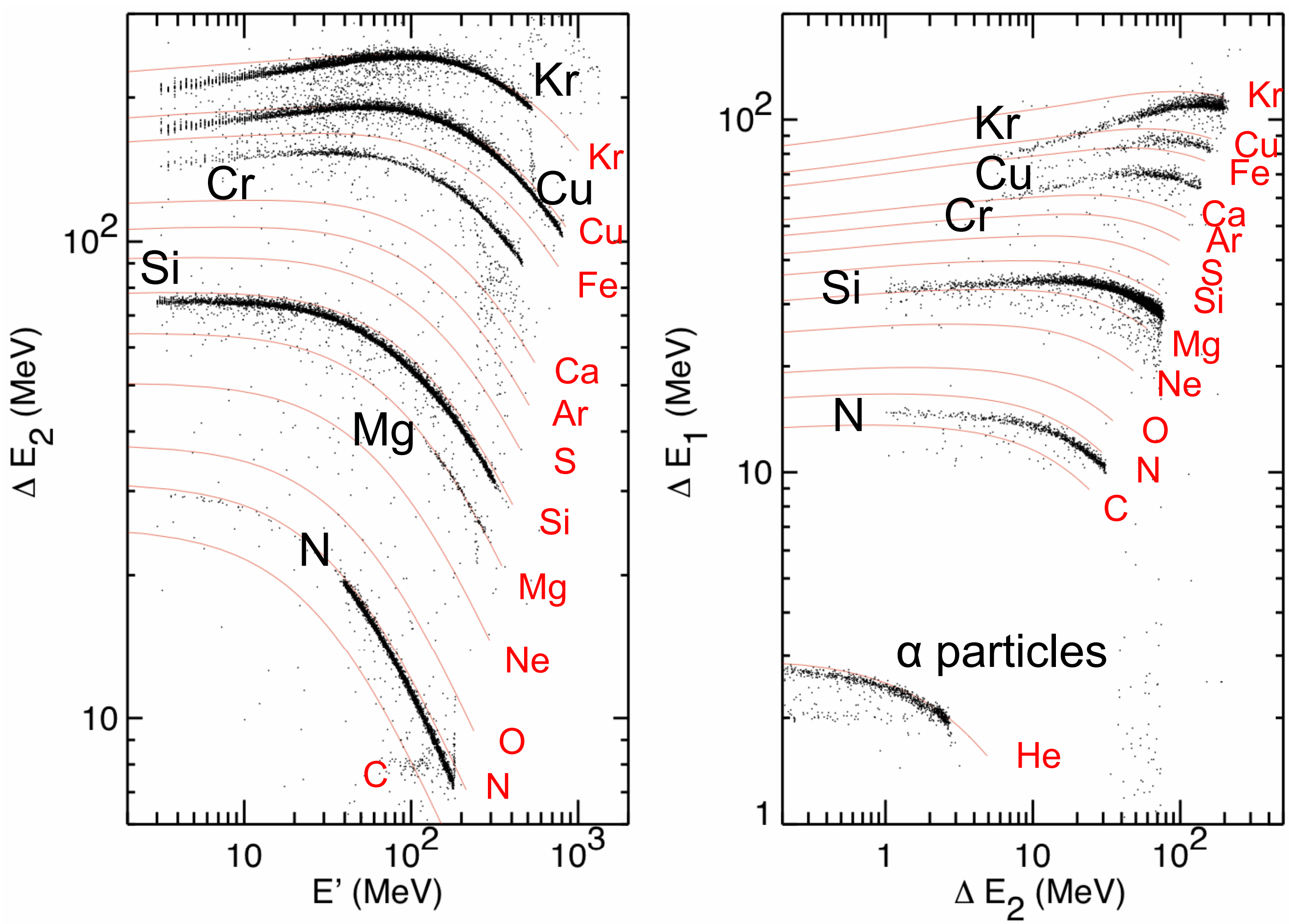


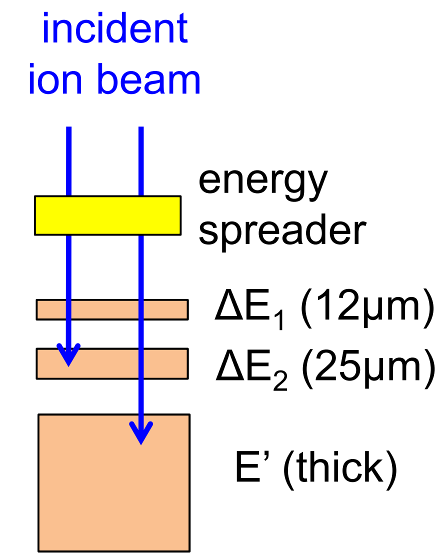
- The detector has performed stably (no indication of leakage current growth problems) for a month, including 16+ days at the maximum operating temperature of 40°C
- Test at GSFC continued through the October government shutdown, but with heating turned off as a safety precaution
- Typical practice on previous missions has been to test candidate flight detectors for about 3 weeks at 40°C

Accelerator Test Using Heavy-Ion Beams

red curves: calculated response; black points: measured events

LBNL 88-inch Cyclotron, 16 MeV/nuc Cocktail Beam, 3 Oct 2013

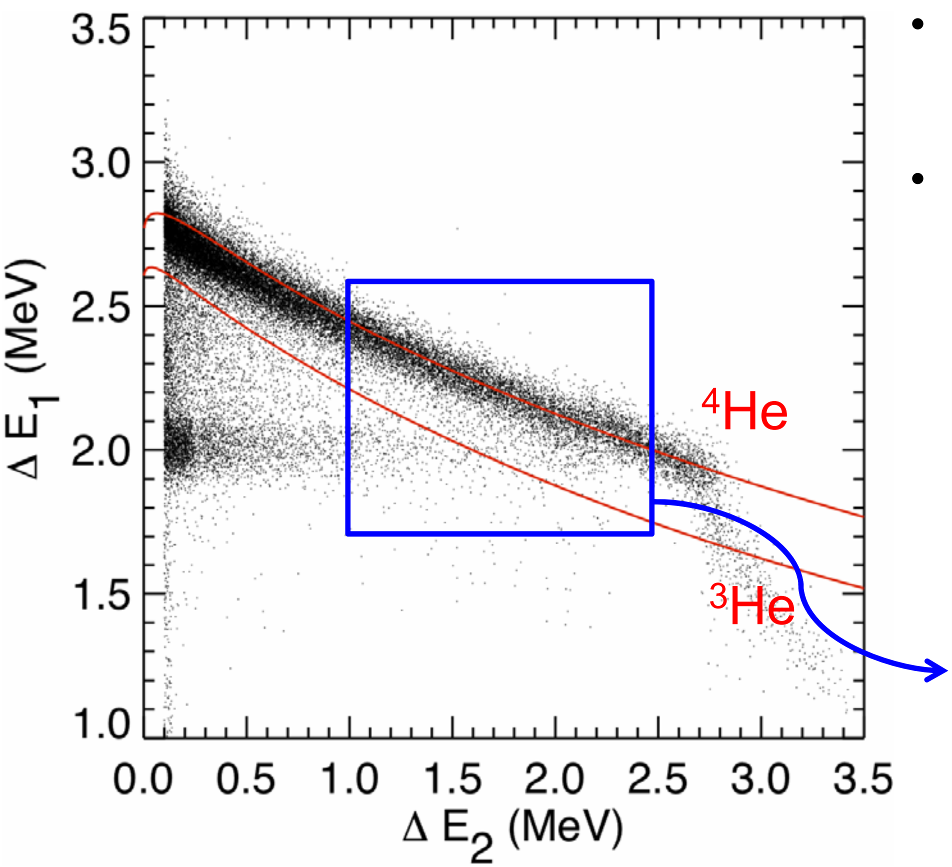




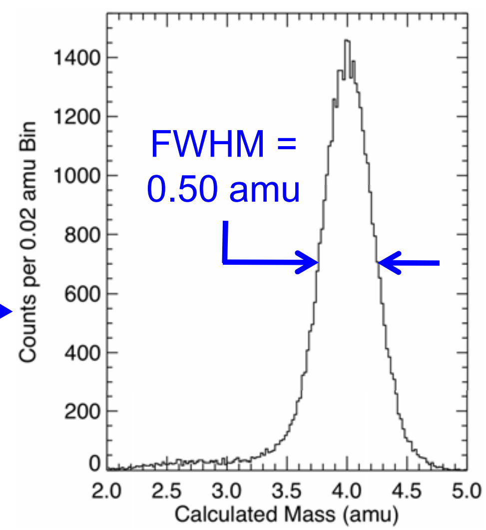
Obtained similar performance using two 12 μm detectors from Micron and two 25 μm detectors from both Micron and LBNL

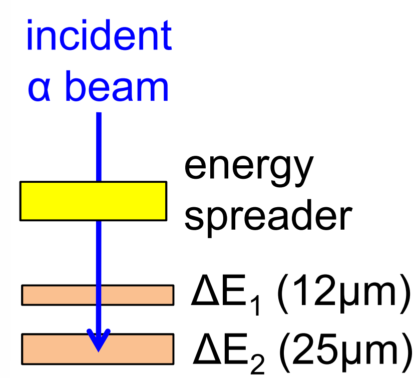
Tests with a Radioactive Source of Alpha Particles

- He track obtained using a 12 μm L0 detector to measure ΔE and a 25 μm L1 detector to measure E'
- Compare with calculated He isotope response tracks
- Adjusted ΔE thickness to 11.8 μm and dead layer to 0.1 μm to improve agreement



- Derived mass resolution demonstrates that detector has the required thickness uniformity
- Thickness variation measured by SOI manufacturer <0.8 μm (wafer to wafer and across individual wafers)





Radiation Tolerance Testing

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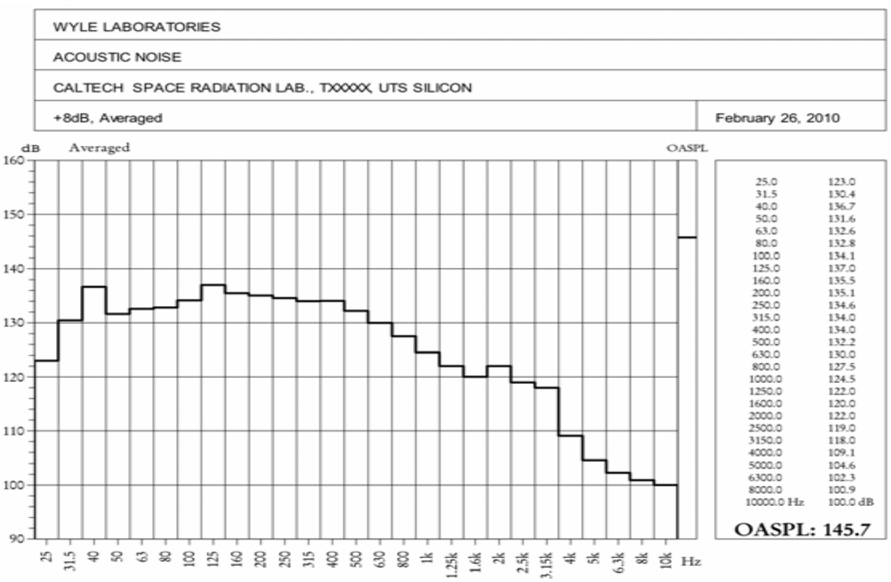
- Thin detectors will receive high radiation dose because, of necessity, there is very little shielding in front of them
- Using the 95% confidence worst-case mission fluences from the EDTRD we have estimated total doses to the L0 and L1 detectors over the SPP mission of about 10 Mrad and 2 Mrad, respectively
- One L1 detector from each manufacturer has been subjected to a total dose test at the JPL high-dose-rate facility (^{60}Co source)
- Detectors irradiated in the dark with bias applied to simulate conditions in flight
- Irradiations done in a series of increasing steps with measurements of characteristics after each step
  - step 1 (16 Oct 2013): 100 krad
  - step 2 (17-18 Oct 2013): 1 Mrad
  - one or two additional dose increments are planned
- Detector leakage currents increased as a result of the irradiations but are still at acceptable levels (<10 nA at a nominal 10 volt bias)
- Alpha particle tests of the detectors showed no degradation of charge collection efficiency or energy resolution

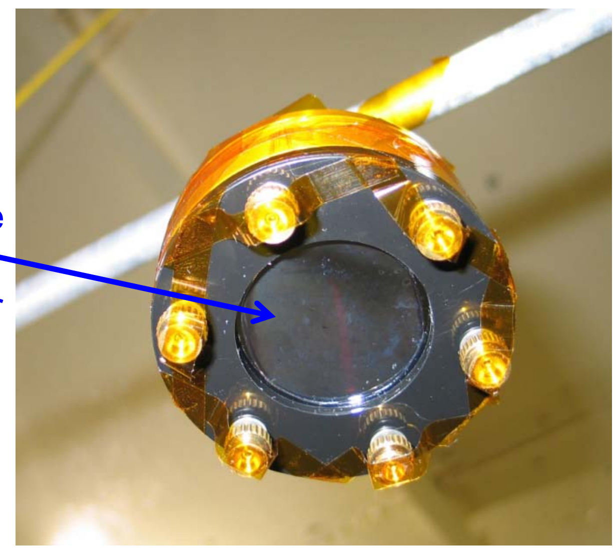
Mechanical Robustness

- Silicon membrane of the diameter planned for the L0 detector was fabricated from an SOI wafer with 10 µm device layer and subjected to an Atlas V acoustic spectrum at a level significantly exceeding the SPP specification
- The sample survived without any problems



highest test level: 145 dB = SPP spec + 8 dB

silicon membrane
10 µm thick
~3.4 cm diameter



Transition to Flight

- Extend selected prototype tests to cover additional detectors that have been fabricated in phase B—determine whether there are any detector-to-detector differences that might affect
    - Yield
    - Selection of manufacturer for flight detectors
    - Test program needed for flight devices
- Select manufacturer for flight detectors

Summary

- New technology for fabricating silicon solid-state detectors at least as thin as 10 µm has been developed based on the use of silicon-on-insulator (SOI) wafers as the raw material
- Detectors have been successfully produced by two manufacturers:
  - Micron Semiconductor Ltd., Lancing, Sussex, England
  - Lawrence Berkeley National Laboratory in collaboration with Caltech
- Prototypes from both sources have been subjected to all of the tests required for achieving TRL6 without problems
- Extension of a few tests is still in progress:
  - Additional time for the thermal-vacuum life test
  - Exposure to additional radiation doses
  - To date, the LBNL/Caltech fabrication has produced L1 detectors but L0 detectors remain to be completed. The LBNL/Caltech process has previously yielded good detectors as thin as 10 µm in sizes comparable to L1. Fabrication of L0 detectors has already passed the critical thinning step.

Solar Probe Plus

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Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

EPI-Hi Electronics

Rick Cook / Branislav Kecman

EPI-Hi Electronics SE and Lead (Caltech)

Outline

Solar Probe Plus
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- Requirements
- Constraints
- Block Diagram
- Instrument - S/C Interfaces
- Pulse Height Analysis System Integrated Circuit
- Minimal Instruction Set Computer
- Housekeeping Chip

- Design/Assembly/Test Flow
- Board Status
- EEE Parts Program and Status
- Resources
- Harness Diagram
- Summary

Key Requirements

- Support 3 independent charged particle telescopes: LET1, LET2 and HET.
  - For each telescope provide for detection of coincident signals from various Si detector elements to define “events” caused by the incidence of individual nuclei, electrons and neutral particles/photons.
  - For each event, provide pulse height analysis of the signal amplitudes in the various stimulated detector elements. Large dynamic range is needed for measurement of electrons through Zn nuclei.
  - Sort and count the events according to particle type and energy.
  - Integrate the counts for the various particle/energy categories over time periods ranging from seconds to hours.
- Format the count rate data into packets and transmit them to the S/C.
- Include in data packets the raw pulse height data for a sample of events to aid in-flight calibration.
- Monitor instrument health by measurement of detector leakage currents, instrument temperatures, power supply voltages and total instrument current draw, and include this “housekeeping” data in telemetry packets.
- Respond to commands for altering threshold voltages, bias voltages, etc. and performing instrument self-tests and auxiliary functions.
- Control instrument operational heaters.

Constraints and their Implications

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Constraints

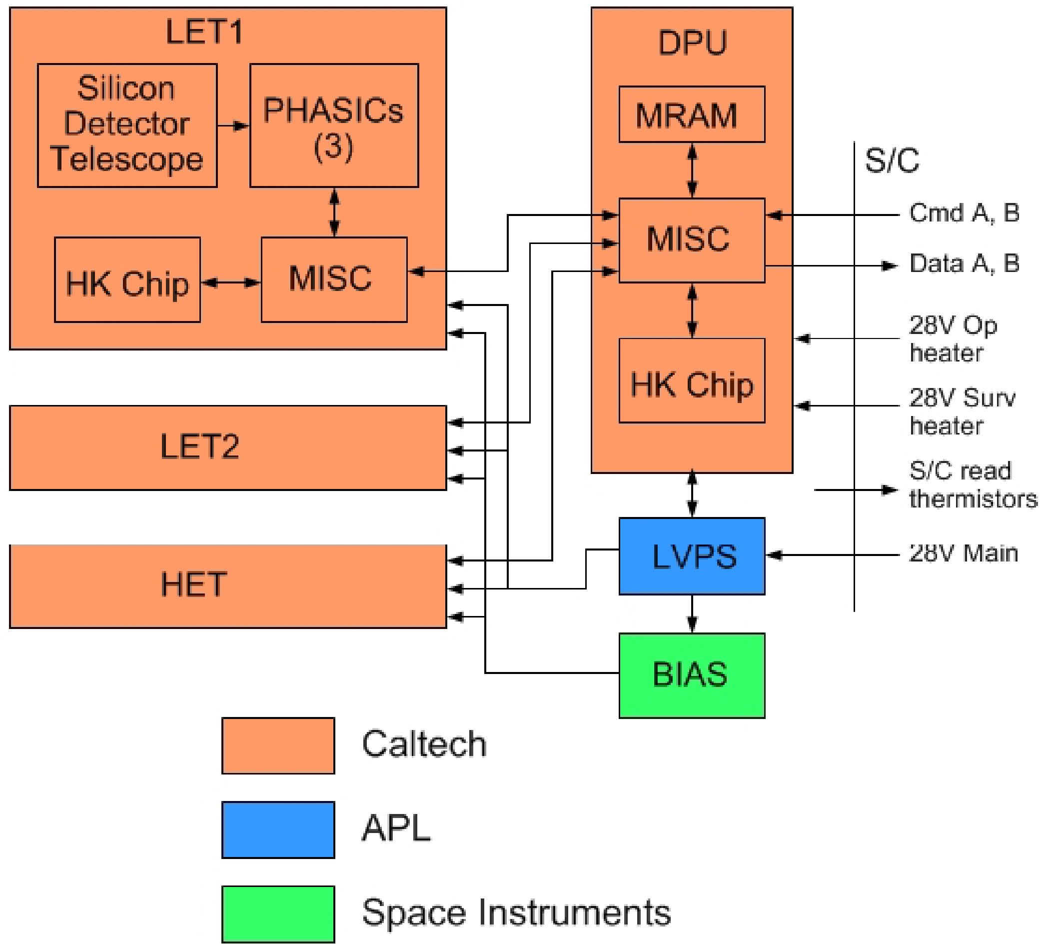
- Both power and mass are very tightly constrained.
- Design should be single string, yet reliable.
- Primary data collection occurs when S/C cannot communicate with Earth.
- Radiation environment is more severe than heritage missions.

Implications

- Reliability through minimization of parts count and use of "natural" redundancy.
- Use of custom rad-hard VLSI: PHASIC and HKCHIP.
- Design should be "bullet-proof" with regard to radiation affects: no latch-up, no processor crash due to SEU, total dose tolerant > 100 krad.
- Design should be capable of autonomous operation during primary data collection period (<0.25 AU from Sun).

EPI-Hi Block Diagram

- 6 boards
- All telescope boards same.
- DPU formats data and provides a single point interface with S/C.
- Low Voltage Power Supply (LVPS) and Bias Supply board are shared.
- Bias Supply board contains a separate supply for each telescope "end", 5 total.
- Logic and MISCs are implemented in RTAX 250 FPGAs, 4 total.
- Heritage from earlier projects: STEREO and NuSTAR.

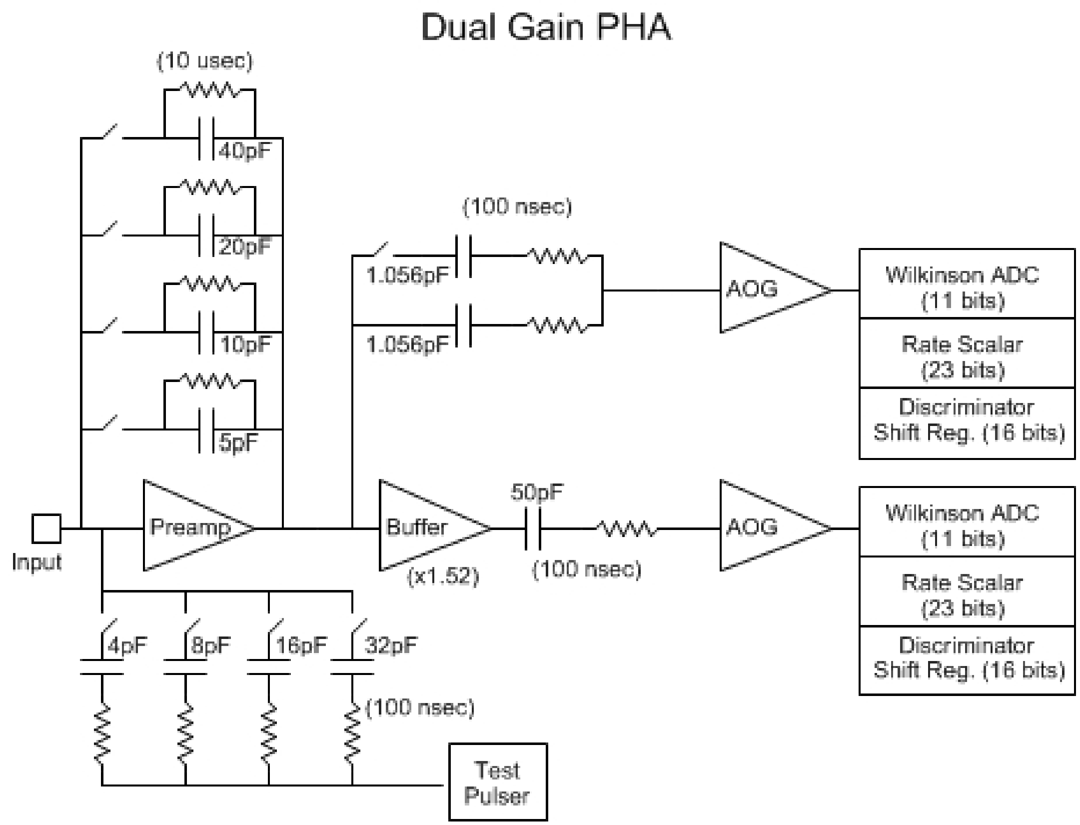


Instrument to S/C Electrical Interfaces

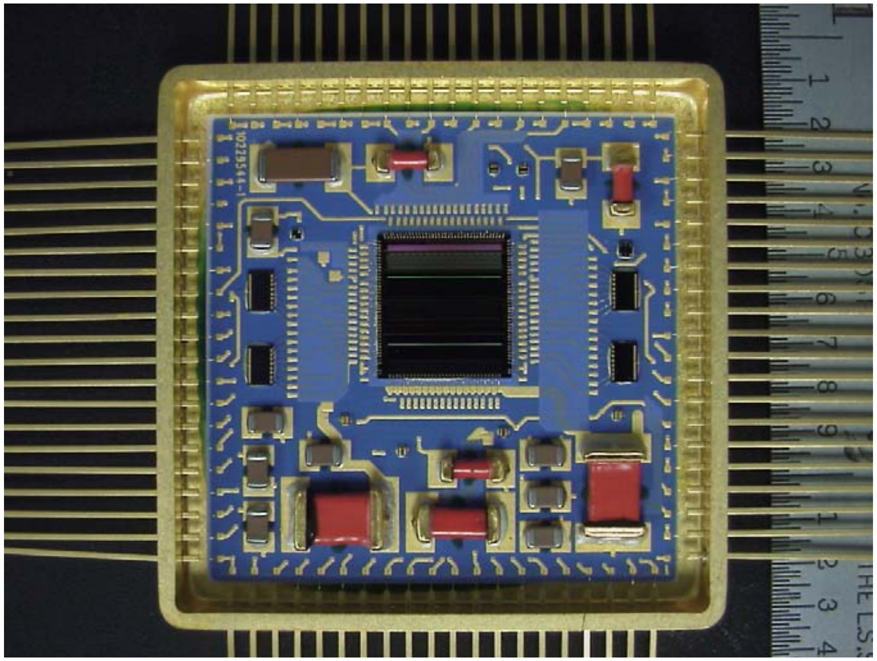
- Interfaces with S/C specified by ICD under APL control.
- Command and data interfaces are 115.2 kbaud LVDS using rad-hard drivers/receivers specified by APL.
- Redundant A and B sides.
- Reset and Timing signals removed from interface by APL for simplicity. Functions included in command signal protocol.
- MISC boot method has been modified to accommodate lack of Reset signal.
- S/C supplies separate 28V power services for survival and operational heaters.
- S/C monitors instrument temp via S/C supplied thermistors.

PHASIC Overview

- PHASIC stands for "Pulse Height Analysis System Integrated Circuit".
- Originally developed and used in NASA's STEREO mission.
- Each PHASIC contains 16 complete dual-gain pulse height analysis (PHA) chains.
- STEREO PHASICs still operational in space.
- Mods for SPP include widening dynamic range, and improving total dose tolerance to >100 krad.

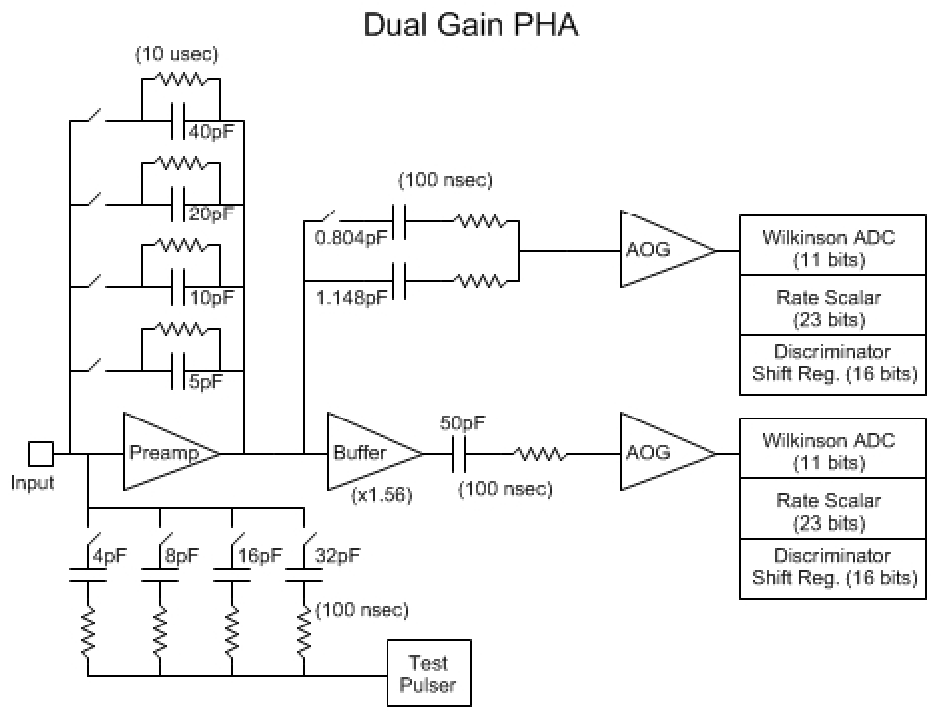


PHASIC Packaging



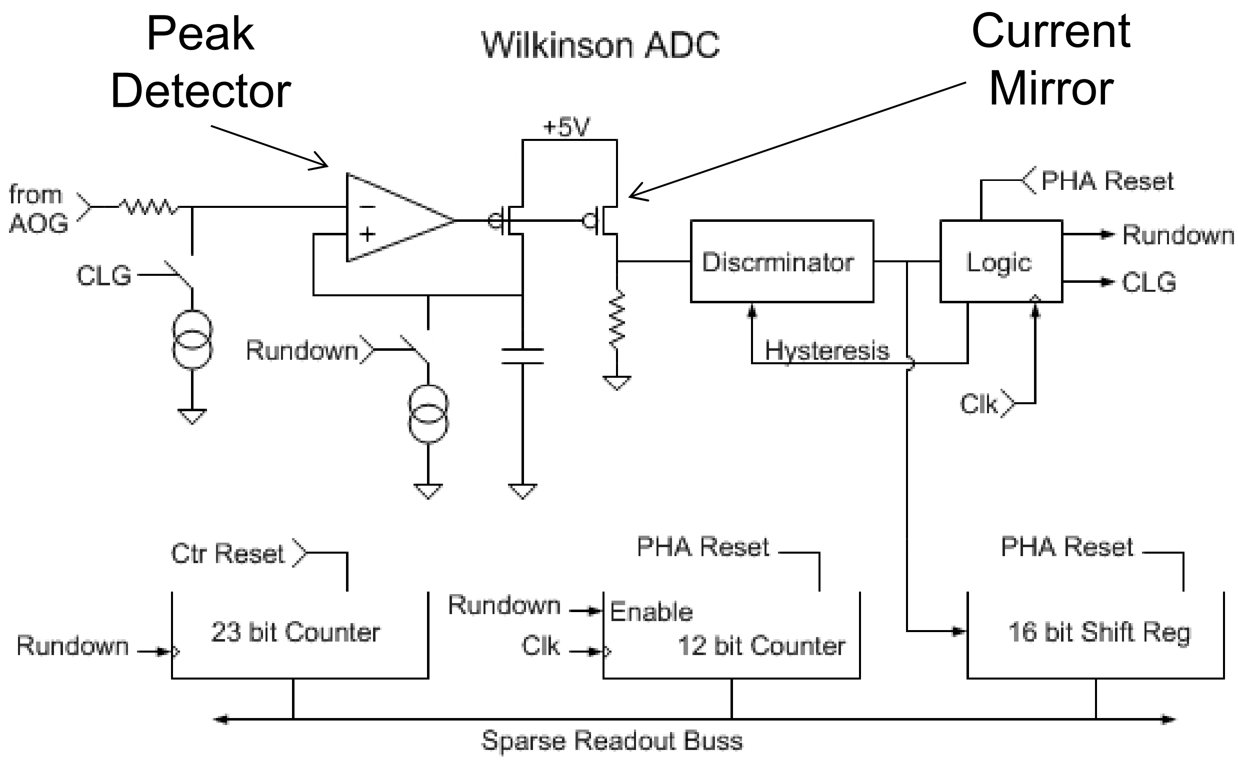
- PHASIC die is installed in an 80-pin hermetic Kovar package along with a few passive components to form a “hybrid” circuit.
- Hybrid substrate design and passives same as for STEREO.
- PHASIC hybrid to be qualified and screened to class H (as on STEREO).
- Passive components include a precision resistor for each PHA chain that sets the rundown current. Allows PHA channel gain to have low <50 ppm/degC temperature coefficient.

PHASIC Mods near Preamp



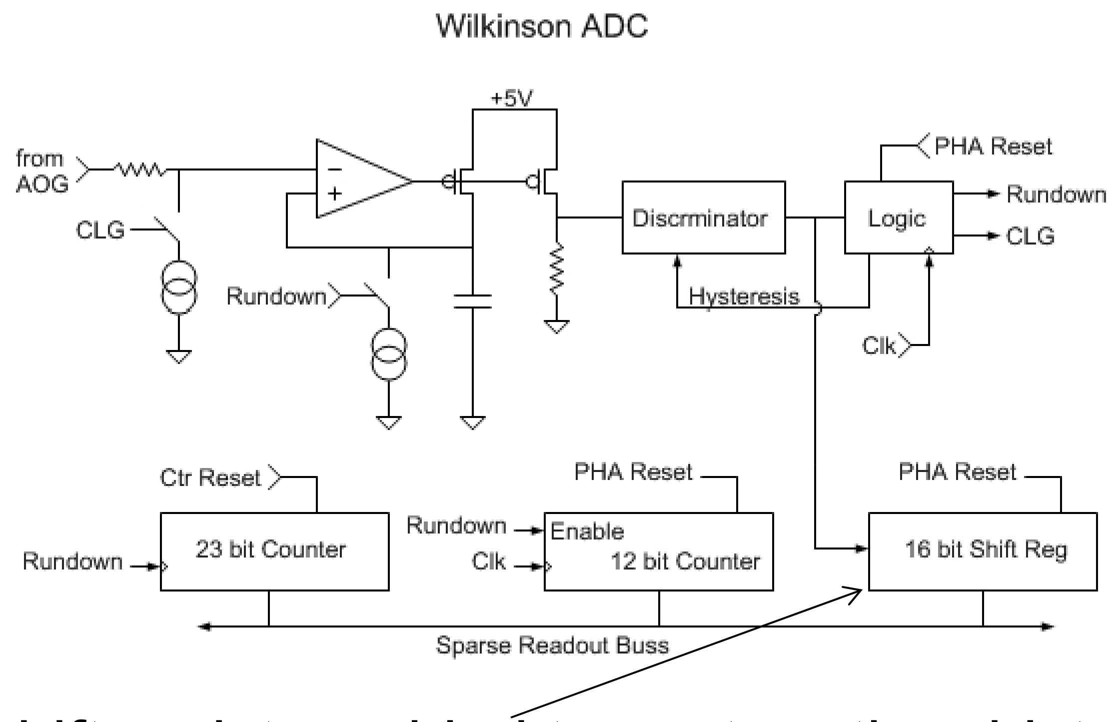
- Preamp output stage changed from “follower” to “open drain” to increase output swing.
- Preamp compensation method changed for lower noise.
- Buffer added in high gain signal chain.
- High/Low gain ratio increased from 20 to 68, with programmable option of 40.
- High/Low gain boundary falls between alphas and carbon for most detectors.

PHASIC Mods near Peak Detector (1/2)



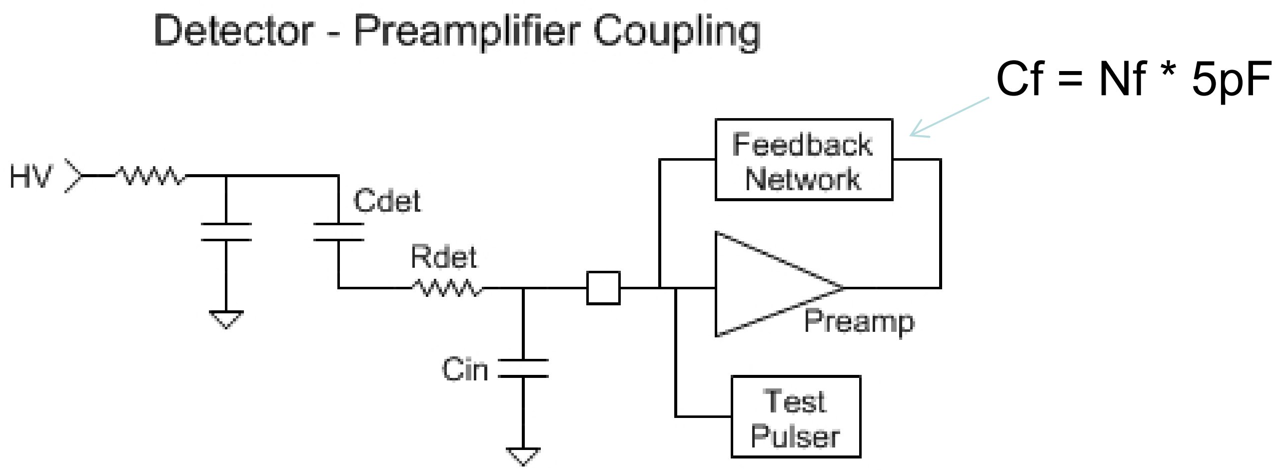
- STEREO Peak detector contained two differential amplifier stages at input. For Solar Probe Plus reduced to one stage but with higher current resulting in lower noise.
- Size of FETs in current mirror at output increased to improve matching and threshold uniformity.

PHASIC Mods near Peak Detector (2/2)



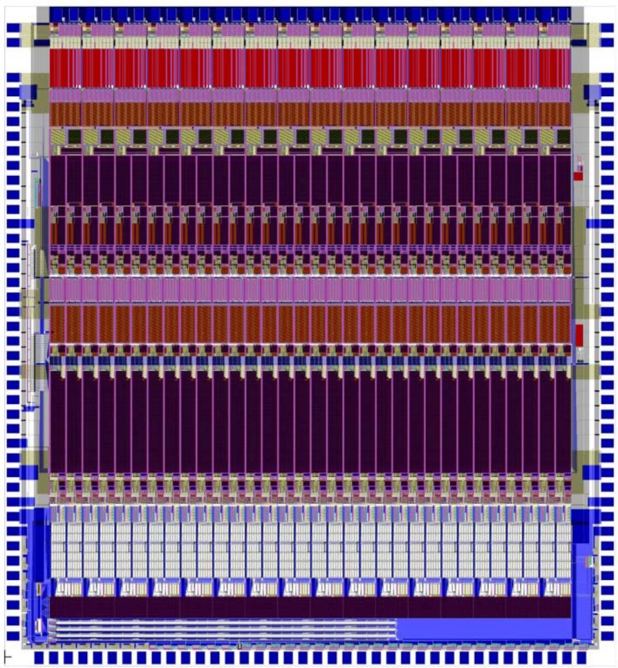
16-bit shift register added to capture time history of discriminator output to aid in cross-talk identification.

Predicted PHASIC Noise/Threshold



Det	Cdet (pF)	Rdet (ohm)	Cin (pF)	Nf	Threshold (MeV)	Full Scale (MeV)	Zn @ 45 degrees (MeV)	Gain Crossover Freq (MHz)	Phase Margin (deg)
L0	208	0	30	1	0.09	268	83	12.3	98
L1	93	30	40	1	0.05	268	251	13.3	65
L2(H1)	20	10000	60	6	0.12	2802	2660	13.4	60
L3(H2)	40	7500	80	9	0.19	4337	4092	10.8	61
H3	30	15000	80	13	0.28	6155	6203	10.5	56

PHASIC Radiation Tolerance



- Total dose tolerance improved by adding proven Aeroflex processing steps to commercial ON-Semi C5N CMOS process.
- Layout modified to comply with slight Aeroflex design rule differences.
- 12 krad improves to >100 krad.
- Latch-up threshold should still be >80 MeV/(mg-cm^2) due to use of guard rings.

PHASIC Status

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- Engineering run though ON-Semi C5N commercial process was completed, yielding EM wafers and dice.
- EM dice installed in STEREO hybrids and tested.
- Systematic noise was issue in STEREO test fixture due to socket. (For SPP some channels need to operate at higher gain than for STEREO.)
- Completed new test fixture without socket. Residual noise was eliminated, allowing full performance testing to proceed.
- Initial test results indicate noise and dynamic range goals achieved and new 16-bit SRs are functional.
- Linearity and threshold testing in progress (should be done by PDR).
- PHASIC Manual has been updated to account for SPP mods.

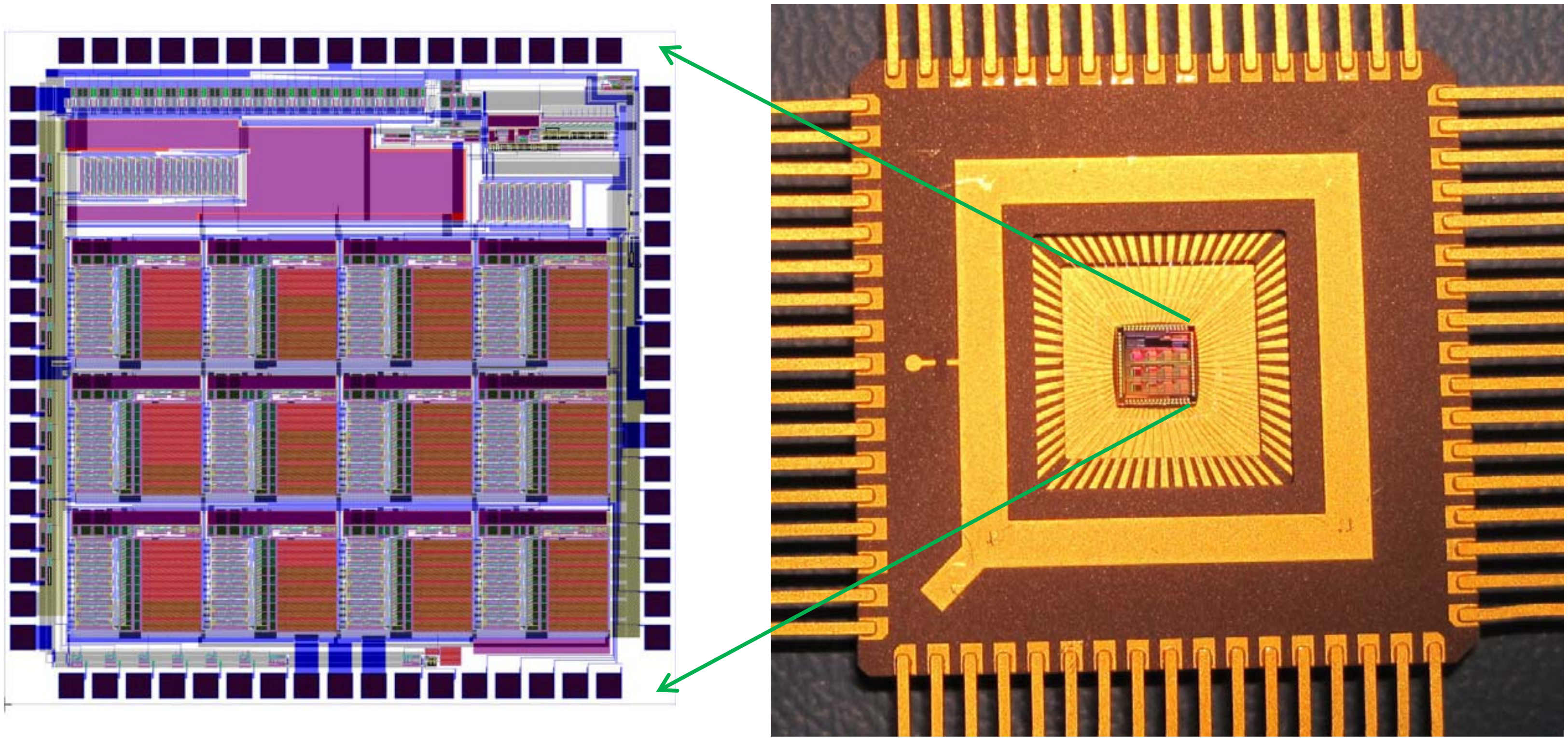
What is a MISC?

- MISC stands for “Minimal Instruction Set Computer”.
- Public domain design concept by Charles Moore, inventor of FORTH.
- Our implementation defined in 2002 for STEREO, with Dr. C.H. Ting.
- 24-bit word width; Four 6-bit instructions per word.
- All instructions execute in single clock cycle.
- Dedicated I/O bus and instructions.
- 11 prioritized interrupts.
- Both MISC design and FORTH operating system stable since 2002.
- Compact design fits nicely in RTAX250.
- Data and Return stacks implemented using “block ram” in RTAX250, with EDAC becomes SEU tolerant.
- RTAX250 implementation (flown on NuSTAR) runs @ 15 MHz.
- MISC uses 36% of RTAX250 “R cells” (flip-flops) and 63% of “C cells” (logic gates), leaving 1050 R cells and 900 C cells for application specific logic.
- Estimated app specific logic for telescope board: 500 Rcell, 300 Ccell based on similar STEREO design, i.e. < 50% of available resources.

HK Chip

- Housekeeping Chip is a new ASIC design for use in EPI-Hi.
- Includes most auxiliary functions needed for a small instrument in a 68-pin hermetic ceramic package.
- Delta sigma modulator, for making DC voltage (0-5V) measurements to monitor power supply voltages, currents, and instrument temperatures.
- 35-input analog multiplexor.
- 12 10-bit DACs with option of rail to rail buffered output.
- 12 digital outputs designed to drive opto-isolated power switches for heater control.
- DACs may be ganged for greater voltage setting resolution.
- DAC outputs may be internally routed to modulator for precision measurement => low precision DACs can be used to generate high precision voltages and improved in-flight PHASIC calibration.

HK Chip Packaging



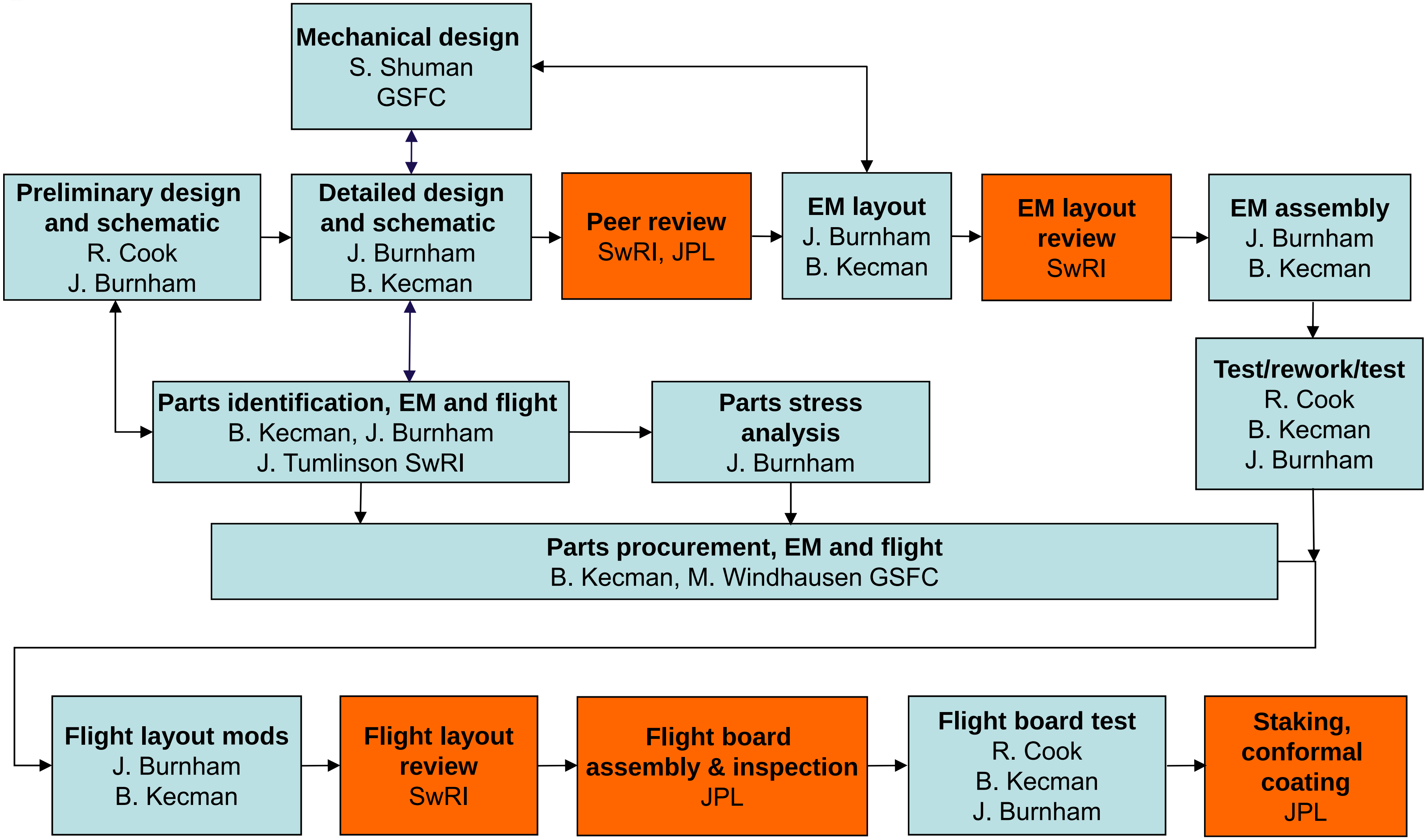
- HK Chip packaged in hermetic 68-pin ceramic package.
- HK Chip to be qualified and screened to level Q, with PIND test included.

HK Chip Status

- HK Chip was laid out using Aeroflex design rules.
- Fabrication of EM parts was done first with ON-Semi C5N process through MOSIS. The 2nd run was on shared wafers with EM PHASIC fab directly through ON-Semi.
- Test results: DAC linearity limited to 8 bits; Delta sigma modulator can provide up to 18-bit performance. Buffer amps, digital outputs and power on reset circuit all perform properly.
- Design judged adequate for flight re-spin with Aeroflex radiation hardening.
- Flight re-spin will occur simultaneously with PHASIC flight fab on same wafers.

Implementation and Status

Design/Assembly/Test Flow



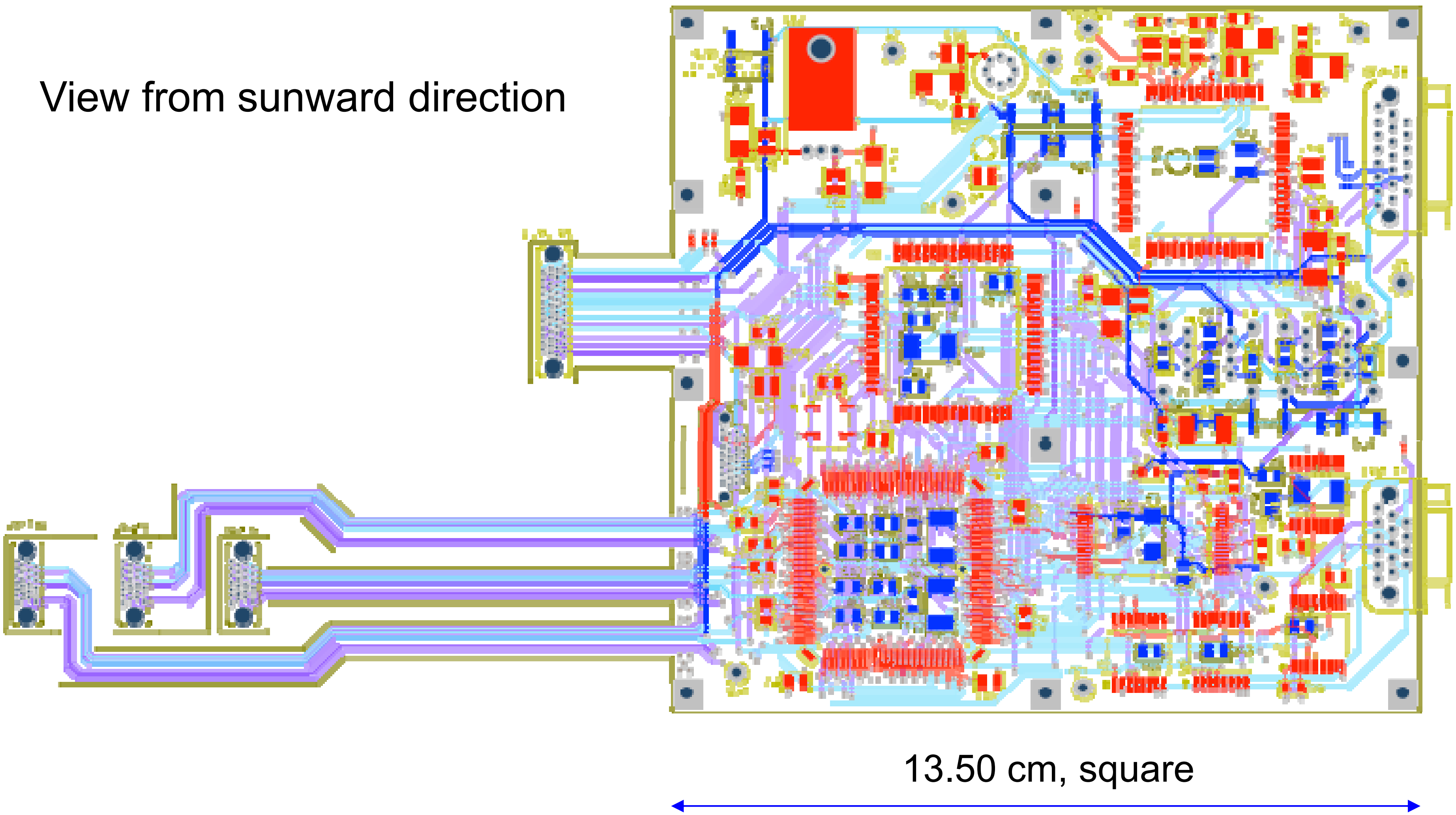
Board Status

Board	Spec	Schem	Peer review	EM layout	EM fab began	EM parts procured	EM test starts at Caltech
Telescope x3	L4	99%	√	20%	No	60%	Jan-Jun '14
DPU	L4	√	√	√	No	80%	2/28/14
LVPS	√	√	√	√	Yes	√	1/27/14
Bias Supply	√	√	√	60%	No	70%	4/7/14

Breadboard	Spec	Schem	Peer	Layout	Fab	Parts	Test
Bias Supply	√	√	N/A	√	√	90%	In progress

DPU Board Layout

View from sunward direction



13.50 cm, square

Bias Supply Board Layout

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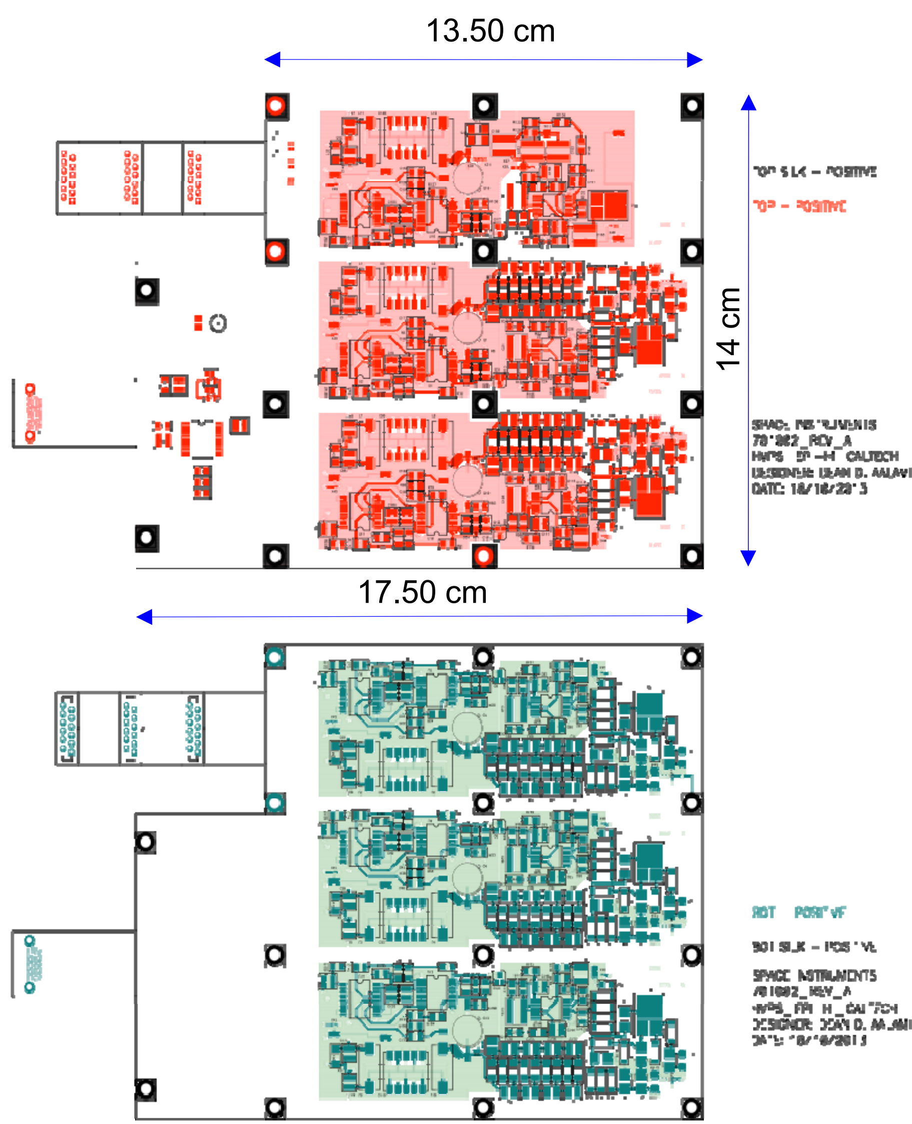
View from sunward direction



EEE Parts Program and Status

- All parts required to meet EEE-INST-002, Level 2
  - PCB approval required for all parts
    - PCB review in process for all parts
- Existing Caltech custom databases used to track inventory and kit history for all parts
- Procurement in process now for prototype/EM parts
- Where possible, flight parts will come from Caltech, GSFC, SwRI and JPL inventory
  - Parts more than 5 years old will have additional testing performed as required by the PCB

Significant Parts

Part Number Part Type	Manufacturer	Heritage	Notes
RTAX250SL-CQ208B FPGA	Microsemi SoC (Actel)	NuSTAR	Existing stock at Caltech
5962R0323601QXC SRAM, 4Mb (128k x 32)	Aeroflex	NuSTAR	Existing stock at Caltech
5962R0422701QXC SRAM, 16Mb (512k x 32)	Aeroflex		
5962R1222201VXC MRAM, 16Mb (2M x 8)	Aeroflex		Common buy with S/C
10229545 PHASIC, Hybrid ASIC	JPL	STEREO	Existing stock at Caltech Modification required
TBD HKchip, ASIC	JPL		Will follow similar process as PHASIC

ASICs: PHASIC and HKchip

- PHASIC: Hybrid ASIC developed for STEREO
  - Using existing stock with modifications
    - New rad-hard wafers will be produced
      - TID and SEL testing planned
    - Heritage die will be removed and replaced
    - Packaging will be performed by JPL Hybrid Lab
    - Assembled part will undergo full screening and qualification performed by JPL and Caltech

- HKchip: New part, monolithic ASIC
  - Will follow the same wafer procurement, packaging and test plan as the PHASIC

Resources - Power

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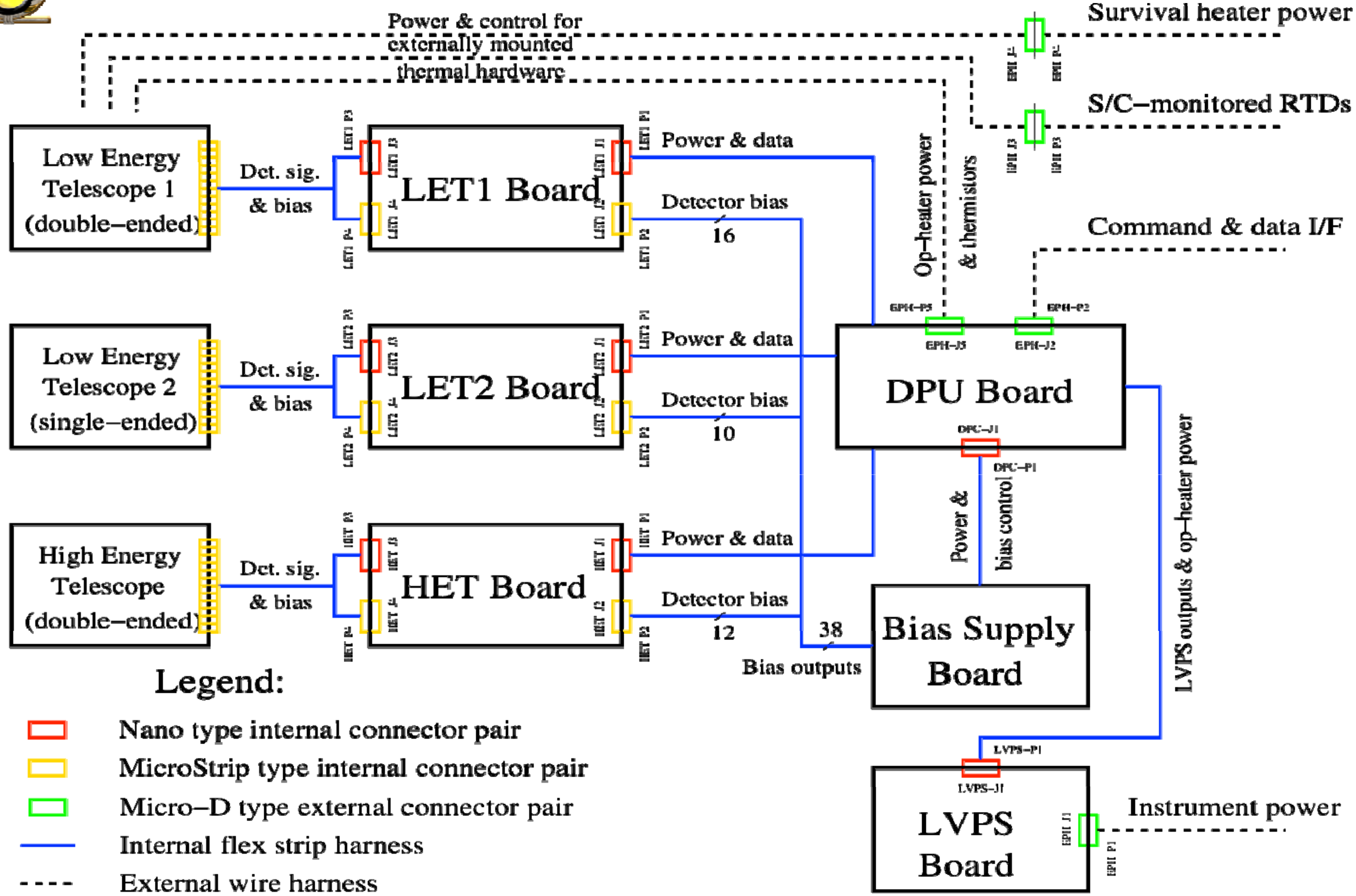
Subsystem	Power [W]
LET1 board	1.06
LET2 board	0.76
HET board	0.95
DPU board	0.62
Bias Supply @ Beginning Of Life	0.12
LVPS @ BOL (70% efficiency)	1.50
Total @ BOL	5.0

End Of Life	
Bias Supply @ End Of Life	0.68
LVPS @ EOL (70% efficiency)	1.74
Total @ EOL	5.8

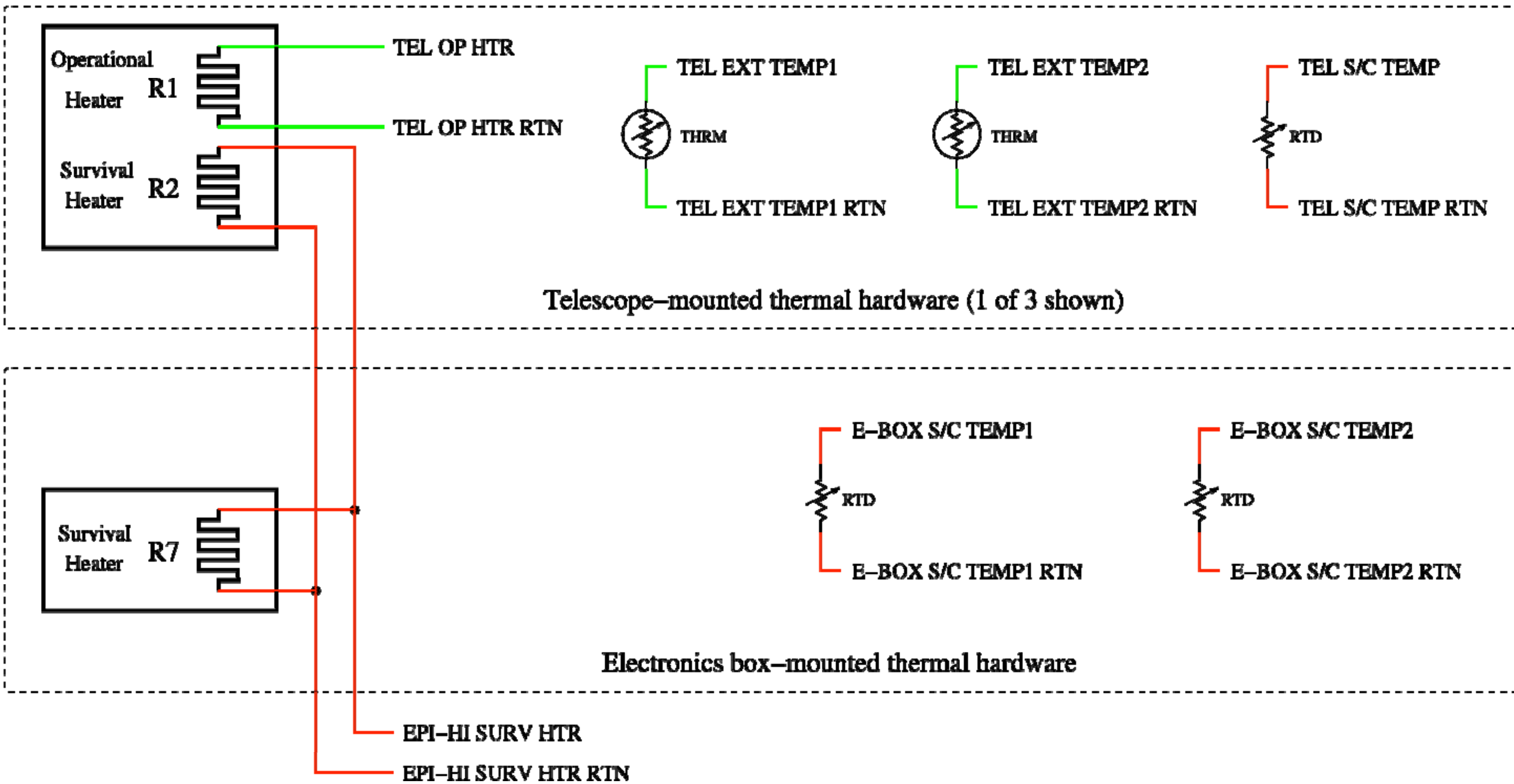
Resources - Mass

Subsystem	Mass [g]
LET1 telescope LET1 board	225 258
LET2 telescope LET2 board	145 233
HET telescope HET board	120 250
DPU board Bias Supply & RF shields LVPS & RF shields	197 225 + 130 160 + 100
Elec. box, hardware & shielding Telescope brackets Thermal hardware MLI blankets	925 + 250 +100 160 50 100
Total	3,628

Harness Diagram



Thermal Harness Diagram



Summary

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- Peer Reviews conducted on designs
  - PHASIC – Dec 2012 – all Action Items closed
  - DPU and Telescope Boards – Sep 2013 – all Action Items closed
    Schematics updated and layouts in process
  - Bias Supply Board – Sep 2013 – all Action Items closed
    Schematic updated and layout in process
- Testing of ASICs has shown good performance that will meet our requirements
- No issues with Parts List
- When all layouts completed and reviewed, fabrication and testing of EM begins

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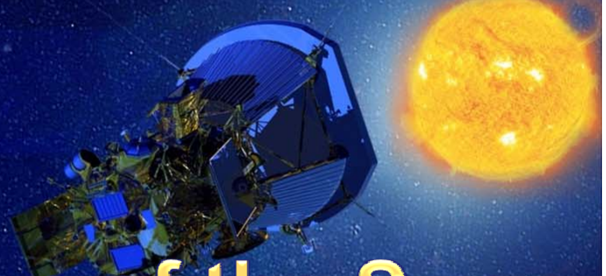

Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

EPI-Hi Software

Andrew Davis

EPI-Hi S/W Lead (Caltech)

Outline

- Requirements
- Overview
- Development Environment
- Data Flow and Software Tasks
- Integration, Test and Verification
- Configuration Management
- Heritage
- Predicted Margins
- Peer Review Summary

Software Requirements

- The Flight Software Requirements Document details the flow-down from higher-level requirements, and from GIS and SIS ICDs
- These requirements are quite similar to those for our work on recent NuSTAR and STEREO missions
- The same modular flight processor and software architecture that we used for NuSTAR and STEREO will meet the EPI-Hi requirements
- The requirements are mapped into a set of modular software tasks, implemented on the EPI-Hi flight processors

Documentation Status

Document	Status/due date
Flight Software Requirements	Baseline draft Delivered
Flight Software Development Plan	Baseline draft Delivered
Flight Software Design Document	Prelim draft delivered at PDR
Flight Software Test Plan	Due by CDR
Test verification matrix	Due by CDR
Instrument Telemetry Data Format Document	Due by CDR
P24 MISC Processor Manual	Delivered
PHASIC User Manual	Delivered

These docs are responsive to the GI ICD, the SI ICD, the PAIP, L4 reqs…

Processor and Software Architecture (1/2)

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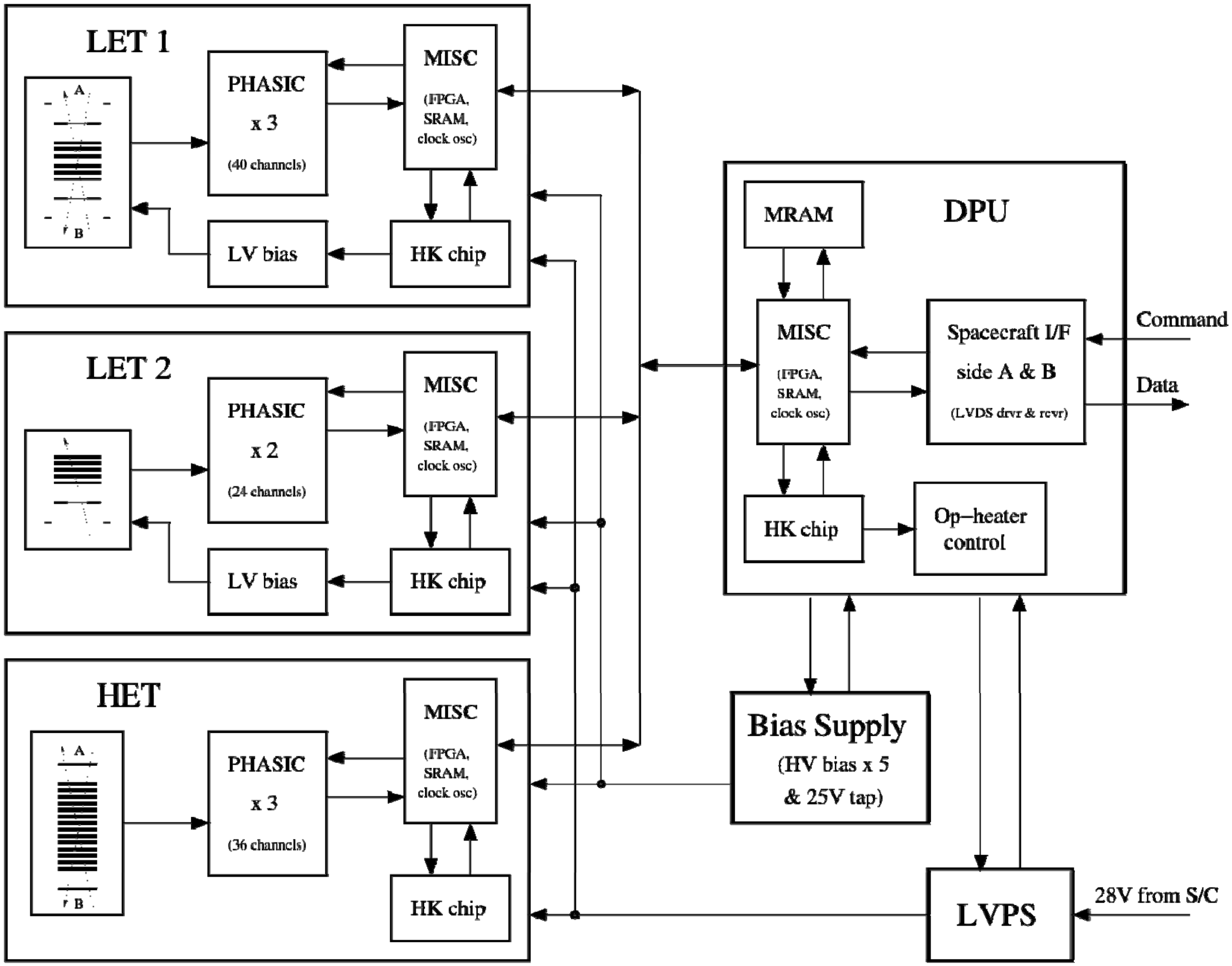
- Software distributed across 4 Minimal Instruction Set Computers (MISCs)
- 1 MISC in DPU, 1 each in LET1, LET2, HET
- Custom FPGA-embedded micro-controller
- Design implemented in Actel RTAX250SL
- Architecture used in STEREO and NuSTAR space missions
- 24-bit CPU, up to 512 Kwords SRAM, Forth operating system, can boot from MRAM or serial interface
- MISC design and Forth operating system stable since 2002
- Only DPU MISC has MRAM (2M×8).
- DPU can boot from MRAM, or via serial uplink from ground
- The three “satellite” MISCs communicate with DPU MISC via RS-422 serial links, 460.8 kbps
- Satellite MISCs booted via serial link by DPU MISC
- Satellite MISCs use boot images from DPU MRAM

Processor and Software Architecture (2/2)

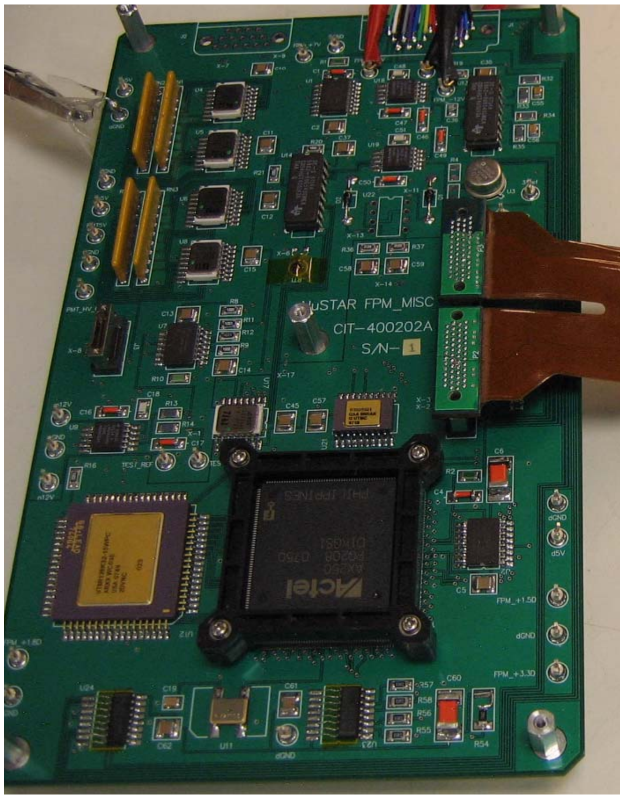


Development Environment (2/2)

Interface to MISC Development Board

- Initial testing of new code takes place on MISC development boards
- Forth system on development boards accessed via serial link to PC
- New code is easily uploaded via the serial link
- Testing of code that accesses hardware is done on EM units
- Low-level MISC I/O routines are stable, and in everyday lab use, where MISCs are used to acquire test data and control test runs
- The same central MISC / multiple-satellite MISC architecture was used for NuSTAR and STEREO
- EM units are preserved after launch, and used for testing/verification of software uploads and command sequences

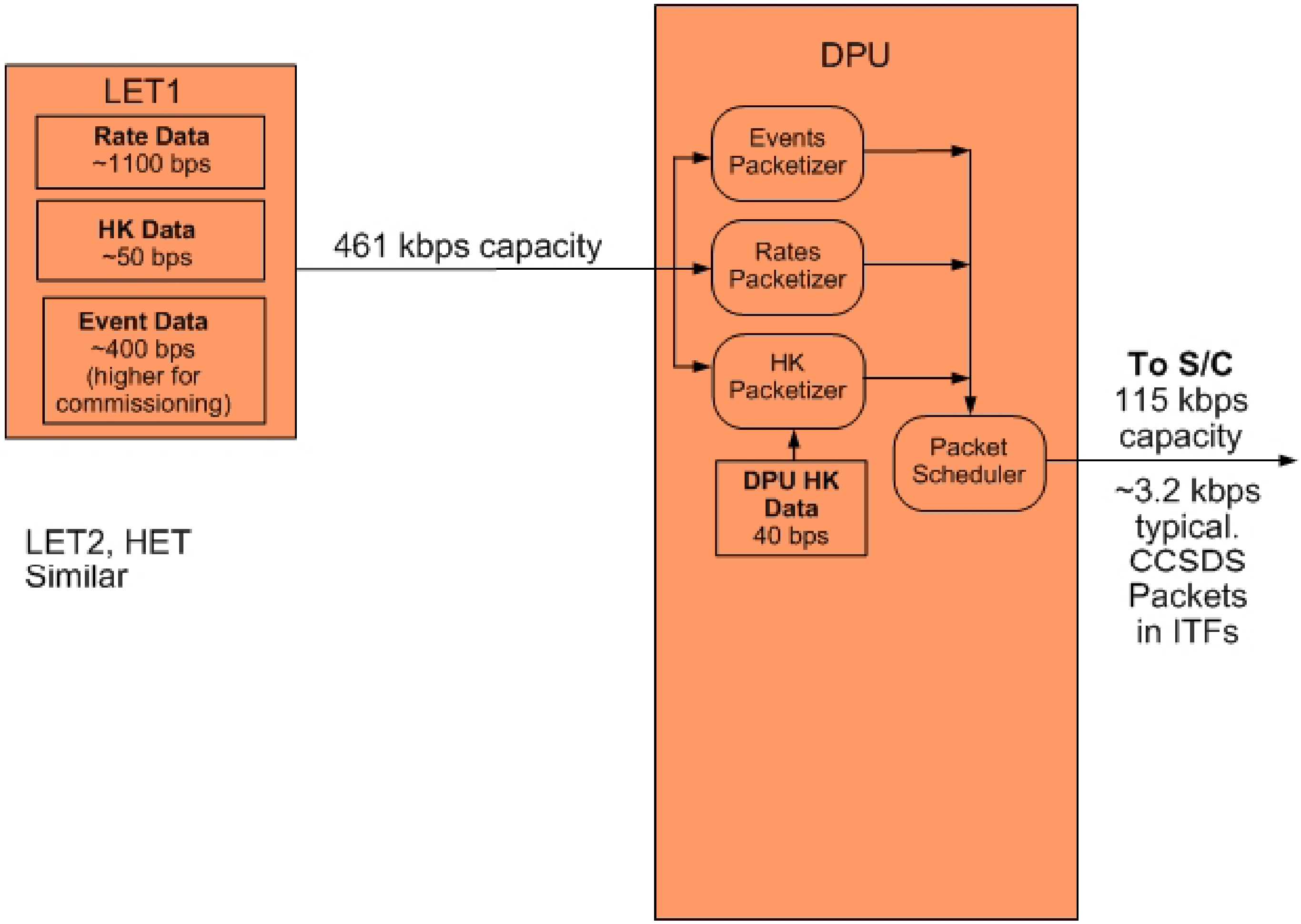
Development Environment (2/2)



NuSTAR MISC EM board

- Initial testing of new code takes place on MISC development boards
- Forth system on development boards accessed via serial link to PC
- New code is easily uploaded via the serial link
- Testing of code that accesses hardware is done on EM units
- Low-level MISC I/O routines are in everyday lab use, where MISCs are used to acquire test data and control test runs
- The same central MISC / multiple satellite MISC architecture was used for NuSTAR and STEREO
- EM units are preserved after launch, and used for testing/verification of software uploads and command sequences

Instrument Data Flow



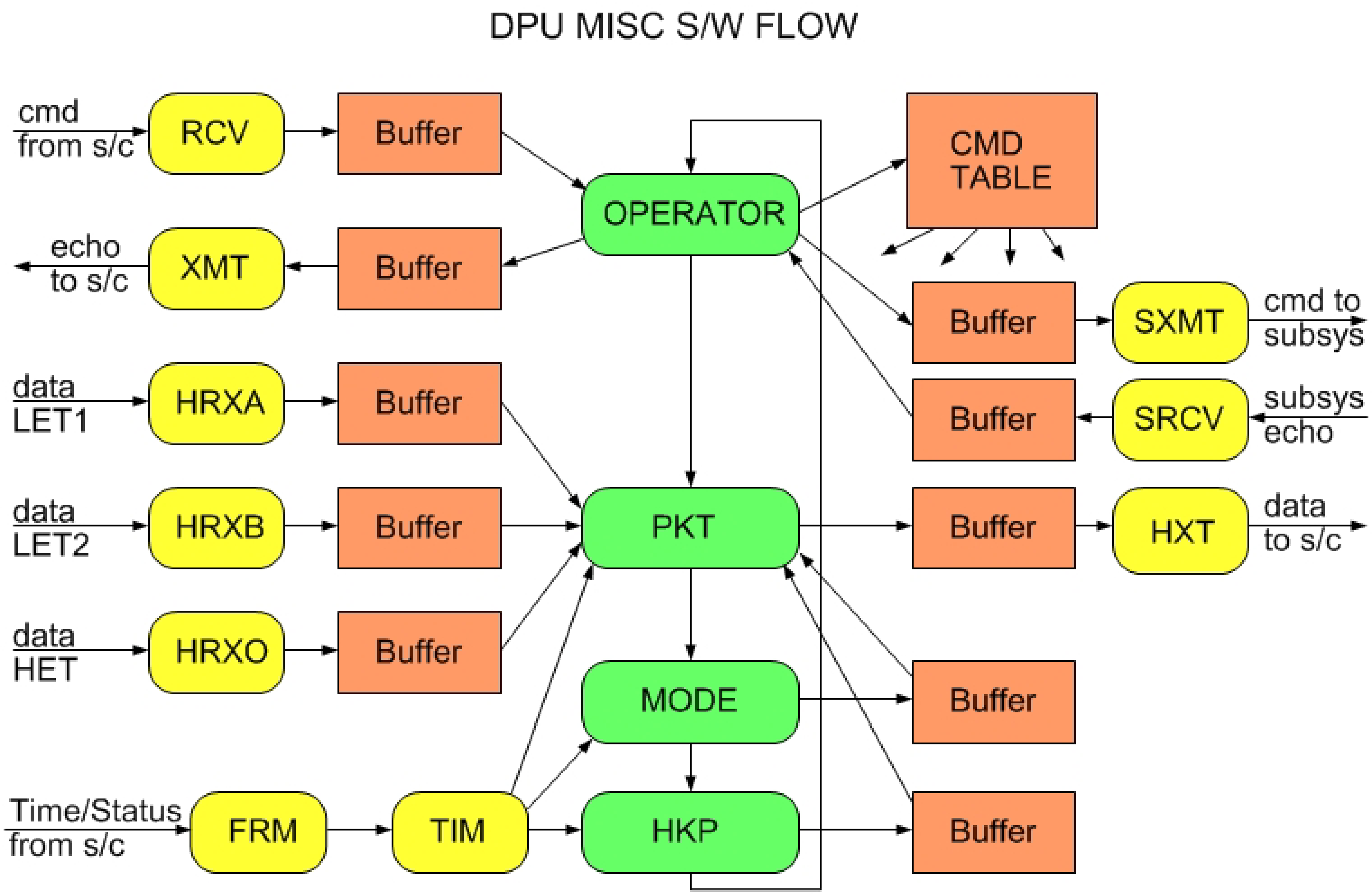
LET2, HET Similar

Note: Typical data rates are preliminary, and subject to change based on our SSR allocation

DPU Software Tasks

- Forth operating system and low-level I/O routines
- Power-on and initialization sequence management
- Satellite MISC serial boot sequence management
- Housekeeping data collection
- Inter-MISC communication management, and data acquisition/buffering from satellite MISCs
- Setup and control of instrument LVPS, bias supply, op heaters
- Receive/Monitor status and time-synchronization data from the spacecraft, and perform autonomous mode adjustments as needed
- Management of software uploads and MRAM “burns”
- Formatting/packetizing and transfer of science & housekeeping data and command responses to the Spacecraft
- Monitor heartbeat from peripheral MISCs, and perform autonomous diagnostics/reboot as needed
- Manage volume of instrument data transferred to SSRs on S/C as function of time

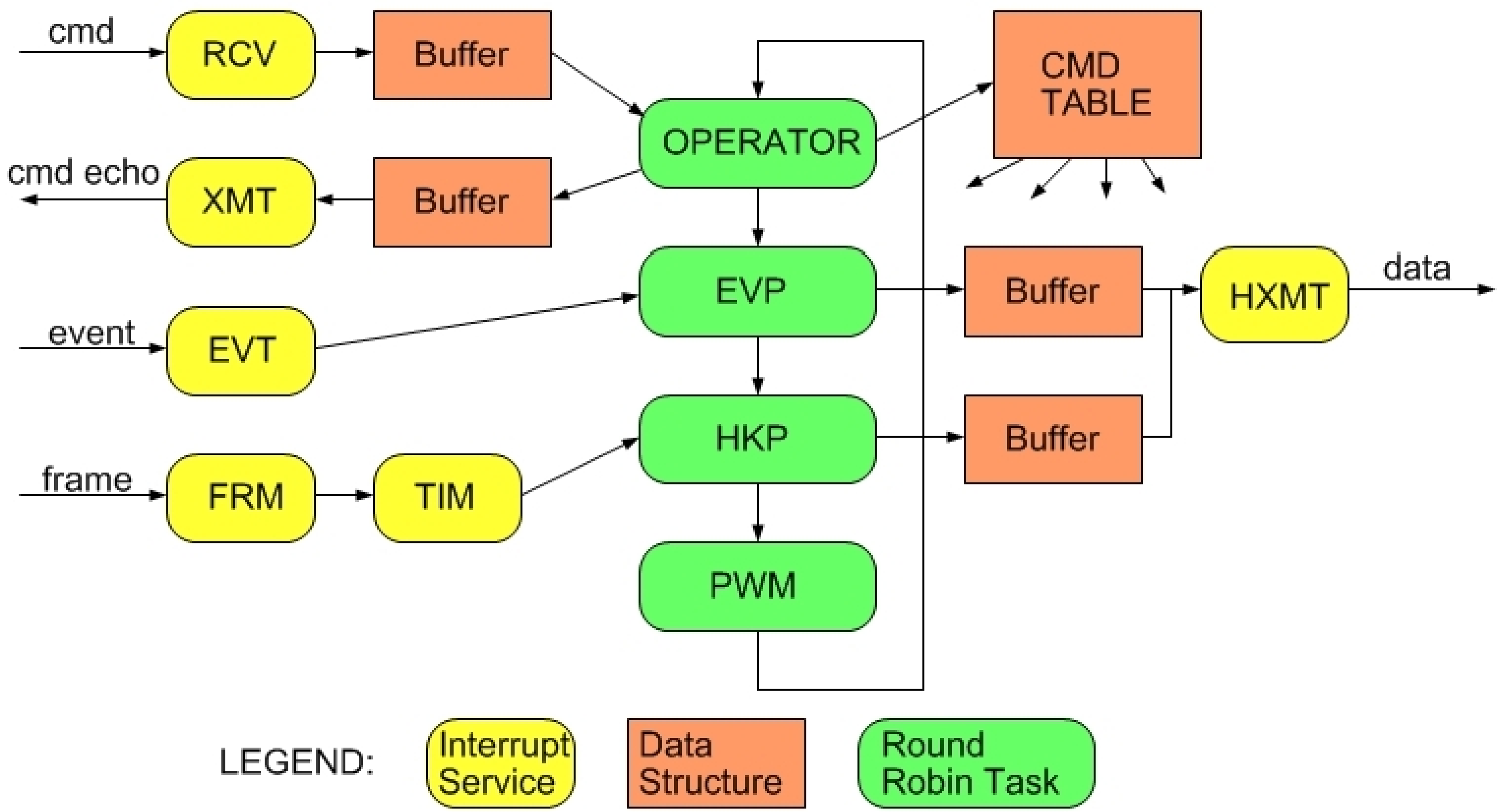
Software Flow – DPU MISC



Satellite MISC Software Tasks

- Forth operating system and low-level I/O routines
- Science data acquisition
- Science data processing and reduction (particle ID)
- Housekeeping data acquisition
- Processing of status, time-synchronization, and command data from the EPI-Hi DPU
- Monitor key counting rates and adjust the telescope operating condition to optimize data quality
- Monitor temperatures and adjust detector gain/offset settings to compensate for temperature variations
- Formatting and transfer of science & housekeeping data and command responses to the EPI-Hi DPU
- Setup and control of PHASICs and HK chips, and any instrument HV, bias supply, heaters, etc. not controlled by the EPI-Hi DPU.
- Dynamic adjustment of detector thresholds during periods of high particle intensity

Software Flow – Detector Module MISC



Integration, Testing and Verification

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The EPI-Hi Flight Software Test Plan document will define this plan in detail. This plan will include a software requirements verification matrix.

- Software tests will start at the module level. As the code builds up, system-level testing will start, and the majority of the test time will be targeted at the system level.
- A Test Readiness Review will precede formal acceptance testing. SPP Project and ISIS personnel will oversee/participate in this review.
- Formal acceptance tests will be performed on the EPI-Hi instrument, including the flight software, during the EPI-Hi integration and test phase.
- During environmental tests and SPP I&T, more experience will be gained with the flight software, real sensor data, and with controlling the instrument via the SOC-MOC interfaces. Flight software changes may be expected as a result. Any changes in the flight software at this stage will result in CCB review, and a repeat of these acceptance tests.
- The acceptance tests for the EPI-Hi flight software will be designed to verify each of the software functional requirements as called out in the requirements documents and also the functions provided by the Forth operating system, the I/O API, and the multitasking software running on the MISC processors.
- A software requirements verification matrix will be created and maintained by the EPI-Hi team to aid in verifying that the software meets the requirements. The matrix will be available for review by the SPP Project. A preliminary software requirements verification matrix will be presented at CDR and a final version will be presented at the Software Acceptance Review, following successful completion of the acceptance tests.
- A Software Acceptance Review will follow the successful completion of the acceptance tests, and the EPI-Hi team will present a test report. SPP Project will oversee/participate in this review.

Software Maintenance, Configuration Management

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Configuration Management Plan is contained in Software Development Plan

- Version control and software archiving: achieved via Subversion version control system (SVN) (http://subversion.apache.org/). The subversion server is hosted and maintained by Caltech Space Radiation Lab IT personnel. It is access-controlled for security, and is backed-up regularly.
- The lead engineer will maintain the structure of the SVN repository, including separate directories for each of the MISC's flight software, separate directories for different software builds, etc.
- All problems and change requests will be documented/tracked in the Software Development Log by the lead engineer. Given such a small dev team, a change request tool such as JIRA is unnecessary overhead.
- After the beginning of I&T with flight hardware, all flight software changes will be approved by a CCB prior to being loaded into flight hardware. Also after this point, Version Description Documents (VDDs) will accompany all Software releases. The VDD will contain the functionality of the release, a list of closed software problem reports, a list of any liens/workarounds, installation instructions, and a list of deliverable source code files.
- The CCB membership will consist of the EPI-Hi lead engineer and software developer, and the Epi-Hi Project Manager, plus any other ISIS or SPP Project engineers that the QA team at SwRI deems necessary.

Software Heritage

The flight software inherits some major components from previous projects:

- The Forth kernel and real-time multi-tasking S/W are the same as for the SEP instrument suite on STEREO, the NuSTAR mission, and the many MISC processors used ubiquitously in ground test equipment at Caltech
- The inter-MISC communication S/W is the same as for STEREO and NuSTAR
- The software for packetizing instrument data into CCSDS packets and scheduling the transfer of data packets to the spacecraft is the same as for STEREO and NuSTAR
- The software for processing instrument commands, routing commands to detector module MISCs, and packetizing command responses is the same as for STEREO and NuSTAR, except for the unpacking of the commands from the telecommand ITF
- The onboard analysis and binning of particle event data by the detector module MISCs has significant heritage from STEREO

Software Heritage – What's Different? (1/2)

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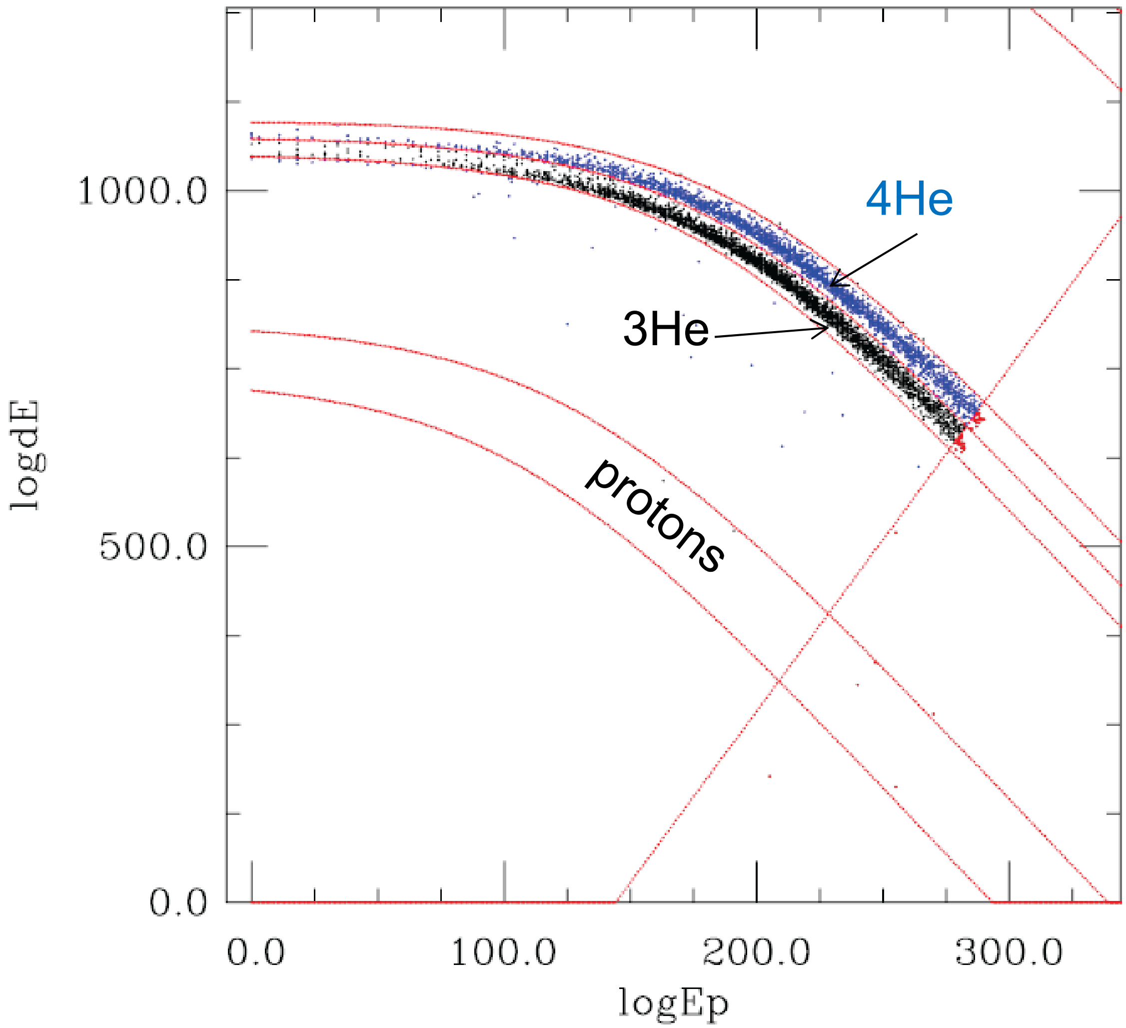
- The instrument boot sequence is quite different, given the lack of hardware reset line and the increased autonomy requirements – see separate boot sequence presentation.
- Each MISC FSW shall provide a capability to execute command sequences, i.e. macros. This is actually inherent in the Forth OS, but we need to write some utility code to make the implementations of timed command sequences simple/friendly.
- The DPU MISC FSW needs to manage a section of MRAM as a "patch file" archive. Need subroutines to transfer between SRAM cmd buffer and the MRAM patch file, and routines to read and execute the patch file. This capability needed to support autonomous reconfiguration to known op state after power-on/reset.
- The DPU shall monitor the telemetry of the detector module MISCs, and perform an SRAM dump and reboot upon detection of a fault.
- Need to understand interaction between EPI-Hi autonomy rules and S/C autonomy rules for all possible fault scenarios.

Software Heritage – What's Different? (2/2)

- Management of the volume of EPI-Hi instrument data telemetered to the Spacecraft as a function of time, based on the solid-state recorder "fill-level" information in the Spacecraft status message, and other commandable parameters
- Extraction of Forth instrument commands from the telecommand ITFs. In previous missions, the S/C unpacked our commands from ITFs/packets for us.
- Although the onboard analysis and binning of particle event data by the detector module MISCs has significant heritage from STEREO, there are new challenges:
  - We want to do a better job on 3He/4He than on STEREO
  - The coincidence equations that operate on the signals generated by each incoming particle event are more complex than on STEREO

Onboard Particle ID – He Isotope Separation



- Output from an LET1 Monte Carlo simulation of 3He and 4He events was used as input to the latest version of our onboard particle ID algorithm, implemented on a MISC test board
- Onboard algorithm maps events into a 2D dE-Eprime space, where boundary-curves define different regions for different species
- Code currently processes events at ~9600 events/second, ~4x faster than max incoming rate

Predicted Memory, CPU Margins

- **LET1 MISC (LET2, HET similar)**
  - SRAM 512kwords available (512k x 24 bits)
    - Basic OS, HK, I/O code + tables 20kwords
    - Event processing, particle ID 210kwords
    - Rates counters, double-buffered 10kwords
    - Event priority buffers 25kwords
  - → SRAM usage ≈ 265/512 = 52%
  - MIPs 12 60% used (Maximum, dominated by event processing during intense SEP events)

- **DPU MISC:**
  - SRAM 128kwords available (128k x 24 bits)
    - Basic OS, HK, I/O code + tables 20kwords
    - Detector module data buffers, & rate accum, double-buffered 30kwords
    - CCSDS Packet buffers 20kwords
  - → SRAM usage ≈ 70/128 = 54%
  - MRAM 2M x 8 bits ~70% used (2 sets of boot images)
  - MIPs 12 20% used

Pre-PDR Peer Review Summary

An EPI-Hi Flight Software Peer review was held October 9th.

Summary of comments received from reviewers:

- We need to review the NASA software standards docs listed in the PAIP, and ensure we are in compliance

Response:

EPI-Hi Flight Software is classified as Class C and not Safety Critical.

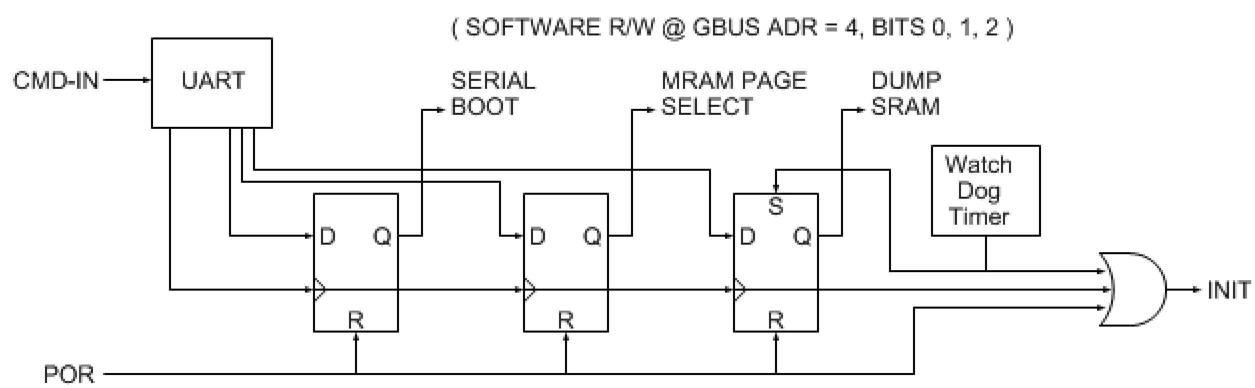
- Given this, we have reviewed
  - NPR 7150.2a NASA Software Engineering Requirements
  - NASA-STD-8719.13 rev B NASA Software Safety Standard
  - NASA-STD-8739.8 w/Change 1 NASA Standard for Software Assurance

We conclude that our plans, processes, and documentation are in compliance with the NASA standards, with some appropriate tailoring approved and monitored by our SwRI Software QA management.

Backup

Boot Logic

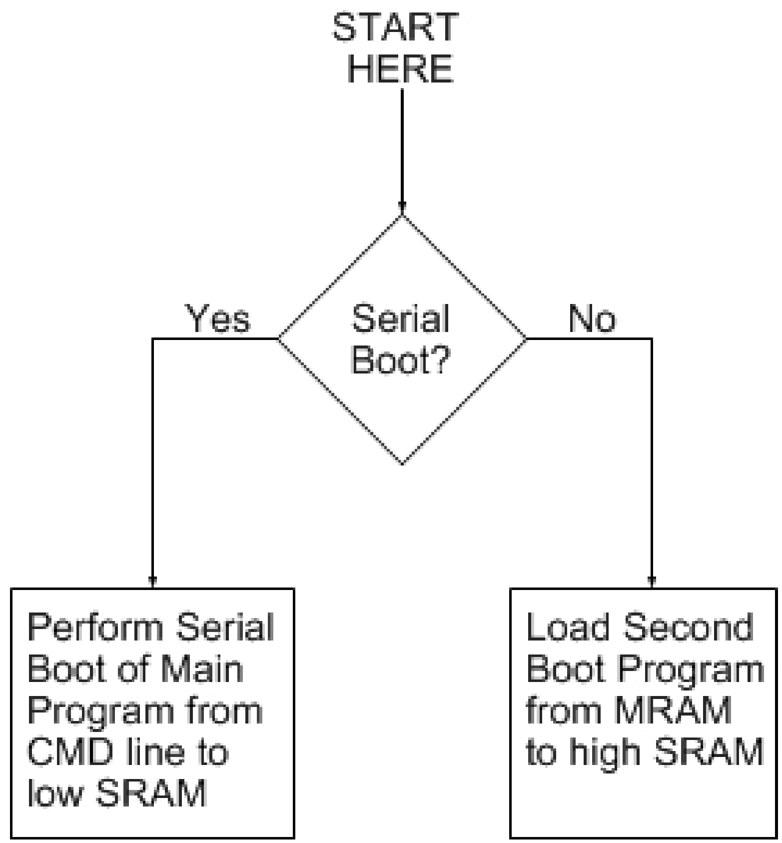
DPU MISC Reset Circuitry Block Diagram



- Supports three ways to initiate boot: Power On Reset (POR), CMD-IN and Watch Dog Timer
- “Reset Bit Field” is writable by CMD-IN and R/W by software
- “Serial Boot” bit determines if boot is to be performed serially via CMD-IN or from MRAM
- “MRAM Page Select” bit determined which page (0 or 1) of MRAM is source of boot images.
- “Dump SRAM” bit determines if SRAM is dumped prior to boot. This bit is set by the watch dog timeout.

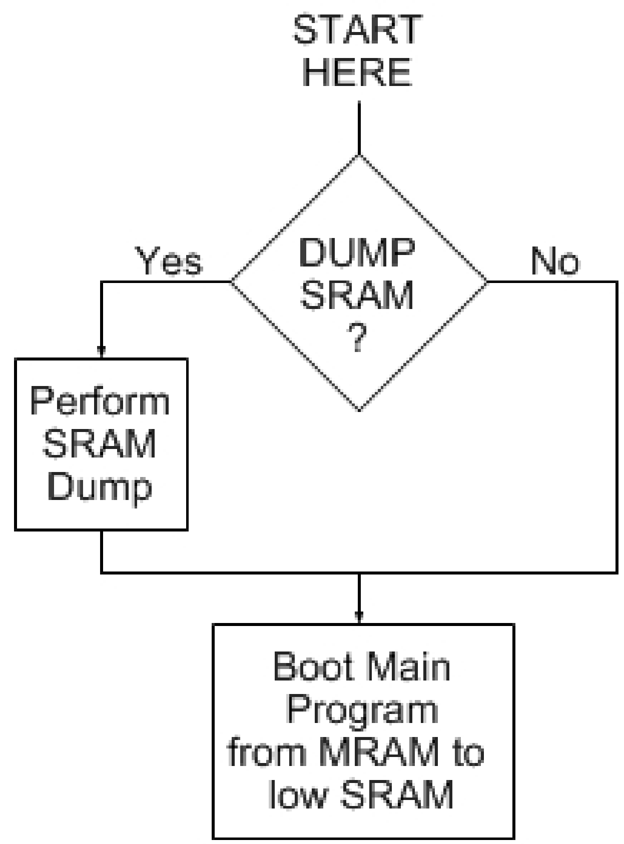
FPGA Resident Boot Program

- Permanently coded as part of FPGA design.
- Simple and small: <64 – 24 bit words
- Either performs serial boot of Main Program into low SRAM via CMD-IN
- Or loads second boot program from MRAM into high SRAM



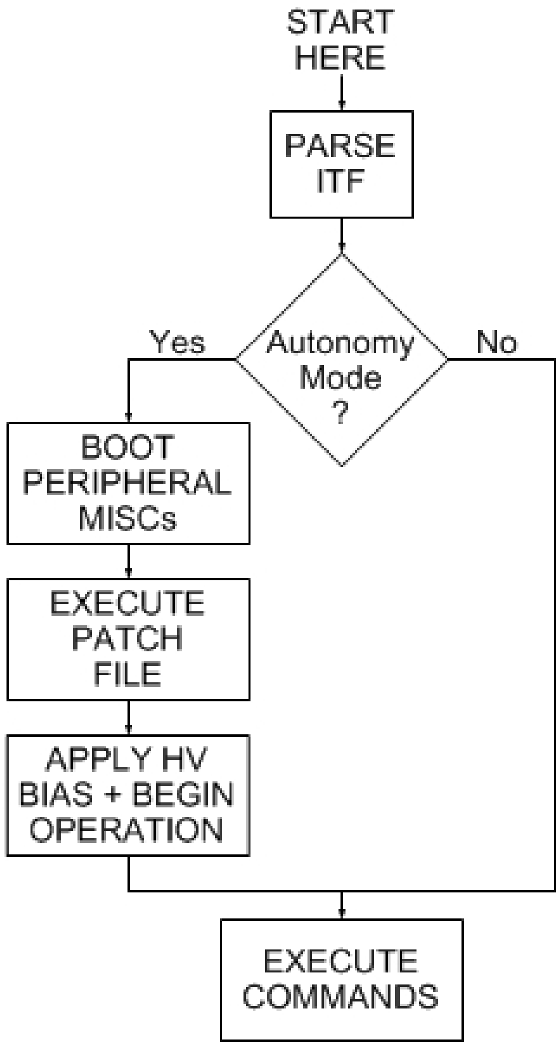
Second Boot Program

- Optionally performs SRAM dump prior to booting Main Program from MRAM to low SRAM.
- SRAM dump is somewhat complex, does not fit into FPGA resident boot program; hence need for second boot program.



Main Program

- Reads and parses ITF from S/C.
- Determines if in "autonomy mode".
- If so, boots peripheral MISCs, executes MRAM Patch File, applies HV bias, begins science operations in mode specified in S/C status message.
- If not, just awaits further commands; i.e. during commissioning.



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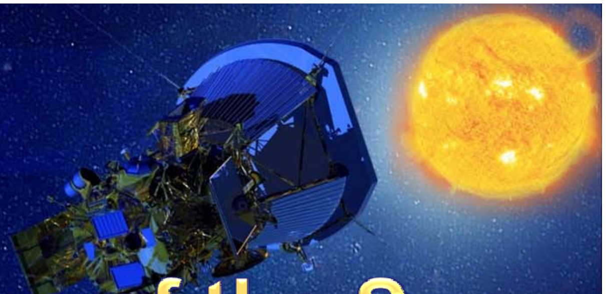

Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

EPI-Hi Mechanical

Sandy Shuman

EPI-Hi Mechanical (GSFC)

EPI-Hi Outline

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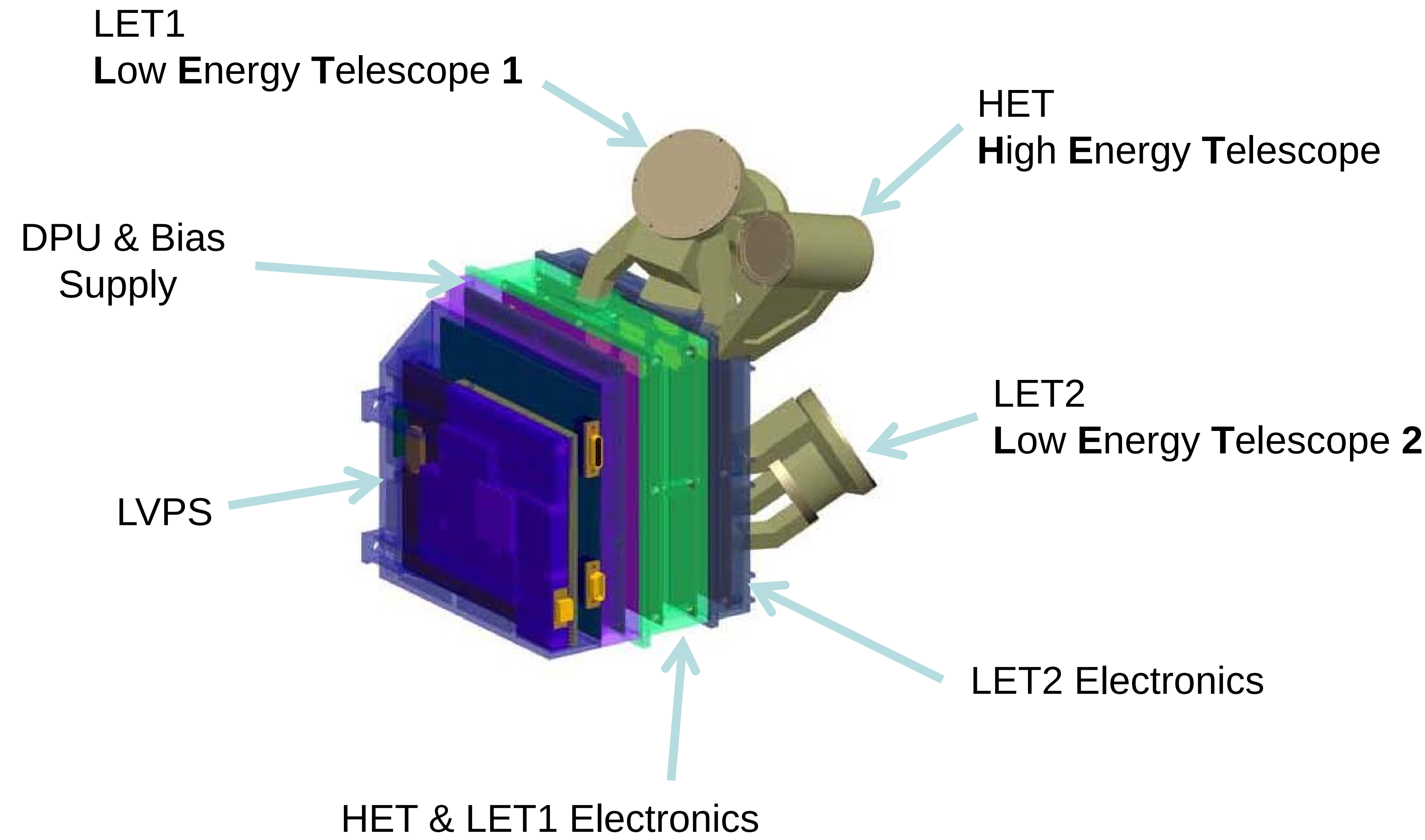
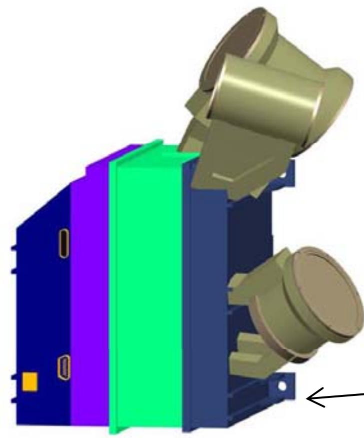
- Overview of Instrument Configuration
- Location on Spacecraft
- Fields of View
- Mass Allocation
- Mechanical Design
- Assembly Process
- Summary of Peer Review Results

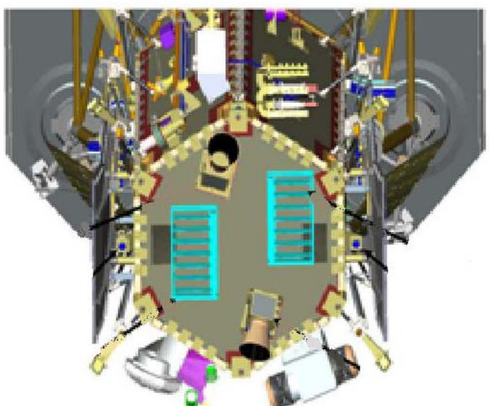
EPI-Hi Component Configuration



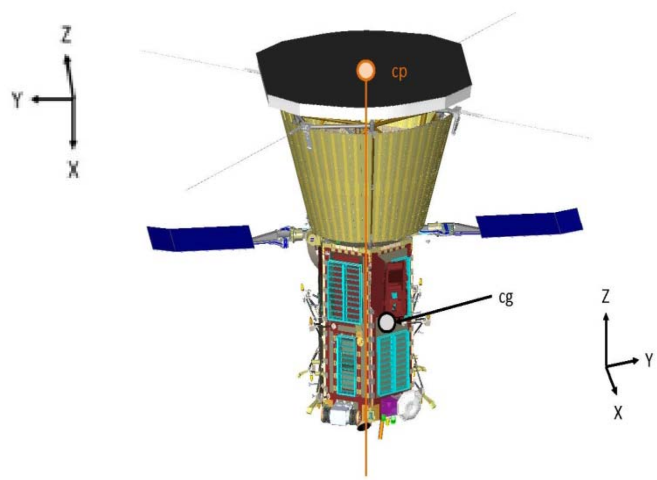
EPI-Hi Instrument

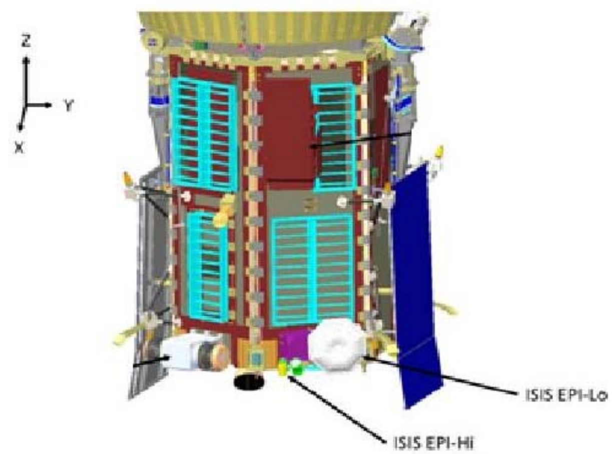
- Location of instrument on spacecraft
  - Located on +X side (RAM side)
  - Lower right mounting bolt on instrument located at: X = 46,16 cm
    Y = 23,39 cm
    Z = 6,13 cm





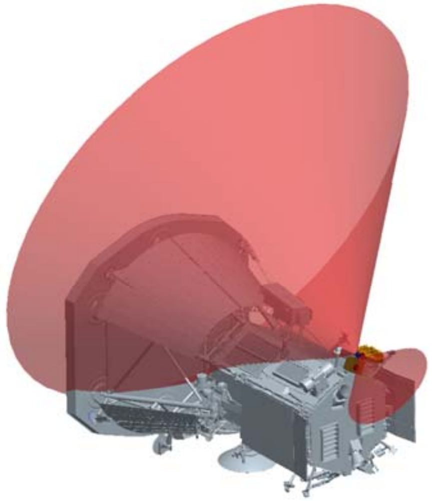
ISIS-EPI-HI

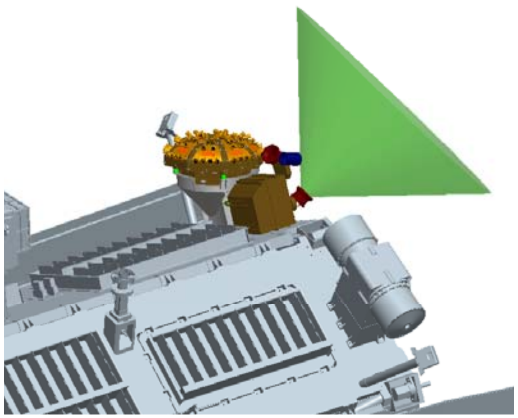




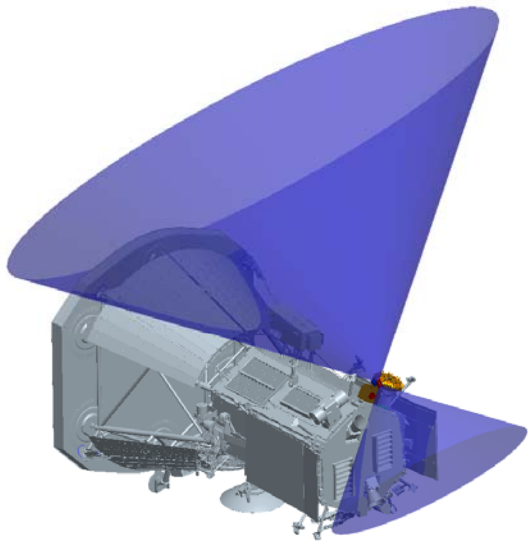
RAM SIDE

EPI-Hi Instrument FOVs





- HET conical 90° FOV
  - Double-ended
  - 20° above S/C-Sun line
- LET1 conical 90° FOV
  - Double-ended
  - 45° above the S/C-Sun line
- LET2 conical 90° FOV
  - Single-ended
  - Orthogonal to LET1 telescope (135° from S/C-Sun line)



EPI-Hi Mass Allocation

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Subsystem	Mass [g]
LET1 telescope LET1 board	225 258
LET2 telescope LET2 board	145 233
HET telescope HET board	120 250
DPU board Bias Supply & RF shields LVPS & RF shields	197 225 + 130 160 + 100
Elec. box, hardware & shielding Telescope brackets Thermal hardware MLI blankets	925 + 250 +100 160 50 100
Total	3,628

EPI-Hi Enclosure Requirements

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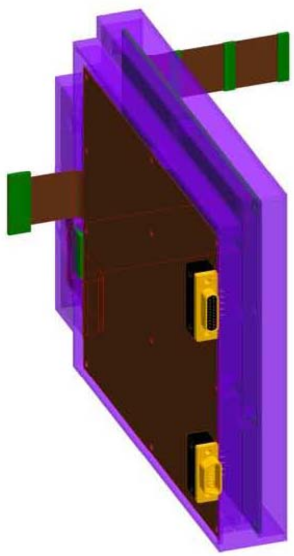
- Work within tight mass constraints
- Design to meet S/C launch environment requirements for Vibration, Acoustics and Thermal conditions
- Design for radiation dose shielding environment
- Package boards maintaining adequate parts clearance board-to-board
- Provide adequate RF and/or ground shielding board-to-board and through the enclosure
- Provide thermal isolation between electronics box and bracket, as well as between telescopes and electronics box

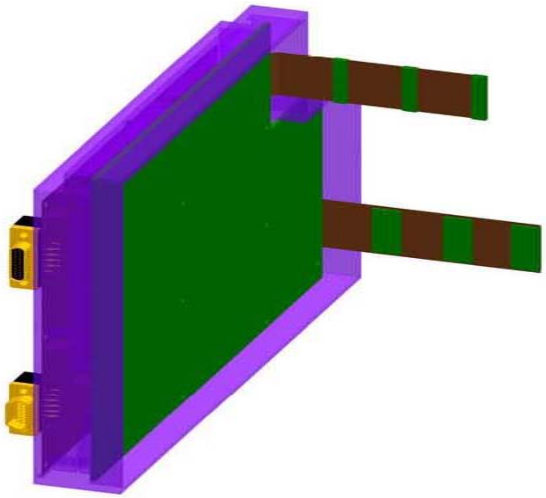
EPI-Hi Electronics Enclosure (1/4)

- Electronics box is made up of 4 major components:
  - LVPS Assembly
  - DPU & Bias Supply Assembly
  - HET & LET1 Electronics Assembly
  - LET2 Electronics Assembly
- Each Electronics Assembly is mounted in a perimeter style frame
- All “frames” when assembled together will provide a continuous RF shield for internal electronics
- Wall thickness will be minimum 1,0 mm (~40 mils) for radiation dose shielding
- Internal shielding between critical components will create separate shielded areas as necessary for proper electronics function
- Board interconnect is achieved using rigid/flex boards with built-in cables terminating to individual nanonics/microstrip connectors on mating boards
- Connections to the S/C will be via standard Micro-D connectors

EPI-Hi Electronics Enclosure (2/4)

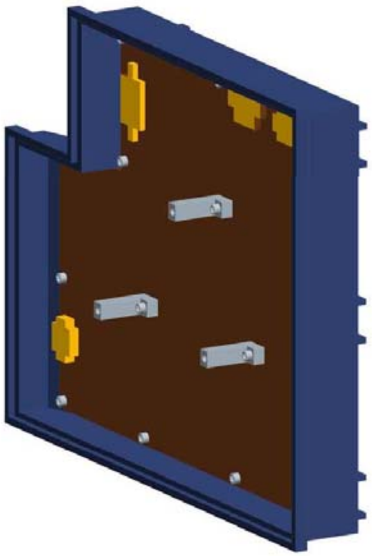


- DPU Board (mounted in one side of frame)
  - Flex connection to telescope boards
  - Flex connection to LVPS
  - S/C cmd&data connector (PCB mount)
  - Thermal harness connector (PCB mt)
  - PCB mounted to machined-in posts in chassis

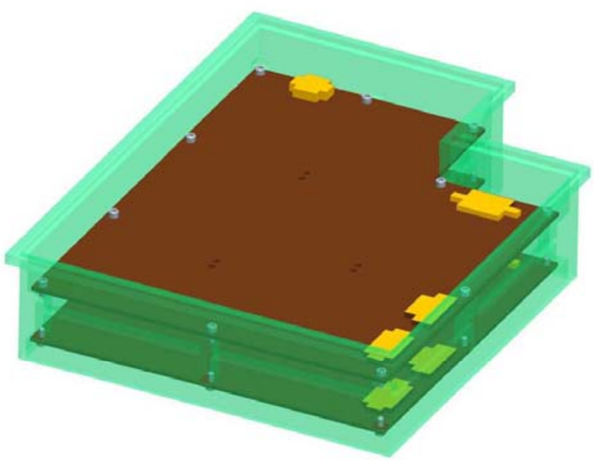


- Bias Supply Board (mounted in one side of frame)
  - Flex connection to 3 telescope boards
  - Flex connection to DPU board
  - R/F shielding
  - PCB mounted to machined-in posts in chassis

EPI-Hi Electronics Enclosure (3/4)

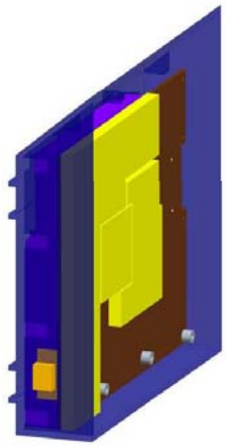


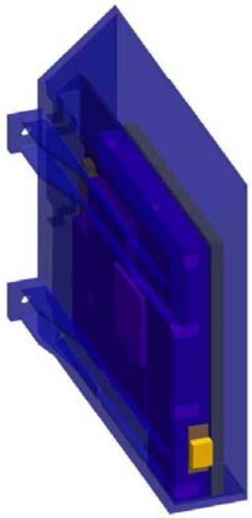
- LET2 Telescope Electronics Assembly
  - Receives flex connection from Bias Supply
  - Receives flex connection from DPU Board
  - Receives 2 flex connections from telescope
  - Housing provides feet for Instrument to enable bracket mounting



- HET & LET1 Electronics Assembly (each board)
  - Flex connection from Bias Supply Board
  - Flex connection from DPU Board
  - 2 flex connections from its telescope
  - PCB mounted to machined-in posts in chassis

EPI-Hi Electronics Enclosure (4/4)





- Low Voltage Power Supply
  - Receives flex connection from DPU Board
  - S/C power connector (PCB mount)
  - Individually shielded primary/secondary circuits top and bottom
  - Housing is tapered to avoid HET FOV
  - Housing provides feet for Instrument to enable bracket mounting
  - PCB mounted to machined-in posts in chassis

*LVPS Board provided by APL
*Chassis and shields designed/provided by GSFC

EPI-Hi Interconnect

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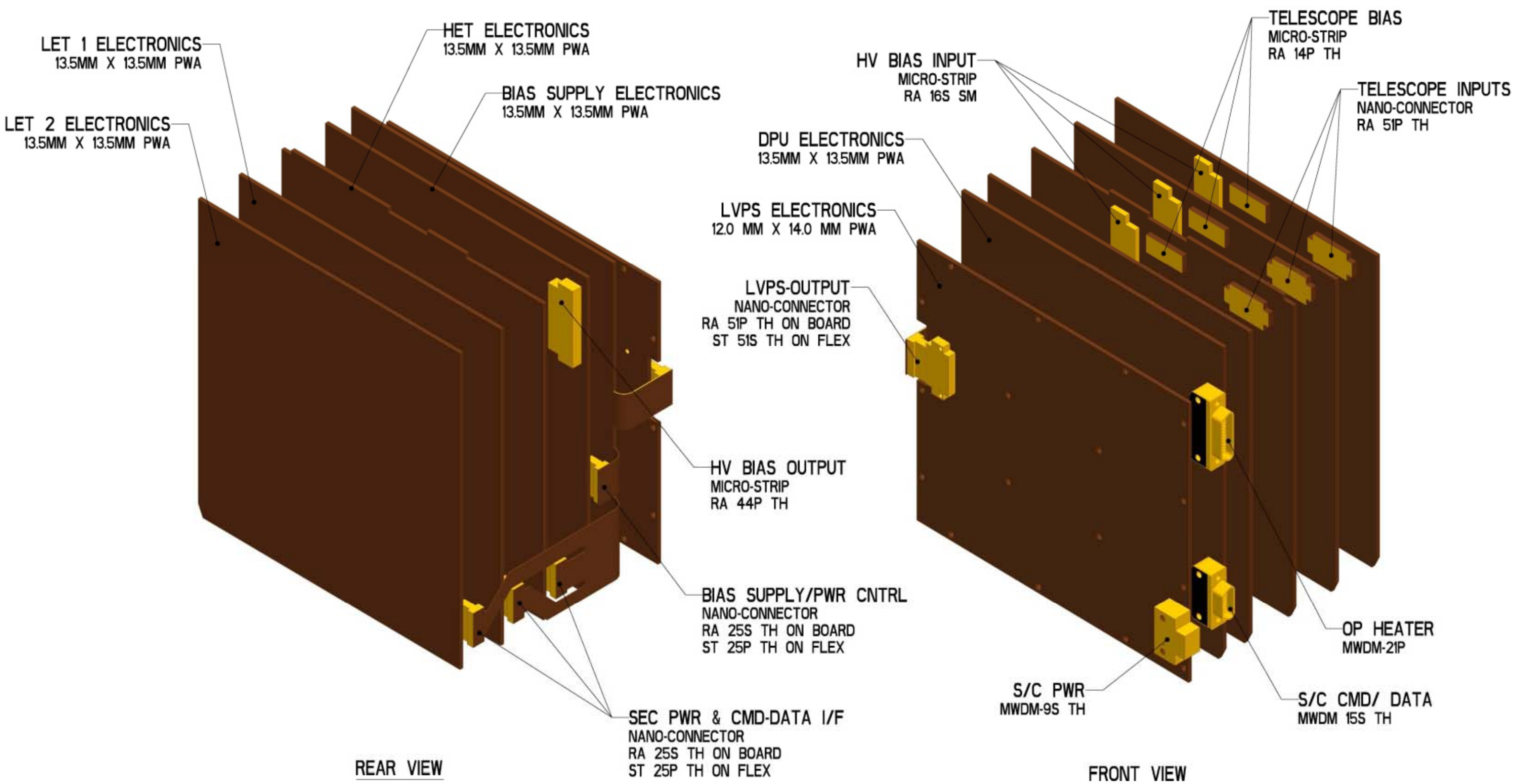
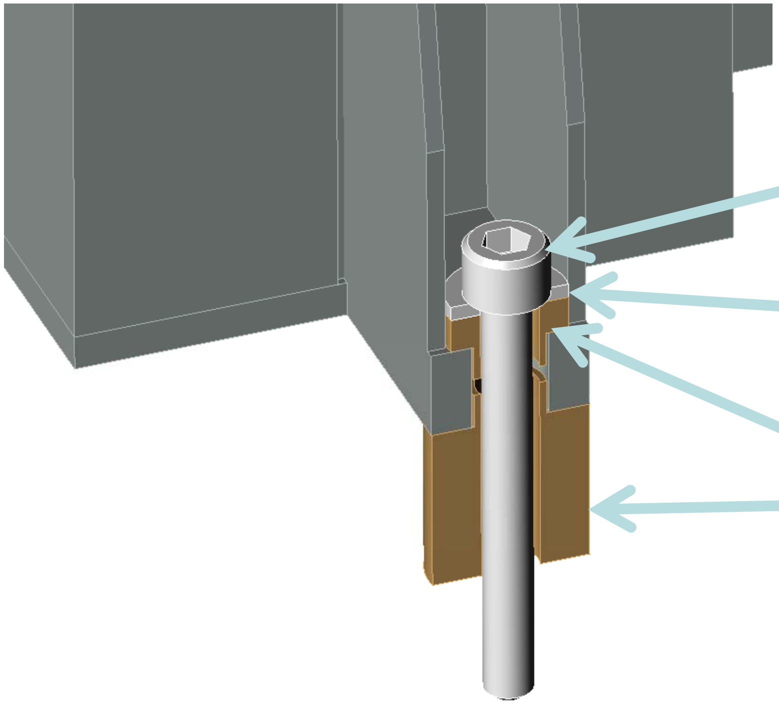


EPI-Hi Thermal Isolation

Typical Mounting Foot Showing Thermal Isolation



EPI-Hi Mount Design Requirements

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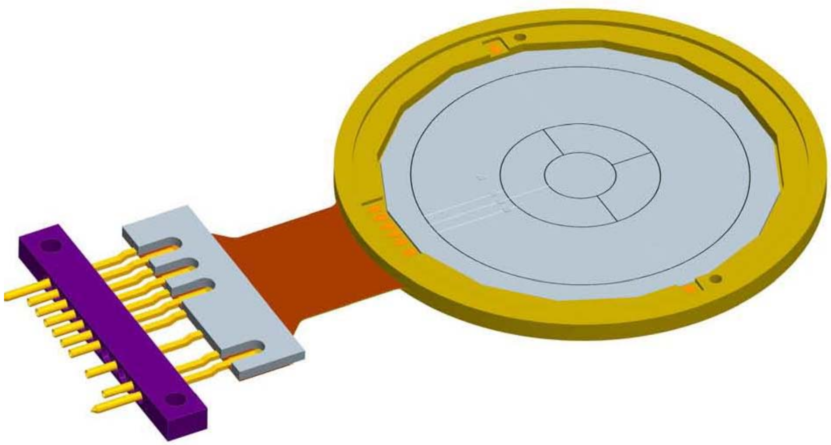
Detector Mounts

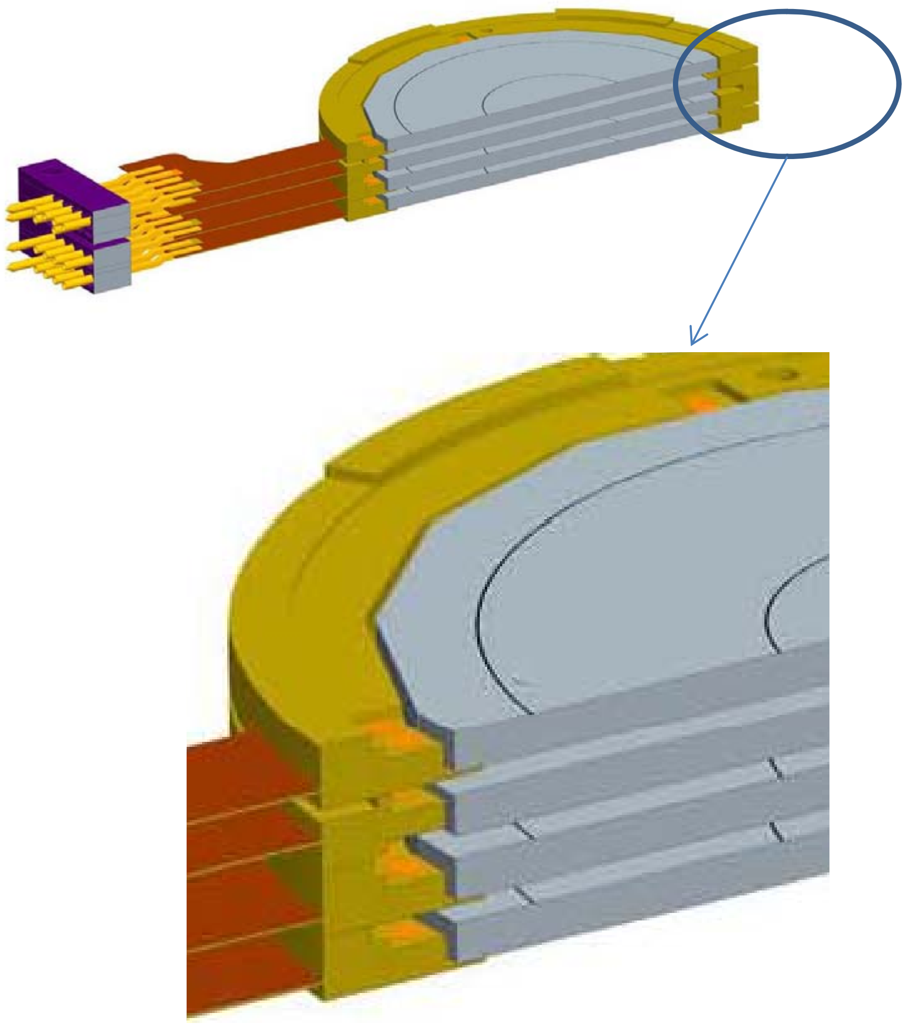
- Able to transmit signals from silicon detectors, via wire bond connections to output connector
- Allows the stacking of detectors maintaining 0,5 mm spacing surface-to-surface between thickest detectors (1,0 mm)
- Allows any detector to be stacked face-up or face-down with any other detector
- Allows for the protection of wire bonds from being crushed on either side when placed on flat surface during storage and/or test
- Provides electrical breakdown protection next to detector, when stacked, of up to 200 V differential between crown of HV wire bonds to conductive surface of opposing detector

EPI-Hi Detector Mount (1/2)



- Recessed detector shelf for silicon detector installation
- Micro-strip connector output
- Flex stiffener to rigidize the area where connector is mounted
- Alignment achieved with alignment pins and concentric stacking shelves on mount and connector
- Tolerancing for mounts will be tightly constrained, but within current CNC machining capabilities
- Detector alignment will be verified through measurement and testing on assembled flight detectors

EPI-Hi Detector Mount (2/2)

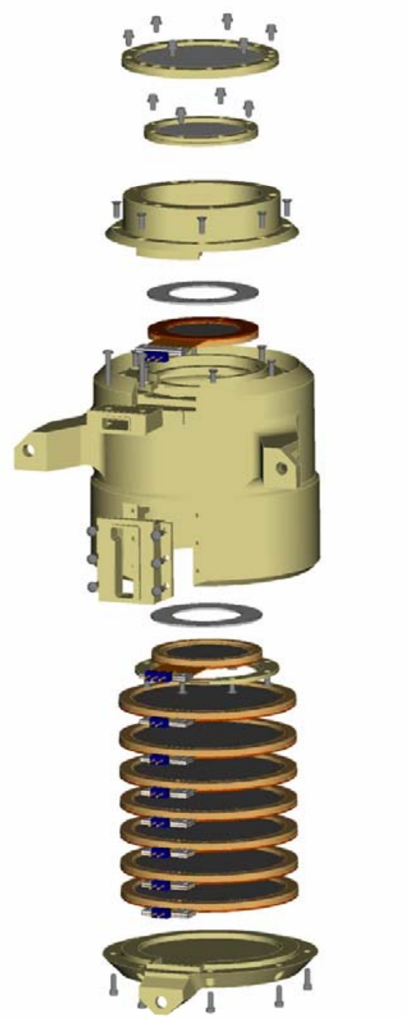


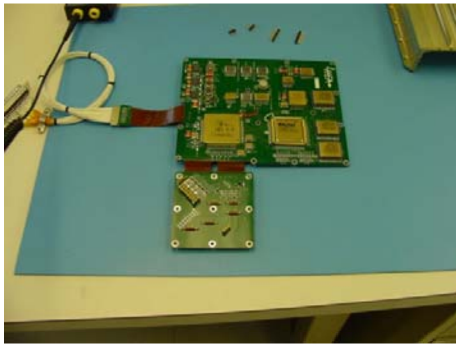
- Mount design allows stacking of detectors face-to-face, face-to-back and back-to-back while maintaining same spacing
- Mounts are spaced 1,5 mm apart when stacked allowing for 0,5 mm separation between thickest detectors
- Detector voltage ranges from ~2 V up to ~200 V
- Mounts provide adequate spacing/protection for wire bond clearance

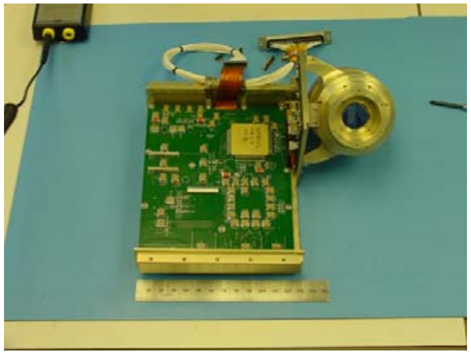
EPI-Hi Telescope Design (1/2)

- 3 telescopes comprised of silicon wafer detectors
- Provides ~6,0 mm of aluminum shielding to block unwanted particles from entering through the housing body
- Will have multiple foils for micro-meteorite/light protection
- Mounted directly to the top of the enclosure, allowing the flex interconnect cable to be routed internally to provide proper RF shielding
- Will be thermally isolated from the electronics enclosure
- Will all have red-tag covers over all aperture openings

EPI-Hi Telescope Design (2/2)



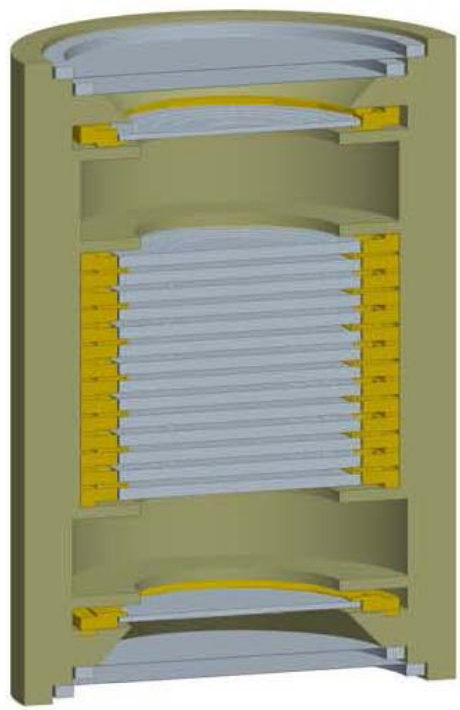




- Heritage design
- Uses alignment pins to stack detectors in telescope body
- Mounting bracket designed into telescope body
- Output signal cable will be completely enclosed in assembly, providing proper shielding

Pictures shown are of STEREO\HET telescope

EPI-Hi High Energy Telescope



- 2- ~127 µm (5 mil) Foils for micro-meteorite/light protection on each end
- Comprised of 16 silicon wafer detectors mounted in rigid-flex mounts
- The front two detectors at each end are spaced apart in order to set a 90° FOV angle

EPI-Hi Low Energy Telescopes

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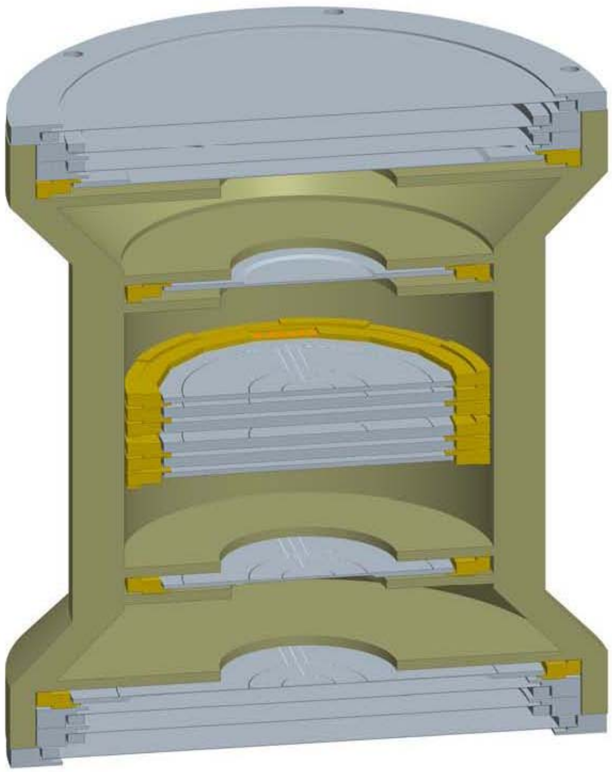
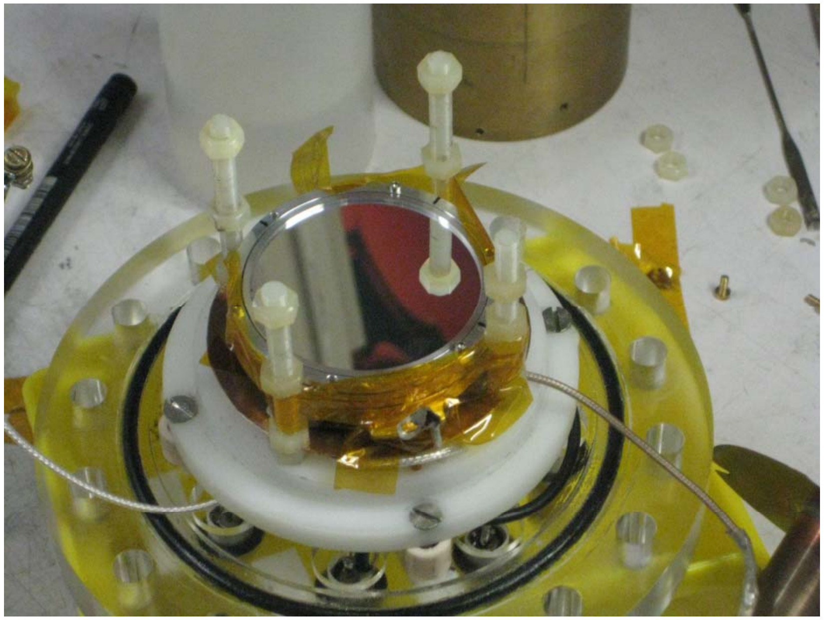


(LET1 shown)

- LET1
  - Double-ended FOV
  - 3 foils for micro-meteorite/light protection on each end
    - Outer foil to be 2 µm polyimide
    - Inner 2 foils to be 1 µm polyimide
  - Comprised of 10 silicon wafer detectors mounted in flex-rigid mounts
  - The front 3 detectors at each end are spaced apart in order to set a 90° FOV angle
- LET2
  - Single-ended FOV
  - Comprised of one half of an LET1 telescope

EPI-Hi LET Foils (1/2)

- All foils will be aluminized polyimide manufactured by the Luxel corporation
- Full sized prototype foils (1, 2, and 4 micron) have been manufactured by Luxel during Phase B
- Prototype foils have been thoroughly tested, including a high-velocity dust test at the Heidelberg dust accelerator



Stack of three Luxel foils (1 micron, 2 micron and 4 micron) in dust accelerator set up

EPI-Hi LET Foils (2/2)

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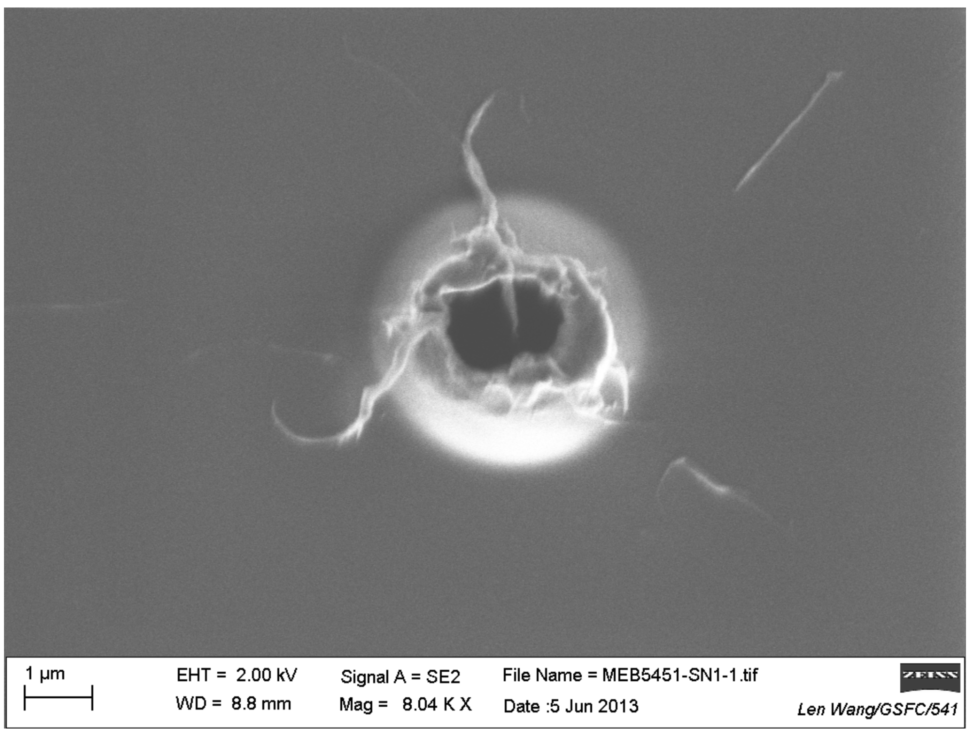
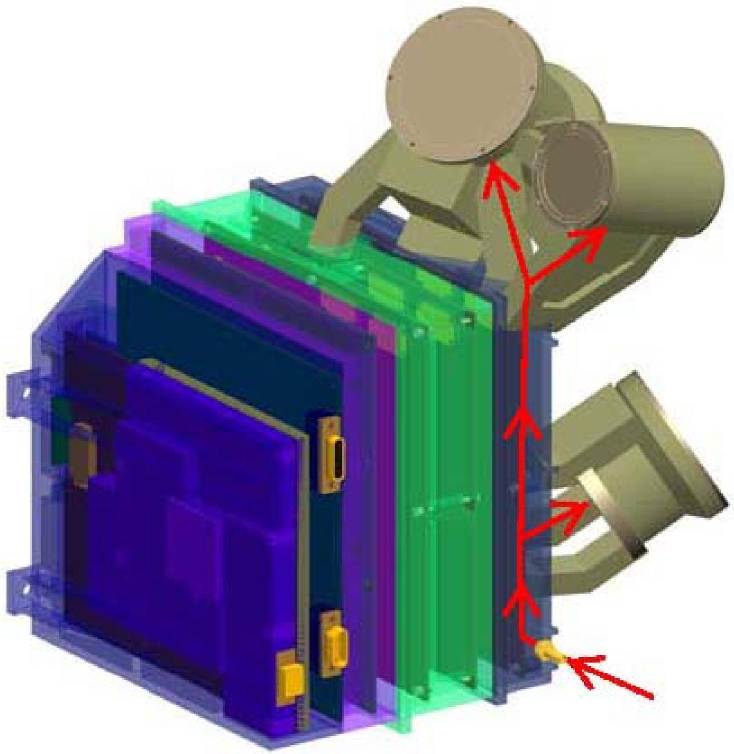
- Dust test shows that holes do not propagate
- Melted polyimide actually appears to strengthen the edge of the hole
- Thermal requirements met with aluminization on the inside surface only



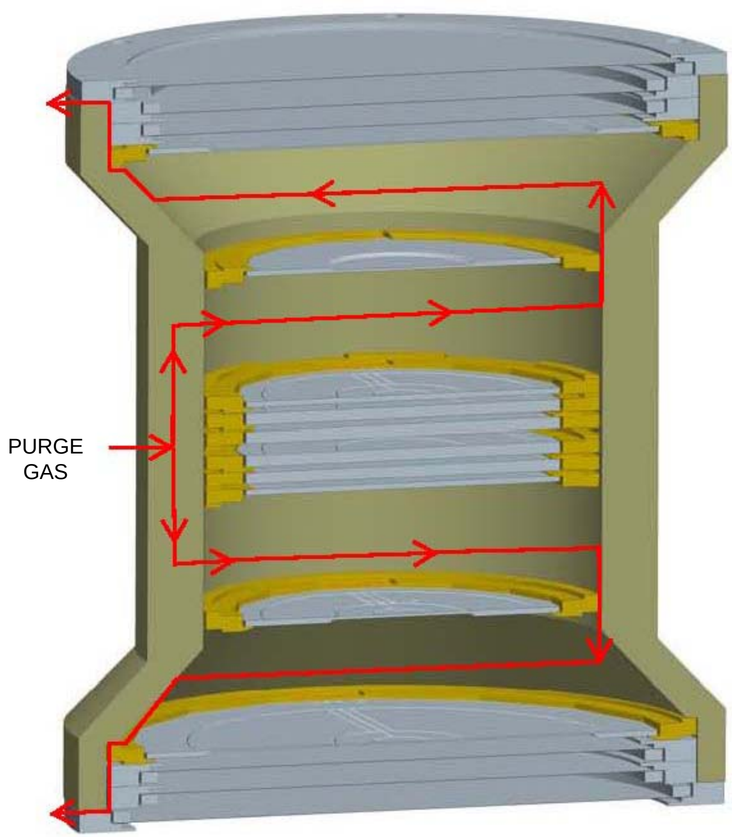
Atomic Force Microscope image from back (exit) side of dust impact in 1 micron thick polyimide

EPI-Hi Telescope Purge



- Purge established to the individual telescopes with a single purge fitting on the outside of the Instrument
- Purge distributed internally through a manifold that sends the purge gas into the center volume of each telescope

EPI-Hi Telescope Venting



- Heritage venting strategy used on several prior missions
- Purge gas enters thru housing into open center volumes
- Gas then flows outwards thru vent slots in housing shelves, detector mounts and foil rings
- Gas exits each end of the telescope thru vent slots below outer foil

EPI-Hi Assembly Flow (1/3)

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- **Electronics Assembly Flow**
  - Assembled board put into its corresponding frame
  - Electronics boards tested independently
  - Boards then interconnected and fanned out like a book for troubleshooting and further testing w/ telescopes attached
  - Purge hoses and fittings installed
  - External RF shields added before assembly is closed up
  - Frames then bolted together, and the last remaining board cabling installed/connected through access panels in frames
  - Access panel covers installed
  - Test, Test, Test

EPI-Hi Assembly Flow (2/3)

- **Telescope Assembly Flow**
  - Processed Silicon wafers placed in mounts and tested
  - Detector selections made and mount thicknesses recorded
  - Detectors stacked in telescope w/ proper shims, covers and spacers
  - Polyimide Foils installed in collimators
  - Collimators/covers installed onto telescope
  - Red Tag/Protective covers installed
  - Telescope tested w/ electronics and radioactive sources
  - Stored for integration to box

EPI-Hi Assembly Flow (3/3)

- **Telescope to Electronics Box Assembly**
  - Mating cable assembled over detector pins and secured in place
  - Closeout cover installed over cable
  - Telescope positioned over electronics, and cable fed through corresponding frame
  - Cables connected at electronics end through access panels in frames
  - Access covers installed
  - Test, Test, Test
  - Telescopes mapped by source testing/accelerator calibrations

EPI-Hi Peer Review Results

- Peer Review conducted earlier this month
- Only 3 issues noted:
  - Thin detectors and implications of environments
    - These have been considered and appropriate testing has been or will be performed
  - PCB/wall-mounted connectors
    - Appropriate measures will be taken to minimize stresses during installation
  - Whether “bolt slip” during instrument/telescope mounting will be sufficient enough to keep telescope FOVs within spec
    - This will be analyzed and verified

Summary

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- Mechanical concept verified with peer review
- All issues from peer review addressed
- Next step, the drawings for Engineering Model, already started

Solar Probe Plus

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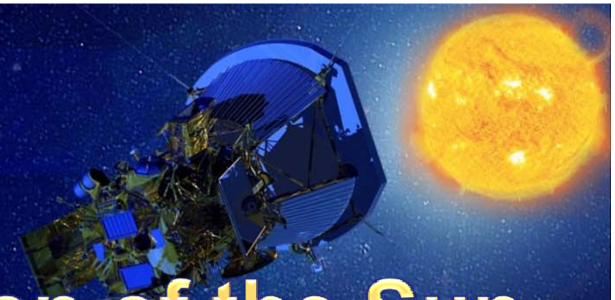


Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

ISIS Power

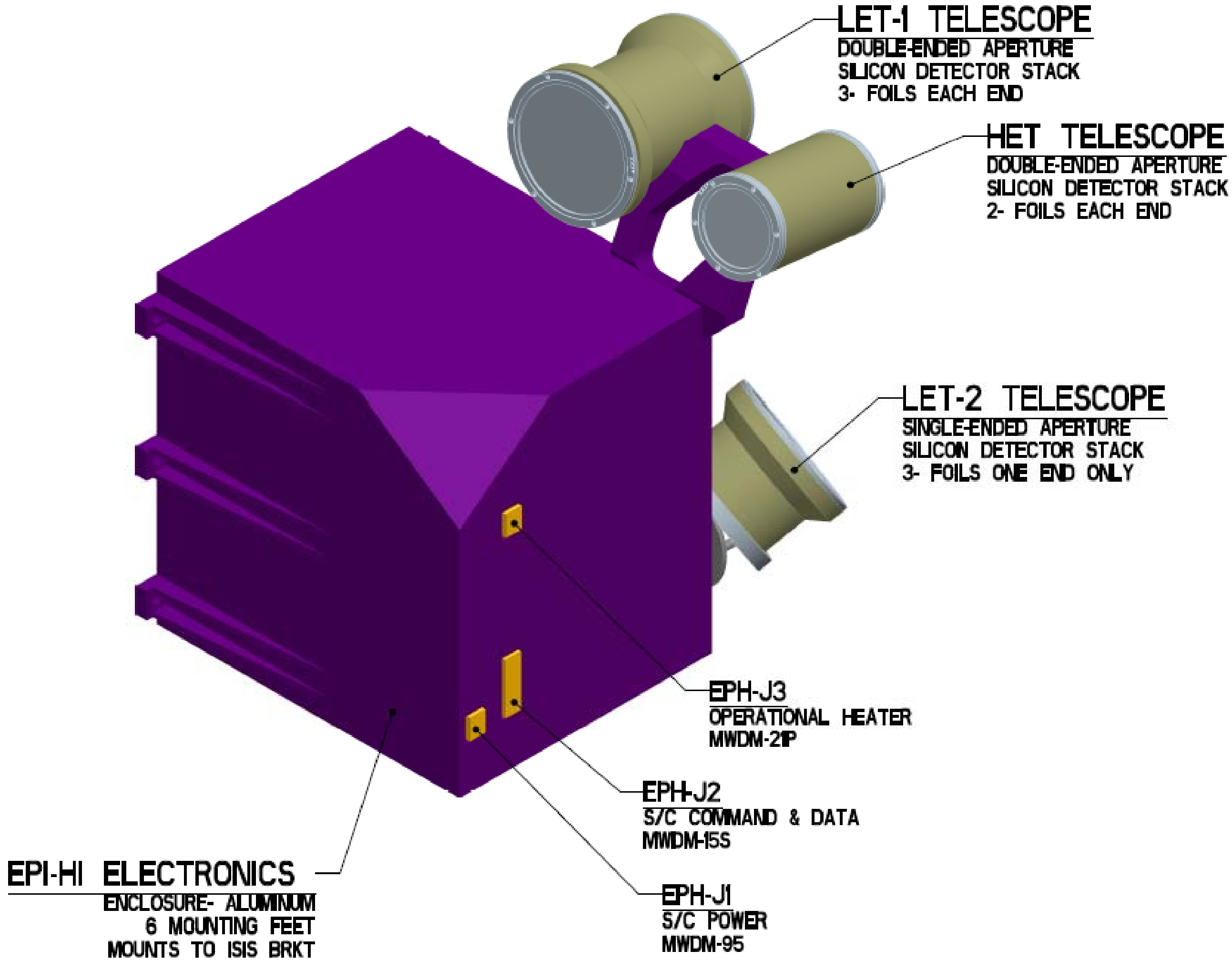
David Do

LVPS Engineer (JHU/APL)

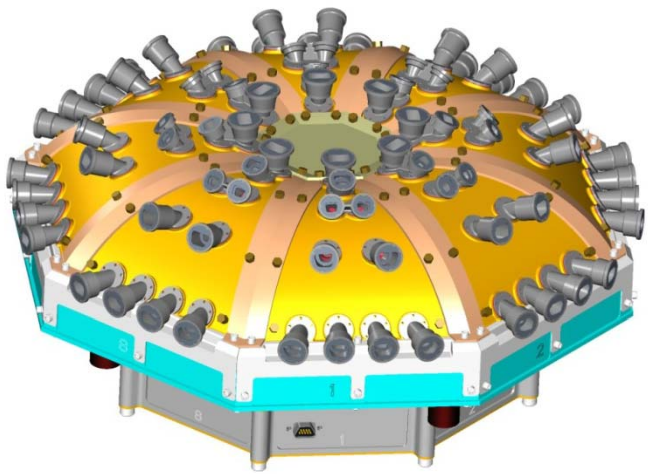
Outline

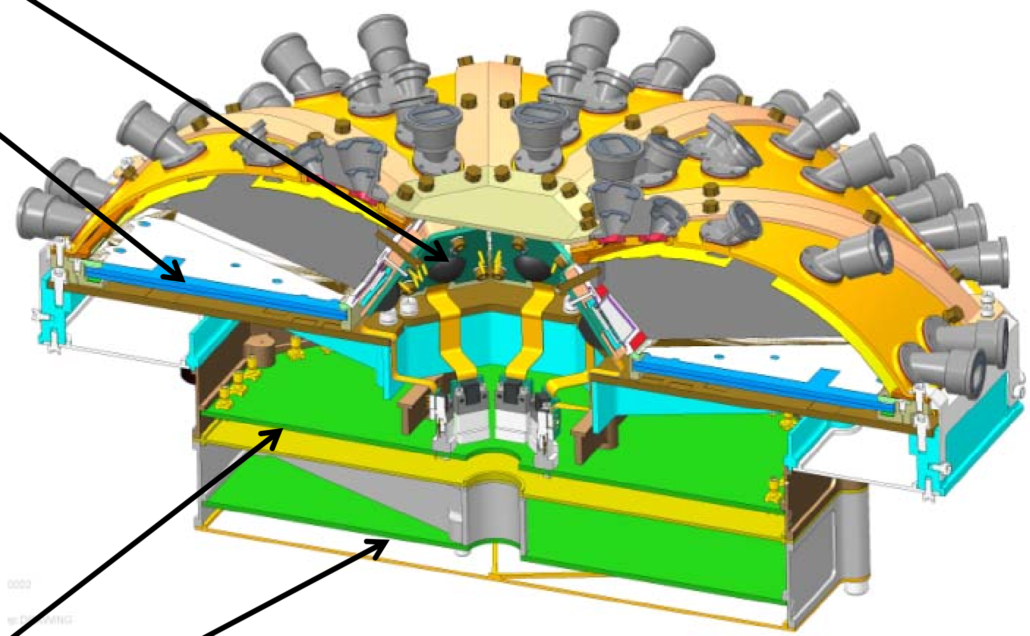
- Overview
- Requirements
- Packaging
- Analysis
- Parts
- Testing
- Status Summary
- Plan Forward
- Peer Reviews

EPI-Hi Electronics Overview

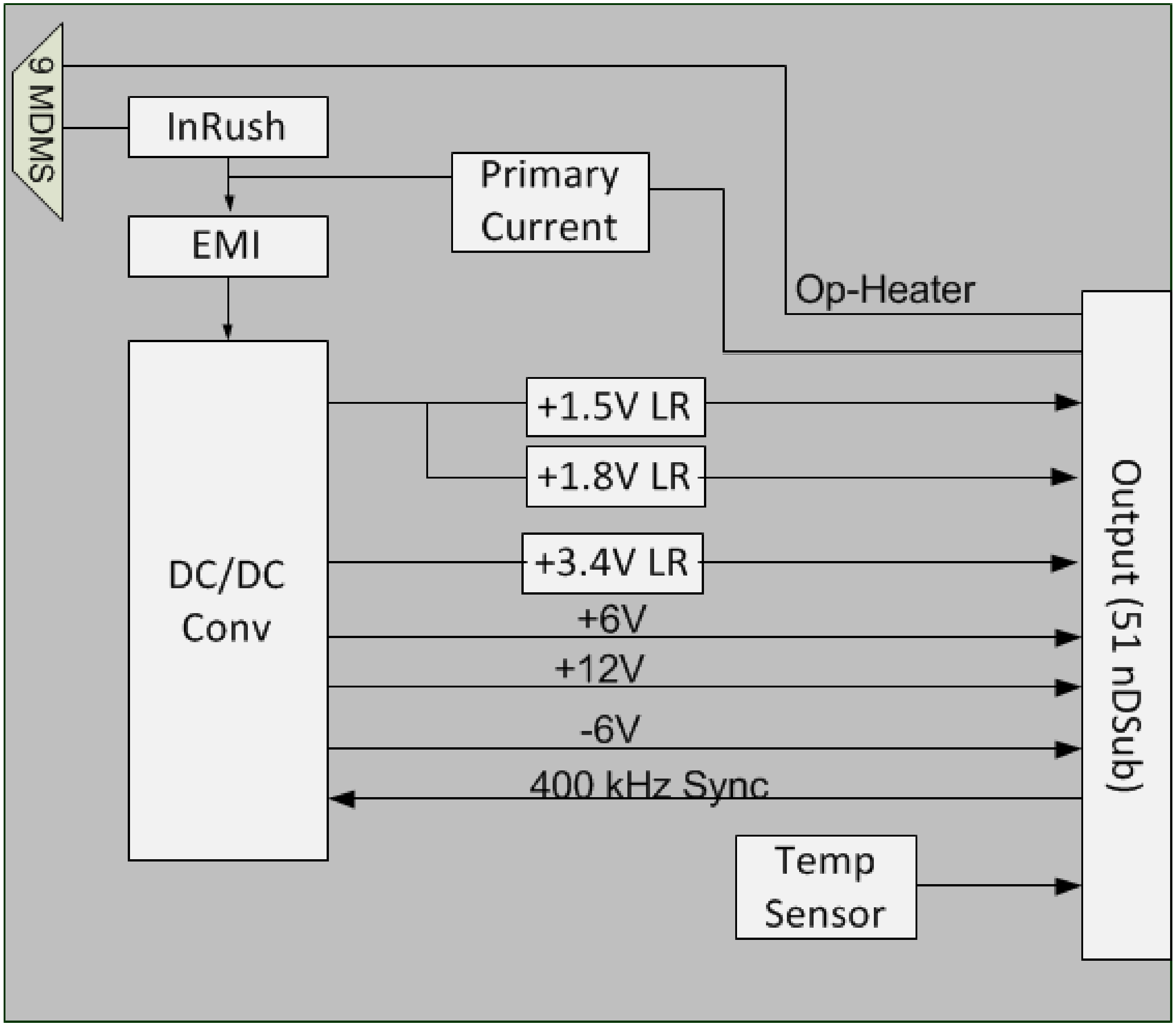


EPI-Lo Electronics Overview

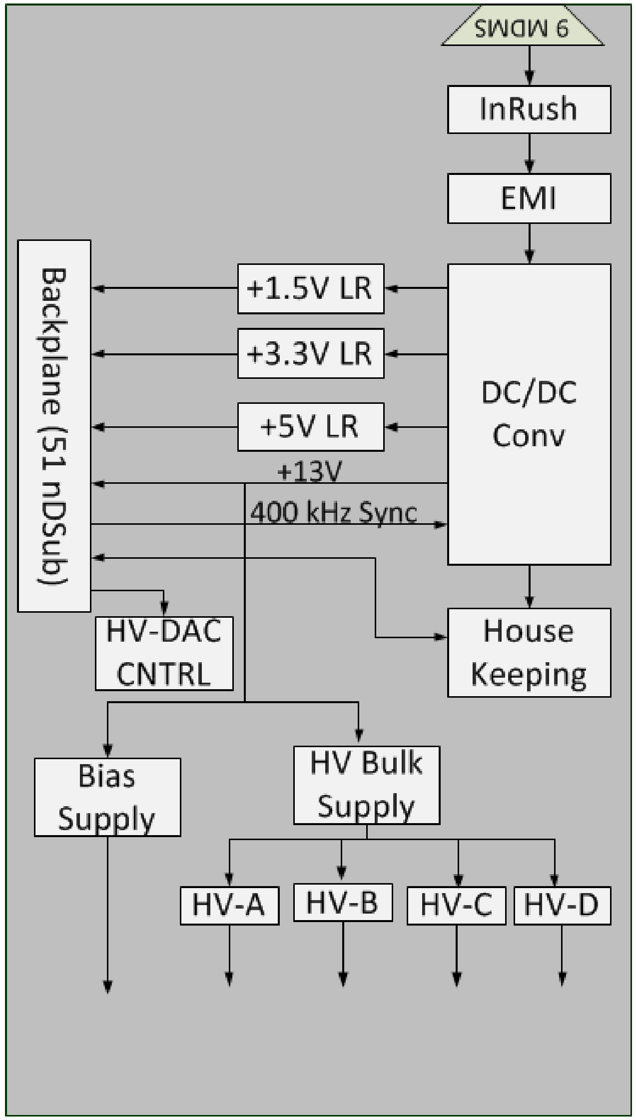




EPI-Hi Block Diagram



EPI-Lo Block Diagram



Environment Requirements

- Thermal
  - Survival is -55°C to +85°C
  - Operational is -35°C to +65°C
- Radiation
  - 25 krad (includes RDM=2 from FASTrad analysis)
  - LET > 80 MeV*cm2/mg

LVPS Major Input Requirements

- Requirements from Solar Probe Bus
- Input Specification
  - Operate over bus voltage of 22 to 35 V
  - Survive any standing or fluctuating voltage from 0 to 40 V
  - Meet EMI/EMC
  - Transformer and power inductor far away from wall
  - Power supplies crystal controlled to a frequency window centered at n*50 kHz with n>=3 and 500 ppm wide over all operating conditions and time.
  - Inrush current limit
  - Primary Secondary isolation >1 MOhm
  - Overall efficiency > 70%

Input Power Requirement

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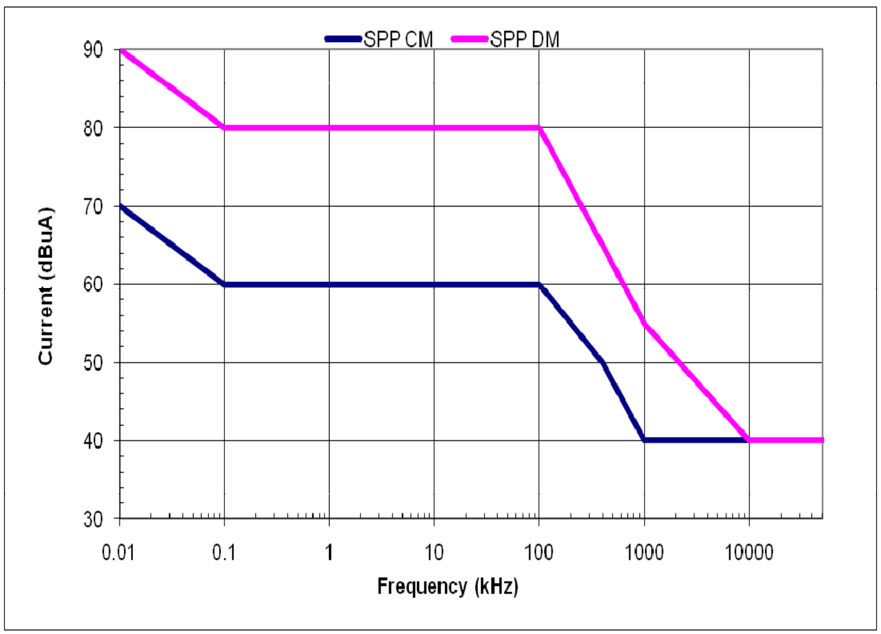
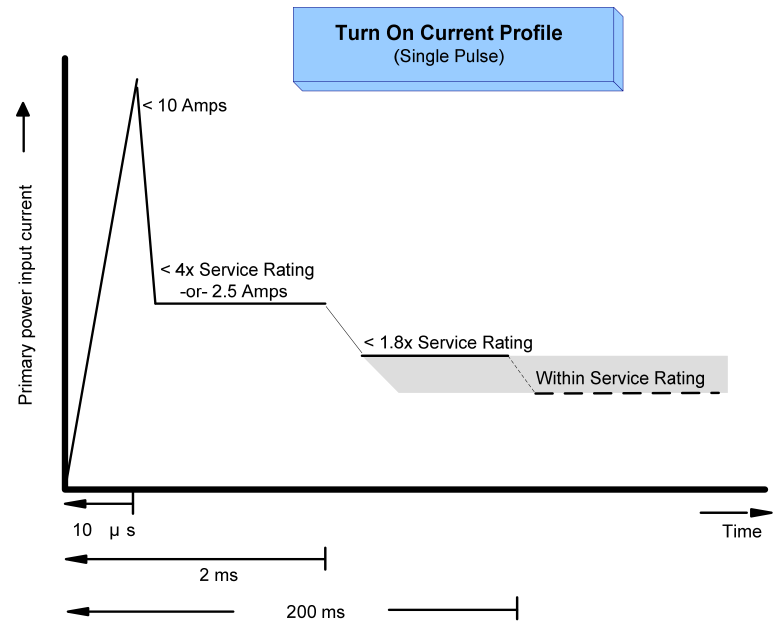
- EMI/EMC
- Inrush Current



CE01& CE03 Limit



In-Rush Current Limit

Interface

- EPI-Hi
  - Input connector: MWDM2L-9SCBRR2-.110-429
  - Output connector: 891-008-51PSBRT1T-429TH

- EPI-Lo
  - Input connector: MWDM_L-9SSMR
  - Inter board connector: 891-008-51PSBRT1T-429
  - Safing connector: 803-005-07M5-3EN
  - Bias voltage connector: 09-9001-1
  - High voltage: Pig tails

Power Topology

- Common for EPI-Hi and EPI-Lo:
  - Main converter is forward with resonant reset operating at 200 kHz. Efficiency is >80%.
  - Digital voltages are linear regulated.

- EPI-Lo HVPS:
  - Bulk high voltage is set at 3.4 kV.
  - High voltages of up to 3.3 kV are controlled through Opto-couplers.
  - Bias voltage is up to 200 V.

Output Requirements

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- EPI-Hi:
  - Generate low voltages: +12 V, +6 V, +3.3 V, +1.8 V, +1.5 V & -6 V
  - Primary input current telemetry
  - Temp sensor
  - Provide path for Op-heater voltage

- EPI-Lo:
  - Generate low voltages: +13 V, +5 V, +3.3 V and +1.5 V
  - House keeping through ADC for primary input current, temperature, output currents and output voltages
  - Generate high voltages and bias voltages to sensors
  - Hard and soft high voltage safing

EPI-Hi Output Requirements

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	Output Regulation	Min Load (mA)	Nom Load (mA)	Max Load (mA)
+1.53V	±2.5%	50	100	150
+1.82V	±2.5%	20	40	60
+3.41V	±2.5%	145	287	430
+6V	±7%	79	338	500
+12V	±7%	8	16	64
-6V	±5%	6	12.6	19

EPI-Lo Output Requirement

Solar Probe Plus
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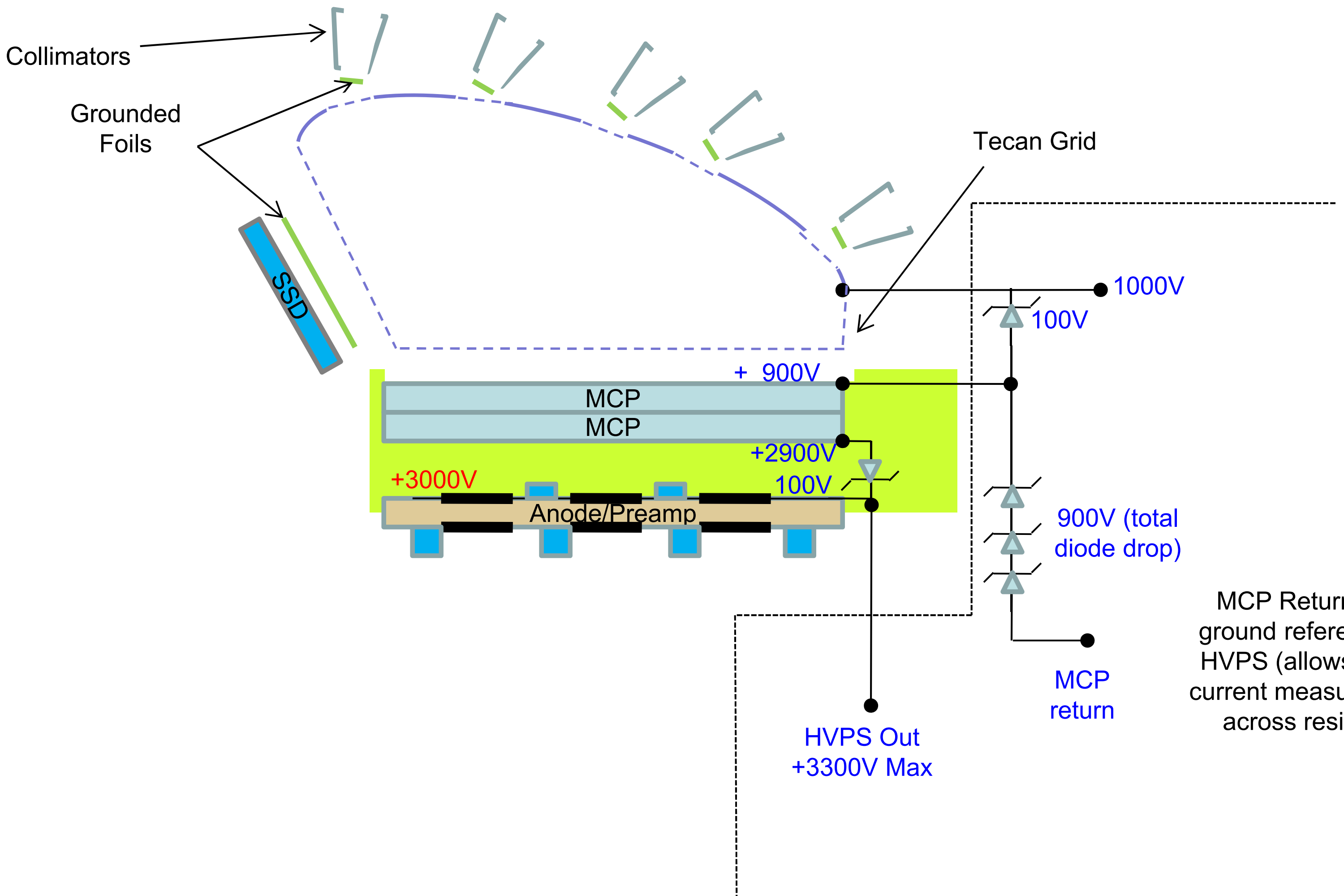
	Outputs Regulation	Min Load (mA)	Nom Load (mA)	Max Load (mA)
+1.5V	±3%	45	80	200
+3.3V	±3%	150	200	460
+5V	±5%	115	135	160
+13V	±5%	10	63	90

Sensor Voltages



MCP Return is a ground reference at HVPS (allows MCP current measurement across resistor)

EPI-Lo HVPS Requirements

Solar Probe Plus
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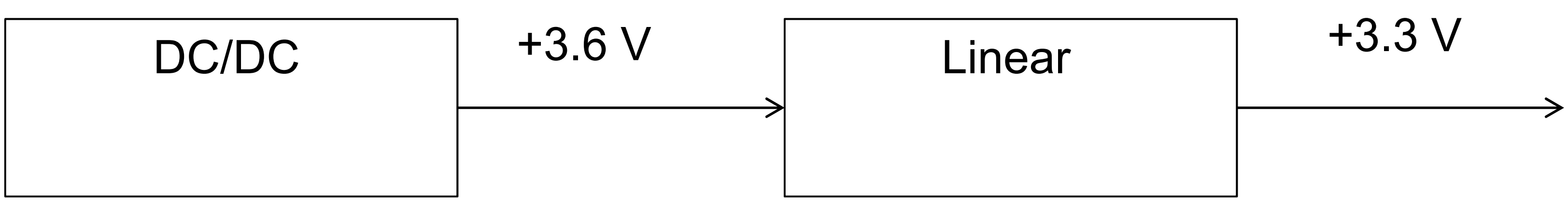
	Max Output Voltage (V)	Min Load (uA)	Max Load (uA)
Bias	200	0	20
Bulk	3400	0	250
HVPS	3300	0	50
Grid	1000	0	1
MCP	900	0	50

HVPS Current Limit

- Control range: 0 uA to 200 uA
- Control granularity: <1 uA
- Response time: <1 ms
- LVPS sends over-current signal to event board
- Event board turns off high voltage output and resets DAC

LVDS Fault Mitigation

- Transformer: primary and +3.3 V winding is well isolated by +13 V and +6 V windings
- +3.3 V is linear regulated from +3.6 V
- Linear pass transistor is rated for 100 V
- Worse case fault LVPS goes to full duty cycle, which results in +7.5 V output on +3.6 V
- Preliminary thermal analysis shows 33°C rise in linear regulator



Worst Case Thermal Analysis

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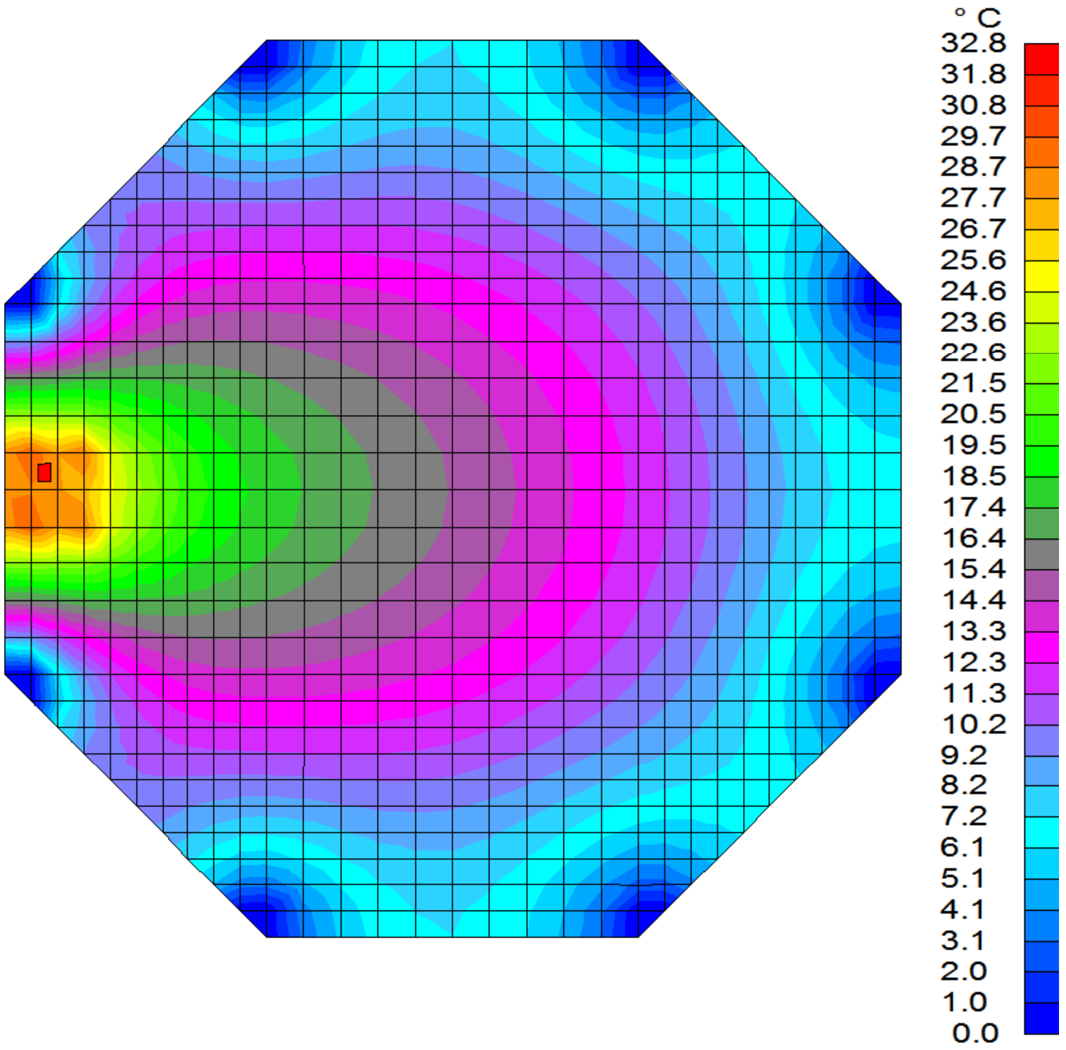
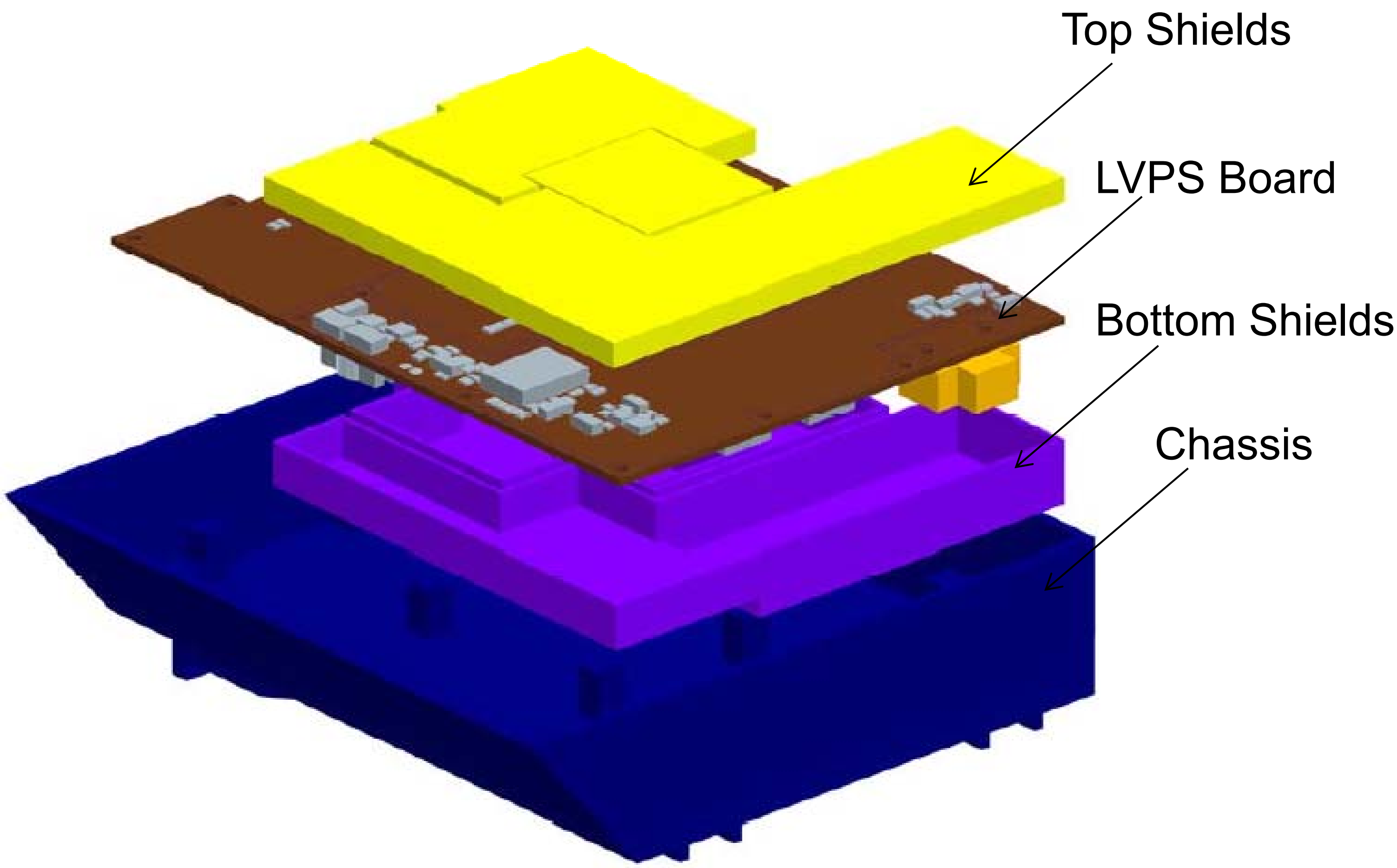
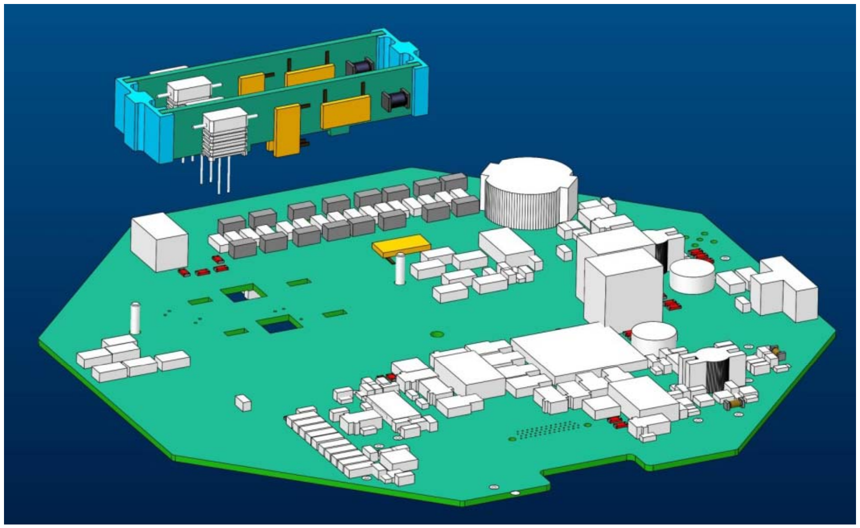
- 6 oz Cu in PWB
- Thermal contours plot shown with 8 W total power dissipation
- Actual power dissipation <2.5 W
- TO-254 temps for 6 oz
  - Junction = 32.8°C
  - Case = 13.2°C

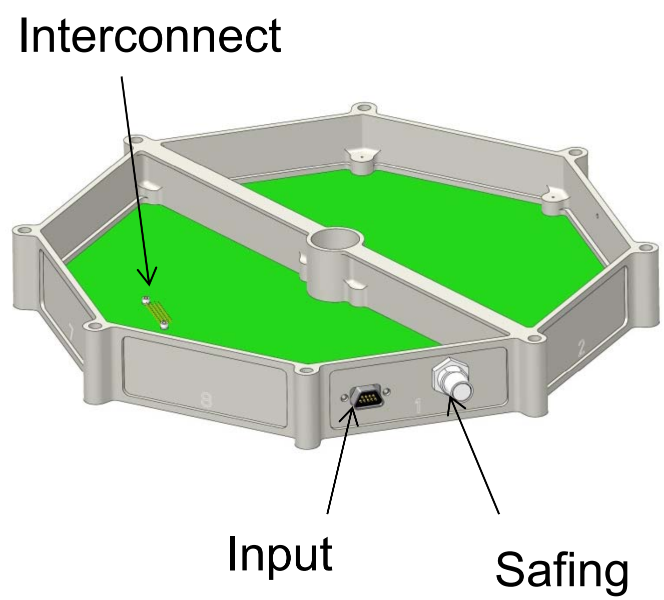


EPI-Hi Package



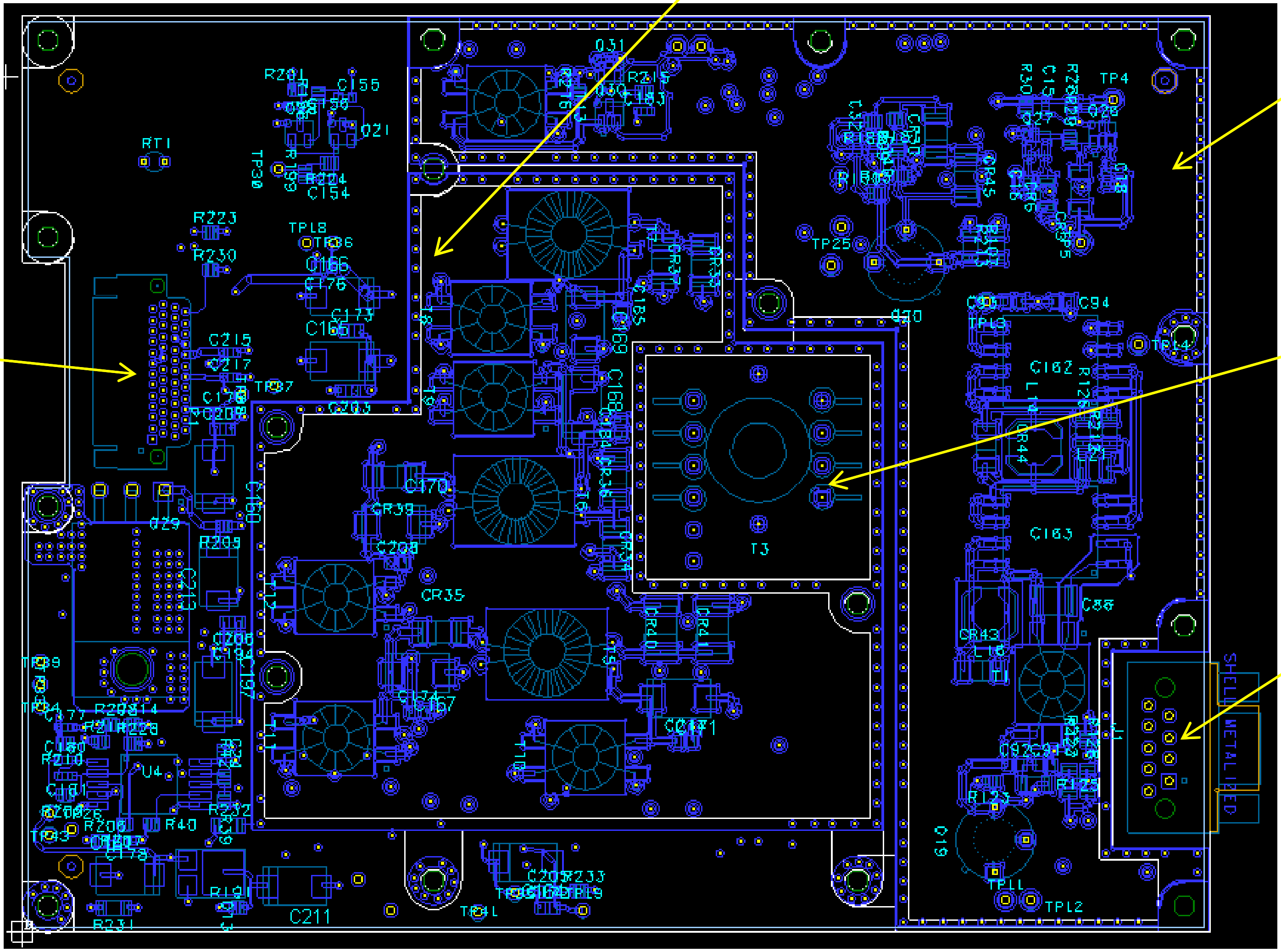
EPI-Lo Packaging



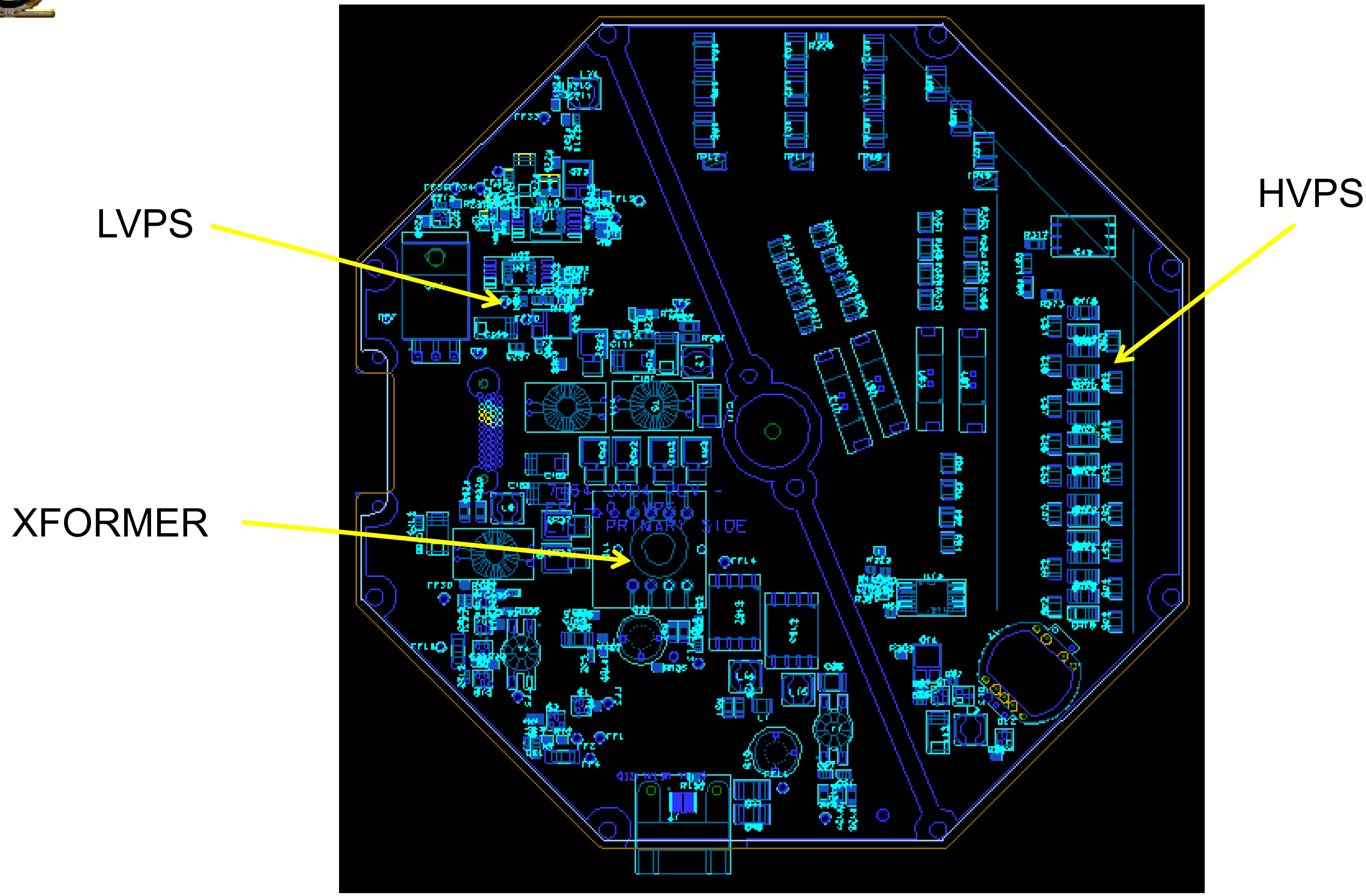


- Packaged in octagon frame
- 2 daughter boards for high voltages
- Stiffener goes across the board
- Power dissipation is estimated <2.5 W

EPI-Hi Board Layout



EPI-Lo Board Placement



Nominal Output Regulation and Efficiency

	Load(A)	Regulation(V)	Power(W)
+1.53V	0.14	1.505	0.2107
+3.41V	0.287	3.69*	0.9758
+6V	0.338	5.97	2.01786
+12V	0.016	11.98	0.19168
-6V	0.012	5.95	0.0714
input	0.159	28	4.452
			78%

- *+3.41V shown pre-regulated. Efficiency is calculated using +3.4 V.
- +3.41 V and +1.82V linear regulator have same design as +1.53 V.

Analysis

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- Preliminary EMI completed
- WCA for digital voltages regulation = ±2.3%

Voltage Regulation WCA Method and Assumptions

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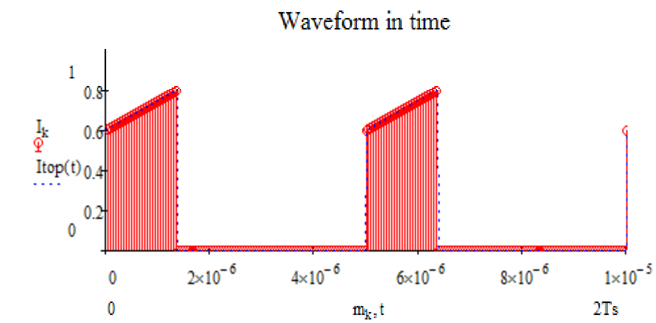
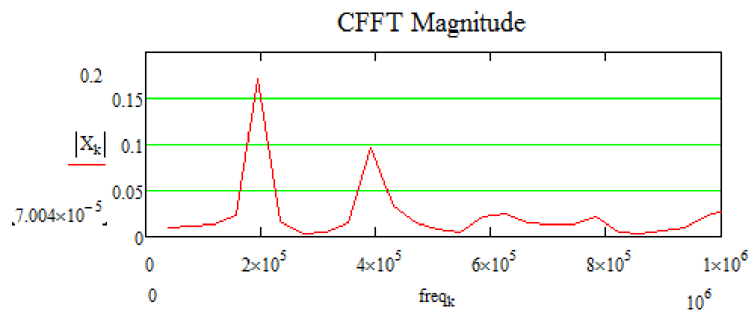
- WCA Method
  - Extreme Value Analysis in Mathcad
- Temperature Range
  - -35°C to + 65°C operational
- Resistors Variation
  - K resistors are 100 ppm (0.8%) + 1% initial tolerance + 2% Aging ≈ 4%
  - E resistors are 25 ppm (0.2%) + 0.1% initial tolerance + 1% Aging ≈ 1.3%
  - Z resistor are 5ppm(0.04%)+ 0.01% initial tolerance 0.16% Aging ≈ 0.2%
- RH1078
  - 100 Krad data from datasheet
- PWM5302S
  - 100 Krad data from datasheet

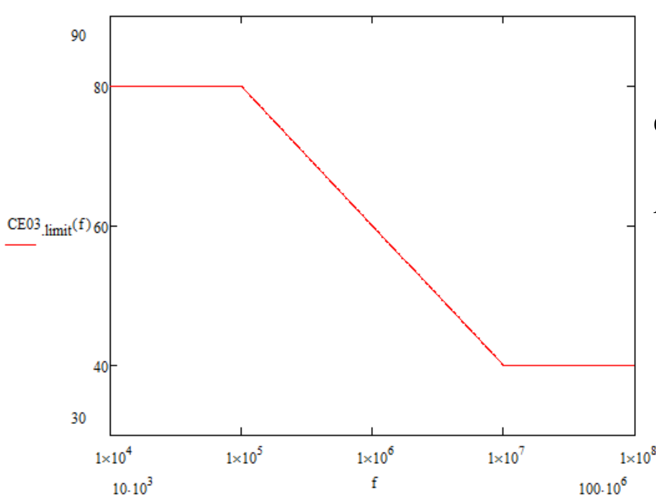
EPI-Lo EMI Analysis



Primary Current in Discrete Time



Primary Current in CFFT

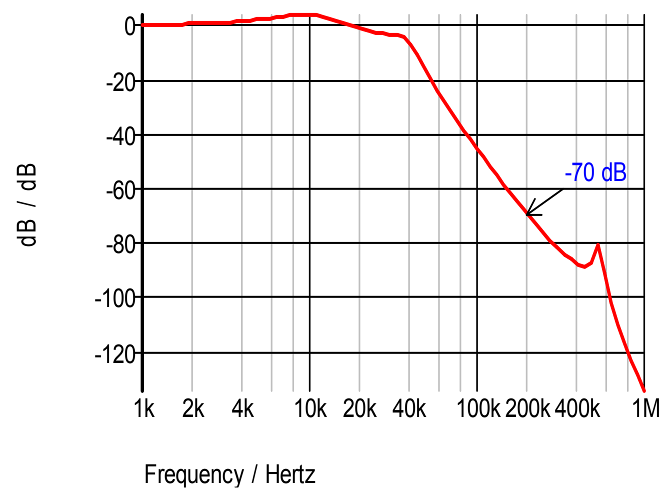


CE03 Limit

$$Iin_{dB} := 20\log\left(\frac{peak}{\mu A}\right) = 104.725$$

$$CE03_{limit}(200kHz) = 73.979$$

$$Aten := Iin_{dB} - CE03_{limit}\left(\frac{1}{Ts}\right) = 30.746$$



EMI Filter Attenuation

Parts

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- All parts are rad-hard to >100 krad
- Parts submitted to PCB. No issues expected.

Part Number	Description	Manufacture
PWM3052S	PWM IC	Aeroflex
ADC128S102QML	12 Bit-ADC	TI
RH1009MW	2.5V Reference	Linear Tech
RH1078MW	Low power Opamp	Linear Tech
M49470X01335KBB	Stacked 3.3uF Ceramic	Presidio
IRHNM57110	100V N Channel FET	IR
JANSR1N5811US	100V Schottky Diode	Microsemi
JANSR2N2222AUB	NPN transistor	Microsemi
JANSR2N3501UB	NPN transistor	Microsemi
66353	High voltage opto	Micropac
ADCMP600	Comparator	Analog Devices

Plans for Testing

- Follows APL manufacturing flow
- Significant highlights:
  - Populate Passive Components with Automatic Measurement.
  - Populate Actives and Install Known Tailors or Tailor Flags
  - Install into Flight Frame
  - Execute Test Procedure to Test and Tailor Entire Board
  - ESS Testing
  - Execute Functional Test Procedure
  - Photograph and Conformal Coat
  - Execute Test Procedure to Calibrate and Characterize Board (over temperature)
  - Release to Next Assembly

Status Summary

- EPI-Hi
  - EM PWB is being fabricated
- EPI-Lo
  - EM is in placement and layout phase

Plan Forward

- EPI-Hi
  - Complete testing EM
  - Fabricate flight
- EPI-Lo
  - Fabricate and complete testing EM
  - Fabricate flight
- Finalize all documentation and procedures for flight build
- Build, tailor, calibrate, and qualify flight units

Peer Reviews

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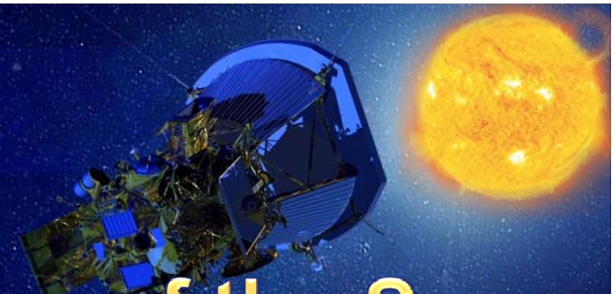
- EPI-Hi LVPS: May 2013, 27 AIs all closed SRI-13-026
- EPI-Lo Power: Aug 2013, 5 AIs all closed SRI-13-029
- Major Action Items:
  - EPI-Hi:
    - Shielding over switching circuits
    - Output loads
    - Output regulations
  - EPI-Lo:
    - MCP voltage accuracy
    - LVDS fault mitigation
    - Bias Voltage Zener diode protection



Solar Probe Plus

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Integrated Science Investigation of the Sun Energetic Particles

NASA • GSFC • JPL • Caltech • SwRI • APL • UNH • U-Az • U-Del

ISIS

Solar Probe Plus

ENERGETIC PARTICLES

Preliminary Design Review

05 – 06 NOV 2013

EMI / EMC

Reid Gurnee

EPI-Lo SE (JHU/APL)

Outline

- EMC Design Considerations
- EMC Grounding
- EMC Testing
- Heritage CE performance
- Summary

EMC Design Considerations (1/3)

- Power supplies crystal controlled to a frequency window centered at n*50 kHz with n>=3 and 500 ppm wide over all operating conditions and time.
  - The LVPS is synchronized to 200 kHz by a 400 kHz clock provided by the digital boards.
  - EPI-Hi has 58.8 MHz oscillator and EPI-Lo has 40 MHz oscillator. Both evenly divide to 400 kHz.
- Transformers and big inductors are placed as far from Box walls as possible.
- Stable currents to minimize changes in Magnetic Emissions
- Control all current paths inside your box to minimize loop area. Cannot use a solid return plane if a trace is the source. Any circuit over 100 milliamps AC or 1 amp DC will be analyzed.
  - LVPS has AC currents on primary transformer that exceed 100 mA.
  - EPI-Hi op-heaters can draw only about 30 mA @ 33V.

EMC Design Considerations (2/3)

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- All Cables outside the metal box must be twisted shielded with 360° shields terminated to the Box with less than 20 mOhms.
  - EPI-Lo has no external cables.
  - EPI-Hi has an external thermal harness for thermal hardware mounted on 3 telescopes and E-box and will meet these requirements.
- EMI Backshells not required by EME but shield must cover connector fully.
  - EPI-Lo and EPI-Hi boxes designed to accommodate backshells for S/C data and power connectors.
- Connector shell to Box resistance before mated < 5 mOhms
- Any cable outside the spacecraft body attached to a device must have either 13 mils shielding or DDD first circuit protection.
  - EPI-Lo has no external cables.
  - EPI-Hi's external thermal harness will have adequate shielding.
  - S/C data / power cable shielding 8 mils (TBR). S/C interfaces designed to handle DDD.

EMC Design Considerations (3/3)

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- All use of Magnetic Materials (Nickel, 400 Series CRSS, etc) must be identified and approved by the project. High Phosphor Nickel coating is allowed because it is not magnetic.
  - EPI-Lo has Nickel grids. Working with Project to develop magnetic mitigation plan.
  - EPI-Hi has no major Nickel parts, only Ni-plated connectors.

EMC Grounding

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- Primary power supplies isolated by >1 MΩ.
- Secondary power supply returns tied to chassis with <2.5 mΩ in only the Box using the power.
- Grounding Diagrams will show all chassis grounds, primary and secondary power feeds and returns, shields, and signals with returns.
- ID all connector pins with first circuits.
- Connectors unused in flight shall have a conductive cover with less that 10 mΩ from cover to Box chassis.
- "Conductive" Box exterior
  - Exterior on EPI-Lo will be MLI StaMet outer finish, and Z93C55 white conductive paint.
  - Exterior on EPI-Hi will be MLI and radiator surfaces.
- Box design must be at least tongue and groove. EMI gaskets on flat joints is acceptable.
  - EPI-Lo utilizes overlap joints and copper tape as necessary to seal seams.
  - EPI-Hi enclosure uses overlap joints, light-tight by design, and copper tape as necessary.

EMC Testing

- Early Testing (Breadboard, Card level, Engineering Model (EM)) can identify a problem when it can still be fixed without major schedule slip.
- Doing conducted emissions (CE) can find most issues.
- Initial CE test on LVPS will occur in Q1 2014. EPI-Hi and EPI-Lo will test EM units for CE in Q4 2014.

Required Tests:	Bonding & Isolation
Conducted Emissions:	CE-01, CE-02, CE-07
Conducted Susceptibility:	CS-01, CS-02, CS-06
Radiated Emissions:	RE-01, RE-02, Mag Sniff
Radiated Susceptibility:	RS-03, ESD

LVPS CE Predicted Performance

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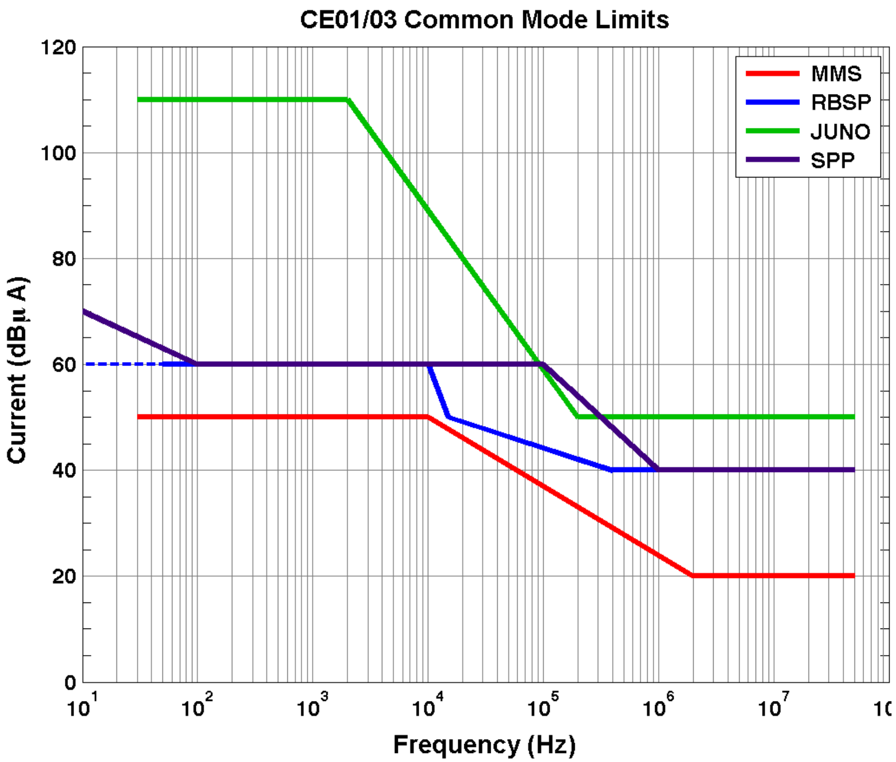
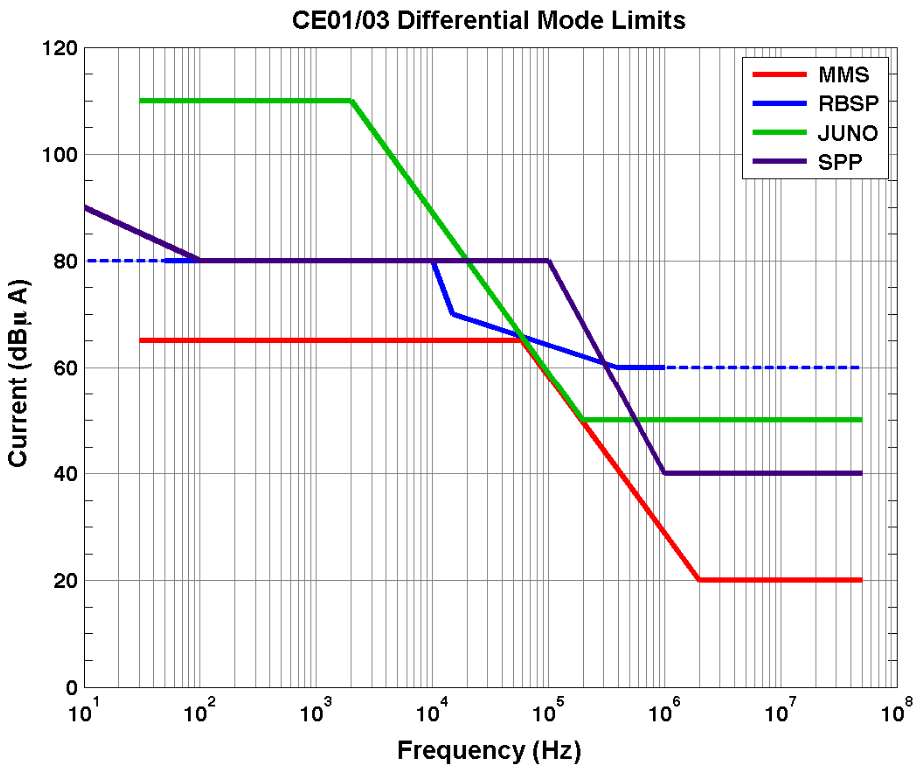
Based on heritage supply that meets MMS requirements





Summary

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- EMI/EMC design considerations being followed
- No CE issues expected
  - Early testing will allow time to mitigate
- EPI-Lo Ni grid concerns mitigated with careful handling, use of non-magnetic tools, and testing

Solar Probe Plus

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Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

ISIS Structural

Nick Alexander

ISIS Mechanical Engineer (SwRI)

Outline

- EPI-Hi Structural Analysis*
  - Requirements
  - FEM/Boundary Conditions
  - Modal Results
  - Stress Results

- ISIS Bracket Structural Analysis
  - Mechanical design/structural requirements
  - ISIS overall mechanical configuration
  - FEM/Boundary Conditions
  - Modal Results
  - Stress Results
  - Structural design margins and plans for strength verification

* EPI-Lo structural analysis shown in EPI-Lo mechanical presentation

EPI-Hi Structural Analysis Requirements

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- Design Requirements taken from SPP Environmental Design and Test Requirements Document (EDTRD), Document 7434-9039 Revision –
  - A structural analysis shall be completed to verify the component structural integrity.
  - Instrument minimum resonant frequency shall be greater than 80 Hz.
  - PWAs shall be designed to have a first structural resonance frequency above 150 Hz.
  - All bus-mounted components and subsystems shall be designed to the quasi-static accelerations derived from the MAC (Mass Acceleration Curve).

EPI-Hi Environments

Random Vibration ASD Specifications

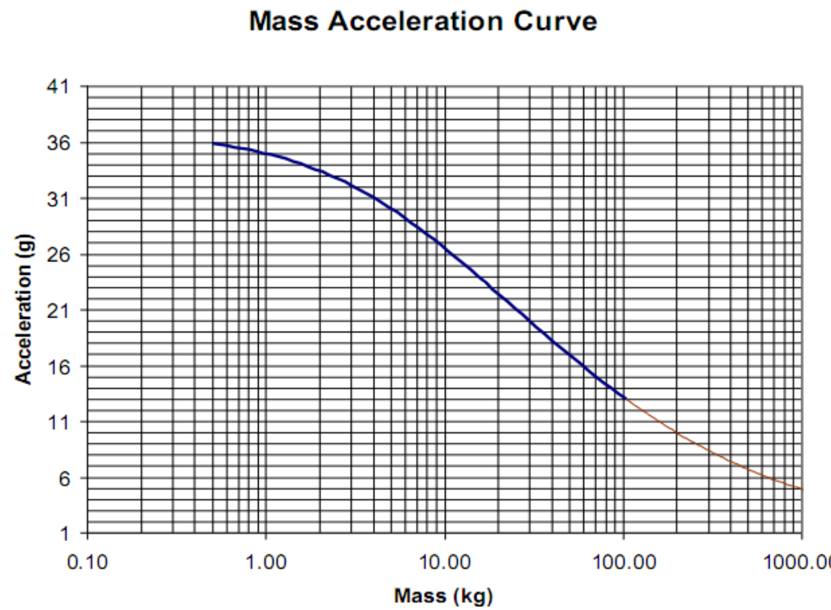
Table 4-8. Side Panels Mounted Components & Subsystems Normal To Panel

Frequency (Hz)	Qualification (G^2/Hz)	Protoflight (G^2/Hz)	Acceptance (G^2/Hz)
20	0.01	0.01	0.01
60	1.25	1.25	0.63
200	1.25	1.25	0.63
350	0.04	0.04	0.04
500	0.04	0.04	0.04
2000	0.01	0.01	0.01
Overall Grms	16.4	16.4	12.6
Duration (mins)	2	1	1

Table 4-9. Side Panels Mounted Components & Subsystems Lateral To Panel

Frequency (Hz)	Qualification (G^2/Hz)	Protoflight (G^2/Hz)	Acceptance (G^2/Hz)
20	0.01	0.01	0.01
35	0.04	0.04	0.04
500	0.04	0.04	0.04
2000	0.01	0.01	0.01
Overall Grms	6.8	6.8	6.8
Duration (mins)	2	1	1

EPI-HI: Y-direction is Normal to Panel;
X & Z-directions are Lateral to Panel



EPI-HI: Mass with uncertainty=4.0 kg
MAC: for 4.0 kg, Acceleration=31 g

Analysis Employs Qualification Level Loads

EPI-Hi Factors of Safety

- The tabulated factors of safety are applied to the limit loads for quasi-static and sine vibration loads.
- For random vibration, an additional factor of 1.28 is added to the factors of safety for ultimate and yield.
- For random vibration analysis, the 3-sigma RMS response from the finite element analysis is employed to calculate margins.
- Margins of safety calculated using equation on right:

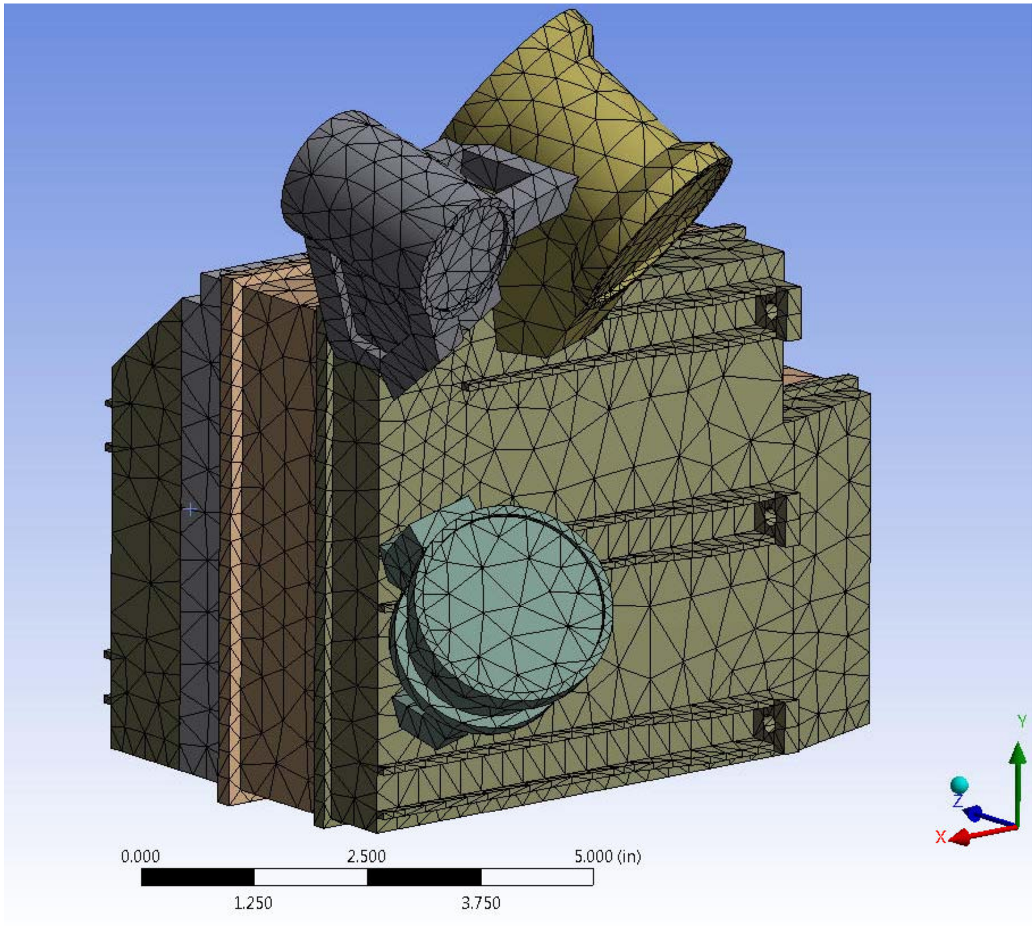
	Ultimate	Yield
Metallic Structures		
Tested	1.40	1.25
No Test	2.60	2.00
Beryllium	1.60	1.40
Composite & bonded structures (1)		
C-C laminate	2.0	NA
Others	1.50	NA
Carbon Foam	4.0	NA
Ceramic, glass		
Pressurized	3.0	NA
Nonpressurized	3.0	NA
Preloaded fastener joint		
External load	1.40	NA
Gapping	1.25	NA
Fitting factor (no test only)	1.15	NA
GSE	5.00	3.00

Includes bonded metallic and/or non-metallic sandwich structure.

$$Margin\ of\ Safety = \frac{Allowable\ Strength}{FS \times Applied\ Stress} - 1.0$$

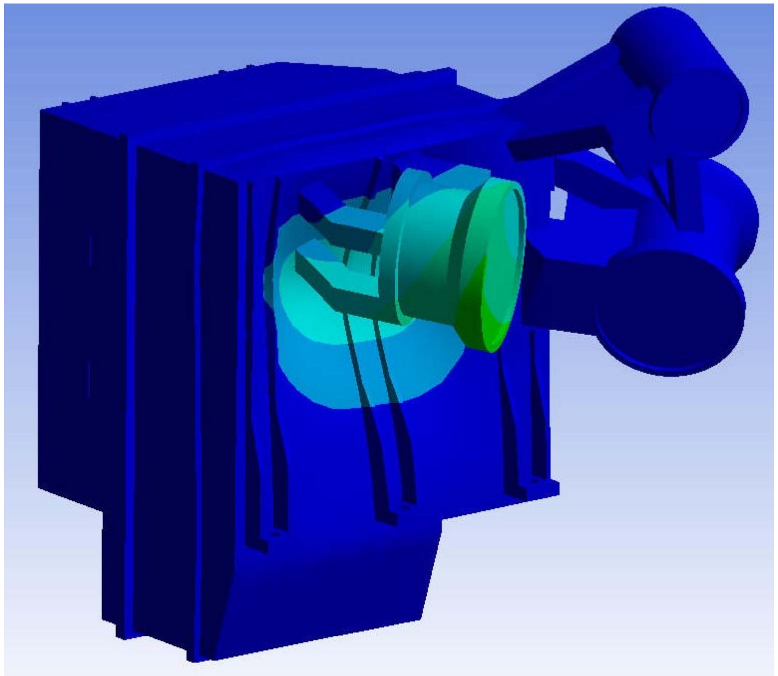
EPI-Hi FEM/Boundary Conditions

- FE Model Mass = 4.026 kg (CBE mass plus uncertainty)
- Fixed at mounting holes on feet (5 places)

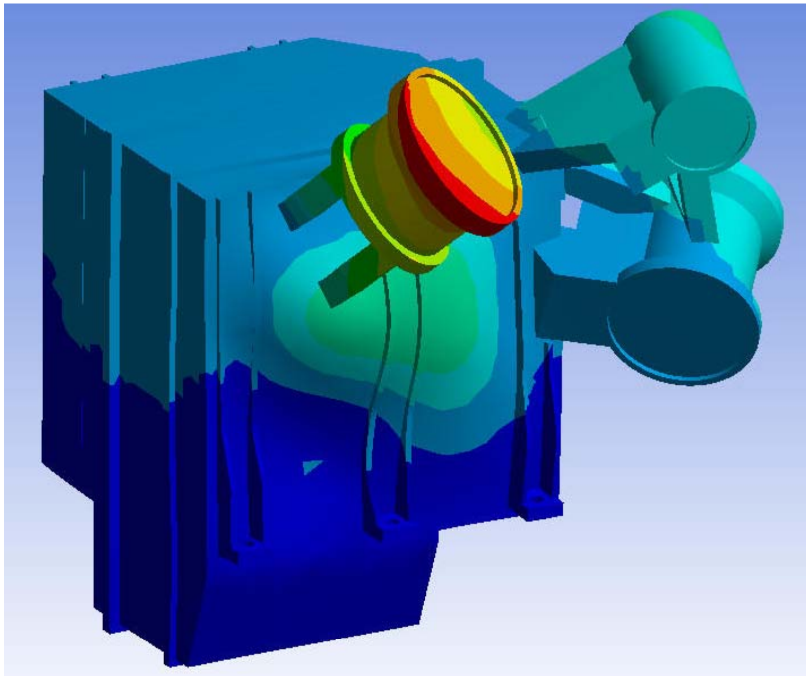


EPI-Hi Modal Frequencies (1/2)

- Instrument Fundamental Frequencies



471 Hz
(side panel diaphragm mode coupled with internal boards)



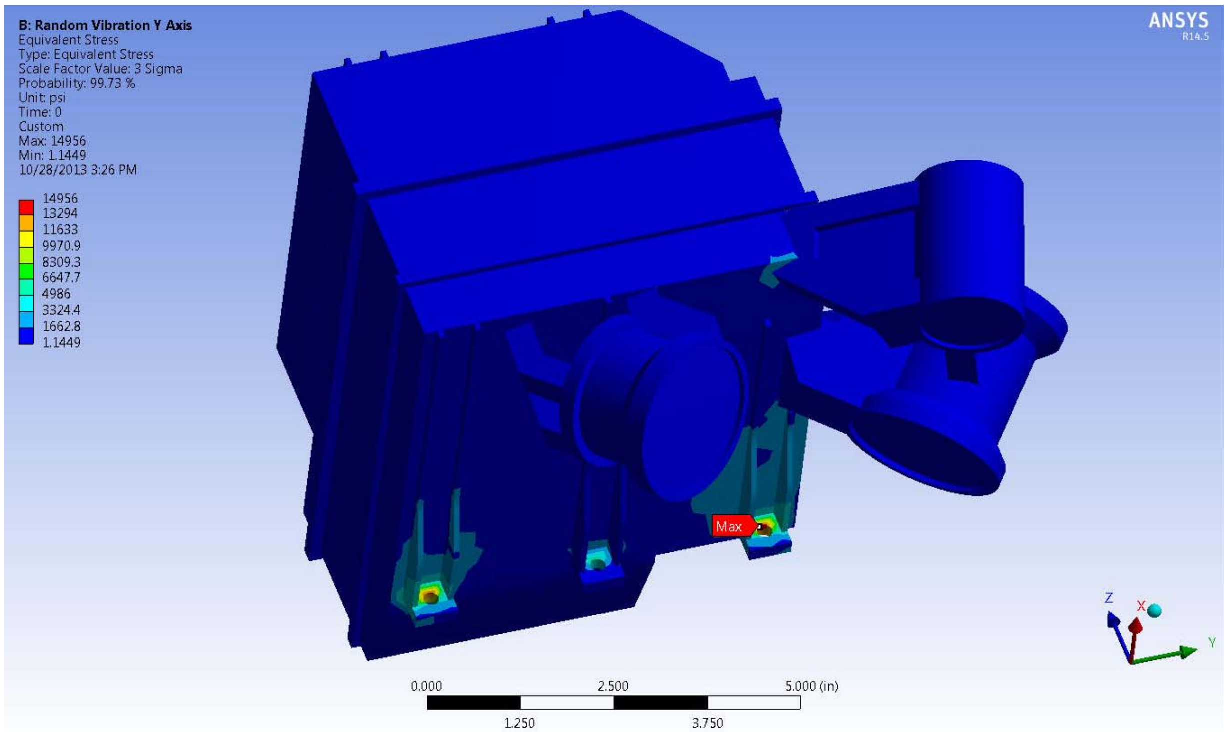
639 Hz
(instrument rocking mode)

EPI-Hi Modal Frequencies (2/2)

- PWA Modes
  - All PWA Fundamental Frequencies > 150 Hz (EDTRD_0307)

PWA	CBE Mass with Uncertainty [kg]	Frequency [Hz]
LVPS	0.350	>700
Bias supply	0.203	361
LET1	0.308	525
LET2	0.282	555
HET	0.282	471
DPU	0.335	361

EPI-Hi Stress Results



Worst Case Stress: 14956 psi; occurs at housing foot in the Y-axis Random Vibration load case

Analysis	Direction	Maximum VM Stress	Location	Material	Yield Strength	Ultimate Strength	Factors of Safety		Margins of Safety	
		[psi]			[ksi]	[ksi]	Yield	Ultimate	Yield	Ultimate
Random Vibration	X	14918	Standoff/Housing	Al 6061-T6	36	42	1.6	1.8	0.5	0.6
	Y	14956	Housing Foot	Al 6061-T6	36	42	1.6	1.8	0.5	0.6
	Z	4841	Standoff/Housing	Al 6061-T6	36	42	1.6	1.8	3.6	3.8
Static (MAC)	X	3071	Standoff	Al 6061-T6	36	42	1.25	1.4	8.4	8.8
	Y	4052	Housing	Al 6061-T6	36	42	1.25	1.4	6.1	6.4
	Z	3375	Standoff	Al 6061-T6	36	42	1.25	1.4	7.5	7.9

ISIS Bracket Mechanical Design Requirements

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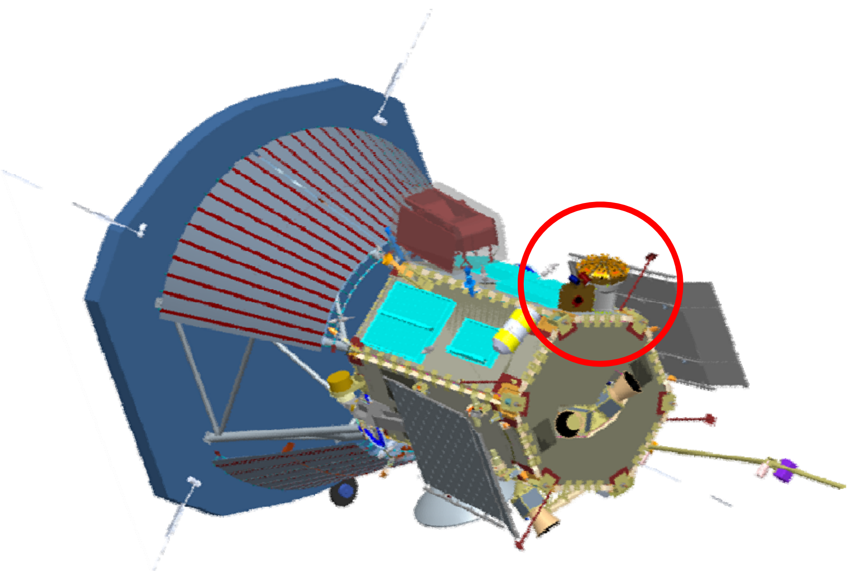
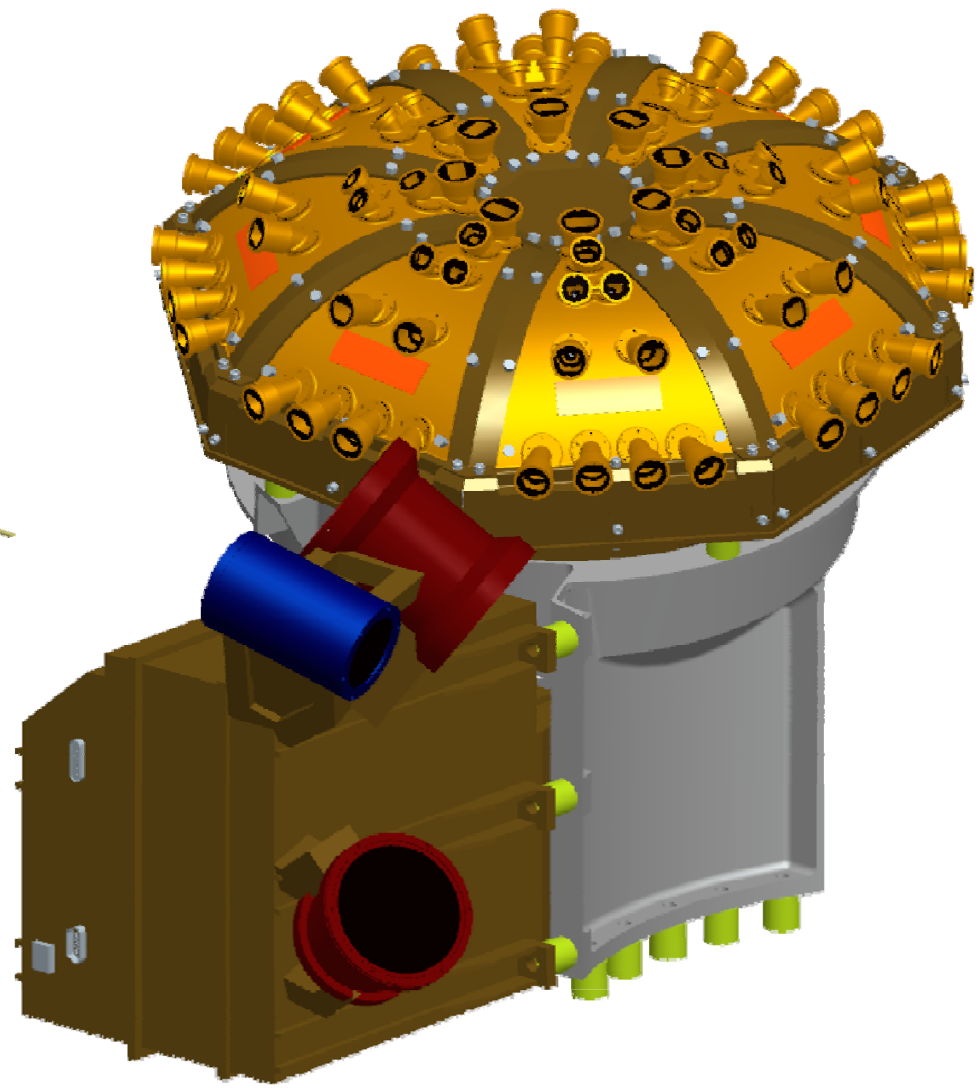
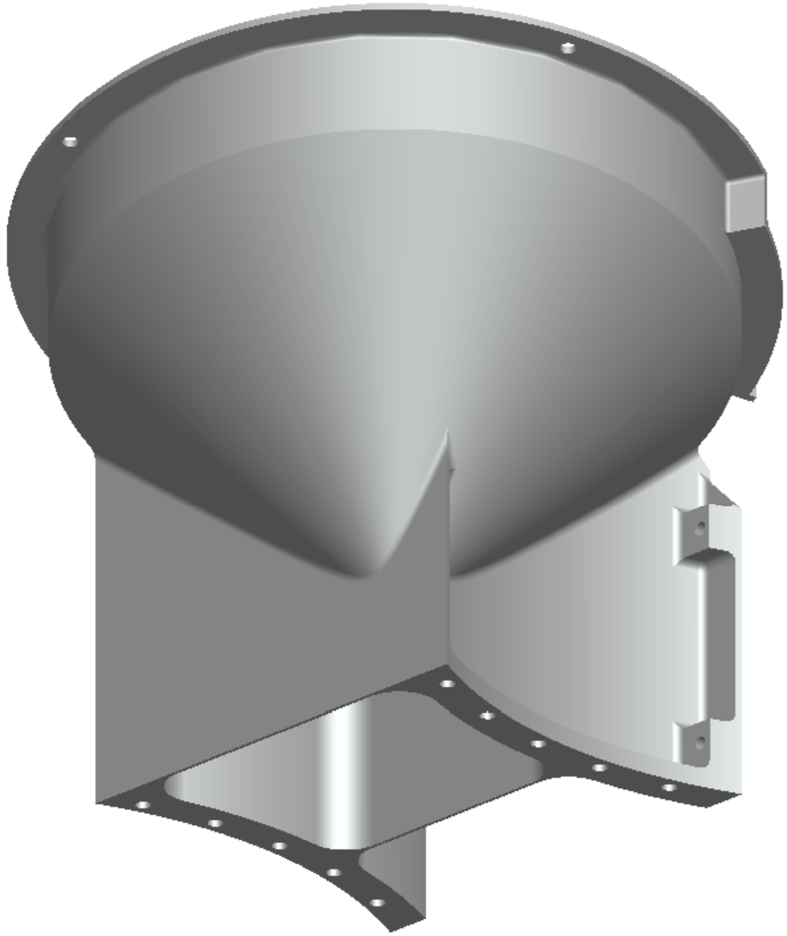
- ISIS bracket must hold EPI-Hi and EPI-Lo in position on the SPP deck
- ISIS bracket must be capable of independently removing EPI-Hi and EPI-Lo, in either order
- ISIS bracket must survive all environments for deck mounted components
  - Random vibration
  - Sine vibration
  - Shock
- All ISIS suite testing shall be performed on the bracket, with instruments or instrument analogs as appropriate

ISIS Mechanical Design Overview





ISIS Bracket Design Overview



ISIS Bracket Fabrication

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- The ISIS bracket can be machined using conventional machining processes
  - Monolithic design, will be machined from a single block
  - All operations can be performed on conventional machines (i.e. lathe, mill, etc.)
- Thermal isolators and mass models will also be fabricated to be used during structural testing
  - G10 isolators will be machined to flight-like quality
  - Mass models to reflect instrument mass properties with flight-like mounting interfaces
- Bracket height increase due to TPS shift can easily be accommodated as needed
  - Working with S/C mechanical team; any shift in the TPS only requires translation normal to the deck to remain adjacent to the umbra

ISIS Bracket FEM/Boundary Conditions

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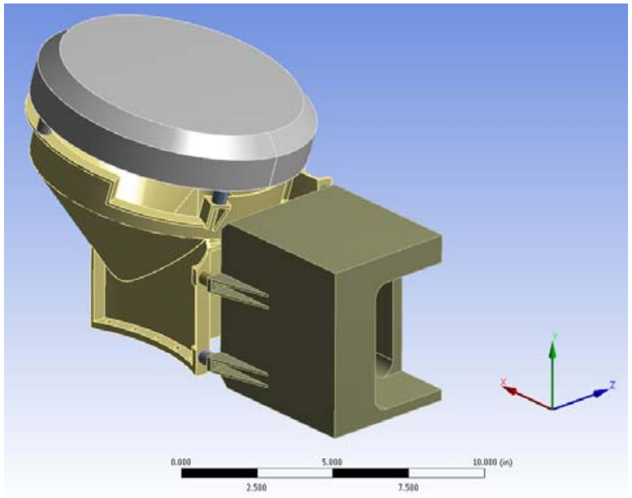
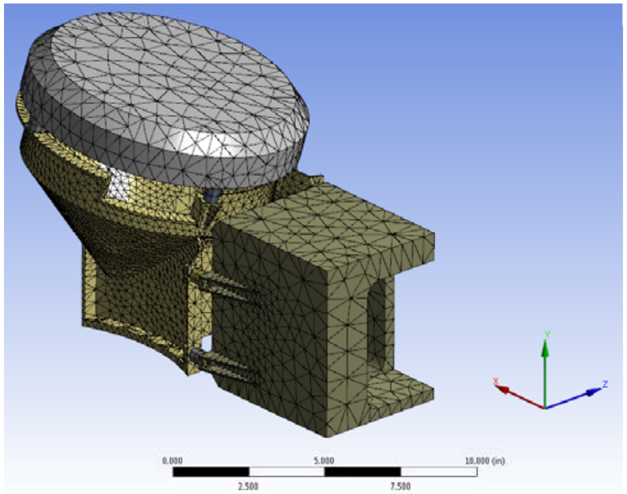
- Model includes bracket, EPI-Hi and EPI-Lo mass models (at max allocation) and thermal isolators
  - Bracket: Aluminum 7075-T6 properties
  - Mass models: Aluminum 6061-T6 properties
  - Thermal isolators: G10 material properties
- Mass models represent accurate mass and CG properties
  - Test results will be easy to compare to model
  - Mass models are stiff enough to not introduce modes
- Edge to surface connections for all mounting interfaces
- Fixed supports on 10 bracket mounting holes





ISIS Bracket FEM - Modal Results

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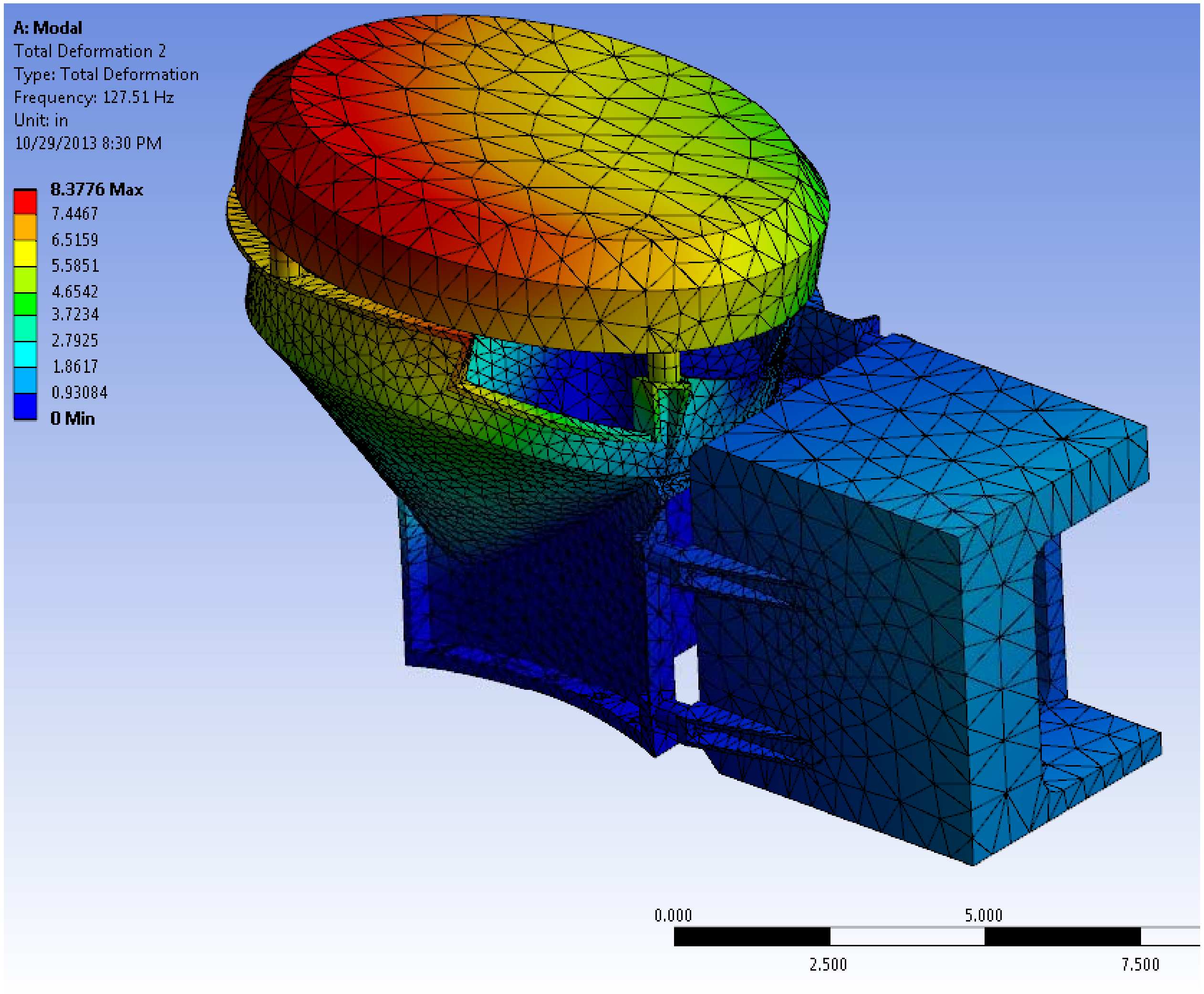
- Primary Mode:
  127.51 Hz
  (rocking mode)

- Requirement:
  80 Hz minimum



ISIS Bracket FEM - Structural Setup

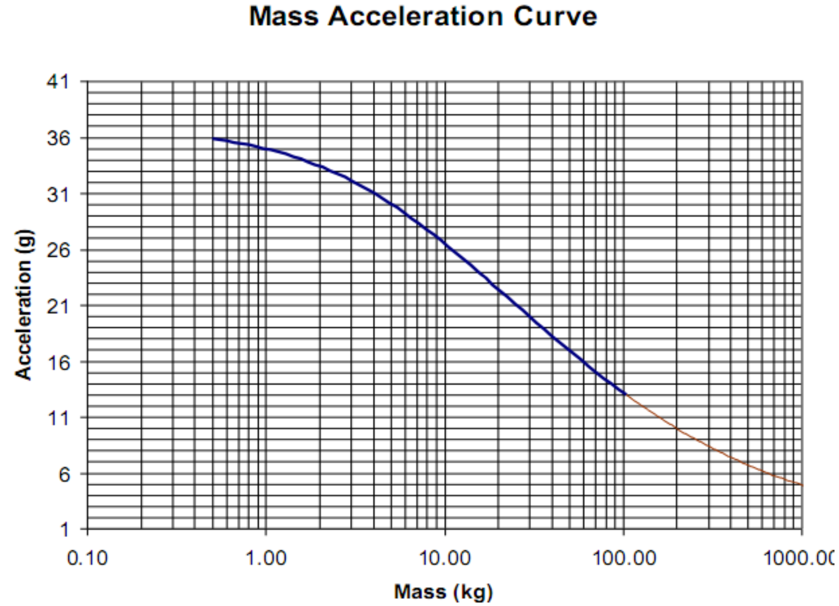
Random Vibration ASD Specifications

Table 4-8. Side Panels Mounted Components & Subsystems Normal To Panel

Frequency (Hz)	Qualification (G^2/Hz)	Protoflight (G^2/Hz)	Acceptance (G^2/Hz)
20	0.01	0.01	0.01
60	1.25	1.25	0.63
200	1.25	1.25	0.63
350	0.04	0.04	0.04
500	0.04	0.04	0.04
2000	0.01	0.01	0.01
Overall Grms	16.4	16.4	12.6
Duration (mins)	2	1	1

Table 4-9. Side Panels Mounted Components & Subsystems Lateral To Panel

Frequency (Hz)	Qualification (G^2/Hz)	Protoflight (G^2/Hz)	Acceptance (G^2/Hz)
20	0.01	0.01	0.01
35	0.04	0.04	0.04
500	0.04	0.04	0.04
2000	0.01	0.01	0.01
Overall Grms	6.8	6.8	6.8
Duration (mins)	2	1	1



ISIS: NTE Mass=7.74 kg
MAC: for 7.74 kg, Acceleration=28 g

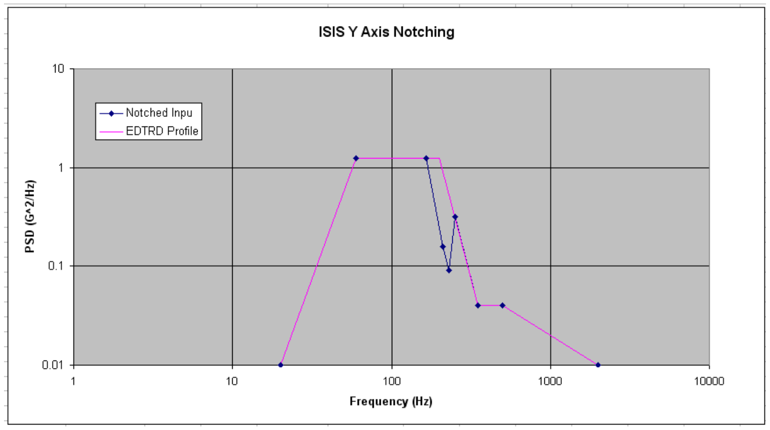
ISIS: Y-direction is Normal to Panel;
X & Z-directions are Lateral to Panel

Analysis Employs Qualification Level Loads with Notching

ISIS Bracket FEM - Notching

- Notching performed on the Y Axis in accordance with ETDRD Section 4.4.7.4
  - CBE Mass: 7.74 kg
  - MAC Acceleration: 28 G
  - MAC Limit Load: 1.25
  - Notching Limit Load: 2657.5 N (35 G)
  - Un-notched Reaction Load: 7498.8 N
  - Notch Depth: 7.65dB, Notch Width: 20 Hz, Ramp: +/-15 dB/Oct
  - Notched Frequency: 220 Hz
  - Resulting Profile

Y Axis Random Vibe	
Frequency	PSD
20	0.01
60	1.25
166	1.25
210	0.159
230	0.091
250	0.3168
350	0.04
500	0.04
2000	0.01



  - Resulting Reaction Load: 5588.7N

ISIS Bracket Structural Design Margins

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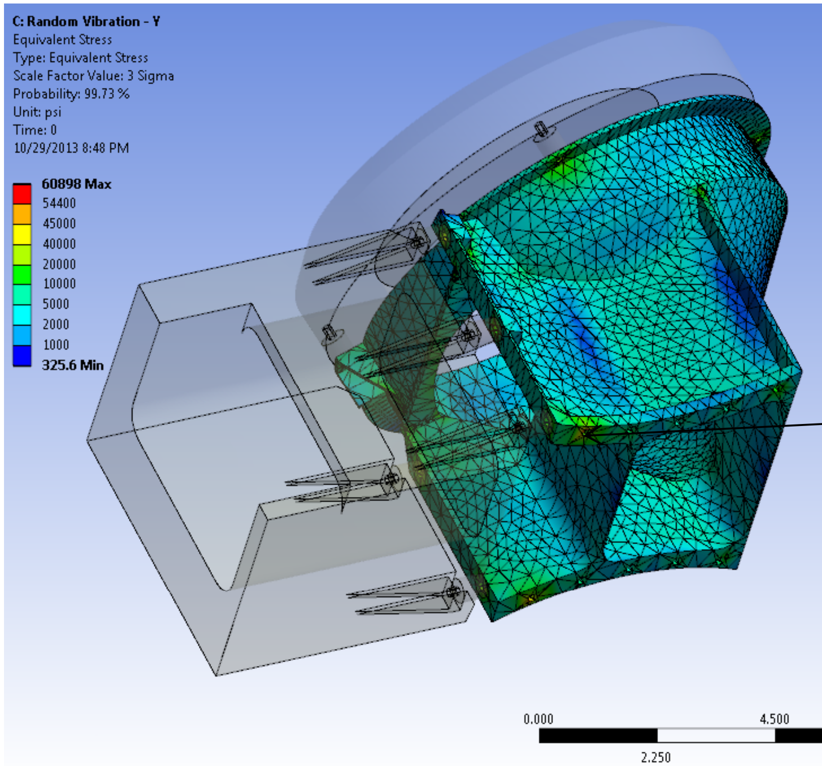
- The tabulated factors of safety are applied to the limit loads for quasi-static, random and sine vibration loads.
- For random vibration analysis, the 3-sigma RMS response from the finite element analysis is employed to calculate margins.
- Margins of safety calculated using equation on right:

	Ultimate	Yield
Metallic Structures		
Tested	1.40	1.25
No Test	2.60	2.00
Beryllium	1.60	1.40
Composite & bonded structures (1)		
C-C laminate	2.0	NA
Others	1.50	NA
Carbon Foam	4.0	NA
Ceramic, glass		
Pressurized	3.0	NA
Nonpressurized	3.0	NA
Preloaded fastener joint		
External load	1.40	NA
Gapping	1.25	NA
Fitting factor (no test only)	1.15	NA
GSE	5.00	3.00

Includes bonded metallic and/or non-metallic sandwich structure.

$$Margin\ of\ Safety = \frac{Allowable\ Strength}{FS \times Applied\ Stress} - 1.0$$

ISIS Bracket Stress Results (Preliminary)



Worst Case Stress: 49979 psi; occurs at S/C Interface Bolt in the Y-axis Random Vibration load case

Analysis	Direction	Maximum VM Stress	Location	Material	Yield Strength	Ultimate Strength	Factors of Safety		Margins of Safety	
		[psi]			[ksi]	[ksi]	Yield	Ultimate	Yield	Ultimate
Random Vibration	X	35233	EPI-Lo Flange	Al 7075-T6	68	78	1.25	1.4	0.5	0.6
	Y	49979	S/C Interface Ft	Al 7075 T6	68	78	1.25	1.4	0.1	0.1
	Z	41057	Buttress	Al 7075-T6	68	78	1.25	1.4	0.3	0.4
Static (MAC)	X	19389	EPI-Lo Flange	Al 7075-T6	68	78	1.25	1.4	1.8	1.9
	Y	11467	EPI-Hi Flange	Al 7075-T6	68	78	1.25	1.4	3.7	3.9
	Z	27022	Buttress	Al 7075-T6	68	78	1.25	1.4	1.0	1.1

ISIS Bracket Structural Testing

- ISIS bracket will be tested at SwRI facilities with EPI-Hi and EPI-Lo mass models
  - G10 thermal isolators will be included
  - Mounted using flight quality mounting hardware
- Tests will check natural frequency, random vibe response, sine vibe response
  - Natural frequency must be >80 Hz (EDTRD_0095)
  - Must survive random vibration loads (EDTRD_0111) per tables in EDTRD 4.4.3
  - Must survive sine sweep loads (EDTRD_0114) per sine environment (TBD) given in EDTRD 4.4.4
  - Pre & post test low-level sine sweeps used to identify any change in fundamental frequency
- Once fabricated and tested at SwRI, ISIS bracket will be used in support of EPI-Hi and EPI-Lo environmental testing

Summary

Solar Probe Plus
A NASA Mission to Touch the Sun

- EPI-Hi, EPI-Lo, and ISIS Bracket modeling have been completed
  - Satisfies EDTRD requirements
  - Have required margins of safety
- Ready to begin EM Fabrication and move into Phase C

Solar Probe Plus

A NASA Mission to Touch the Sun

Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

ISIS Thermal

Gregory J. Dirks

ISIS Thermal Lead (SwRI)

Outline

- Driving Instrument Thermal Requirements
- Thermal Design and Implementation
  - Thermal Management
  - Heaters and Sensors
  - MLI Design
  - Materials and Finishes
- Predicted Performance and Margins
  - Thermal Model Details
  - Design Cases
  - Optical Properties and Power Dissipation
  - Predictions and Margins
- Plans for Thermal Verification
- Summary

Requirements (1/2)

- Design Temperature Limits

EPI-Hi

Component	Hot Op. (°C)	Cold Op. (°C)	Cold Surv. (°C)
EPI-HI HET	40	-25	-40
EPI-Hi LET1	40	-25	-40
EPI-Hi LET2	40	-25	-40
EPI-Hi DPU	40	-25	-40
EPI-Hi Bias	40	-25	-40
EPI-Hi LVPS	40	-25	-40
EPI-Hi HET Tel	30	-25	-40
EPI-Hi LET 1 Tel	30	-25	-40
EPI-Hi LET 2 Tel	30	-25	-40

EPI-Lo

Component	Hot Op. (°C)	Cold Op. (°C)	Cold Surv. (°C)
Detector	35	-30	-45
Anode Board	55	-30	-45
Event Board	55	-30	-45
Power Board	55	-30	-45
Dome	35	-30	-45

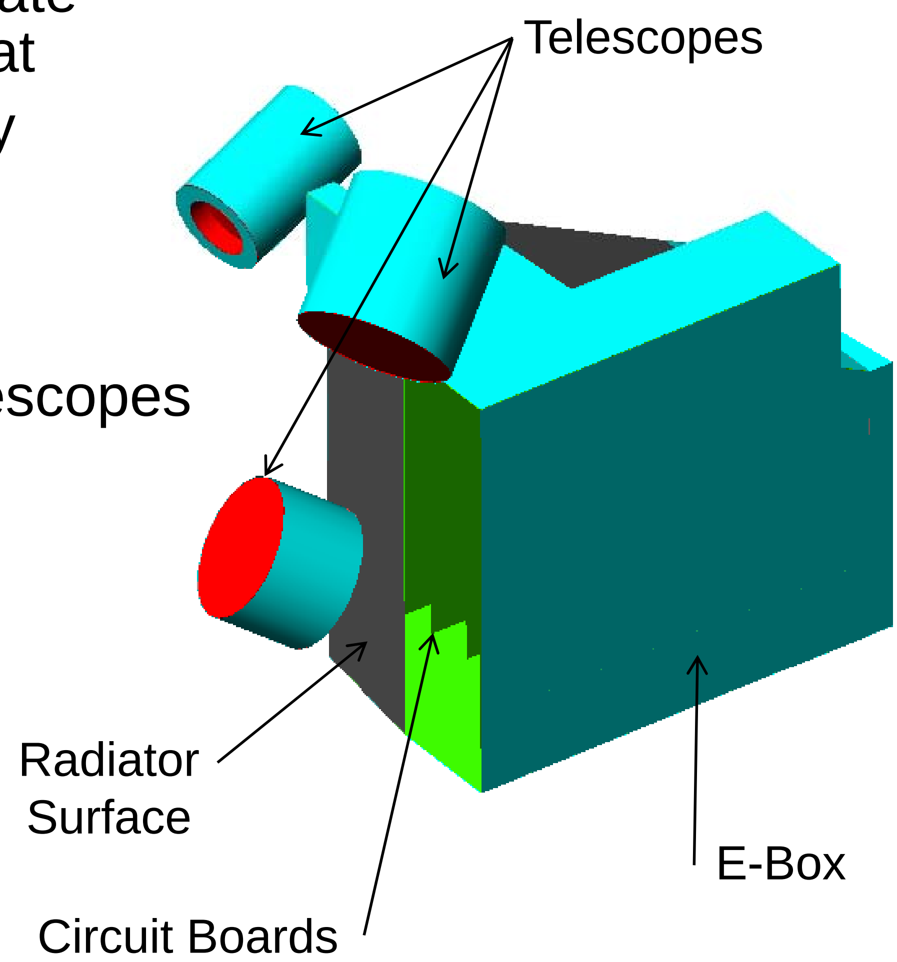
- Margin Guidelines – Includes Test and Model Uncertainty
  - Hot Limits 10 C and Cold Limits 5 C (Heater Controlled)

Requirements (2/2)

- Interface Temperatures
  - Operational: -25 / +65 C
  - Non-Operational: -30 / +70 C
- Heaters
  - 75% Maximum Duty Cycle
  - Resistance Determined at 26 V

Design (1/3)

- EPI-Hi
  - E-box Radiator to Dissipate Internally Generated Heat
  - Telescopes Conductively Isolated from E-box
  - Operational Heaters on Telescopes
  - Survival Heaters on Telescopes and E-box
  - MLI on Surfaces Except Apertures, Radiator, and Bottom (S/C Facing)



Design (2/3)

Solar Probe Plus
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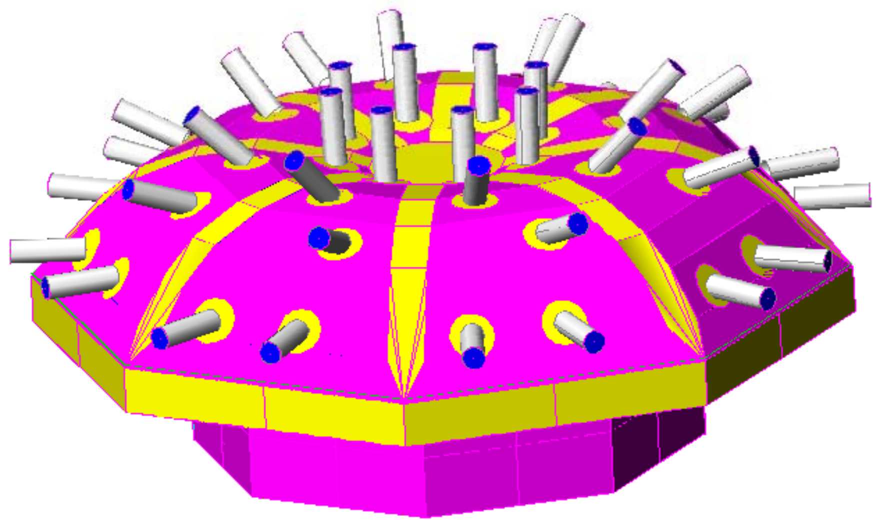
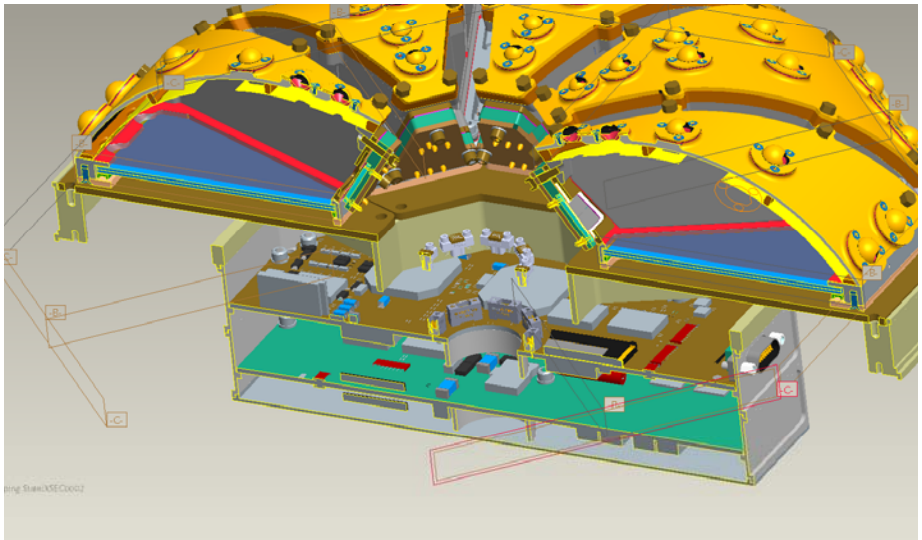
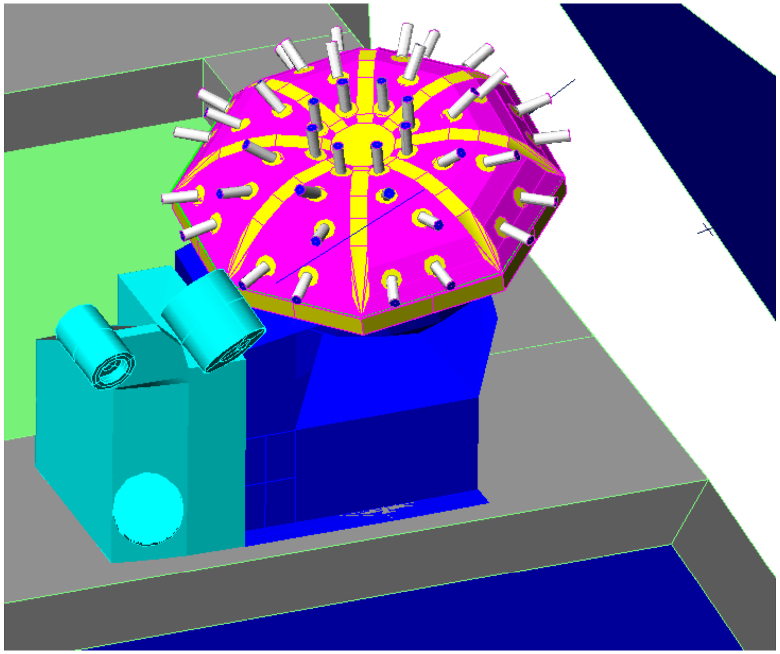
- EPI-Lo
  - Wedge Radiators (8) to Dissipate Internally Generated Heat
  - Eight Survival Heaters (One on Each Wedge)
  - MLI on Surfaces Except Apertures and Radiators

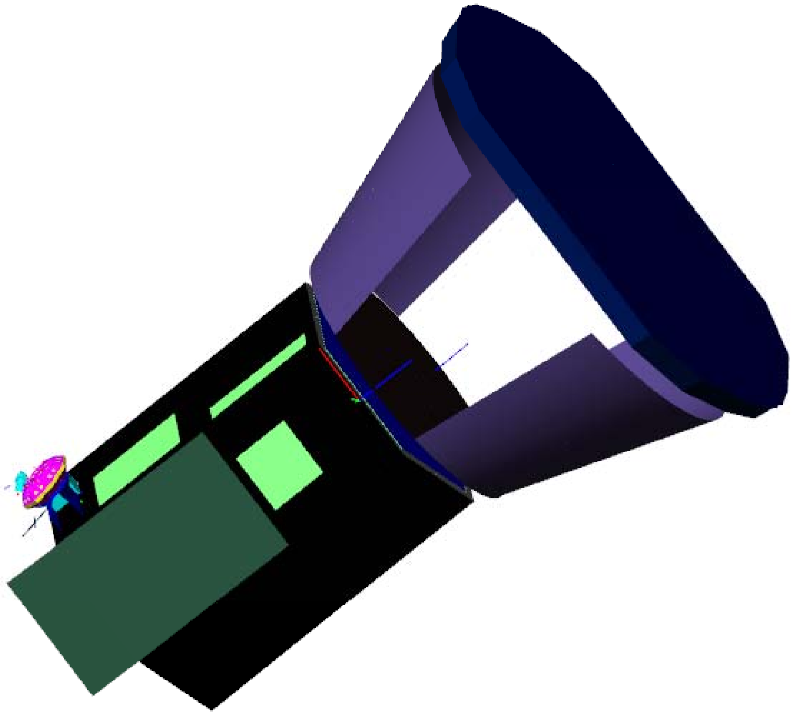




Design (3/3)

- ISIS
  - EPI-Hi and EPI-Lo are Thermally Isolated from the Bracket
  - Bracket is Thermally Isolated from the S/C





Heaters and Sensors (1/2)

Solar Probe Plus
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- EPI-Hi Heater Operations
  - One S/C Thermistor on Each Telescope and Two S/C Thermistors on E-box (Primary and Redundant)
  - Operational Heaters on Telescopes are All on One S/C Service, but Controlled by E-box
  - Survival Heaters on Telescopes and the E-Box are All on One S/C Service and Controlled by S/C with Sense Location Currently Baselined as the E-box
  - Survival Heaters Also Used to Warm Instrument to Cold Operational Temperature for Cold Turn On by using Different Set Points

Heaters and Sensors (2/2)

Solar Probe Plus
A NASA Mission to Touch the Sun

- EPI-Lo Heater Operations
  - Two (Primary and Redundant) S/C Thermistors on Dome for Heater Control and One More (To Be Positioned)
  - All Survival Heaters are on One S/C Service (Separate from EPI-Hi) Controlled by S/C with Sense Location Currently Baselined as One of the Wedges
  - Survival Heaters are Used to Warm Instrument to Cold Operational Temperature for Cold Turn On by Using Different Set Points
  - Survival Heaters are Also Used to Maintain Minimum Cold Operating Temperature During Low Power Operating Conditions

MLI

- Coverage
  - Entire Instrument Other than Apertures, Radiators, and Under EPI-Hi Electronics
- Specifications/Construction
  1. Outer Layer #1: 1.6 Mil Germanium Black Kapton with Nomex Scrim (Germanium facing space and Black facing Spacecraft)- 1 Layer
  2. Outer Layer #2: 2 Mil VDA1 Kapton (Aluminum facing space and Kapton facing Spacecraft)- 1 Layer
  3. Internal Layers: 10 layers of .25 Mil VDA2 Mylar altered by 11 layer of Dacron B4A netting.
  - Each Separate Blanket Grounded with Wire to S/C
  - Vented Using Edge Mesh Screens Directed away from Apertures
  - Edges and Seams Sealed using GBK Tape
  - Blankets Secured using G-10 Buttons and SS Snap Rings

Materials and Finishes

- Radiators
  - Z-93 Conductive White Coating
- MLI
  - Germanium Black Kapton (GBK)
- Apertures
  - EPI-Hi: Metalized Polyimide
  - EPI-Lo: Z-93
- Thermal Isolators
  - G-10 Fiberglass

Thermal Model

- EPI-Hi Modeled by Vertex Aerospace
  - Rommel Zara and Santino Rosanova
- EPI-Lo Modeled by APL
  - Shawn Begley
- Bracket Modeled by Vertex Aerospace
- ISIS Model Integrated by Vertex Aerospace
- All Models Created using Thermal Desktop Software
- Pre-PDR Model Delivered to S/C in June
- Good Correlation between Instrument and S/C Results

Design Cases

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- Hot Operational
  - +65 C I/F Temperature
  - EOL Power and BOL Optical Properties
  - Low MLI e* = 0.03
- Cold Operational
  - -25 C I/F Temperature
  - BOL Power and BOL Optical Properties
  - High MLI e* = 0.05
- Cold Non-Operational
  - -30 I/F Temperature
  - BOL Optical Properties and e* = 0.05
- Hot Non-Operational
  - 1.02 AU with +70 I/F Temperature
  - EOL Optical Properties and e* = 0.03

Optical Properties

- Radiator: Z-93 White Coating
  - BOL: a = 0.15, e = 0.91
  - EOL: a = 0.45, e = 0.91
- MLI Exterior: GBK
  - BOL: a = 0.49, e = 0.81
  - EOL: a = 0.55, e = 0.78
- EPI-Hi Apertures
  - HET BOL: a = 0.31, e = 0.46
  - LET BOL: a = 0.35, e = 0.35

Power Dissipation

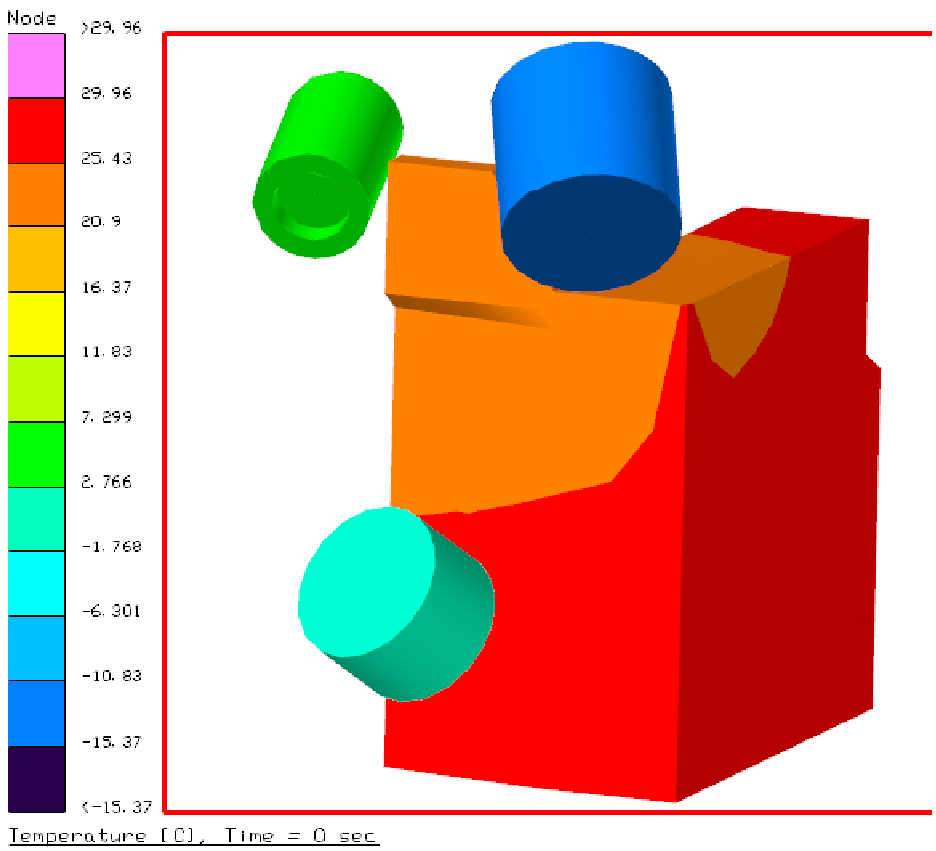
- ISIS Power Distribution
  - Cold Case uses CBE, Hot Case uses CBE+Cont.

EPI_HI Heatloads	Cold CBE, W	Hot w/Contingency, W
Bias Supply	0.14	0.38
DPU	0.71	0.79
HET	1.10	1.22
LET 1	1.19	1.32
LET 2	0.90	1.00
LVPS	1.77	2.06
Total	**5.81**	**6.77**

EPI_LO Heatloads	Cold CBE New, W	Hot w/Contingency New, W
Detector	0.20	0.24
Event	1.13	1.36
Power Supply	1.94	2.33
MCP	0.52	0.62
Anode	0.38	0.46
Total	**4.17**	**5.00**

Predictions (1/9)

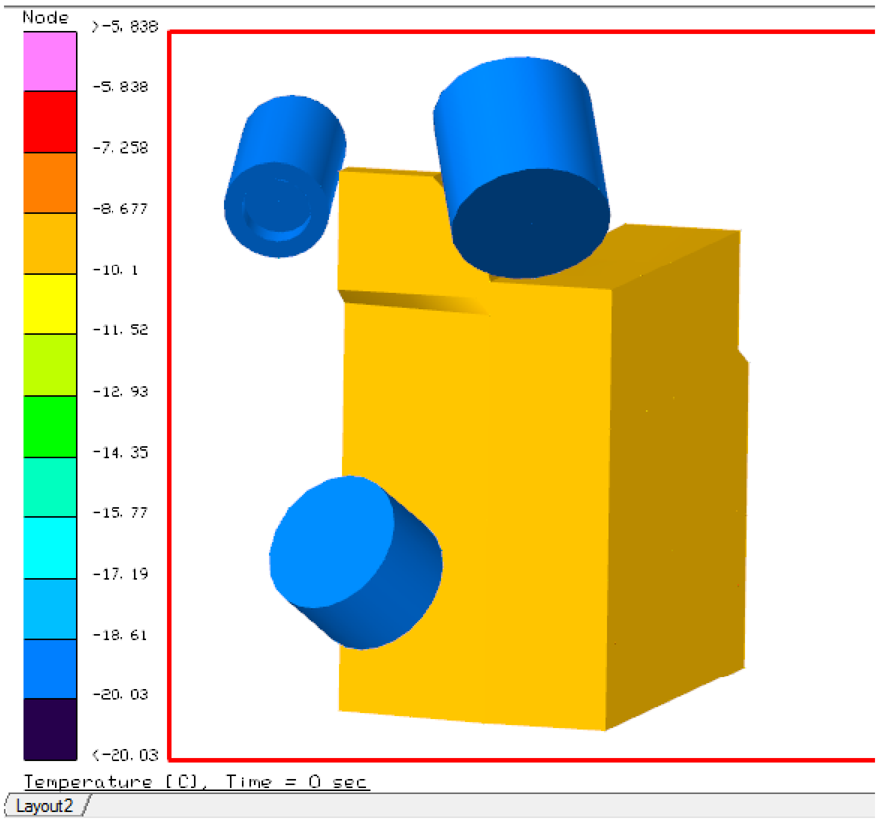
- EPI-Hi Hot Operational



Component	Limit (°C)	Predict (°C)	Margin (°C)
EPI-HI HET	40	29.4	10.6
EPI-Hi LET1	40	29.5	10.5
EPI-Hi LET2	40	27.3	12.7
EPI-Hi DPU	40	28.2	11.8
EPI-Hi Bias	40	28.6	11.4
EPI-Hi LVPS	40	29.6	10.4
EPI-Hi HET Tel	30	3.5	26.5
EPI-Hi LET 1 Tel	30	-15.0	45.0
EPI-Hi LET 2 Tel	30	-0.5	30.5

Predictions (2/9)

- EPI-Hi Cold Operational

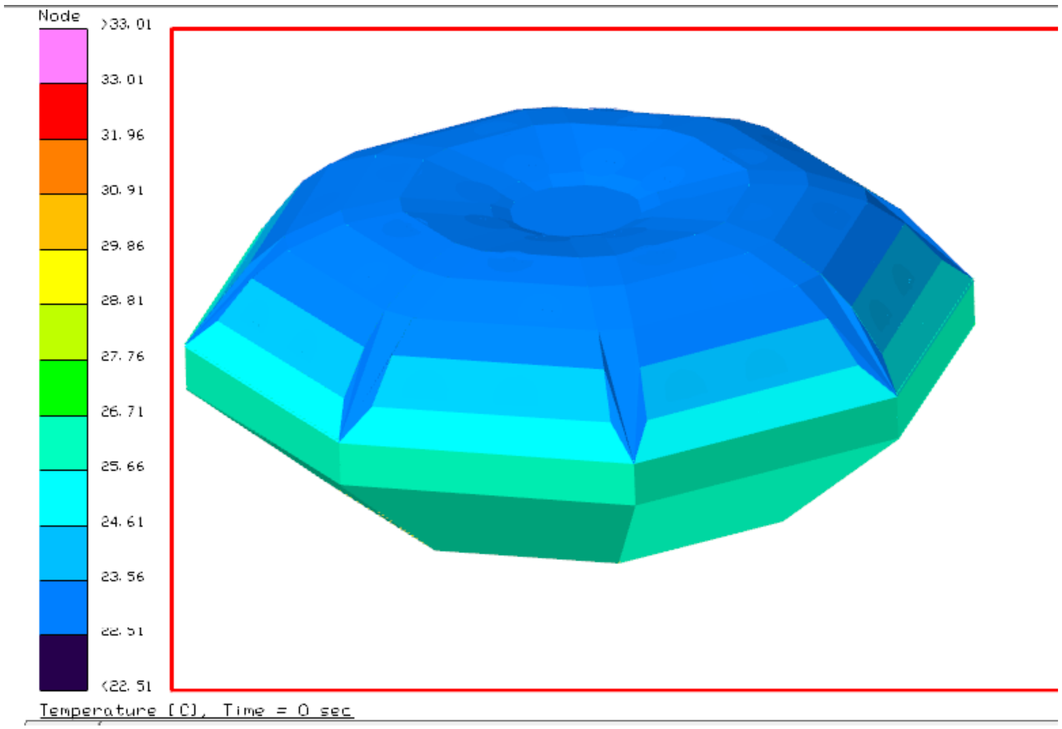


Component	Limit (°C)	Predict (°C)	Margin (°C)
EPI-HI HET	-25	-2.9	22.1
EPI-Hi LET1	-25	-2.9	22.1
EPI-Hi LET2	-25	-4.8	20.2
EPI-Hi DPU	-25	-4.1	20.9
EPI-Hi Bias	-25	-3.8	21.2
EPI-Hi LVPS	-25	-2.6	22.4
EPI-Hi HET Tel	-25	-20	5
EPI-Hi LET 1 Tel	-25	-20	5
EPI-Hi LET 2 Tel	-25	-20	5

Heater Location	Heater Power(W)
EPI-Hi HET TEL	0.05
EPI-Hi LET1 TEL	0.08
EPI-Hi LET2TEL	0.32
TOTAL	0.45

Predictions (3/9)

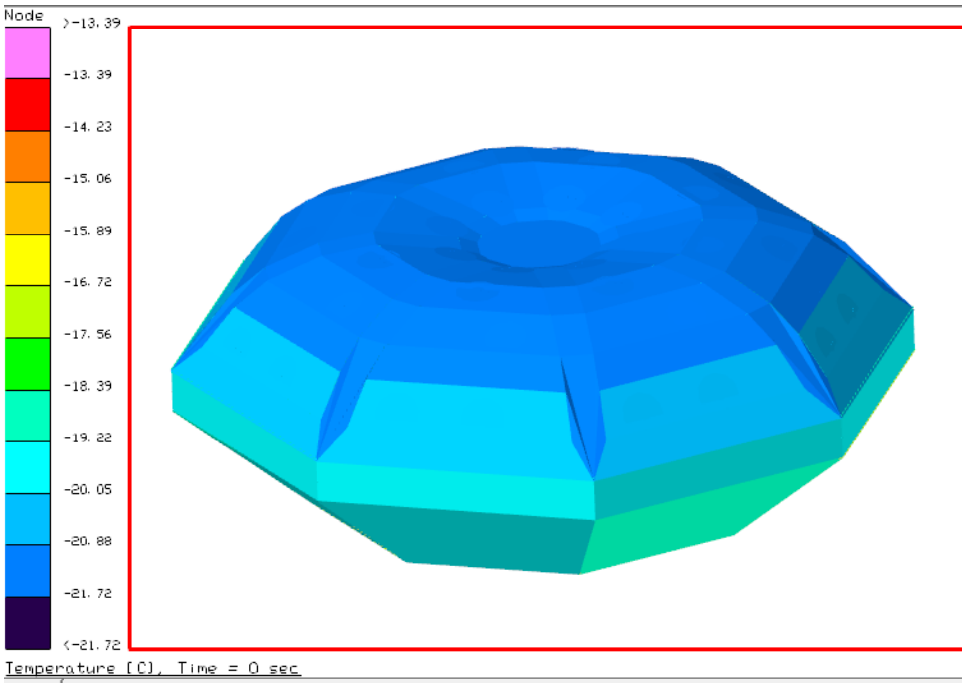
- EPI-Lo Hot Operational



Component	Limit (°C)	Predict (°C)	Margin (°C)
Detector	35	24.8	10.2
Event	55	27.2	27.8
Pwr. Supply	55	28.9	26.1
MCP	55	25.2	29.8
Anode	55	23.8	31.2

Predictions (4/9)

- EPI-Lo Cold Operational



Component	Limit (°C)	Predict (°C)	Margin (°C)
Detector	-30	-10.0	20.0
Event	-30	-8.4	21.6
Pwr. Supply	-30	-7.0	23.0
MCP	-30	-8.8	21.2
Anode	-30	-11.1	18.9

Predictions (5/9)

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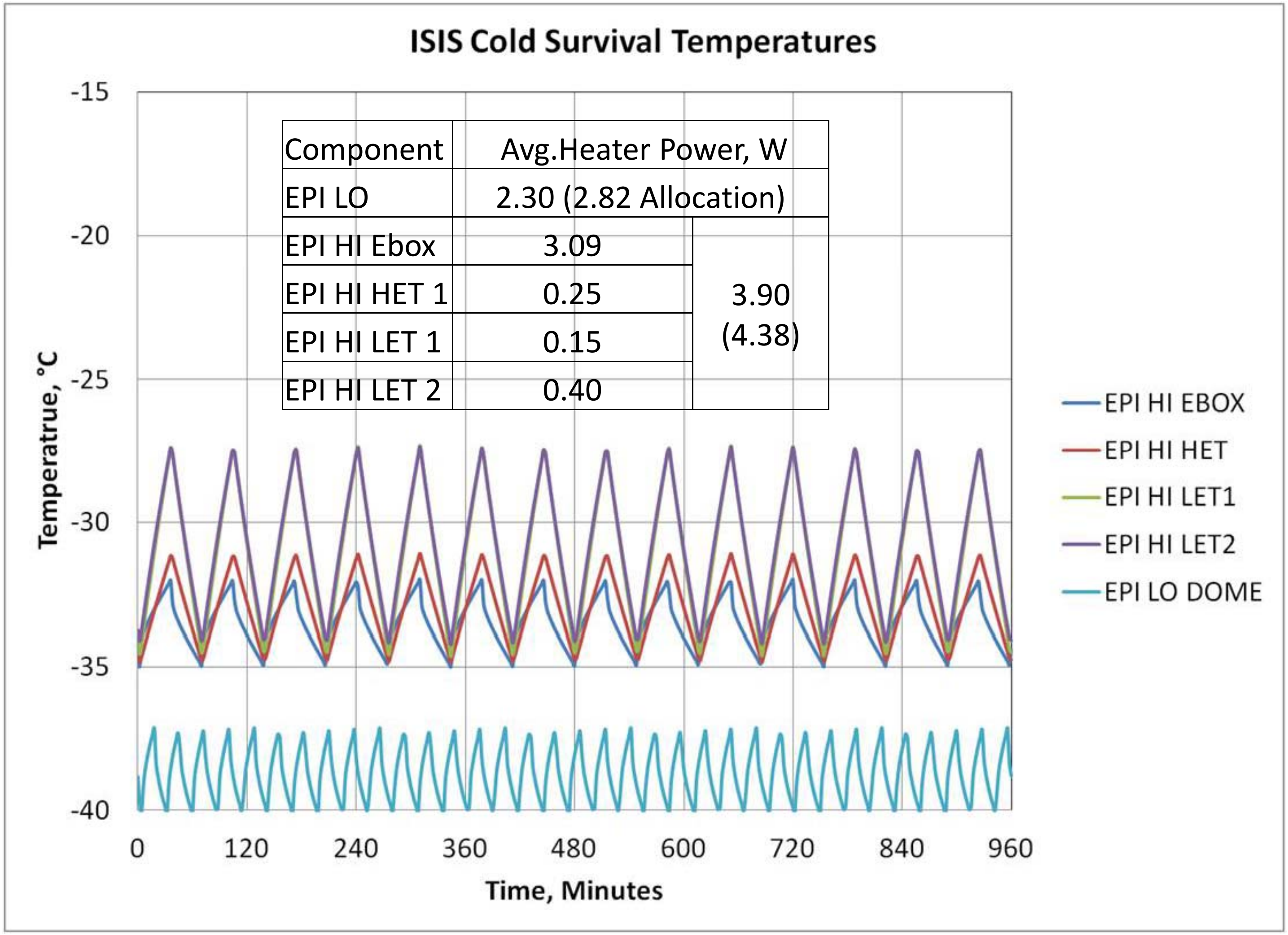
- ISIS Heater Sizing
- EPI-Lo Operational CBE Power of 4.17 W is Duty Cycled at 75% for a Heater Instantaneous Power of 5.56 W (26 V).
  - Temperature Setpoints of -25°C/-22°C (Operational)
  - Temperature Setpoints of -40°C/-37°C (Non-Operational)
- EPI-Hi Operational CBE Power of 5.81 W is Duty Cycled at 75% for a Heater Instantaneous Power of 7.74 W (26 V).
  - HET TEL: 0.3 W
  - LET1 TEL: 0.8 W
  - LET 2 TEL: 0.5 W
  - EBOX: 6.15 W
  - Temperature Setpoints of -20°C/-17°C (Operational)
  - Temperature Setpoints of -35°C/-32°C (Non-Operational)

Predictions (6/9)

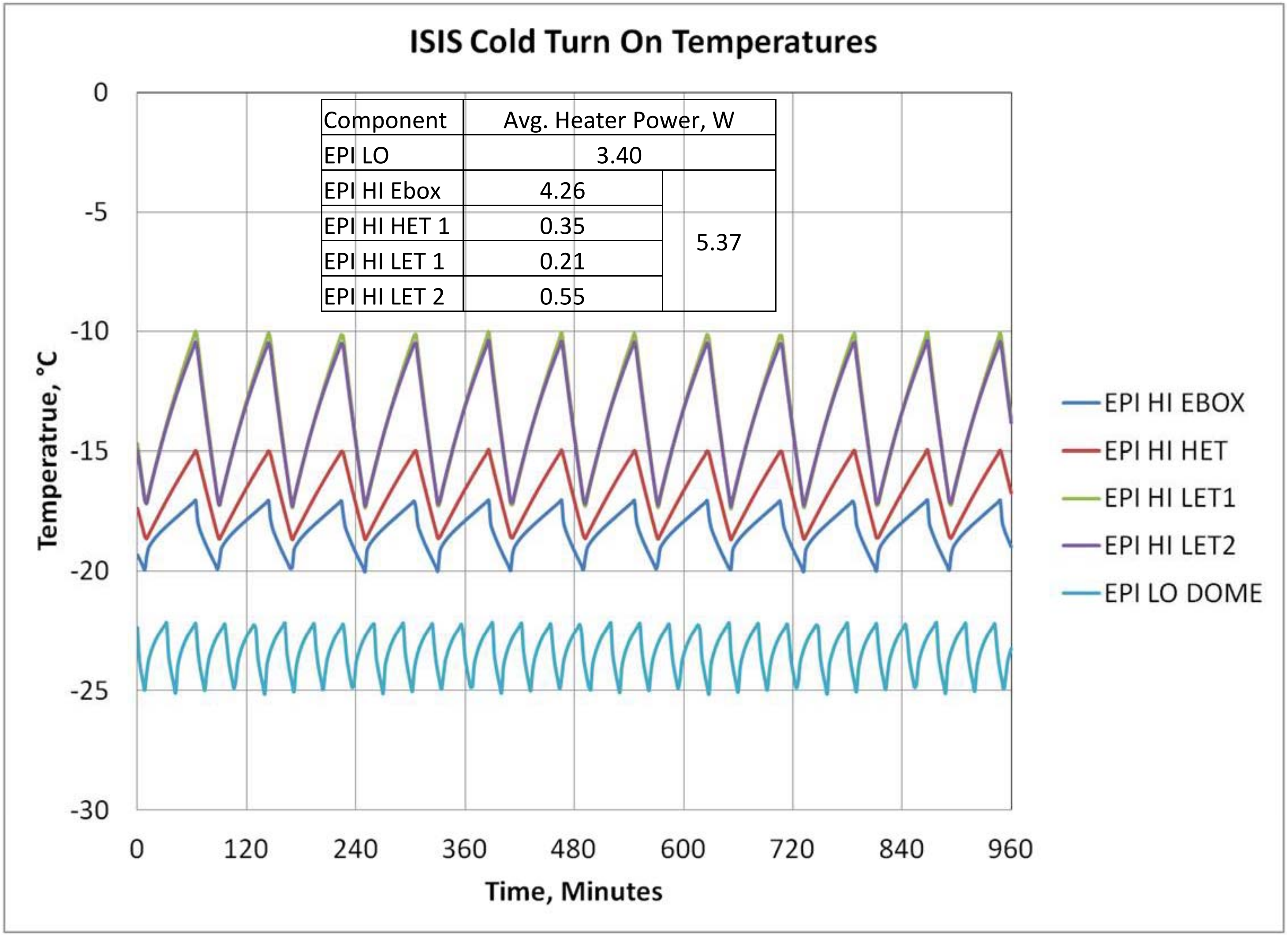
- ISIS Cold Non-Operational Temperatures



Component	Avg.Heater Power, W	
EPI LO	2.30 (2.82 Allocation)	
EPI HI Ebox	3.09	3.90 (4.38)
EPI HI HET 1	0.25	
EPI HI LET 1	0.15	
EPI HI LET 2	0.40	

Predictions (7/9)

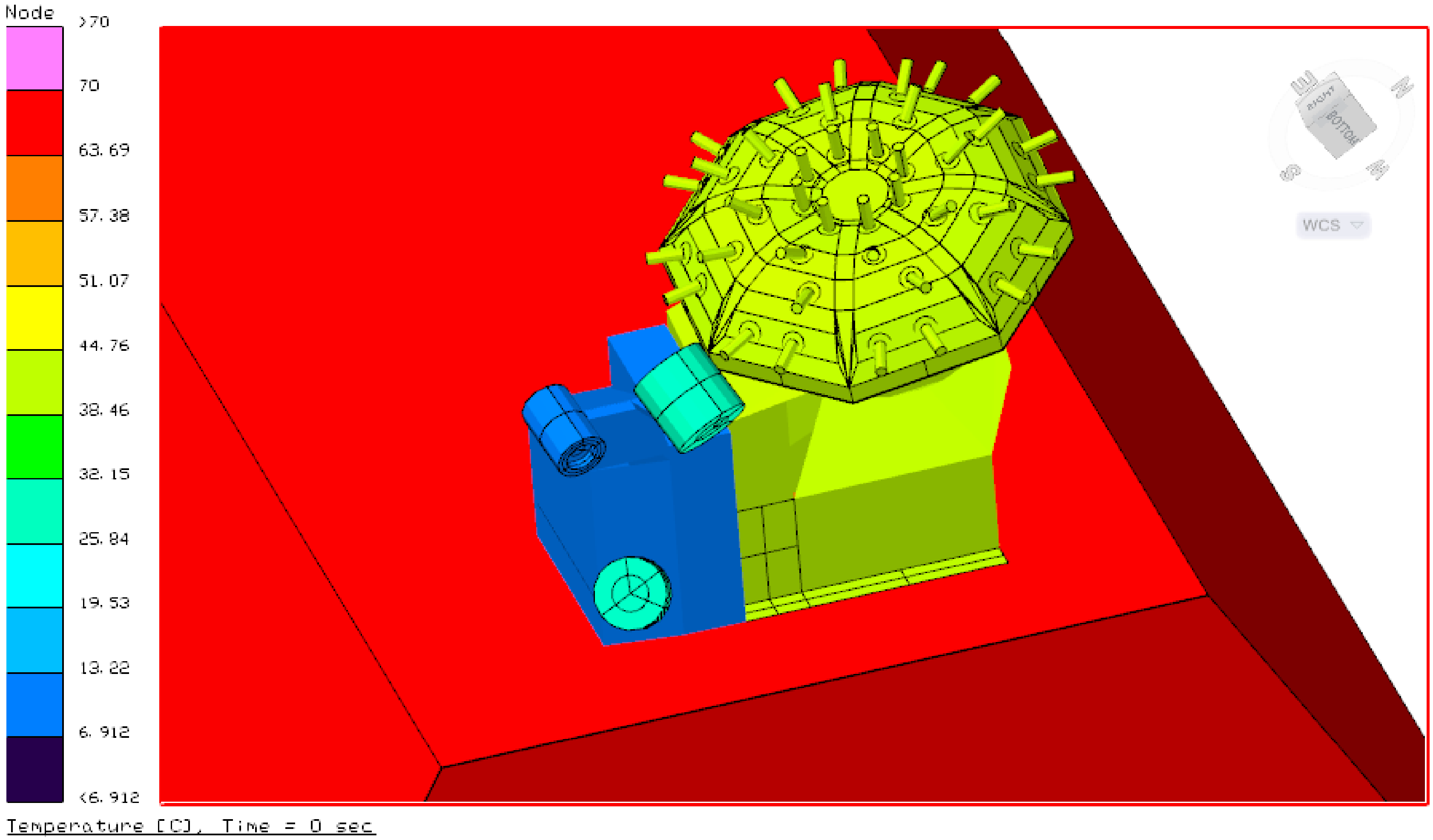
- ISIS Warm Up Temperatures



Component	Avg. Heater Power, W	
EPI LO	3.40	
EPI HI Ebox	4.26	5.37
EPI HI HET 1	0.35	
EPI HI LET 1	0.21	
EPI HI LET 2	0.55	

Predictions (8/9)

- ISIS Hot Non-Operational Temperature Plot



Predictions (9/9)

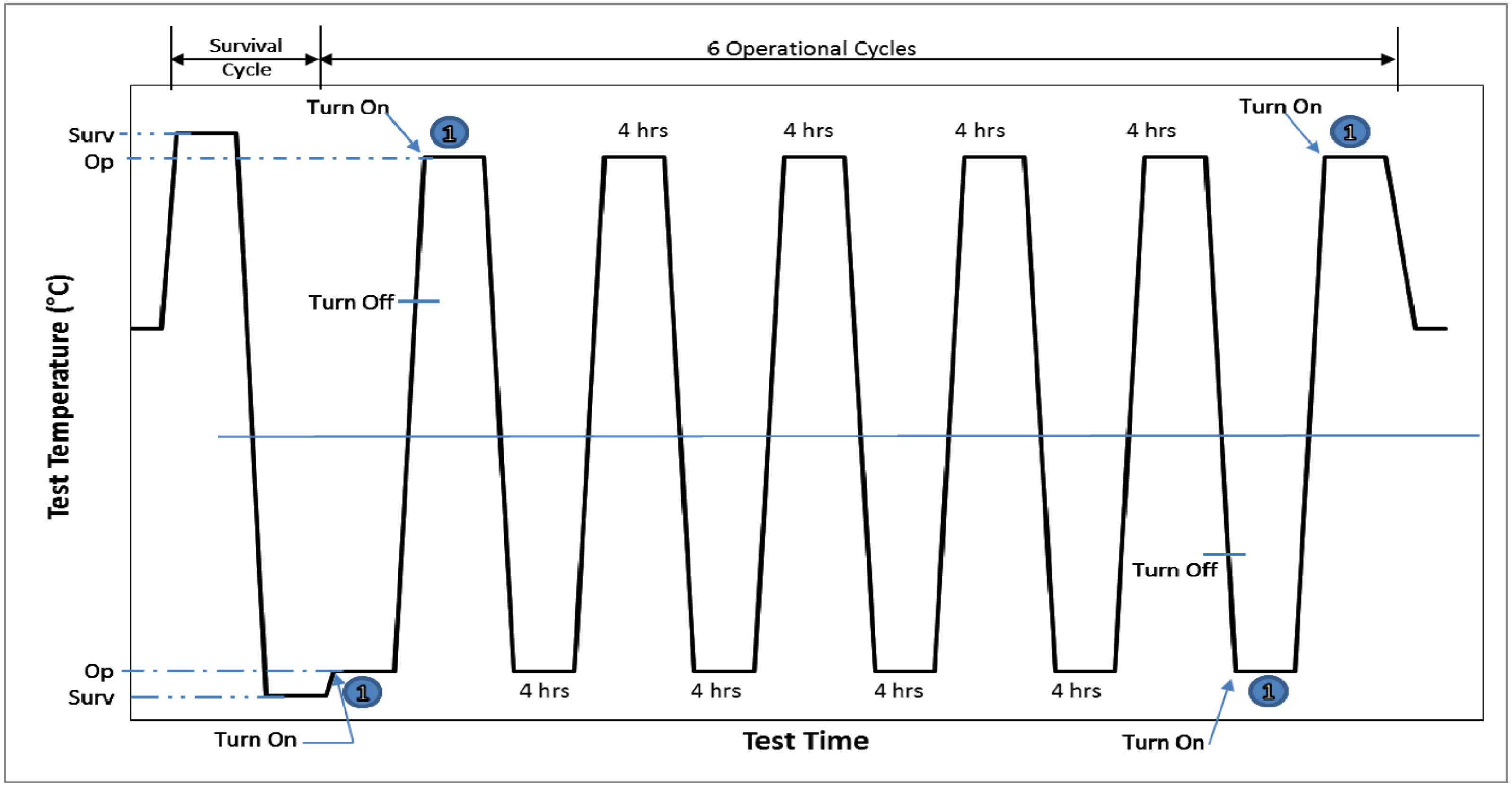
- ISIS Hot Non-Operational Temperature Table

Component	Hot Surv Predict, °C	Hot Surv Limit, °C	Margin, °C
IS_ISIS_TEL_HET	7.0	55.0	48.0
IS_ISIS_TEL_LET1	26.8	55.0	28.2
IS_ISIS_TEL_LET2	30.8	55.0	24.2
IS_ISIS_EPI_HI_BIAS	8.9	55.0	46.1
IS_ISIS_EPI_HI_DPU	9.1	55.0	45.9
IS_ISIS_EPI_HI_HET	8.9	55.0	46.1
IS_ISIS_EPI_HI_LET1	8.9	55.0	46.1
IS_ISIS_EPI_HI_LET2	9.1	55.0	45.9
IS_ISIS_EPI_HI_LVPS	9.2	55.0	45.8

Component	Hot Surv Predict, °C	Hot Surv Limit, °C	Margin, °C
IS_ISIS_EPI_LO_DETECTOR	42.5	55.0	12.5
IS_ISIS_EPI_LO_EVENT	42.2	55.0	12.8
IS_ISIS_EPI_LO_PWR_SUPPLY	42.1	55.0	12.9
IS_ISIS_EPI_LO_MCP	42.3	55.0	12.7
IS_ISIS_EPI_LO_ANODE	42.2	55.0	12.8
IS_ISIS_EPI_LO_DOME	42.7	55.0	12.3

Verification (1/2)

- ISIS Thermal Vacuum Profile
  - Six Operational Cycles
  - One Survival Cycle



Verification (2/2)

- ISIS Thermal Balance
  - Three Cases: Hot Operational, Cold Operational, and Cold Survival
  - Temperature Controlled Baseplate to S/C I/F Temperature Limits
  - Radiators with View to LN2 Cooled Chamber Shroud
  - Verify Heater Duty Cycle
  - Verify Interface Conductances
  - Correlate Thermal Model

Summary

Solar Probe Plus
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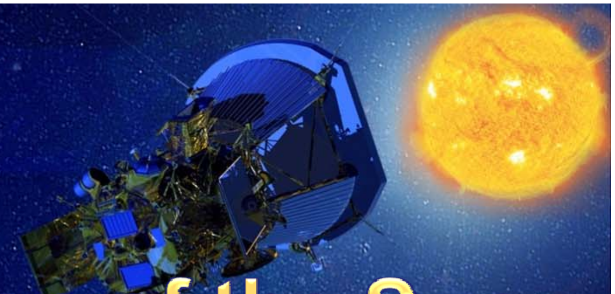
- Instrument Requirements (Temperature Limits) are Defined
- Thermal Environments and Interfaces are Defined
- Resources (Heater Power) have been Iterated and Baselined
- The Thermal Design Presented and Analyzed Meets all Requirements in the Specified Environments within the Allocated Resources

Solar Probe Plus

A NASA Mission to Touch the Sun



Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

Assembly, Integration, and Test

John Dickinson

ISIS SE (SwRI)

Outline

- EPI-Hi Assembly, Integration, and Test Flow
- EPI-Lo Assembly, Integration, and Test Flow
- EDTRD Test Levels:
  - Acoustic
  - Vibration
  - Thermal-Vacuum profile
  - Observatory Environmental Testing
- Summary

Typical Test Flow for Components and Instruments (EDTRD)

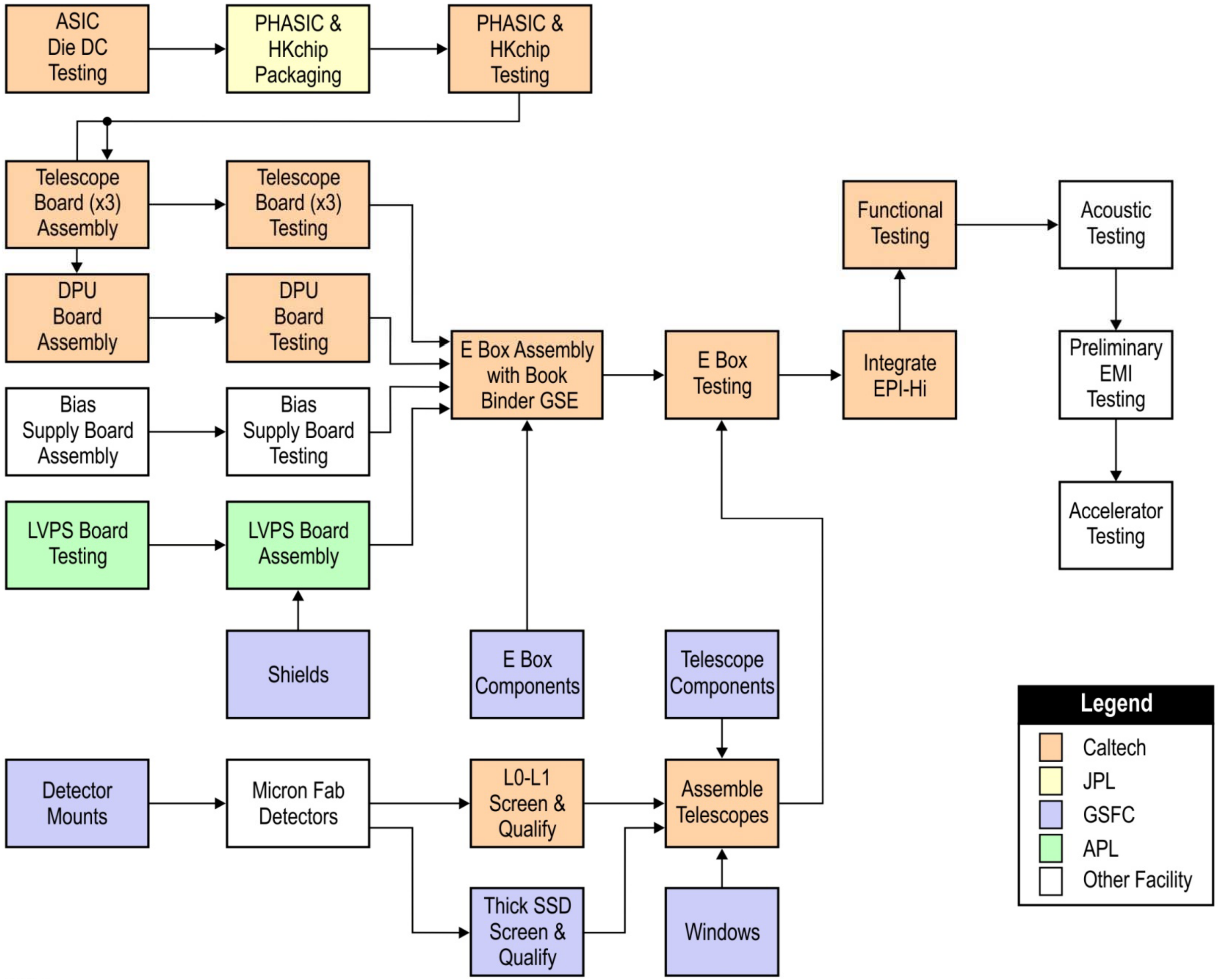
Test	Subsystem / Instrument Requirement
Magnetic Field (test magnetic hardware)	X[b]
Hermeticity (tanks, cooling system)	*
Comprehensive Performance Test	X
EMI/EMC	X
Initial Optical Alignment	*
Mass Properties	X[a]
Pre Vibration Survey	X
Sinusoidal Vibration	X
Random Vibration	X
Pressure Profile	
Shock (self induced)**	*
Acoustic	*
Strength	X
Post Vibration Survey	X
Deployments	*
Performance Test	X
Thermal Vacuum Balance	*
Thermal Vacuum Cycle	X
Bake-out	X
Final Optical Alignment	*
Comprehensive Performance Test	X

X Test is required

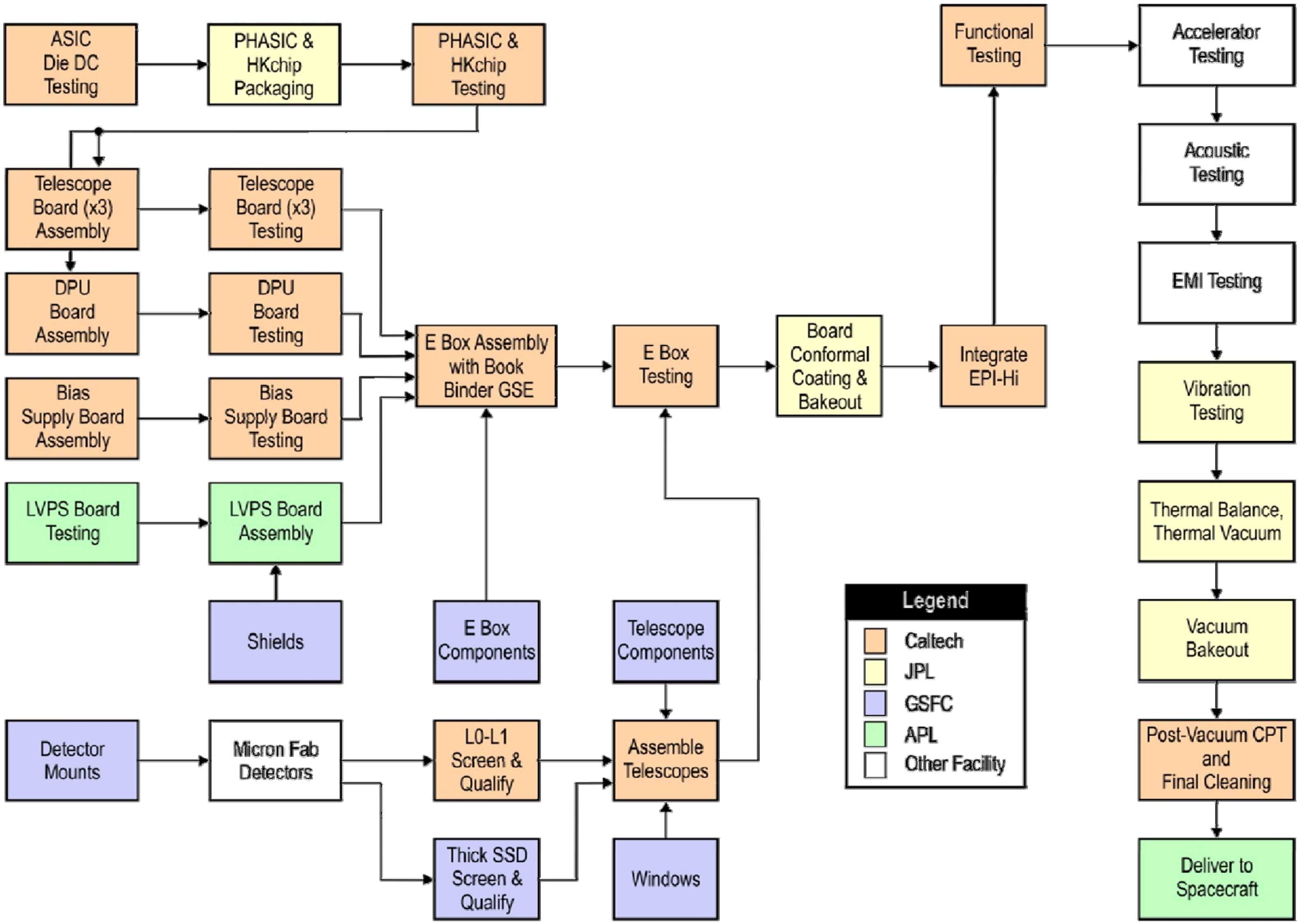
* Test is conditionally required, see relevant sections

Not Performed on ISIS

EM EPI-Hi Assembly, Integration, & Test

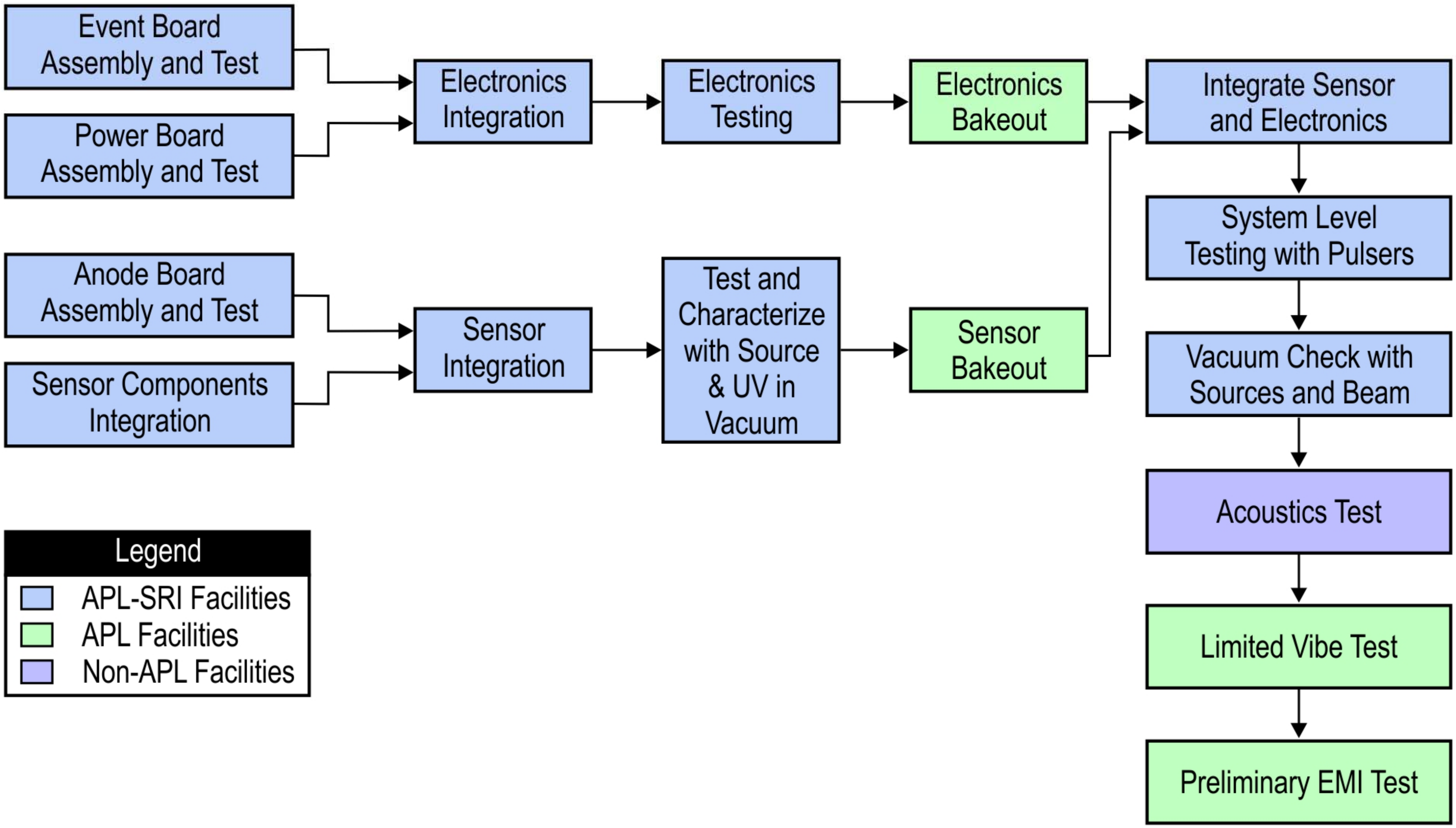


FM EPI-Hi Assembly, Integration, & Test



Performance Tests performed between Qualification Tests

EM EPI-Lo Assembly, Integration, & Test



FM EPI-Lo Assembly, Integration, & Test

Solar Probe Plus
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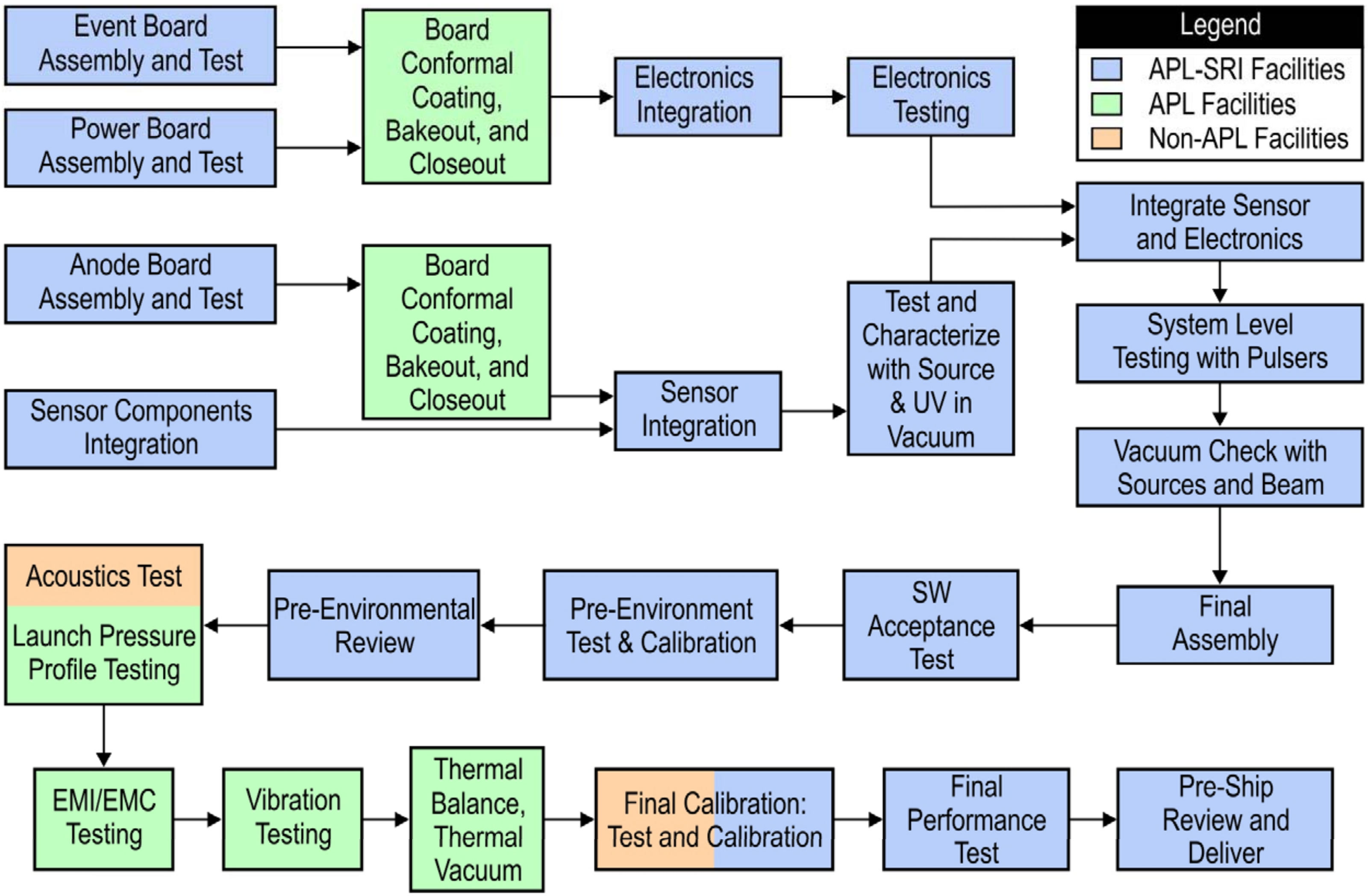
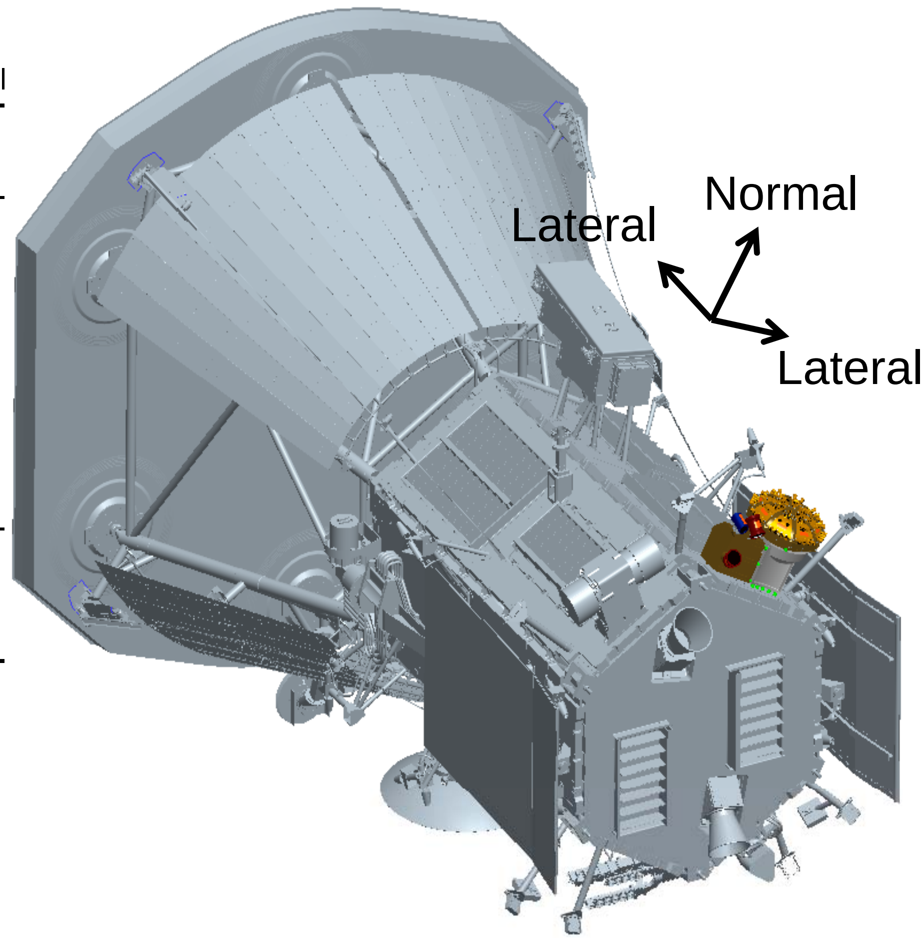


Performance Tests performed between Qualification Tests

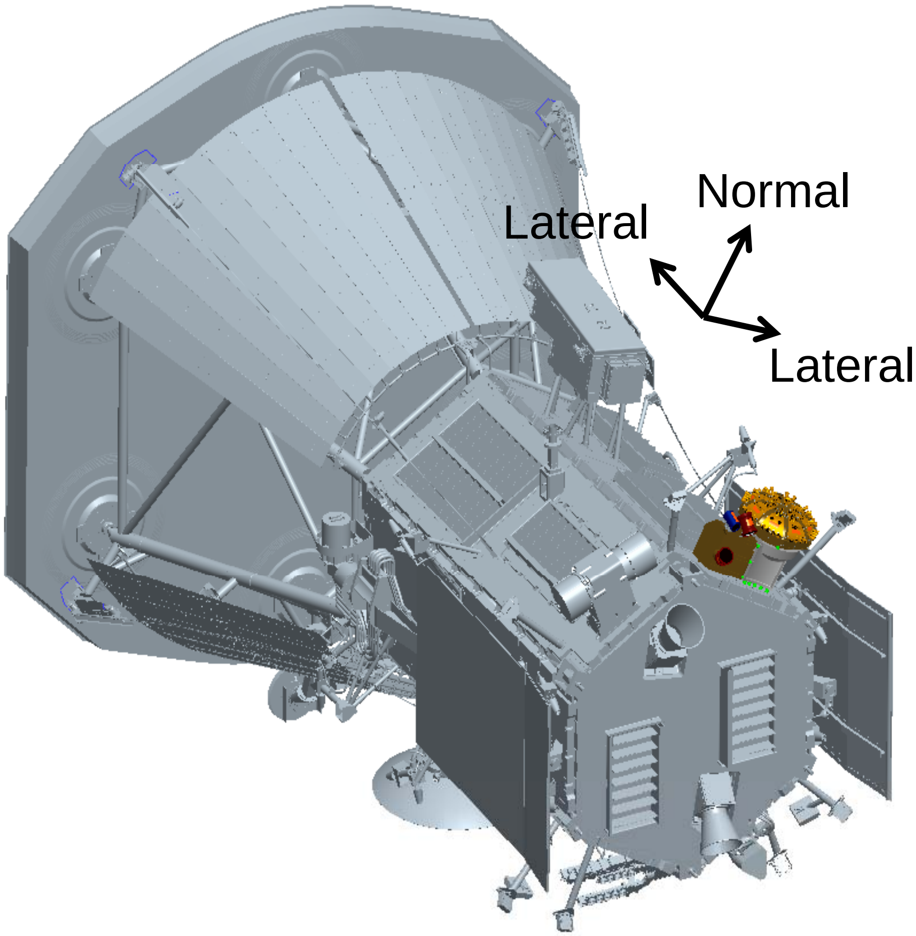
Normal Vibration Levels

Side Panels Mounted Components & Subsystems Normal To Panel

Frequency (Hz)	Qualification (G^2/Hz)	Protoflight (G^2/Hz)	Acceptance (G^2/Hz)
20	0.01	0.01	0.01
60	1.25	1.25	0.63
200	1.25	1.25	0.63
350	0.04	0.04	0.04
500	0.04	0.04	0.04
2000	0.01	0.01	0.01
Overall Grms	16.4	16.4	12.6
Duration (mins)	2	1	1



Lateral Vibration Levels



Side Panels Mounted Components & Subsystems Lateral To Panel

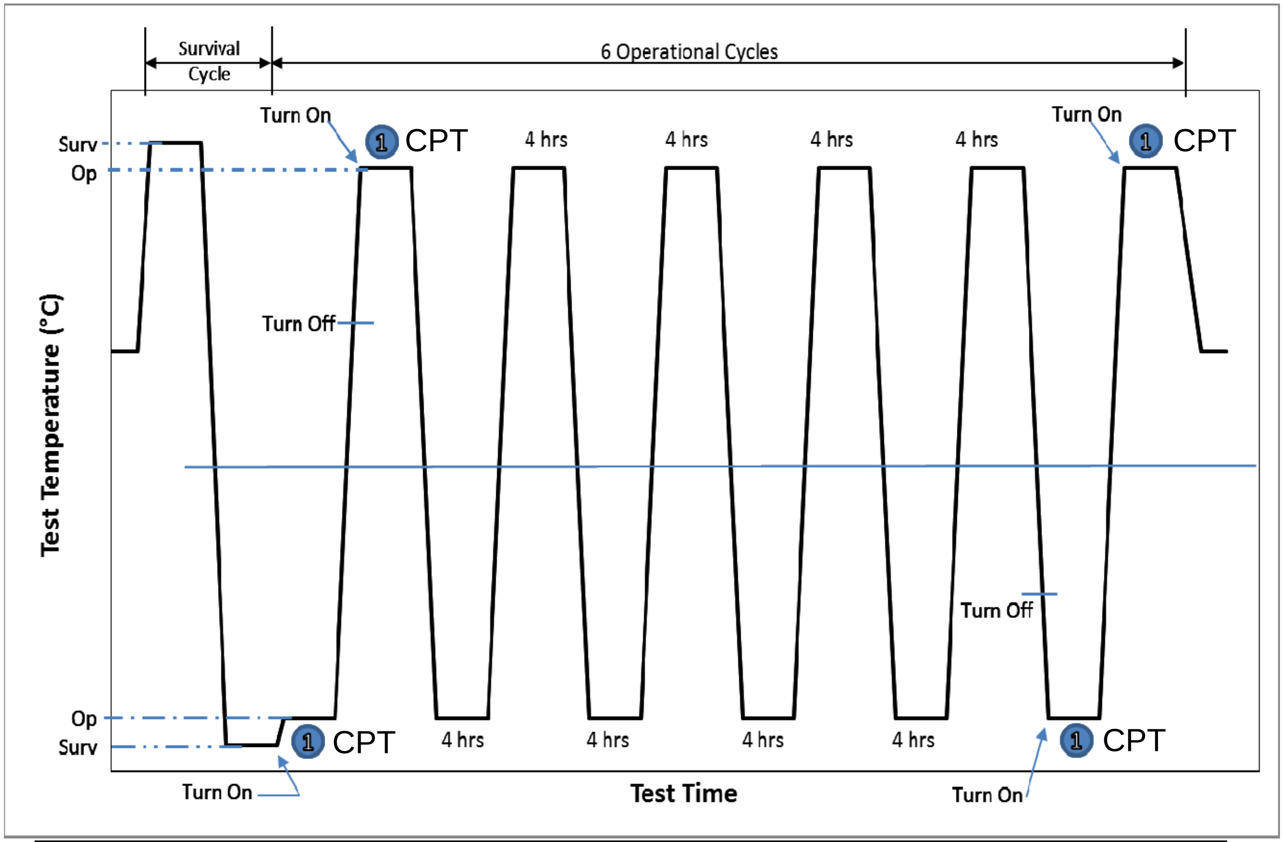
Frequency (Hz)	Qualification (G^2/Hz)	Protoflight (G^2/Hz)	Acceptance (G^2/Hz)
20	0.01	0.01	0.01
35	0.04	0.04	0.04
500	0.04	0.04	0.04
2000	0.01	0.01	0.01
Overall Grms	6.8	6.8	6.8
Duration (mins)	2	1	1

Acoustics Levels

Table 7-2. Acoustic Flight Levels

1/3 Oct Center Freq (Hz)	MEFL (dB)	1/3 Oct Center Freq (Hz)	MEFL (dB)
32	123.0	630	120.5
40	124.8	800	119.1
50	126.2	1000	117.8
63	127.5	1250	116.4
80	128.3	1600	115.0
100	128.8	2000	113.6
125	129.0	2500	112.3
160	128.7	3150	110.9
200	127.5	4000	109.5
250	126.0	5000	108.1
315	124.3	6300	106.8
400	123.3	8000	105.4
500	121.9	10000	104.0
		OASPL	138.1

Thermal Vacuum Test Cycles



Instrument Subsystem	Design / Test Operating Temperture Range (C)	Non-op Survival Temperature Range (C)	Survival Heater Equivalent Resistance (Ohms)	Operational Heater Equivalent Resistance (Ohms)	Set Point Temperature Range (C)
EPI-Hi	-25 / +30	-40 / +50	87	1056	-35 to -32
EPI-Lo	-30 / +35	-45 / +50	121	---	-40 to -37

Observatory Environmental Testing

Table 2-3. Typical Test Flow for Observatory

Typical Test Flow for Observatory Test	Observatory Requirement
Magnetics (each box before integration on S/C)	X
Baseline Comprehensive Performance Test	X
EMI/EMC[1]	X
Initial Mass Properties	X
Initial Optical Alignment	X
Pre & Post Vibration Survey	X
Sinusoidal Vibration	X
Acoustic	X
Modal Survey	X
Strength	X
Deployments (N/A for ISIS)	X
Comprehensive Performance Test	X
End-to-End Test[2]	X
Spacecraft Magnetic Swing Test	X
Thermal Vacuum Balance	X
Thermal Vacuum Cycle	X
Comprehensive (functional) Performance Test (hot during TV)	X
Comprehensive (functional) Performance Test (cold during TV)	X
Mission Simulation (during TV)[2]	X
Comprehensive Performance Test[3]	X
Final Optical Alignment	X
Final Mass Properties	X

X Test is required

Summary

- EM is used as a pathfinder for FM integration and test
- Selected EM environmental testing provide risk reduction
- FM unit undergoes instrument level environmental testing to EDTRD levels
- EM is used for command and procedure testing after FM delivery to spacecraft and to support commanding activities after launch

Solar Probe Plus

A NASA Mission to Touch the Sun

Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

Flight Operations

Eric Christian

ISIS Deputy PI (GSFC)

Outline

- Initial commissioning
- Nominal operations
- Instrument command loads
- Instrument autonomy requirements
- Flight operations staffing
- Off-nominal operations
- Summary

Initial Commissioning

- EPI-Hi turns on first (EPI-Lo needs two week out-gassing period)
- ISIS Statistics Gathering and Threshold Scans
  - Analysis parameters will be tuned with pre-flight calibrations, but it is likely that some fine-tuning will be required
  - After initial instrument turn on and checkout it is important that the ISIS instruments gather as much data as possible (especially raw event data)
  - Threshold scans will be required to determine optimal threshold values
  - EPI-Lo does not need to be on continuously
- ISIS EPI-Lo and EPI-Hi Table Loads and/or Software Updates
  - Table updates expected (adjustment of flux box bins) 3 weeks into statistic gathering period
  - Software updates might be needed
  - Based on STEREO experience, EPI-HI will require ~10 opportunities (on separate days) to send commands in the first two months
  - Necessary to obtain/analyze at least a few hours of new data in between command opportunities to test whether the commands worked
  - Therefore, need to collect data between commanding opportunities

Nominal Operations

EPI-Hi and EPI-Lo operate the same whenever powered-on except for the volume/content of the data sent to the S/C inside/outside 0.25 AU

- **Spacecraft- Sun Distance R<0.25 AU (Normal Science Mode)**
  - Full nominal power
  - High data collection rate
  - Burst data (EPI-Lo)
- **Spacecraft- Sun Distance: 0.25 AU < R (Low-rate Science Mode)**
  - Full power whenever possible
  - Reduced data collection rate (fits within ISIS telemetry allocation)
  - Commanding window should be scheduled late in the series of telemetry passes, although it may not be used every orbit
  - Minimize power cycling the HV supplies

Instrument Command Loads

- Commanding of EPI-Hi and EPI-Lo
  - “Flat-Sat” at UNH used to test command loads
    - Development of Flat-Sat will be Phase D work
    - Constraint Checking Modules
  - Standard Commanding performed via GSEOS at UNH SOC
  - Commissioning and Contingency response, commanding may optionally be done by EPI-Hi and EPI-Lo via GSEOS directly through MOC
- Planning for instrument operations
  - Planning software
    - Automated routines and templates for initial planning
    - Interactions with ISIS SOC interfaces for finalization of planning
  - Develop rough plans three orbits ahead
    - Test command load
  - Develop definitive plans one orbit ahead
    - Final testing
    - Upload

Autonomy

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- Instrument Autonomy requirements considerably more than in initial SPP proposal and more than EPI-Hi has experienced in previous missions
- Main additional requirement is the ability to record the instrument state and return to that state autonomously after instrument power cycling, due to either s/c telemetry time periods or anomalous safing of instrument
- ISIS will implement operational mode changes via instrument autonomy logic supplemented by a macro capability

Flight Operations Staffing

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- FLEXIBLE
  - variability of telemetry and commanding requires flexible staffing
- Priorities (in order)
  - Analysis of health and safety housekeeping
  - Analysis of snapshot science data to determine interesting time periods (relayed to other SPP instruments) and science optimization
  - Full analysis of science data and generation of data products

Off-nominal Operations

- Plan to avoid them

- Small amounts of critical housekeeping will give team a heads-up
- Instruments designed to dump diagnostic data when possible
- “Deep bench” of scientists and engineers with many years of experience to draw from

- ISIS will work with the SPP operations team to do what is necessary to prudently diagnose issues and bring instruments back to nominal operations

Summary

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- ISIS Instrument operation modes designed to reduce complexity
- Autonomous instrument operations simplify SPP spacecraft operations
- ISIS team will develop all of the processes necessary to verify commanding and provide safe and efficient instrument operations

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Ground Support Equipment

Reid Gurnee

EPI-Lo SE (JHU/APL)

Outline

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- Board Level GSE
- Spacecraft emulators
- GSEOS
- Safe / Arm plugs
- Calibration GSE
- Mechanical GSE
- Summary

Board-Level GSE (EPI-Lo)

- Each EPI-Lo lead engineer is responsible for developing their own board-level GSE
  - **Power Board**: Load board, active load, HV load, breakout box, breakout board, I2C stimulus
  - **Event Board**: energy and TOF preamp boards, test port box, breakout box, I2C slave, commercial pulsers
  - **Anode Board**: Commercial pulsers, scope, HV power supply
- All GSE is peer reviewed. Custom GSE is calibrated as needed.

Board-Level GSE (EPI-Hi)

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- EPI-Hi engineering team develops a board-level GSE for Caltech-designed boards that can be shared between boards based on common subsystems (MISC, I/F to a PC)
- Test procedure written for each board, all GSE calibrated
- EPI-Hi subcontractors develop their own board-level GSE for LVPS and Bias Supply
- EPI-Hi mechanical GSE holds the rigid-flex board stack in binder style, allowing individual boards to “open” like book pages for testing before installation into the flight E-box.

Spacecraft Emulator

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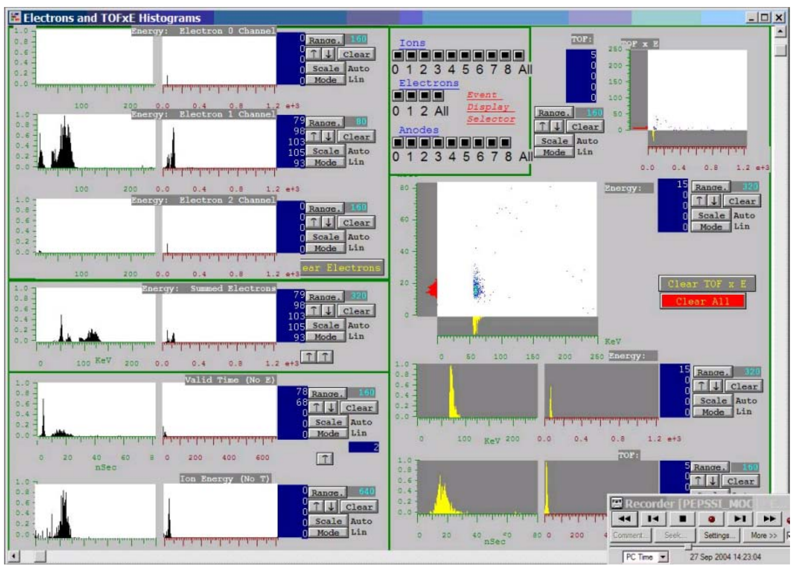
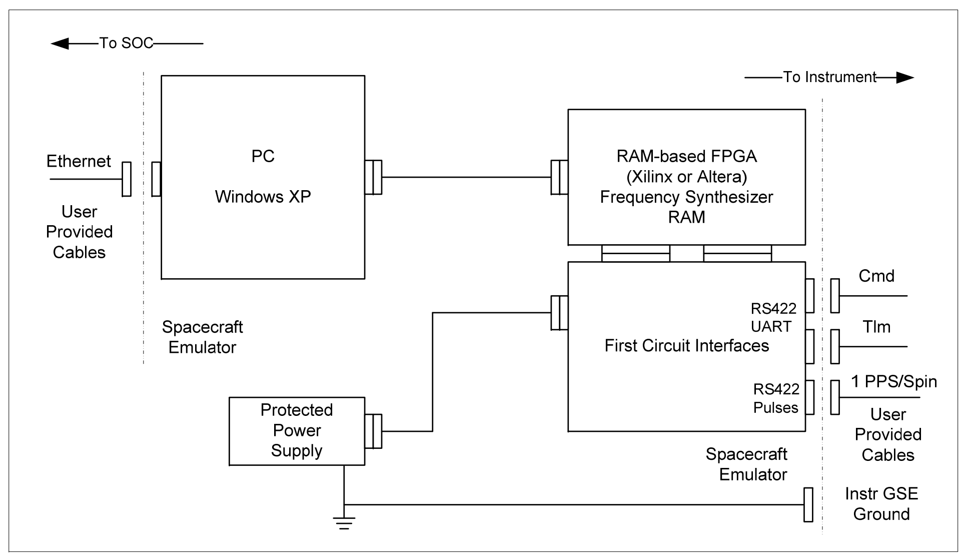
- Mini emulator
  - Provides Instrument Data Interfaces only, No Power Interfaces, No Temperature Interfaces
  - Provides virtual 1PPS
  - GSEOS Interface is fully compliant
  - Non-flight use only
- Full emulator
  - Provides Instrument Data, Power and Temperature Interfaces (no power supply)
  - Provides virtual 1PPS
  - Designed for use with flight hardware
- GSE verification performed by project
- Spacecraft Emulator Deliveries to ISIS
  - Mini: (2 for EPI-Hi; 1 for EPI-Lo)
    - SN 3 : ISIS-EPI-HI Delivered on 6/28/13
    - SN 7 : ISIS-EPI-HI Delivered on 7/16/13
    - SN 10 : ISIS-EPI-Lo Delivered on 7/11/13
  - Full: (2 for EPI-Hi; 1 for EPI-Lo)
    - April and May 2014

GSEOS

- Common GSE software for all instruments
- Display screens and instrument customizations can be used through all development cycles from bench testing, I&T deployment, to flight operations
- Same platform used for EM, Flight, and Spacecraft operations
  - Test scripts can be developed by individual teams, tested on EMs, and then executed at the S/C level
- Software verification performed by project





Safe / Arm Plugs

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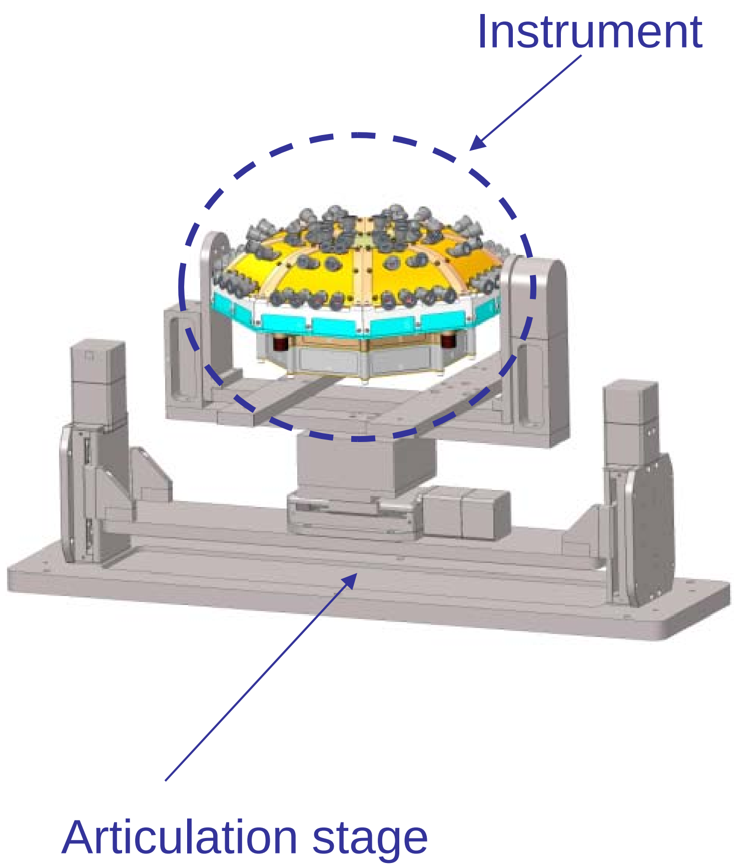
- EPI-Lo has a HV air-safe plug
  - When installed HV is limited to air safe levels (hardware and software limited)
  - Plug will be removed for S/C TV testing
  - Plug will be permanently removed during final closeout
- Instrument covers
  - ISIS instruments will have red-tag covers to protect the apertures
  - Covers will be temporarily removed for S/C TV testing
  - Covers will be permanently removed during final closeout

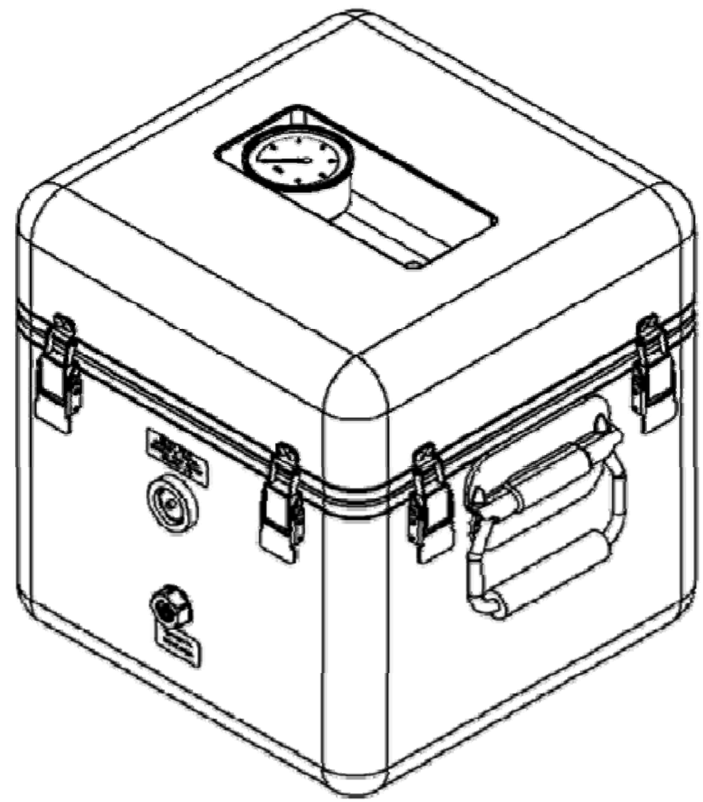
Calibration GSE for Instrument Articulation (EPI-Lo)

- Requirements
  - Use in APL accelerator facility
    - Vacuum compatible (low outgassing)
  - Cover full FOV for one octant
- Status
  - Specified and purchased custom system from Newmark Systems
  - Received January 2009
  - Re-furbished in 2012 at Newmark. Added additional controller and position sensor feedback on all motors
  - Fully set up in vacuum chamber with all feed-throughs and control software
- Future Work
  - Build adaptor plate for EPI-Lo
  - Test with mass prototype



Mechanical GSE

- Shipping Container
  - Requirements
    - N2 purged, humidity controlled and monitored
    - Low outgassing
    - Shock mounted and monitored
    - Hermetically sealed with pressure relief valve
- Purge Suitcase
- Environmental Test Fixtures
  - Thermal Vacuum Fixture
  - Vibration Plate Fixture



Summary

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- GSE highly leveraged from previous programs
- Most EPI-Lo GSE is built and ready for instrument testing
- GSEOS and spacecraft emulator from SPP project reduces risk and advances the instrument-development process

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Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

Verification

Nigel Angold

ISIS Systems Engineering (SwRI)

Outline

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- Documentation
- Verification Process Definition
  - Verification Program Concept
  - Verification Program Planning
  - Verification Methods
  - Requirements Verification Matrix
  - Verification Process
- Performance Requirements
- Environmental Requirements
- Interface Requirements
- Assurance Requirements
- Verification Summary

Documentation

SPP System Verification and Validation Plan, 7434-9099

ISIS Verification and Validation Plan, 16105-ISIS_VVP-01

- These documents define the Verification Process:
  - Verification Program Concept
  - Verification Program Planning
  - Verification Methods
  - Requirement Verification Matrix
  - Verification Process

Verification Process Definition (1/8)

Verification Program Concept:

- ISIS instrument requirements verification is part of the overall SPP verification campaign.
- EPI-Lo requirements will be verified by APL.
- EPI-Hi requirements will be verified by Caltech.
- Tracking of all ISIS requirements verification will be performed by the ISIS Systems Engineer, reporting to the SPP Requirements & Verification Engineer.

Verification Process Definition (2/8)

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Verification Program Planning:

- Verification and Validation Plans produced before PDR.
- Test and Calibration Plans, inputs for I&T produced before CDR.
- Test, Verification and Calibration reports generated throughout all pre-launch phases.

Verification Process Definition (3/8)

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Verification Methods:

- **Test**
  Most requirements should be verified by test or supported by quantitative test data.
- **Analysis**
  Some requirements cannot be verified by test (e.g. due to cost or physical limitations) or may not be fully verifiable by testing alone.
- **Demonstration**
  Applied to some qualitative requirements that cannot be easily tested or requirements that cannot be tested over a full range of relevant scenarios.
- **Inspection**
  Used to verify a design characteristic or method or where a requirement may be satisfied solely by the review of documentation.

Every requirement must be verified by one or more of the above methods.

Verification Process Definition (4/8)

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Requirement Verification Matrix:

- Tracking of verification by means of matrices containing:
  - Requirement Reference Number
  - Requirement Description
  - Verification Method: one or more of Test, Analysis, Demonstration and Inspection
  - Verification Activity
  - Closure Status: Closed, Open, Waived, Deferred, etc.
  - Closure Date
  - Responsible Organization
  - Comments

Verification Process Definition (5/8)

Example Verification Matrix entries from ISIS IRD:

Req. #	Requirement	Verification Method (1)	Verification Activity	Closure Status (2)	Closure Date	Responsible Organization	Comments
ISIS-100	The EPI-Lo instrument shall provide measurements of energetic electrons with an energy range of <=0.05MeV to >=0.5MeV.	Analysis & Test	Simulation and spot test using radiation sources.				
ISIS-110	The EPI-Lo instrument shall provide measurements of proton and heavy ion angular distributions using sectors of width ≤30°.	Analysis & Test	SIMION analysis and test. Test in accelerator with articulation stage.				
ISIS-123	The EPI-Lo instrument shall comply with maximum mass constraints, as specified by the SPP to ISIS ICD, 7434-9058	Test	EPI-Lo mass measurements				
ISIS-207	The EPI-Hi instrument shall be capable of measuring protons and heavy ions with at least 6 bins per decade.	Analysis & Test	Test pulser measurements and Monte Carlo simulations with spot checks using accelerator beams.				
ISIS-218	The EPI-Hi instrument shall have ≥π/2 unobstructed field of view (FOV) in both sunward and anti-sunward hemispheres for the measurement of energetic protons/heavy ions including coverage within 10° of the spacecraft-Sun line, subject to the constraints and FOV obstructions specified in the SPP to ISIS ICD, 7434-9058.	Analysis & Inspection	Analyze obstructions using CAD model and inspect mounting on the spacecraft after integration to verify the accuracy of that analysis.				
ISIS-224	The EPI-Hi instrument shall comply with maximum power constraints, as specified by the SPP to ISIS ICD, 7434-9058.	Test	EPI-Hi CPT				
ISIS-350	The ISIS instruments shall be capable of implementing real-time commands via CCSDS packets in files uplinked via CFDP, as defined in the MOC to SOC ICD, 7434-9078.	Test	ISIS instrument CPTs				
ISIS-356	The ISIS instruments shall be capable of providing real-time instrument health and status data in telemetry formats specified by the SPP to ISIS ICD, 7434-9058, when required by mission operations for routine monitoring of housekeeping data and status.	Test	ISIS instrument CPTs				

(1) Verification Method: Test, Analysis, Inspection or Demonstration. (2) Closure Status: Open, Closed, Waived or N/A

Currently tracking 82 instrument requirements in the IRD Verification Matrix

Verification Process Definition (6/8)

Verification Process:

- Development of Verification Procedures
  - Procedures approved by the design engineer, the systems engineer, the project manager, and QA and released prior to execution.
  - They will comply with the format requirements and configuration control authority of the originating agency (APL, Caltech, or SwRI).
- Performance of Test Readiness Reviews
  - Required before installing flight hardware into a test environment.
- Test Execution
  - Test engineer assigned
  - QA participation
  - Equipment calibrated before test
  - Test procedures under document control

Verification Process Definition (7/8)

Verification Process continued:

- Post-test Reviews
  - Test results are reviewed and approved by the ISIS SE to ensure adequate verification of requirements.
  - All hardware non-conformances or failures shall be documented.
  - Any corrective actions identified shall be processed by the cognizant engineer and elevated as appropriate.
  - For any test failure, the reason must be identified.
  - Hardware under test / test setup must not be disturbed in any way that prohibits duplication of a test failure.
  - The post-test review will result in a "pass" or "fail".
- Completion of the Verification Matrix
  - Verification is tracked by entering data into the Verification Matrix.

Verification Process Definition (8/8)

Verification Process continued:

- Requirement Closure
  - A requirement will be declared “closed” when all verification activities planned for the requirement have been completed satisfactorily.
- Waivers and Deviations
  - In cases where it may be acceptable that a requirement is not met, a waiver or deviation will be filed with the JHU/APL SPP Project Office, and NASA Goddard Program Office, as appropriate.
  - The SPP waivers and deviations process is documented in the SPP Configuration Management Plan, 7434-9006.
  - All hardware non-conformances or failures shall be documented.

Performance Requirements

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Performance requirements are defined in:

- Level 1 Requirements for the Solar Probe Plus Mission
- SPP Mission Requirements Document (Level 2), 7434-9047
- SPP Level 3 Payload Requirements Document (Level 3), 7434-9051
- ISIS Instrument Requirements Document (Level 4), 16105-ISIS-IRD-01

Level 2 - 4 documents:

- Each document contains a Requirement Verification Matrix.
- Level 2 and 3 verification typically inspection of documention verifying lower level requirements found in the ISIS IRD.
- ISIS Systems Engineer will flow verification data up to the appropriate document owners.
- The Requirement Verification Matrix is maintained as an Excel spreadsheet that the SPP Requirements & Verification Engineer uses to import data into the SPP System Requirements Database, DOORS.

Environmental Requirements

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Environmental requirements are defined in:

- SPP Contamination Control Plan, 7434-9011
- SPP Environmental Design and Test Requirements Document, 7434-9039
- SPP Electromagnetic Environment Control Plan, 7434-9040

Environmental requirements documents:

- Each document contains a Requirement Verification Matrix.
- ISIS Systems Engineer will flow verification data up to the appropriate document owners.

Interface Requirements

Interface requirements are defined in:

- SPP to ISIS ICD, 7434-9058
- SPP General Instrument to Spacecraft ICD, 7434-9066
- MOC to SOC ICD 7434-9078

Interface requirements documents:

- Each document contains a Requirement Verification Matrix.
- ISIS Systems Engineer will flow verification data up to the appropriate document owners.

Assurance Requirements

Assurance requirements are defined in:

- SPP Product Assurance Implementation Plan (PAIP), 7434-9003
- EPI-Lo Product Assurance Implementation Plan (PAIP), 7464-9001
- EPi-Hi Product Assurance Implementation Plan (PAIP), CIT-SPP-004

Assurance requirements documents:

- Each document contains a Compliance Matrix
  - Comply
  - Do not Comply
  - Comply with Caveats
  - N/A
- The SPP System Assurance Manager is responsible for verification of Assurance requirements.

Verification Summary

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- ISIS has a clearly defined Verification Process that is documented in the ISIS Verification and Validation Plan.
- Requirement Verification Matrices will be used to track Performance, Environmental and Interface Requirements.
- Assurance Requirements will be tracked using Compliance Matrices.

Solar Probe Plus

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Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

EPI-Lo Calibration

Don Mitchell

EPI-Lo Scientist (JHU/APL)

Outline

- Overview
- Species and Energy Ranges
- Facilities
- Calibration Plan
- Test Flow
- In-Flight Calibration

EPI-Lo Calibration

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- EPI-Lo measurements are intended to generate the information needed to derive differential intensities (j[cm^2 -sr-s-keV]$^{-1}$)
- The goal of EPI-Lo characterization and calibration efforts is to develop the quantitative procedures for converting the count rates (R [counts s^{-1}]) reported by EPI-Lo into estimates of j for the various defined ranges of energies, particle species, and arrival angles
- “Calibration” for a particle instrument like EPI-Lo means determining the following:
  - Transfer function from counts into flux (physical units)
  - Characteristic of “Rate-in” versus “Rate-out”
  - Response to visible and ultraviolet light
  - Response to high energetic particle backgrounds

Calibration Types

- Foreground
  - Ions and electrons in the energy range of interest to the instrument
- Background
  - Electrons
  - Characterize the rates from penetrating radiation
  - Characterize response to Solar Wind and/or photoelectron impact
- Light
  - Characterize rejection of UV background, primarily H-alpha
  - Characterize rejection of sunlight and glint

Foreground Calibration Requirements

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- Foreground Electrons
  - 40 keV to 1000 keV (Needed for understanding backgrounds)
    - 1 keV to 30 keV — Electron Gun at APL
    - 30 keV to 100 keV — Radioactive sources at APL
    - 125 keV to 1.6 MeV — Accelerator at GSFC

- Foreground Ions (H, He3, He4, O, Fe)
  - 40 keV to 15000 keV (Level 4 Requirements)
  - (Goal: protons to 20 MeV)
    - 3 keV to 170 keV — Accelerator at APL
    - 30 keV to 5 MeV — Degraded alpha sources
    - 125 keV to 1.6 MeV — Accelerator at GSFC
    - 1 MeV to 20 MeV — Accelerator at LBL

Test as You Fly

- The instruments will be tested in flight-like environments
- Since the instrument will need to operate in a high background environment, we will characterize response to high energy penetrating radiation, UV light, and low energy plasma (all potential sources of background counts for EPI-Lo)

Background Calibration Requirement

- Background Electrons
  - 2 eV to 10 MeV (from the expected environment)

1 eV to 100 eV	Hot filament at APL
1 keV to 50 keV	Electron Gun at APL
125 keV to 1.6 MeV	Accelerator at GSFC
1 MeV to 10 MeV	Accelerator at Idaho

- Background Ions
  - 3 keV to 50 MeV (from the expected environment)

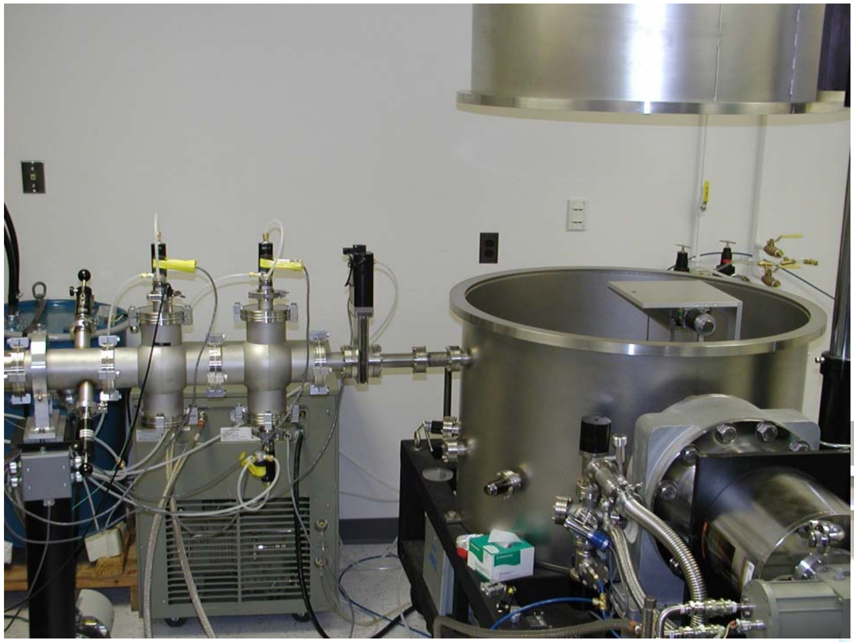
3 keV to 170 keV	Accelerator at APL
30 keV to 5 MeV	Degraded alpha sources
125 keV to 1.6 MeV	Accelerator at GSFC
1 MeV to ~100 MeV	Accelerator at LBL

- Photons
  - UV and visible lamps at APL

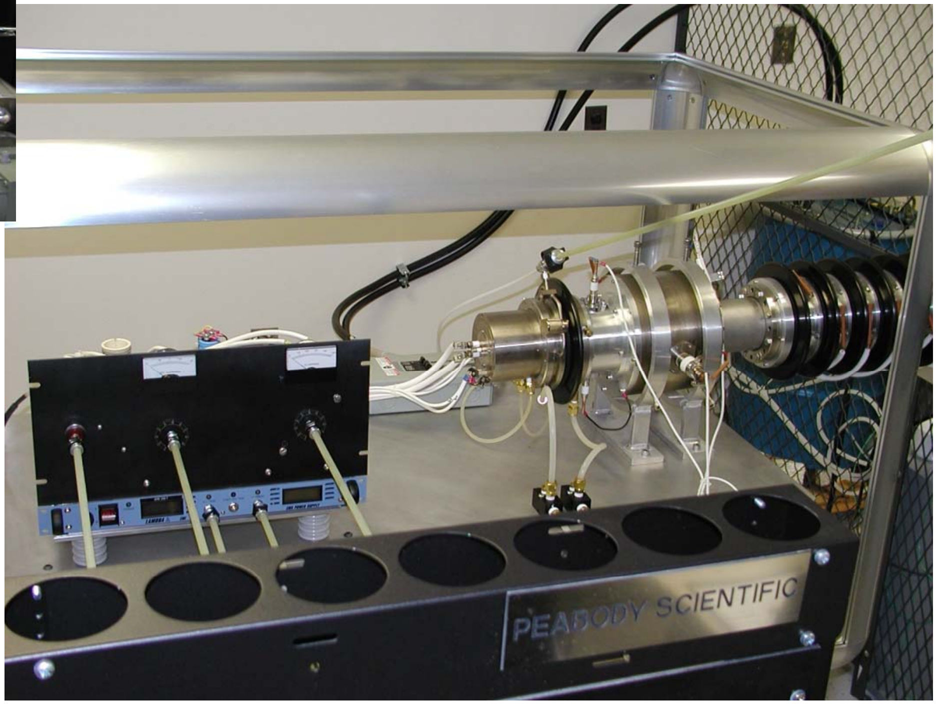
The JHU/APL Calibration Facility

- The APL particle accelerator is a versatile system capable of producing a broad range of ion species at energies from 20 to 170 keV
- The system includes an electron-impact ionization source, extraction gap, Einzel Lens and Wien filter mounted in the insulated terminal structure along with all associated power supplies
- The system will produce beams of H, He, O, and noble gas ions with intensities over the range of 100’s to 1,000,000 particles/cm^2/sec at the target position (mm^2 - cm^2)
- We also have a variety of radioactive sources as stimulus

The JHU/APL Calibration Facility



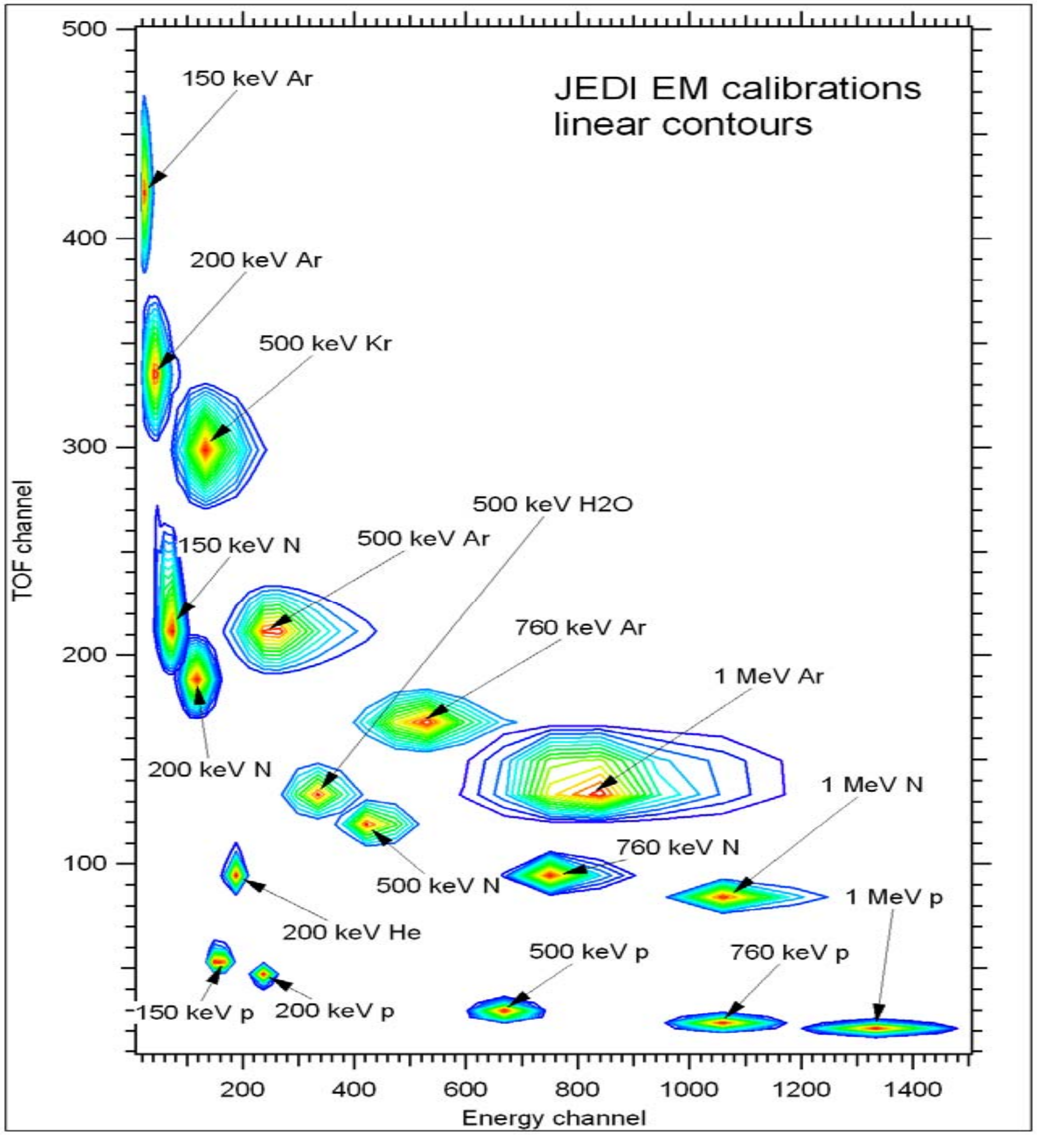
- All ions from a gas source
- Energy continuously tunable: 3 to 170 kV
- Wien filter
- Beam intensity between 10 and 10^{10} ions/cm^2/s
- Purposed built articulation stage



Beam Tests at GSFC

- It is planned to have four calibration sessions at the accelerator at the Goddard Space Flight Center. Each session starts with a one-day setup, check, and pump:
- Session 1: Exploratory run to characterize EPI-Lo
- Session 2: Use H beam to scan both angles to complete characterization of the transfer function
- Session 3: Characterize sensor response with e-beam from ~100 keV to 1 MeV
- Session 4: Use heavy ions (He, O, and Ar) to characterize the instrument response

Representative Results from JEDI Cal.



EPI-Lo Test Summary

- Prototype “EM” Testing
  - Validate instrument design and performance
    - Energy response
    - Instrument efficiency
    - Instrument geometry factor
  - Establish testing procedures
- Flight Model (FM)
  - Verify instrument design and performance
    - Energy response
    - Instrument efficiency
    - Instrument geometry factor

Calibration Approach (Flight Units)

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- FM Unit
  - All instrument integration activities will be performed in a Class 5 clean room environment
  - Test in bell jar to characterize geometry, energy response, and sensitivity
  - Calibrate using particle sources and in Beam Facilities at APL to characterize energy response, sensitivity, dynamic range
  - Compare with EM results to cover gaps in energy coverage
- Test Philosophy:
  - FM will be extensively calibrated, and performance compared with more extended energy range EM calibrations (LBL, GSFC)
  - Pre- and post-environmental qualification spot calibration
  - In-flight cross calibration between EPI-Lo and EPI-Hi

EPI-Lo Calibration Schedule

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- Final calibration for FM slated for three weeks
- Major calibration efforts will be performed at APL facility
  - Substantial understanding of the instrument performance will be made with the EPI-Lo EM characteristics

Tests at Instrument Level

	Element	Property	Requirement*	Expected Performance	Calibration Accuracy
System Level	**Calibration mode without Collimator**	Energy-ToF plane characteristic	Verify simulation to 20%	Verify simulation to 5%	5%
		Input/output rate at system level	Known to 10%	Known to 2%	1%
		Background rejection	> 90%	> 95%	2%
		Mass resolution	Discriminate between e^-, H+, 3He+, 4He+, C, O+,	< 0.5 AMU (H+) < 1 AMU (CNO) < 2 AMU (Fe+)	0.5 AMU
		Absolute efficiency	Known to 50% for e^-, H+, He+, CNO+	10%	10%
	Calibration mode with collimator	Scattering of ions	< 10%	< 5%	2%
		Scattering of electrons	< 10%	< 5%	2%
		Properties at octant boundaries	Known to 30%	Known to 5%	5%
		Efficiency as a function of entrance	Known to 20%	Known to 5%	5%
		Angular resolution	30°	25°	3°
		Geometric factor	> 0.05 cm^2-sr	0.061 cm^2-sr	0.01 cm^2-sr
		Full calibration: verify previous measurements			
	Flight mode	Input/output rate at system level	Known to 30%	Known to 10%	10%
		Verify all modes			
		Verify all timing windows			
		Throughput of event classification			
		Efficiency of counters			
		Energy-ToF plane characteristics			
		Threshold settings			
		Temperature dependent			

***Science requires relative/absolute accuracy: 20%/50%. Ground calibration 20% precision, reduced to 10% in flight.**

In-Flight Calibration

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- On-orbit and cruise calibration achieves relative calibration to 10% precision
  - Uniformity confirmed by evolution of pitch angle distribution from onset to shock passage.
  - Such calibrations cover the entire energy and FOV coverage with linear instrument response (targeted rates, no pulse pileup)
- Built-in features to determine on-orbit instrument ion performance
  - Measure pulse-height spectrum of secondary electrons from incident protons as function of time-of-flight
  - Unit has built-in stimulus to inject known pulse through the front-end electronics

Summary

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- Calibration plan satisfies all Level IV requirements
- Calibration facilities have been identified that meet EPI-Lo needs
- APL operates and maintains the key EPI-Lo calibration facility which allows maximum flexibility

Backup

Accuracy & Precision

Parameter	Required	Goal (Capability)	Comment/Heritage
Electron Energies	50 - 500keV	25 - 1000 keV	Electron capability from JEDI, RBSPICE
Ion Energies	50 keV/nucleon – 15000 keV Total E	40 keV/nucleon – 20000 keV Total E	Capability partially based on RBSPICE capabilities. Top energy ~250keV/nuc for Fe
Energy Resolution	45% for required energy range	40% for required energy range	Telemetry limited
Time sampling	5 sec	1 sec	Telemetry and/or statistics limited
Angle resolution	<30° x <30°	Ions, ~15° x 12° to <30° x <30° e-, 45°	Varies with elevation
Pitch Angle (PA) Coverage	0° -90° or 90° -180° , some samples in both hemispheres	0° -90° or 90° -180° , some samples in both hemispheres	
Time for Full PA	1 – 5 sec	1 – 5 sec	Telemetry limited
Ion Composition	H, He3, He4, C, O, Ne, Mg, Si, Fe	H, He3, He4, C, O, Ne, Mg, Si, Fe	He3/He4 ~50 to 1000 keV/nuc
Electron Sensitivity: I=Intensity (1/cm^2.sr)	j = 1E1-1E6/cm^2-s-sr	Sensor-G:0.144 (cm^2.sr) Pixel-G: ~0.02 (cm^2.sr) Up to 6E6 1/s counting	j=Intensity (1/cm^2-s-sr) G=Geom. Factor (cm^2-sr) 8 pixels/sensor
Ion Sensitivity	j = 1E1-1E6/cm^2-s-sr	Sensor-G:0.16 (cm^2.sr) Pixel-G: ~0.002 (cm^2.sr) Up to 3.5E6 1/s counting (TOFxE)	80 pixels/sensor

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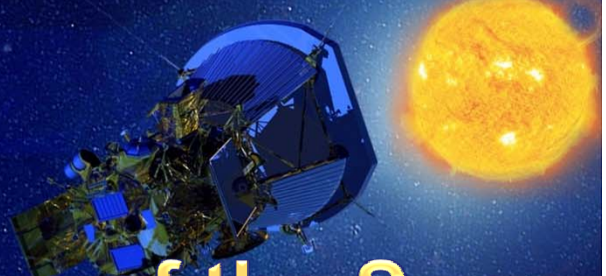

Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

EPI-Hi Calibration

Richard Mewaldt

EPI-Hi Scientist (Caltech)

Outline

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- Introduction
- Species and Energy Ranges
- Calibration Plan
- Facilities
- Test Flow
- In-Flight Calibration
- Summary

Introduction

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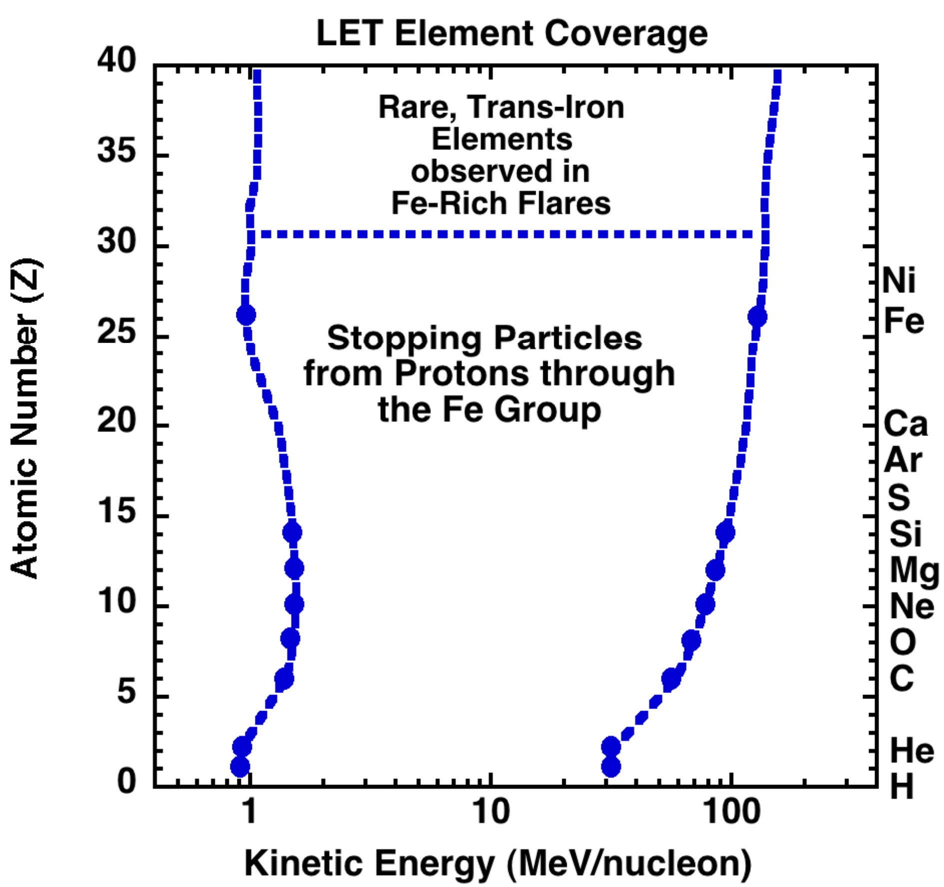
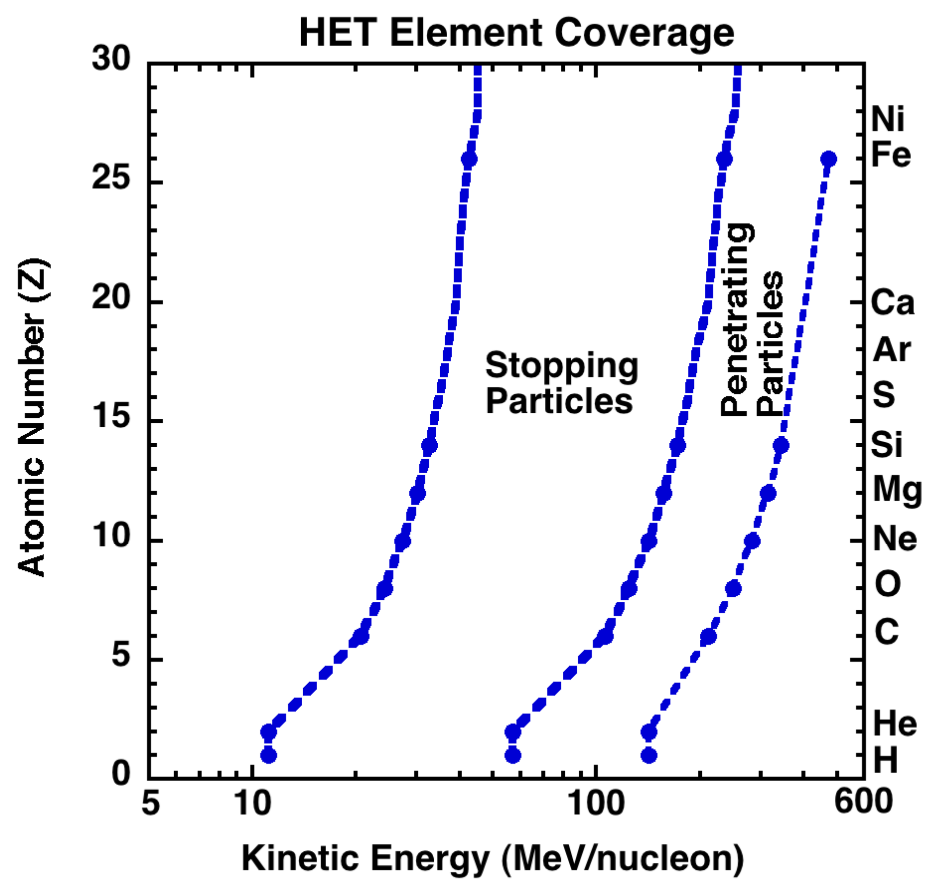
- EPI-HI Measurement Requirements:
  - Composition, energy spectra, and angular distributions of ions and electrons in flare and CME-related SEP events, and at shocks
  - Required Species for EPI-Hi
    - H, ^{3}He, ^{4}He, C, O, Ne, Mg, Si, Fe ≤ 1 MeV/nuc (TBR) to ≥ 50 MeV/nuc
  - Required Species for Mission
    - Electrons with ≤ 0.5 MeV to ≥ 3 MeV
  - SEP Directional Distributions
  - The combined LET and HET fields of view are required to measure SEP angular distributions over ≥ p/2 sr in both the sunward and anti-sunward directions
- EPI-Hi Measurement Goals:
  - SEP Ions: Composition and energy spectra of ~16 species with 1 ≤ Z ≤ 28 and trans-Fe element groups
  - SEP Electrons with ≤ 0.5 to 6 MeV

Species and Energy Ranges

LET and HET energy coverage for stopping elements is shown below. Note that LET and HET have considerable energy overlap. Also shown is the energy range over which HET can identify penetrating ions. Required species are indicated by blue dots. LET will also measure rare trans-Fe species often overabundant in ^{3}He-rich flares.





Calibration Plan

- Lab measurements of electronic gains, offsets, linearity, thresholds, noise, and temperature variations
- Alpha-particle and heavy-ion measurements of detector uniformity
- Accelerator measurements of heavy-ion dE/dX-E-Range parameters, combined with modeling
- Monte-Carlo simulations of detector performance
- Monte-Carlo determinations of LET and HET geometry factors for directional sectors
- GEANT-4 calibrations of the HET and LET electron response
- Accelerator measurements of heavy-ion dE/dX–E' "tracks" for new flight detectors and end-to-end testing/tuning of on-board particle identification algorithms
- Validate high-rate performance
- In-flight measurements that optimize/validate on-board particle identification processes

Calibrating Detector Energy Thresholds

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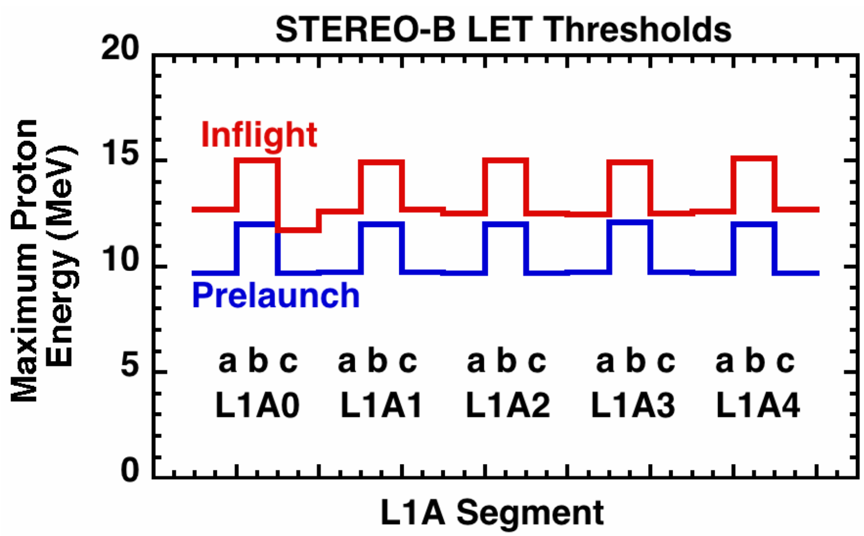
Each dual-gain PHA chain contains a precision test pulser that will be used to measure the preflight and in-flight trigger thresholds of 88 separate detector segments in EPI-HI. The Table below shows data for STEREO LET-B sensor. The goal is to have equal proton response in all directions. Typically, in-flight thresholds can be lower than pre-flight thresholds.

STEREO-B Prelaunch and Inflight Discrimninator Settings

Detector	Segment	Thick (microns)	Area (cm2)	Launch Thresh (MeV)	Flight Thresh MeV
L1A0	a	22.7	0.8	0.188	0.153
	b	21.7	0.4	0.153	0.129
	c	22.7	0.8	0.188	0.163
L1A1	a	26.2	0.8	0.218	0.178
	b	26.3	0.4	0.185	0.156
	c	26.1	0.8	0.217	0.176
L1A2	a	29.9	0.8	0.248	0.203
	b	29.8	0.4	0.210	0.177
	c	29.1	0.8	0.242	0.199
L1A3	a	24.5	0.8	0.203	0.167
	b	24.2	0.4	0.171	0.144
	c	24.7	0.8	0.205	0.169
L1A4	a	25.7	0.8	0.213	0.174
	b	26.0	0.4	0.183	0.153
	c	25.2	0.8	0.209	0.170



Measuring Gains/Offsets of PHASICS

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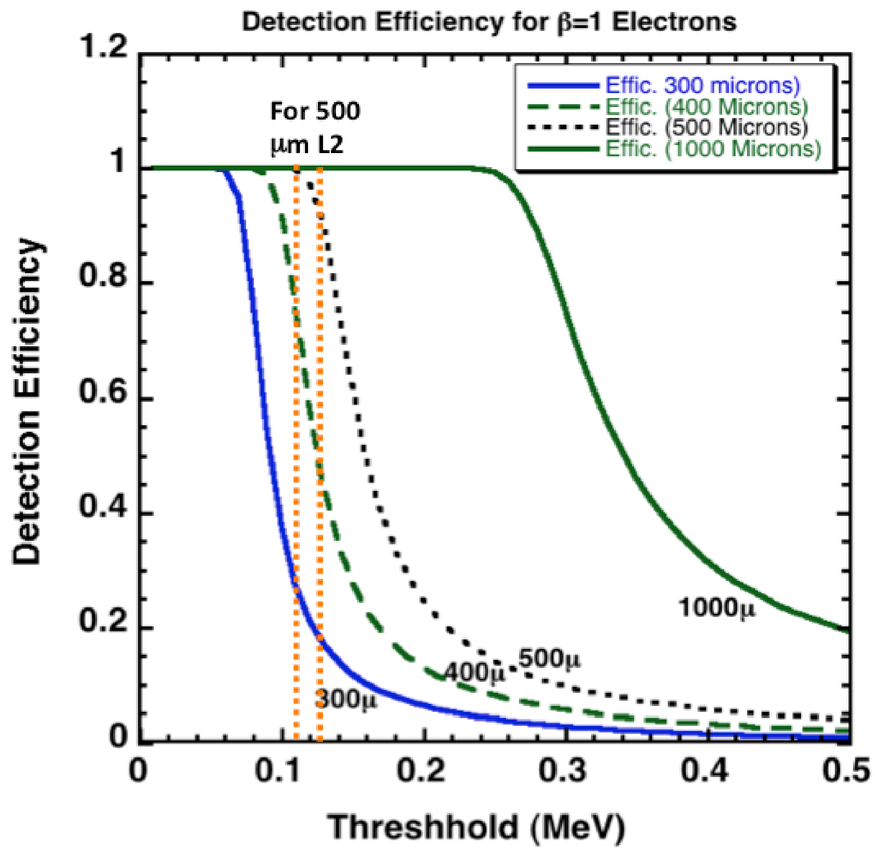
- Onboard particle identification requires accurate calibrations of the flight electronics and their dependence on temperature
- Onboard measurements of the nuclear charge (Z) and kinetic energy (E) of energetic particles requires accurate pre-launch and in-flight measurements of the gain and offset of each PHASIC dual-gain PHA
- Since the SPP orbit may lead to temperature variations, need to also measure the temperature coefficients of each PHASIC
- The LET and HET designs also provide for periodic in-flight calibration of each ADC on a grid of logarithmically-spaced points.
- Fortunately, the PHASICs are relatively stable with temperature.

STEREO PHASIC	Gain Temperature Coeff.:	<50 ppm/deg. C
Performance:	Offset Temperature Coeff.:	<0.1 Channel/°C

Monte Carlo Simulations

- Monte Carlo simulations were used throughout the LET & HET design process to identify and optimize parameters controlling charge and energy resolution.
- Such simulations continue to be important in evaluating accelerator and laboratory measurements of detector and electronic performance.
- For example, this GEANT-4 simulation illustrates the L2 threshold requirements for measuring electrons with LET. For an L2 thickness of 500 mm a trigger threshold of 0.110 - 0.125 MeV gives 95% - 100% detection efficiency for all electrons of interest (0.5 – 6 MeV)

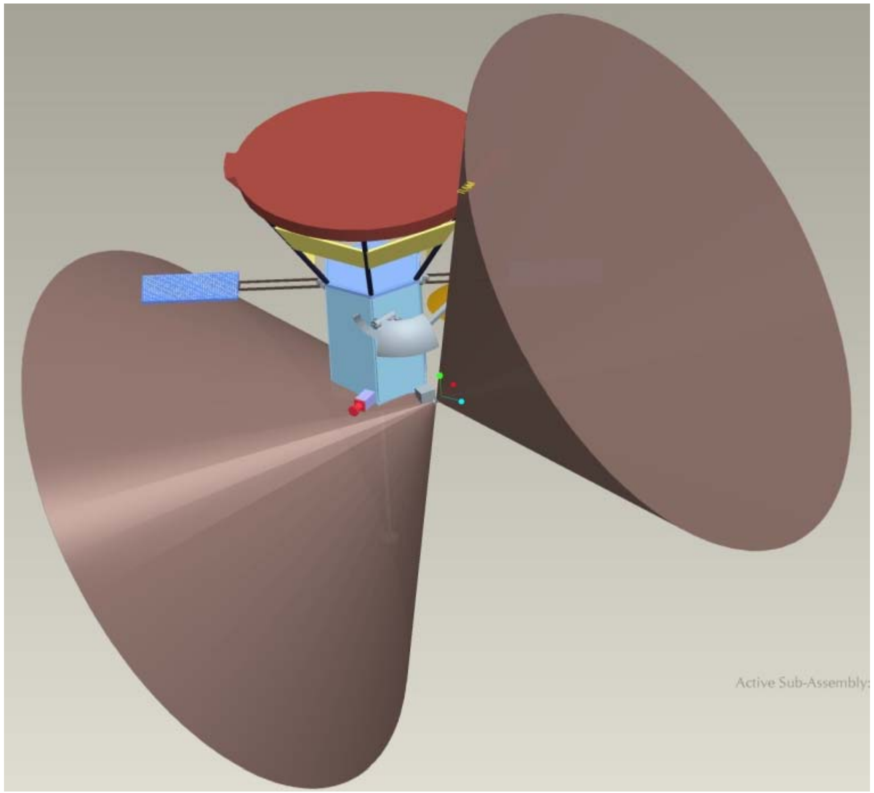


Simulation by A. Labrador

Calibrating LET/HET Fields of View

The combined LET and HET fields of view are to cover ≥ π/2 sr in both the sunward and anti-sunward directions (see LET-1 example below).

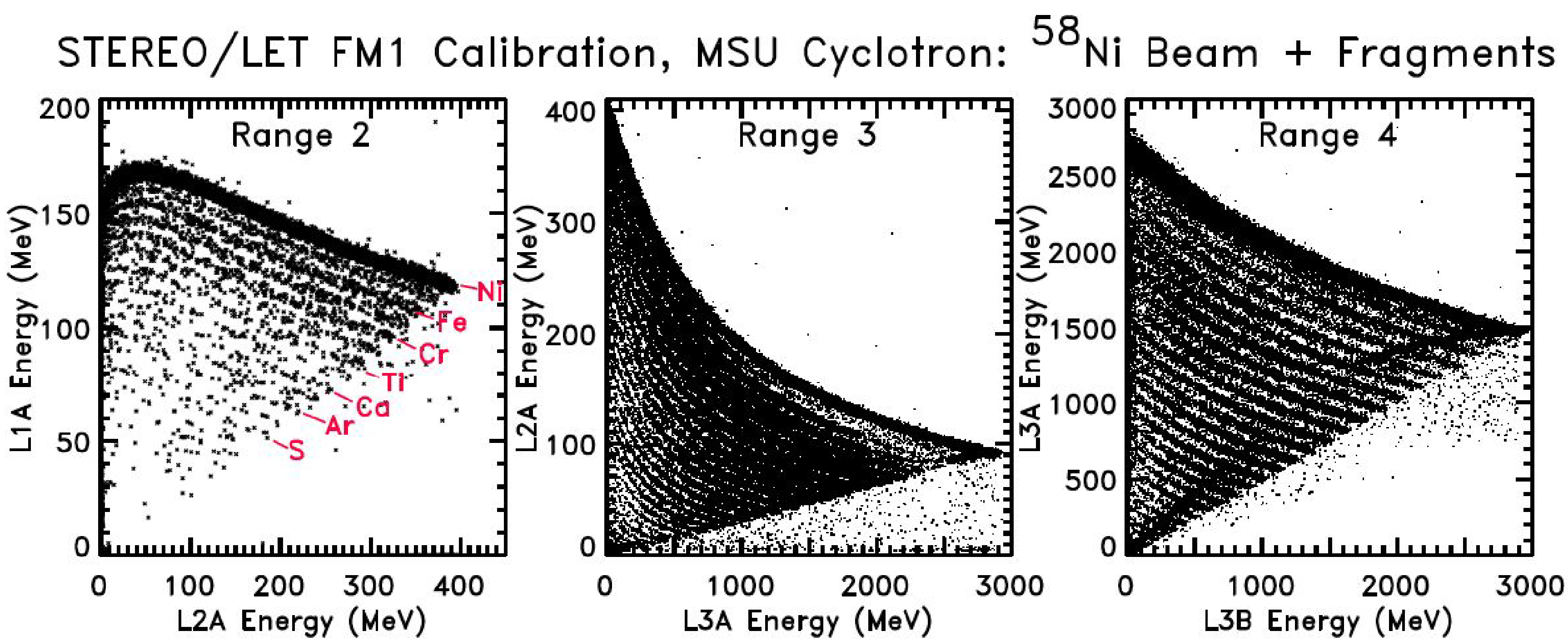
- The geometry factor and directional coverage of each of the 25 sectors within each cone will be determined with a Monte Carlo calculation taking into account the pointing directions of the three telescopes relative to the spacecraft and Sun and any obstructions.
- The relative geometry factor of each sector can be validated in-flight during the decay phase of SEP events when solar energetic particles become nearly isotropic in the solar wind rest frame.



LET-1 Field of View

Facilities – Accelerator Calibration Data

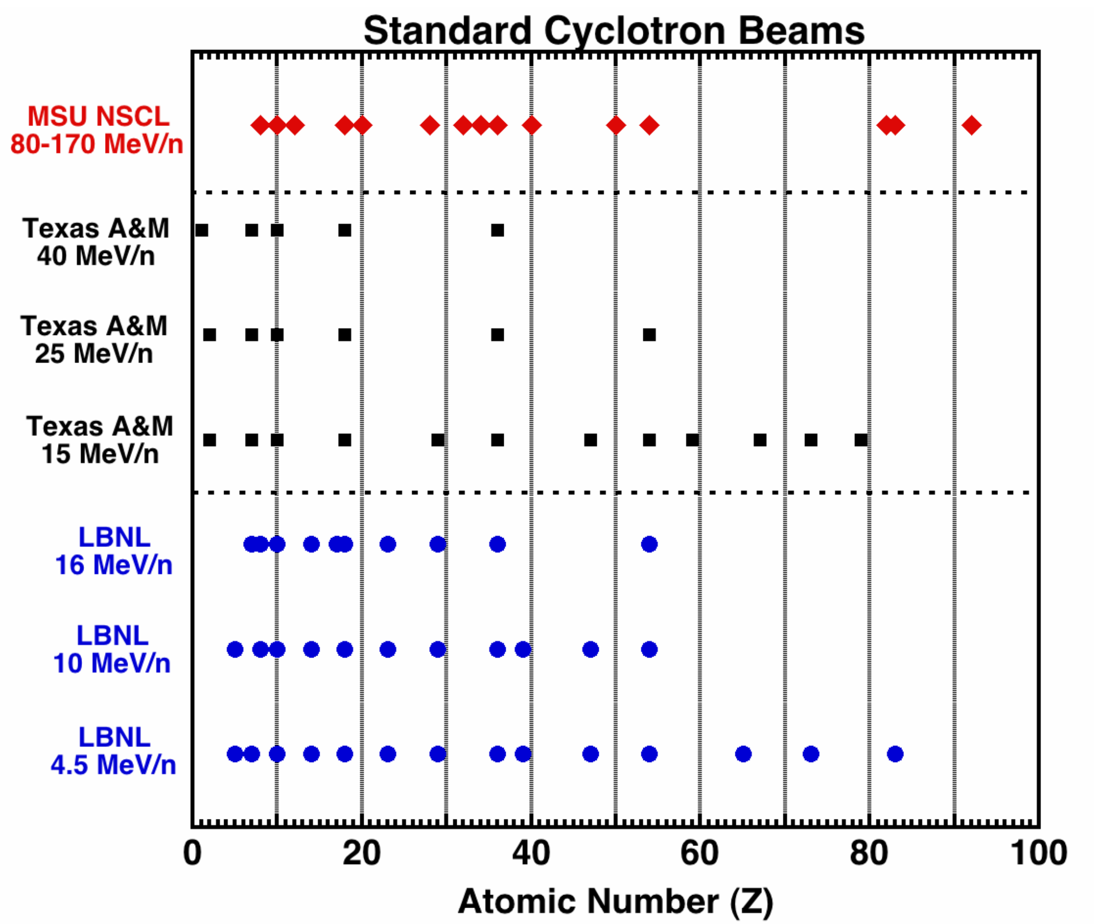
- LET & HET use ΔE vs. Residual Energy (E') to measure SEP composition
- The ΔE vs. E' tracks for lighter species are obtained by fragmenting a heavy-ion beam on a polyethylene target
- The example below from STEREO/LET uses a ^{58}Ni beam at the MSU NSCL
- This also provides an end-to-end test of the onboard identification system



Mewaldt et al. 2008

Facilities – Accelerator Calibrations

There are three appropriate heavy-ion accelerators in the U.S.



- All 3 cover the key heavy-ion charge range (6≤Z≤28) and also provide for trans-iron (Z>30) calibrations.
- However, only MSU covers the full energy range of EPI-Hi.
- The MSU accelerator also reaches high enough energy to produce a much greater yield of lower-Z fragments.
- In the past we have also used the heavy-ion accelerator in Darmstadt, Germany.

Propose an accelerator calibration of EPI-Hi (or the engineering unit) for 2016

Electron Calibrations

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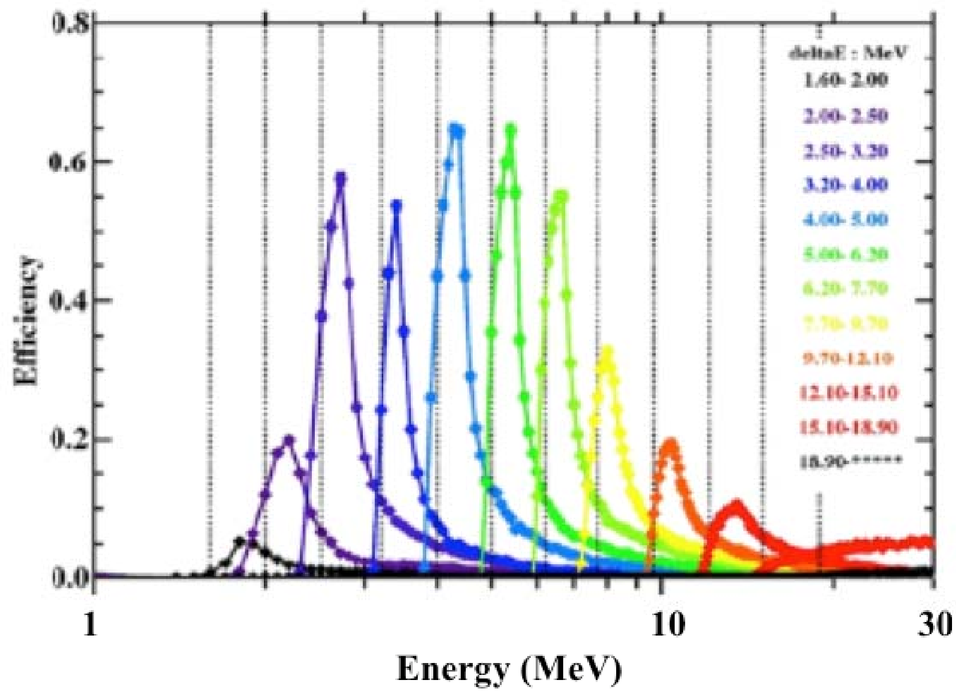
HET and LET will measure energetic electrons with 0.5-6 MeV

- The HET and LET electron response will be calibrated with GEANT-4, used to calibrate the REPT sensors on the Van Allen Probes (Baker et al. 2012)
- HET is 13.5 mm of Si deep compared to a 23-mm depth for REPT
- Based on REPT and SAMPEX/PET calibrations, a HET/LET energy range covering 0.5 – 6 MeV is achievable
- The LETs will provide electron measurements over a more limited energy range (~0.5 – ~4 MeV)
- Routine testing of the HET/LET electron response will use ß-decay sources like ^{106}Ru and ^{90}Sr.



REPT electron calibration using GEANT-4

Calibration Test Flow (1/2)

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Overview of Key Steps

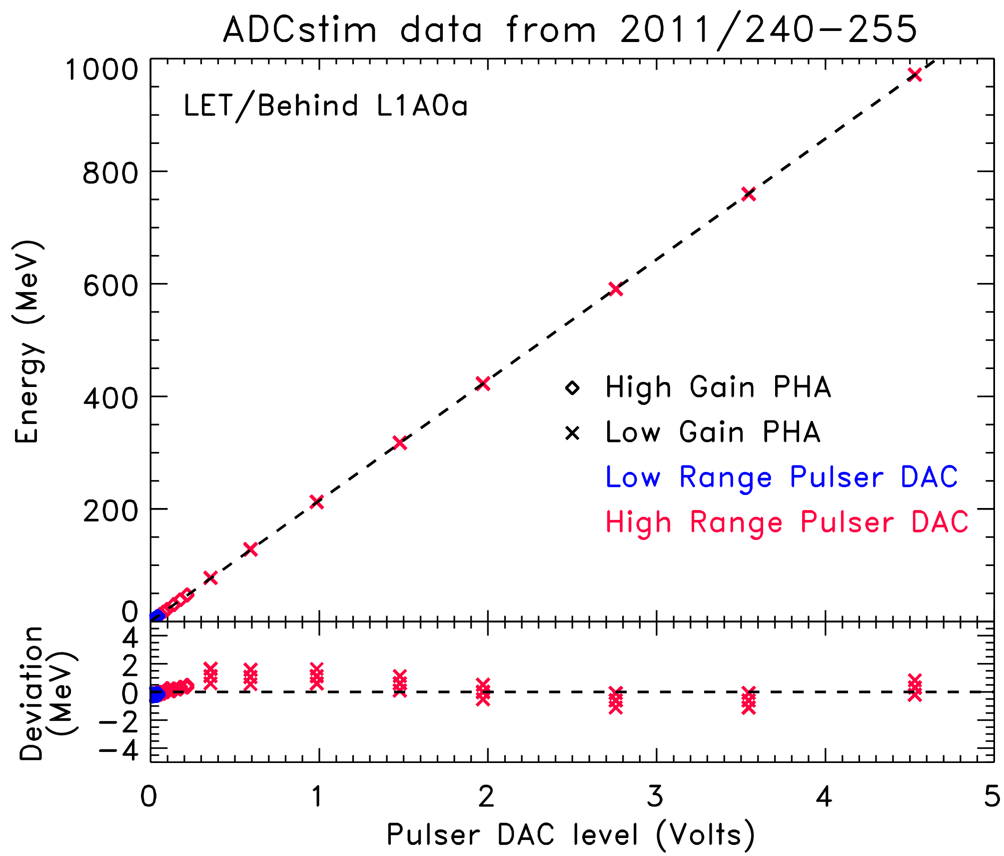
- Determine how the Science Requirements drive detector, electronics, and software requirements (noise, resolution, dynamic range, near-Sun environment)
  - (requirements on detector thickness, uniformity, noise)
  - (requirements on PHASIC noise, dynamic range, radiation hardness)
- Evaluate expected instrument performance with calculations and simulations
- Develop new detector/electronic hardware; new flight software
- Test new detectors, hardware, software with real/simulated particles to determine if they meet requirements.
  - (Accelerator and lab tests; simulations)
- Perform an end-to-end test of all systems at a heavy-ion accelerator
- In-flight tuning and validation of onboard analysis routines

Calibration Test Flow (2/2)

Calibrate New Detectors, PHASICS, and Software		
Task	**In Progress**	**Scheduled For**
New, thin SSDs meet uniformity and response requirements	√	
Calibrate transfer function of flight PHASICS vs. temperature		End of 2014
Propose for beam time at MSU Superconducting Cyclotron Lab		2014
Calibrate HET and LET SEP electron response using GEANT-4		mid-2016
Test SEP electron detection and ɣ-ray background with lab sources		mid 2016
Validate on-board analysis routines at accelerator		mid-2016
Determine location of element tracks at MSU accelerator		mid-2016
Inflight tuning and validation of on-board analysis routines		≥2018

In-Flight Electronics Calibration

The gain, offset, and threshold of each PHASIC channel will be periodically calibrated onboard using built-in DACs that stimulate multiple detectors. The Figure shows an example of in-flight calibration data from STEREO/LET. Such calibrations are especially important if the temperatures of the LET and HET electronics vary significantly over the course of the SPP orbit.



In-Flight Calibration

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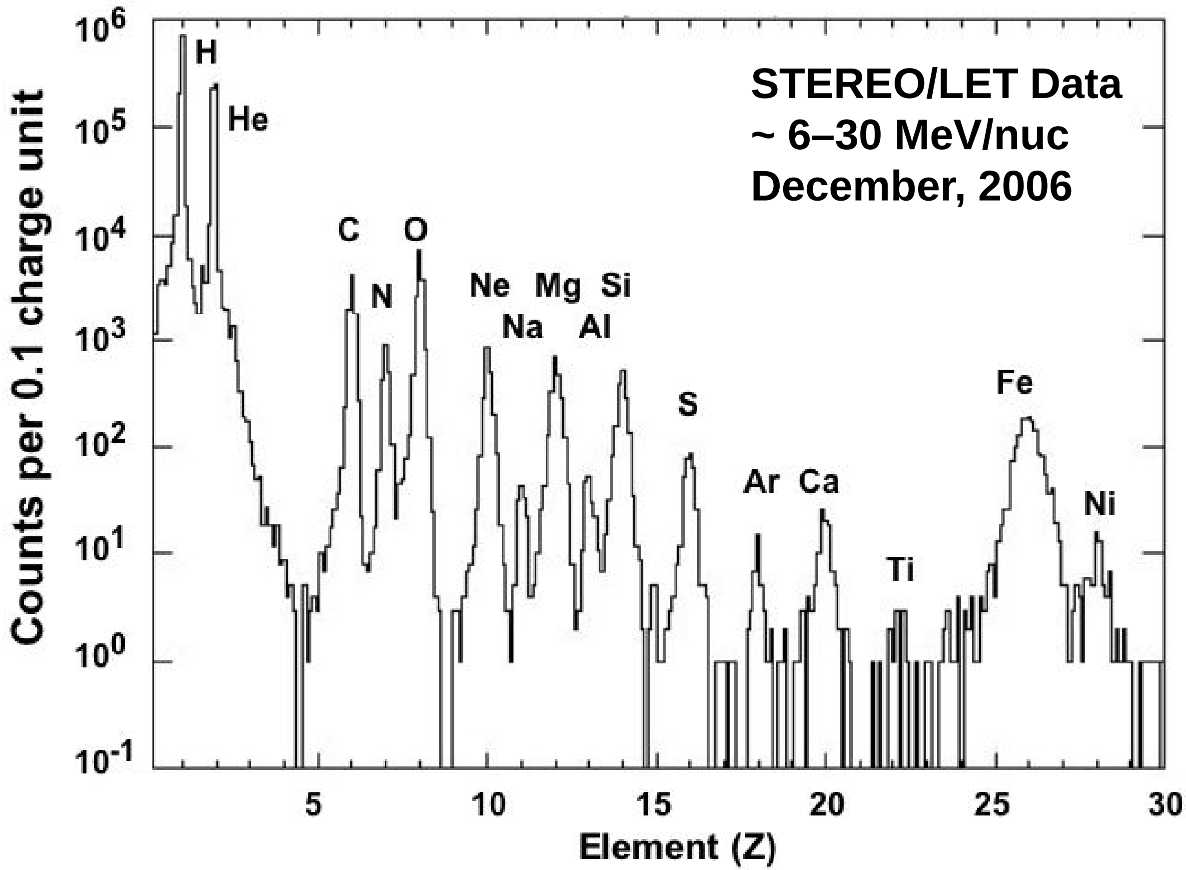
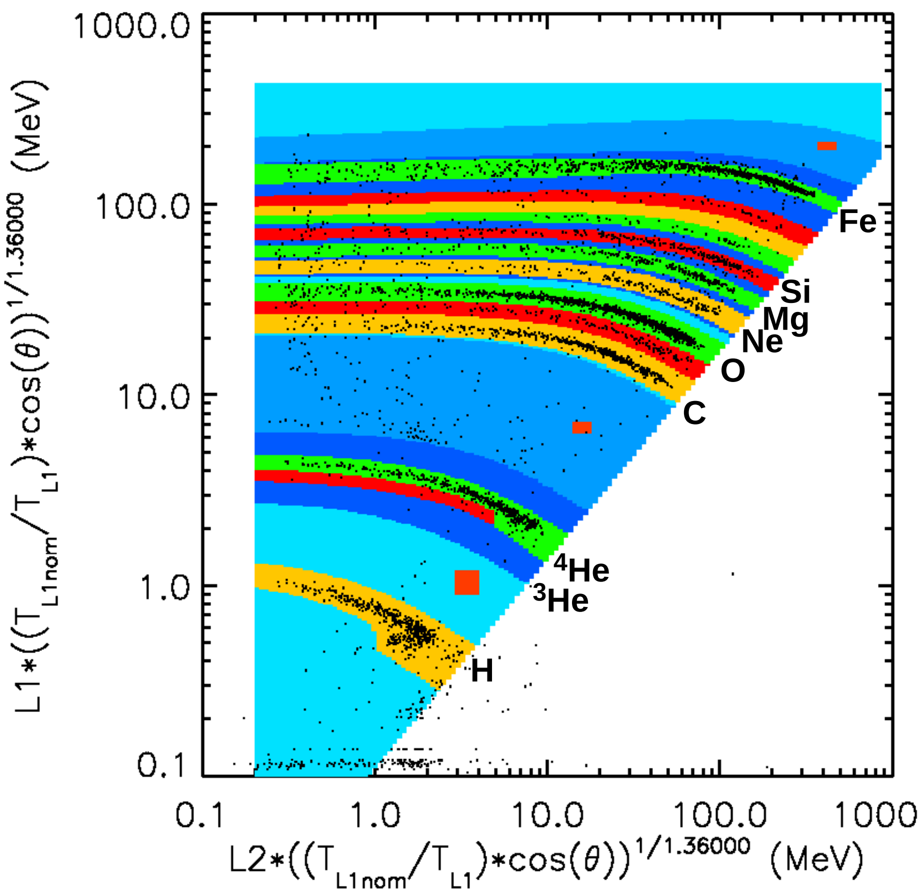
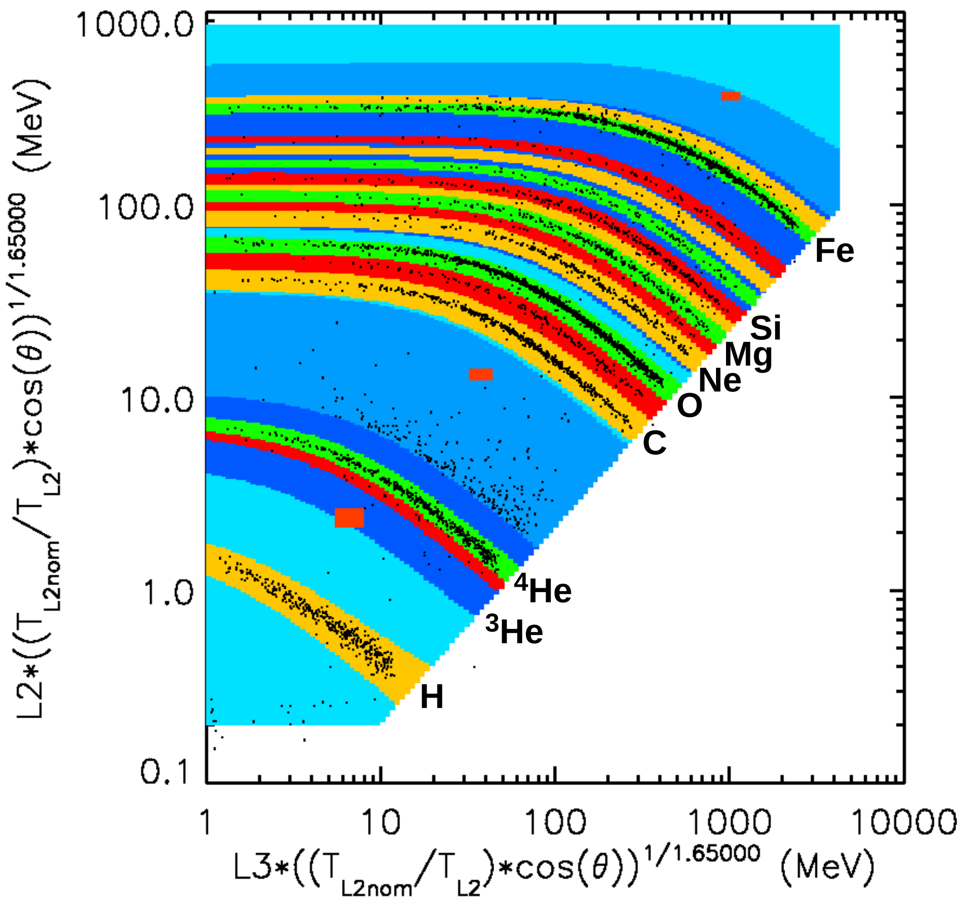
Pulse-height data from the EPI-Hi LET and HET sensors will provide the final calibration of the on-board particle identification system. Shown are STEREO LET data from the Dec. 2006 SEP events. Sixteen elements are resolved.
EPI-Hi should provide similar resolution extending to ~100 MeV/nuc.



In-Flight Calibration

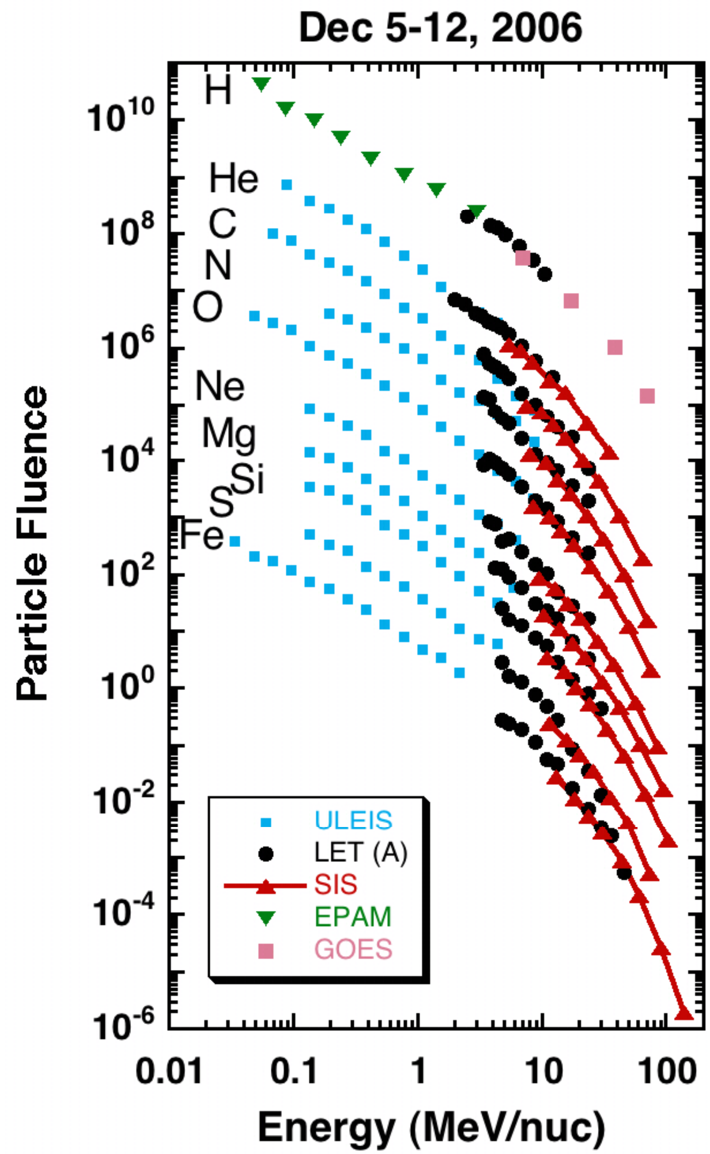
STEREO/LET event data from the Dec. 2006 SEP events are plotted on the L1vsL2 and L2vsL3 matrices after correction for incidence angle and individual L1 and L2 segment thicknesses (~25 and ~50 μm thick). Colored bands show regions used for on-board particle identification. EPI-Hi detectors range from 10 μm to 2000 μm thick.





In-flight Energy Spectra

- To achieve EPI-Hi science requirements the nuclear charge (Z) and kinetic energy of SEP ions must be measured to construct energy spectra.
- Shown at right are energy spectra that combine ACE, GOES & STEREO data measured while the STEREOs were still near Earth. They cover the same energy range as EPI-Lo & Hi (~0.05 to >100 MeV/nuc). Measured intensities are plotted with no correction factors.
- The approaches outlined here will enable EPI-Lo and EPI-Hi to produce similar energy spectra.



Summary

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- Both pre-flight and in-flight calibrations of sensors, electronics and software are essential for meeting the science and measurement requirements of EPI-Hi.
- The plan for calibrating on-board analysis of SEP ions requires both accelerator and in-flight calibrations
- EPI-Hi measurements of SEP electrons will rely on GEANT-4 calibrations, using tests with radioactive sources as a cross check

Solar Probe Plus

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Integrated Science Investigation of the Sun Energetic Particles

NASA • GSFC • JPL • Caltech • SwRI • APL • UNH • U-Az • U-Del

ISIS

Solar Probe Plus

Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

Performance Assurance

Joerg Gerhardus

ISIS Mission Assurance Lead (SwRI)

Outline

- Requirements
- Performance Assurance Implementation Plan
- Organization
- Quality Assurance
- EEE Parts Engineering
- Safety
- Summary

SPP PA Requirements and PAIPs

Tailored SMA Requirements negotiated with the SPP project:

- Solar Probe Plus (SPP) Instrument Mission Assurance Requirements Compliance Matrix
- SPP document # 7434-9096 Rev. A
- Iterative process between SPP and ISIS SMA teams utilizing best practices and combined knowledge of the diverse teams at all participating organizations

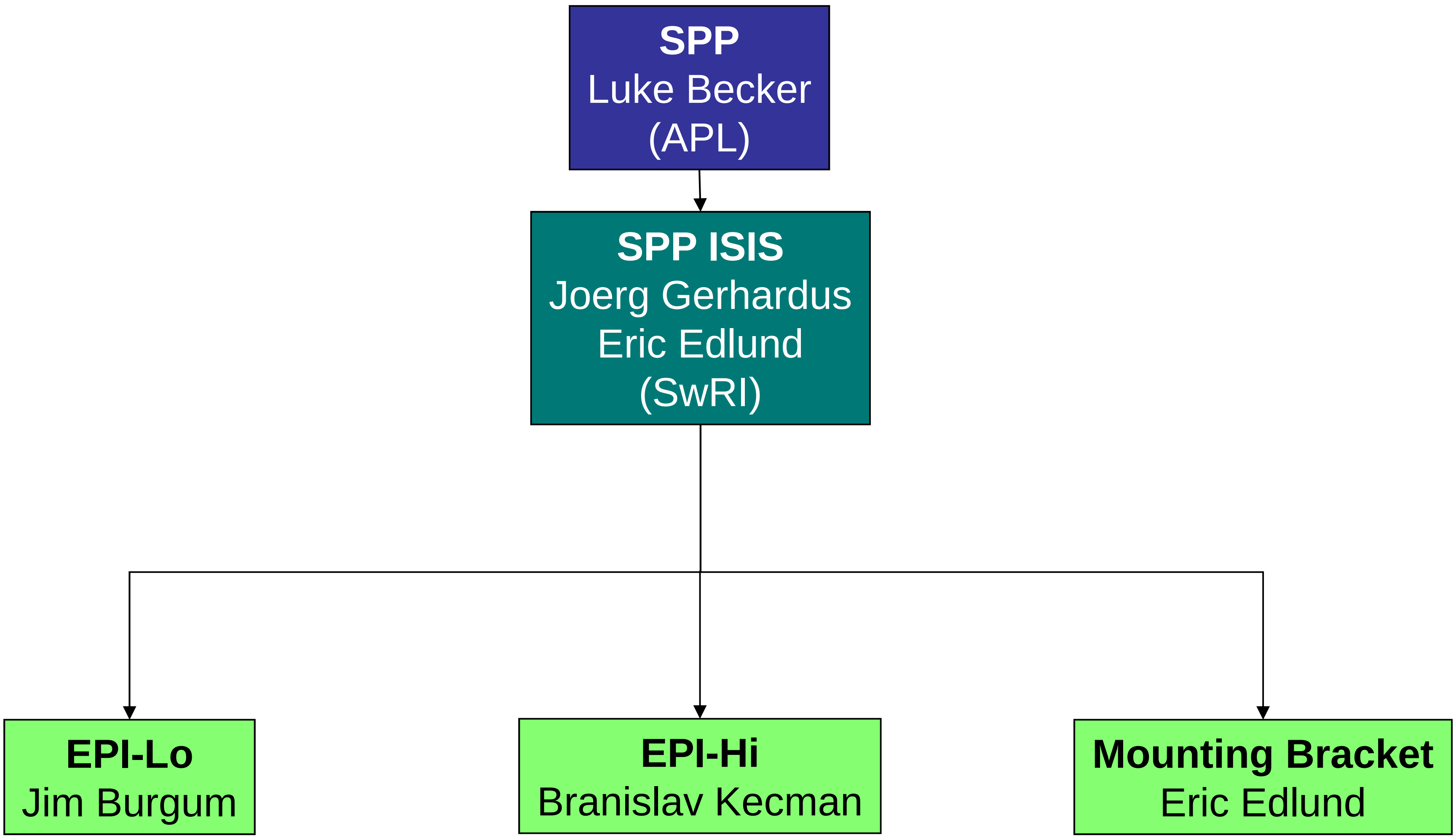
ISIS Implementation through plans (PAIP) and operating procedures:

- ISIS: SwRI document 16105-SPP-IMAR-COMPMAT-01 Rev. 0, released 10/07/13
- EPI Lo: Solar Probe Plus (SPP) Performance Assurance Implementation Plan; APL document # 7434-9001 Rev. -, released 10/14/13
- EPI-Hi: Caltech document CIT-SPP-004 Rev. -, released 10/07/2013

Performance Assurance Implementation Plan

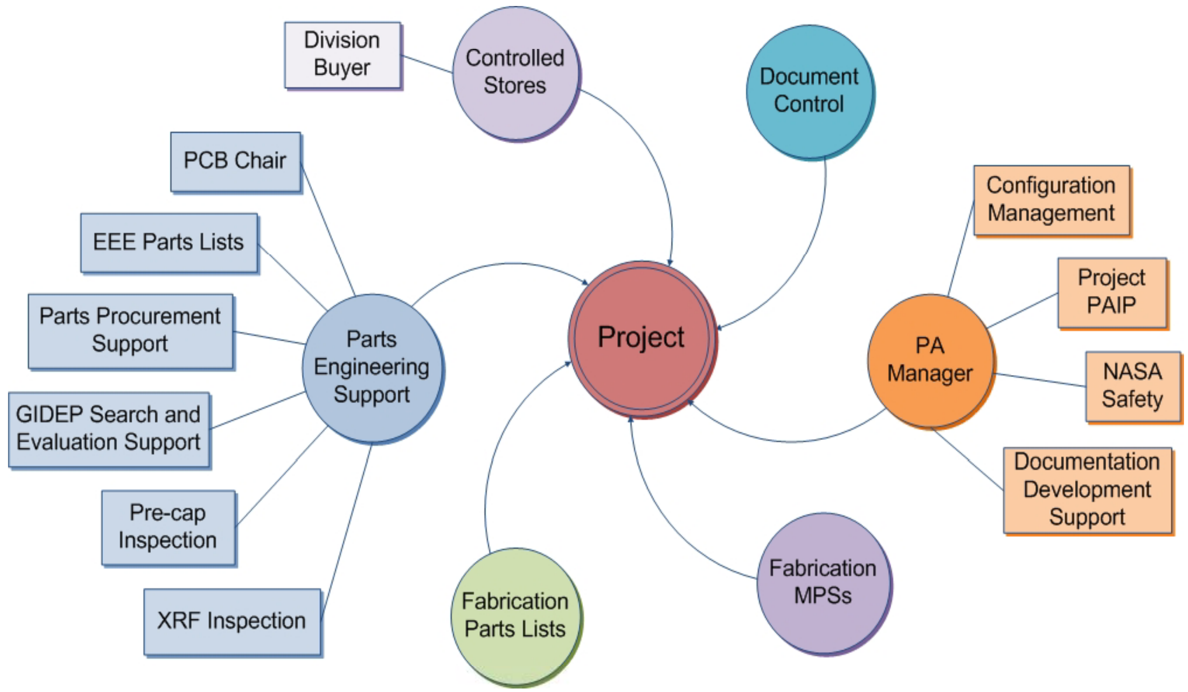
- Deliverables
- General Quality Requirements
  - Procurement
  - QA Surveillance
  - Training and Certification
  - Design and Development Review Process
  - Configuration Management
  - Non Conformance Process and Reporting
- Hardware Quality Requirements
  - Manufacturing, Inspection, Assembly, Test, and Inspection Planning
  - Controlled Stores
  - Fabrication processes
  - Inspection
  - Acceptance Test Verification
  - Handling Packaging, Shipping
- Software Quality Requirements
  - Requirements Analysis
  - Reviews
  - Verification and Validation
- Safety
- Reliability Assurance
- EEE Parts Program

PA Organization Chart

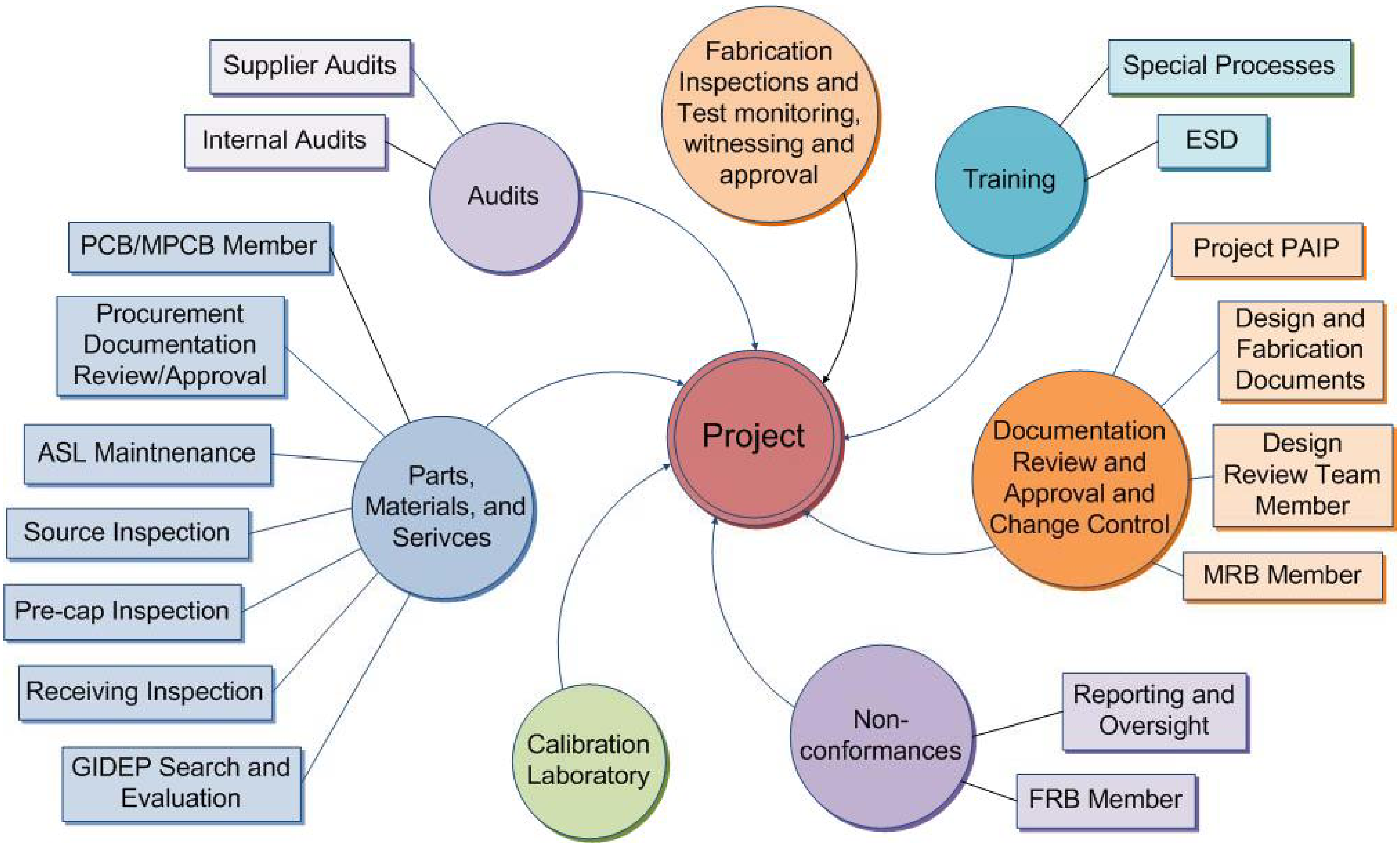


Project Quality Assurance

- Project Team PA
  - Reliability engineering
  - Parts acquisition oversight
- Division 15 PA Manager and Staff
  - Coordinate Div 15 Resources
- Independent Project Quality Engineer
  - Oversight & Coordination
  - QA Engineering
  - QA Inspections
- Partner QA
  - Implement local PAIP and support SwRI's SPP ISIS PA Lead



Quality Tasks



Design Assurance

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- Hardware designs governed by:
  - Design process and controls
    - Requirements definition
    - System engineering process
    - Design planning
    - Peer reviews and checklist
    - Verification and validation
    - Control of design changes
  - Software designs governed by:
    - Structured software development process
    - Contract reviews, software development folder, planning
    - Review of requirements, and checklist
    - Software design specification, design peer reviews, and checklist
    - Coding standards, configuration control, and code walkthroughs
    - Test plans, test preparations, formal testing, and reporting
    - Independent QA surveillance and reporting

Quality Assurance (1/2)

- Procurements per released drawing and indentured parts list
- Periodic GIDEP alert verification performed on EEE parts list
- QA Receiving Inspection of EEE parts for flight hardware
- Flight PWB procurement and coupon testing at GSFC
- SwRI coordinates PCB effort for SPP ISIS with mission-level PCB

Quality Assurance (2/2)

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- Non-conformance control:
  - Per organization's established procedures
  - MRB and FRB established
  - All non-conformances will be processed as Anomalies or Problem/Failure reports and reported through SwRI to APL as required
- Workmanship
  - Technicians and inspectors are certified to NASA 8739 standards. Vince Ganley and Connie Ovalles are the in-house Level B certified instructors and are available to support other organizations as needed
- ESD
  - Engineers, operators, and technicians are certified to NASA-STD-8739.7 / ANSI ESD S20.20.

Software Quality Assurance

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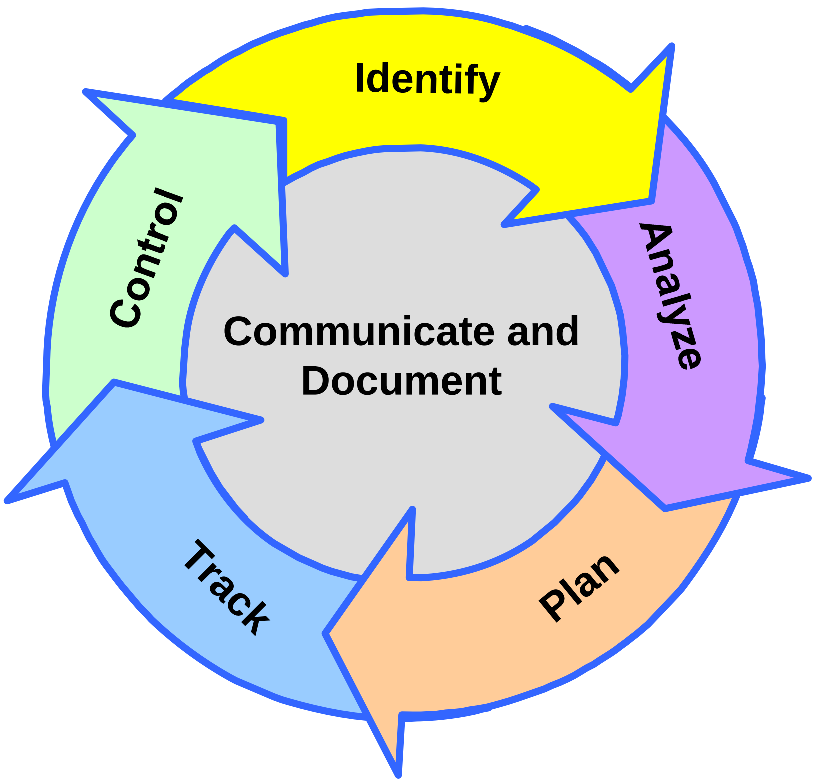
- ISIS SQA follows the AS9100 quality program in monitoring software activities which includes review of project documents, witnessing acceptance testing, tracking action items and defects, and performing surveillances/audits
- QA has approved the ISIS Software Development Plan (SDP), which references the EPI-Hi/Lo SDPs
  - Software Development Plan Solar Probe Plus Project ISIS Instrument Software, Document No. 16105-ISIS-SDP-01, Rev 0 Chg 0, September 2013
- Regular surveillances of EPI-Hi and EPI-Lo software activity will focus on the teams compliance to their SDP and their organization's quality/procedural requirements.
  - On-site surveillances by the SwRI SQA at EPI-Lo and EPI-Hi are planned

EEE Parts Engineering

- Primary role is to support ISIS hardware developers with meeting EEE parts requirements as called out in Solar Probe Plus Parts Control Plan, SPP document 7434-9001 Rev A
  - SwRI has significant experience working with APL & GSFC Parts Engineering Branch
  - Ensure that all parts presented to SPP Parts Control Board are compliant to the PCP
- Provide procurement support where necessary
  - Significant stock available at SwRI
    - This has already been useful to aid in prototyping and EM hardware
      - Avoid long lead times and expensive minimum buys
- Support coordination of common buy activities as requested
  - Allows for 1 consolidated response for the ISIS suite

Safety



- SPP ISIS will provide Safety inputs
  - The NPR-8715.3A process circle summarizes the overall safety program risk management approach
- Safety Hazards Analysis
- Implementation of hazard controls
- Verification

EPI Hi/Lo Hazards and Mitigations

- EPI-Lo:
  - High Voltage
    - 200V bias voltage to the SSDs
    - Fully contained inside the instrument
    - Only operated in high vacuum
    - Safe/arm limiting plug design
  - Ionizing Radiation Sources
    - Planned use of the following sources (radiation datasheets have been provided to SPP):
      - Am-241 foil, 100uCi, Type A2 Capsule
      - Bi-207, 10uCi, MF-1 Disk, 25.4mm OD x 5.08mm AD, 100-200ug/cm2 Acrylic Window
      - Ba-133, 10uCi, MF-1 Disk, 25.4mm OD x 5.08mm AD, 100-200ug/cm2 Acrylic Window
- EPI-Hi:
  - High Voltage
    - 250V bias voltage to each detector within the three telescopes
    - Fully contained inside the instrument
  - Ionizing Radiation Sources
    - Planned use of the following sources:
      - Beta / gamma sources — 106Ru, 207Bi: <0.1 mCi
      - Alpha sources — 228Th, 241Am, 244Cm : <10 mCi
      - alpha source for producing knock-on protons — 210Po : <10 mCi
- General Hazard:
  - Nitrogen purging
    - Controlled flow rates in ventilated areas
    - Conducted by trained personnel
    - Monitoring O_2 levels (where necessary)

Summary

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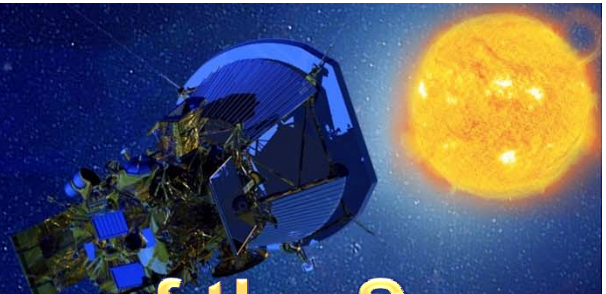
- SPP ISIS Performance Assurance plans and requirements are in place
- PAIPs written in response to the tailored SPP MAR Matrix
- SwRI QA independently verifies that we follow plans



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Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

Risk Status

John Dickinson

ISIS SE (SwRI)

Outline

- Risk Mitigation Plan Overview
- Team Member Roles
- Risk Management Plan Flow
- Risk Analysis Score Card
- Risk Summary
- Progress on Top Risks
- Tracking the “life cycle” of one of the top risks
- Summary

Risk Mitigation Plan Overview

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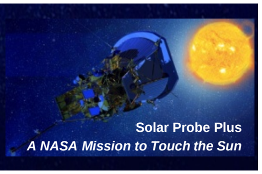
- Team members constantly weigh potential risks
- Team members can suggest a risk at any time
- With team member input, SE enters risk into PIMS
- Instrument leads generate risk mitigation plan including potential cost and schedule, technical, and safety impacts
- SE assesses probability and consequences of risks
- Once a mitigation strategy is selected by team and confirmed by SE/PM, it is executed
- SE ensures risks are handled by assigning and tracking action items
- Team members review risks in weekly meetings
- PM and SE will continuously monitor and audit risk list
- PM elevates risks that impact other instruments or ISIS resources to SPP Project in PIMS system (web-based tool, open to SPP)
- PM and SE consensus is required for risk closure with SPP Project concurrence as needed

Team Member Roles

- Bottoms-up approach
- All team members
  - Assess threats to determine if any are risks
  - Provide risk details to SE for entry into PIMS
  - Analyze identified risks
- Instrument Team Leads (Wiedenbeck/Cummings and McNutt/Seifert)
  - Manage and report on instrument risks
  - Determine mitigation strategies
  - Determine how risks might affect the SPP mission
- ISIS SE (Dickinson)
  - Assist ISIS PM as needed, especially with technical input and analyses
  - Review mitigation plans
  - Address concerns from SPP Project Office
  - Ensures risks are documented as appropriate
- ISIS PM (Weidner)
  - Oversee and manage risk list
  - Work with SE and instrument teams to determine risk mitigation plans
  - Report major risks to SPP Project in Monthly Risk Status Reports

General RMP Flow



Input	Steps	Involved Parties	Output
What can go wrong?	**Identify** Identify Risks (Condition, Likelihood Event, & Consequence)	- Any team member	Risk Statement
Risk Data: analyses, reviews, assessments	**Review & Analyze** Evaluate (severity, probability, time frame). Classify & Prioritize risk	- Review: ISIS SE - Analysis: Owner - Classification: ISIS SE	Risk Classification Risk Prioritization
Resources Re-plan Mitigation	**Mitigation Planning** Decide what, if anything, should be done about the risks	- Owner - Instrument Team Manager	Research Watch Acceptance Rationale Mitigation plans
Program Data	**Implement & Track** Monitor risk metrics and verify/ validate mitigation actions	- Owner - Instrument Team Manager - ISIS SE/PM	Status reports on: Risks Risk Mitigation Plans
	Control Make risk decisions	- Owner - Instrument Team Manager - ISIS SE/PM	Close or accept risks Invoke contingency Continue to track

Risk Analysis Score Card

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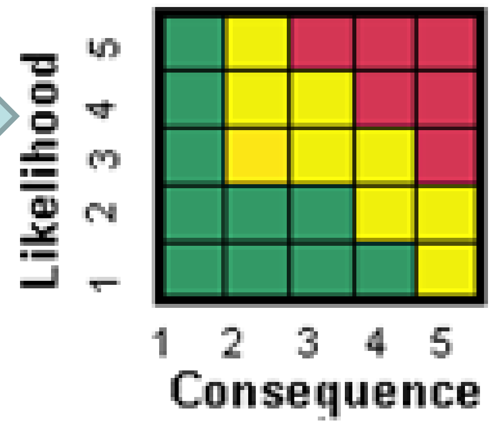
Likelihood Bins	**Safety** (likelihood of safety event occurrences)	**Technical** (Estimated likelihood of not meeting mission technical performance requirements)	**Cost/schedule** (Estimated likelihood of not meeting allocated Cost/Schedule requirements or margin)
5 Very High	($P_s > 10^{-1}$)	($P_T > 50\%$)	($P_{CS} > 75\%$)
4 High	($10^{-2} < P_s \le 10^{-1}$)	($25\% < P_T \le 50\%$)	($50\% < P_{CS} \le 75\%$)
3 Moderate	($10^{-3} < P_s \le 10^{-2}$)	($15\% < P_T \le 25\%$)	($25\% < P_{CS} \le 50\%$)
2 Low	($10^{-6} < P_s \le 10^{-3}$)	($2\% < P_T \le 15\%$)	($10\% < P_{CS} \le 25\%$)
1 Very Low	($P_s \le 10^{-6}$)	($0.1\% < P_T \le 2\%$)	($P_{CS} \le 10\%$)



LEVEL	Minimal (1)	Minor (2)	Medium (3)	Major (4)	Very High (5)
Safety	Negligible safety impact	Minor injury with no lost work time	Injury with lost work time	Severe injury	Death or permanent disabling injury
Technical	Negligible technical impact	Decrease in instrument capability/margin. But all instrument requirements met, or need for requirement definition or design/implementation workaround	Major loss of instrument capability	Loss of Instrument (EPI-Hi or EPI-Lo)	Loss of one or more Level-1 science requirements
Cost	ISIS Project cost overrun of less than 1% of allocated	ISIS Project cost overrun between 1% to 3% of allocated	ISIS Project cost overrun between 3% to 10% of allocated	ISIS Project cost overrun between 10% to 20% of allocated	ISIS Project cost overrun of greater than 20% of allocated
Schedule	Negligible schedule slip	Schedule slip not on critical path	Schedule slip affecting critical path but not launch or post-launch critical event	Schedule slip of 1 to 3 months	Schedule slip of greater than 3 months

Risk Summary

Likelihood \ Consequence	1	2	3	4	5
5	11				
4	13 17				
3		7 14	6 19		
2		1 2 3 5 8 9	4 15 16		
1	18 12		10		

Progress on Top Risks

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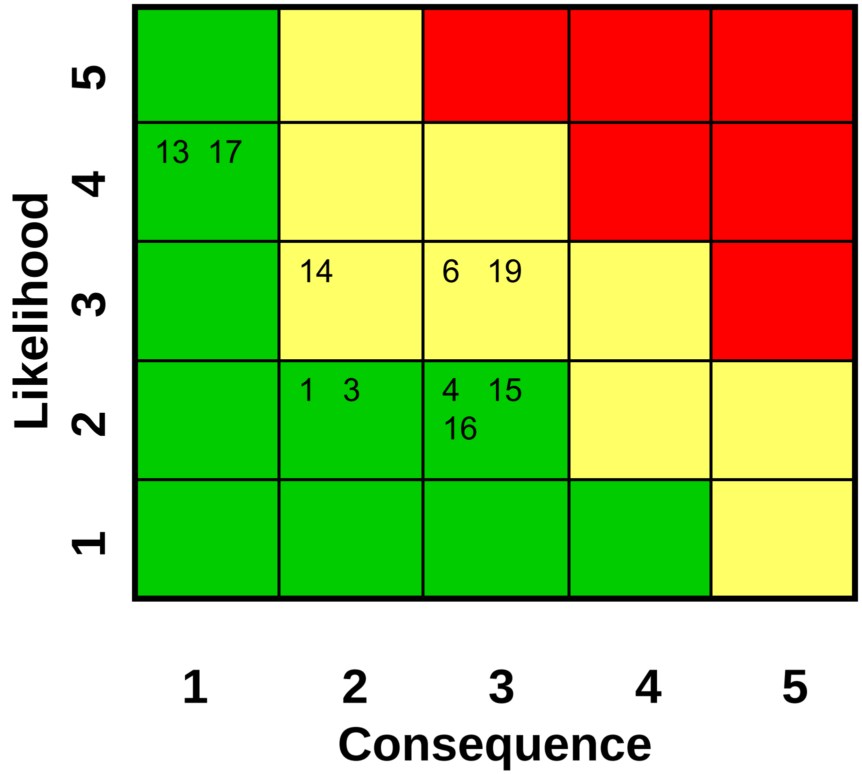

Rank	Trend	Risk ID	Approach	Risk Title
1	⇨	6	R	ISIS Vibration Levels
2	⇩	19	R	ISIS Increased Autonomy
3	⇨	14	R	ISIS Shock Testing
4	⇩	4	R	EPI-Lo Dust Impact Susceptibility
5	⇩	15	R	ISIS Increased Ground Software Demands Due to Autonomy
6	⇩	16	R	ISIS Increased Instrument FSW Demands Due to Autonomy
7	⇩	13	R	ISIS Time Tagged Commands
8	⇩	17	R	Configuring ISIS Based on Solar Distance
9	⇩	1	R	EPI-Hi Thin Detector Availability
10	⇩	3	R	EPI-Hi LET Thin Windows and Dust Impact Susceptibility

Criticality	L x C Trend	Approach
High	⇩ Decreasing (Improving)	M - Mitigate
Med	⇧ Increasing (Worsening)	W - Watch
Low	⇨ Unchanged	A - Accept
	☐ New Since Last Period	R - Research

RISK: EPI-Hi LET Thin Windows and Dust Impact Susceptibility

Description **ID: 3**	**Given that thin windows are fragile and the mission dust environment could be harsher than initially expected; there is a risk that dust impacts could result in damage to the windows during flight,**
Consequence	which will result in a compromise in the resolution of the EPI-Hi telescopes.
Overall Status: Accepted(Active)	Consequence: 2 Likelihood: 2
Status Message	EPI-Hi windows survived Heidelberg dust testing and showed stacked window configuration is effective at mitigating dust penetration to detectors. Even holes produced by penetrating particles result in very limited access of UV light to detectors.
Mitigation Plan 1 Status: Completed Trigger Date: 01 May 2013	Title: Perform Dust Testing Description: The integrity of the windows in a stacked configuration will be tested in a dust environment to determine the efficacy of the windows in protecting the detectors from dust and maintaining structural integrity to block UV light.
Mitigation Plan 2 Status: Not Started Trigger Date: 01 Nov 2013	Title: Baffling for Dust Protection Description: If risk of catastrophic damage due to dust impacts does not appear acceptably low, EPI-Hi could increase the baffle size to limit the affected angle of dust on the detectors. Trade: mass is used to buy down damage risk.
Backup Mitigation Plan Status: Not Started Trigger Date: 01 Nov 2014	Title: Significant Thickness Increase Description: If risk of catastrophic damage due to dust impacts does not appear acceptably low, EPI-Hi could use significantly thicker window for LET2 (single ended) telescope. Trade: measurement quality is reduced to buy down catastrophic damage risk.

Process: Initiation

- Initial concerns about dust
  - The SPP dust environment is not known
- There are sensitive apertures on the ISIS instruments
  - SSDs sensitive to UV light contamination (background noise)
- The need for detector protection was known
  - Windows were required to protect the detectors from UV light
  - Various materials were allowable, so long as they were light-tight, had an outer surface with low α/ε
- Realization that windows are sensitive
  - While protective windows were expected in the design, it was not known what configuration would be required or adequate to mitigate the dust environment
- A risk was written to capture the progress of this concern

Process: Mitigation Approach

- In order to mitigate the risk, more information was needed about the environment, the window configuration, and the response of the windows to dust impacts in the environment
- ISIS worked with Doug Mehoke and the project to refine dust models
  - ISIS actively participated in early discussions of the most appropriate dust model to apply to the mission
  - Project ran simulations on the environment accounting for ISIS geometry to produce impact statistics
- ISIS established a plan for testing of candidate windows at Heidelberg dust impact facility
  - Few dust accelerator facilities in the world
  - Dust impact plan was established
  - Eric Christian travelled to Heidelberg with the samples to perform the test
- ISIS used dust impact results to determine a viable window configuration

Process: Mitigation - Dust Testing

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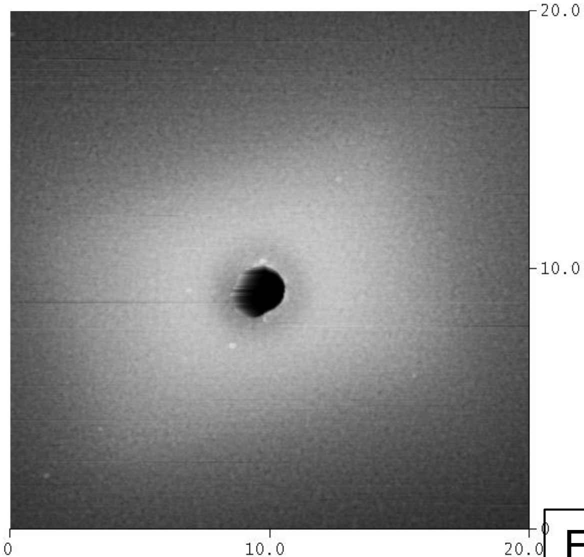
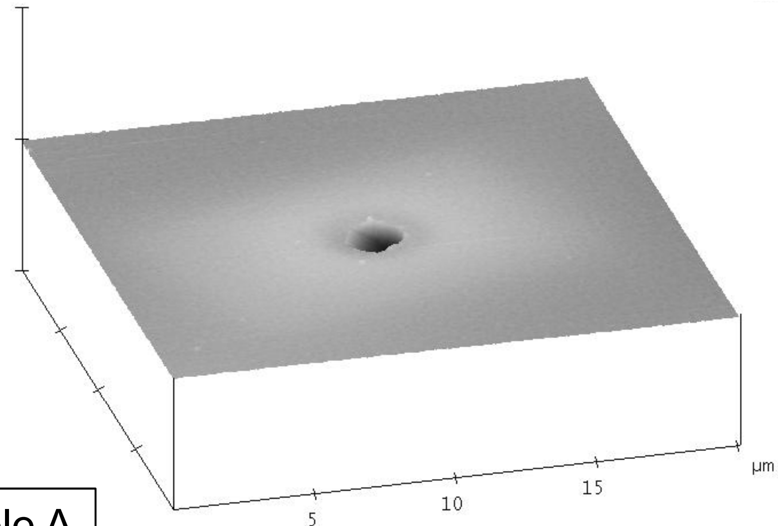
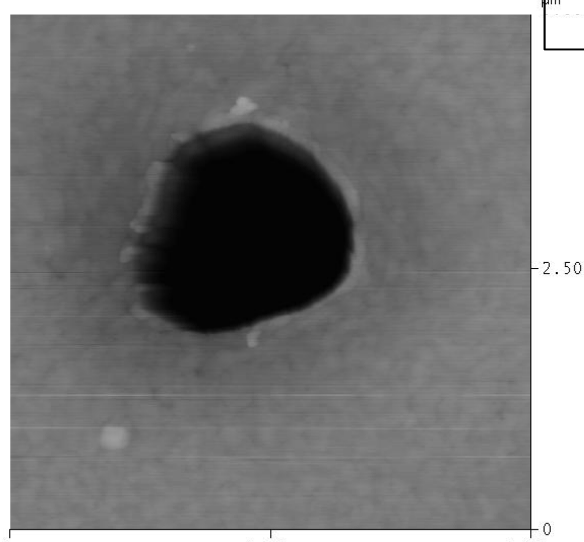


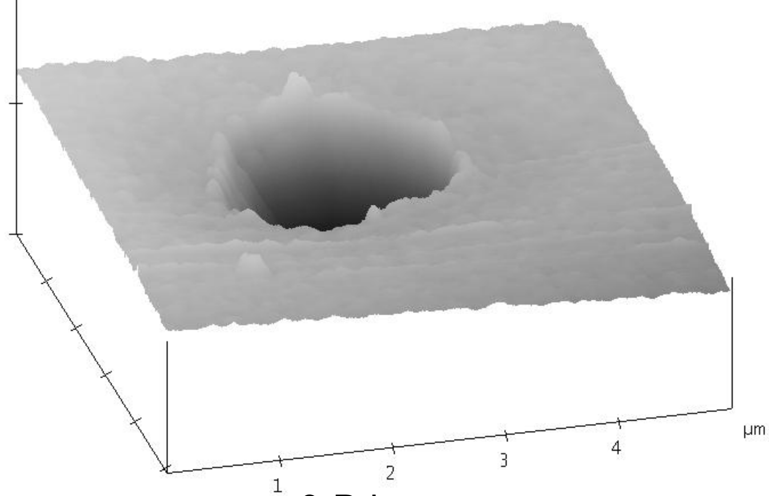


Foil #1, Hole A
Top Shown

The diameter of the hole: ~2.1 µm



Height image



3-D image

Process: Mitigation - Dust Testing

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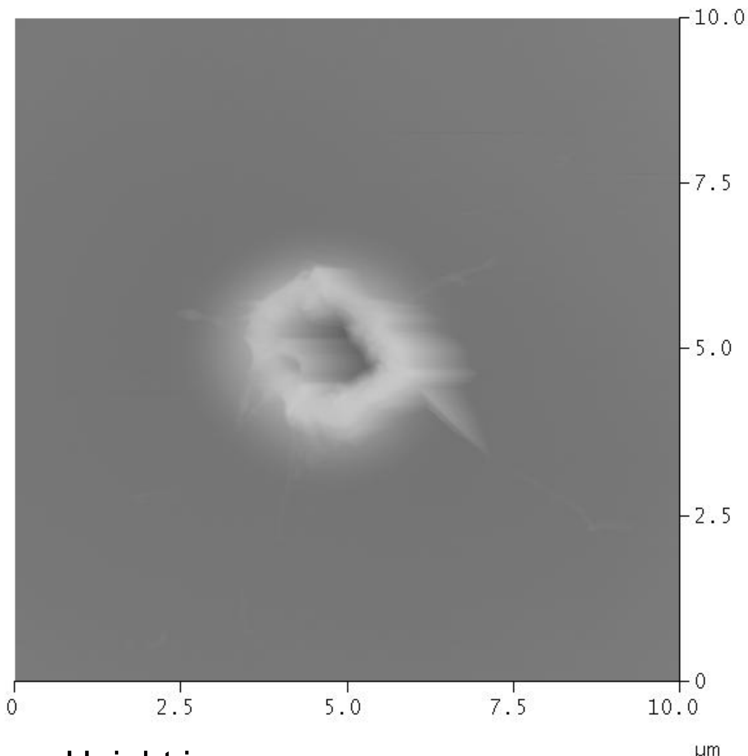
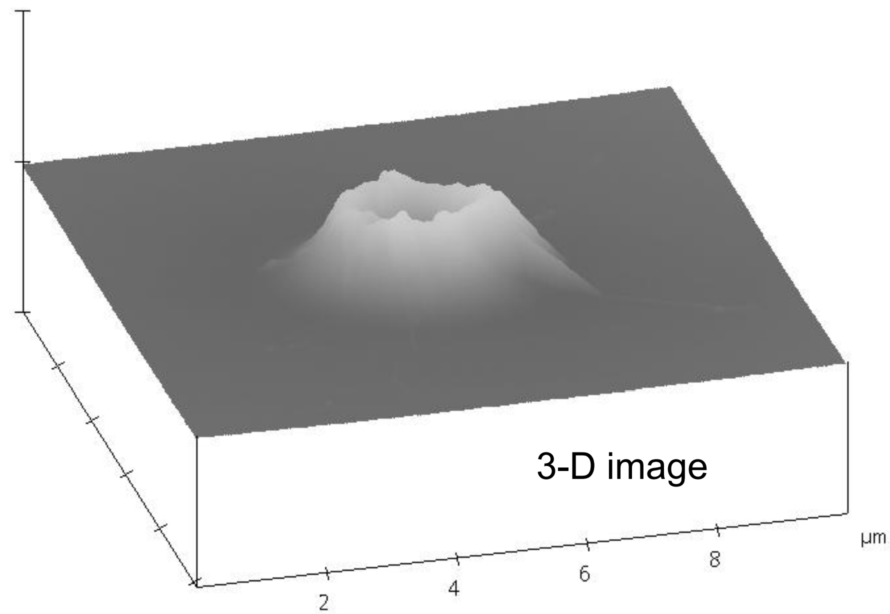
Foil #1, Hole A Bottom Shown



Height image



3-D image

The height of the crater: ~0.9 µm

Note that there are some artifacts in all AFM images due to AFM tip shape and scanning speed

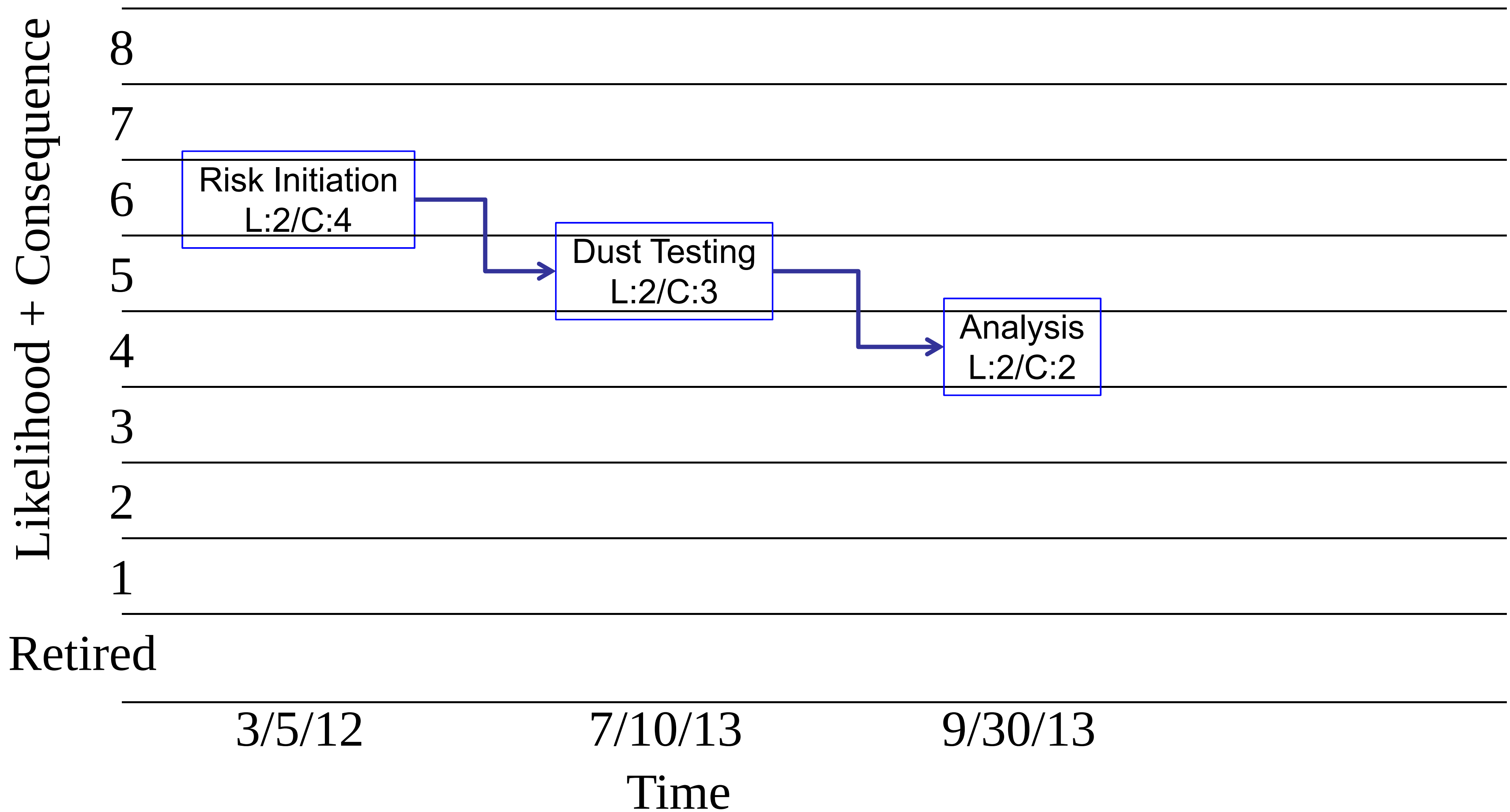
Process: Analysis and Results

- Tests showed the Windows performed as we had hoped

- Dust impacts did not propagate into large-scale tears
- Affected regions remained on the order of the particle size
- Triple stack of Windows effectively stopped lower energy particles (in some cases first two Windows were penetrated, but third was only dented)
- Even when full penetration occurs, collimation provided by the stack of Windows limits UV background

- Risk level was lowered through a combination of test and analysis

Process: Road Map



Summary

- ISIS risk process is effective and active
- Excellent coordination between SPP Project Team and ISIS in making analyses and running tests to reduce risk
- ISIS has made good progress in driving down and mitigating early risks during Phase B
- New risks will continue to be identified, and this process will be used to systematically work these risks down

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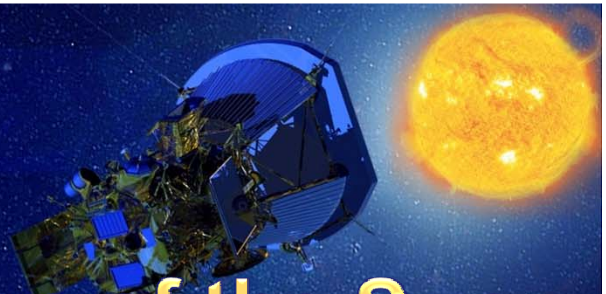

Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

Action Items

Nigel Angold

ISIS Systems Engineering (SwRI)

Outline

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- Sources of Action Items
- SwRI Action Item Tracking
- APL / Caltech Action Item Tracking
- ISIS Action Items from Meetings
- Summary of ISIS Action Item Tracking

Sources of Action Items

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- No action items assigned to ISIS at MDR
- Other action items from:
  - PDR, CDR, SIR, PER, PSR
  - Peer Reviews
  - I&T
  - Fabrication Readiness Reviews, Test Readiness Reviews etc.
  - SPP-ISIS meetings
  - Internal ISIS meetings

SwRI Action Item Tracking (1/2)

SwRI has its own tracking system for action items:

- Project Information Management System – Action Item Management PIMS-AIM
  - PIMS-AIM tracks the action item history and automatically distributes status updates, due date reminders, closure memos
  - The ISIS Project Manager is responsible for PIMS-AIM
  - The ISIS Systems Engineer (SE) is responsible for tracking the disposition of ISIS action items
  - For reviews, in addition to PIMS-AIM tracking, an Internal Design Review Report (IDRR) form is generated and signed off by the review chair when all action items are closed

SwRI Action Item Tracking (2/2)

- PIMS-AIM will be used to track action items from:
  1. PDR, CDR, SIR, PER, PSR
  2. EPI-Hi Peer Reviews
  3. EPI-Hi I&T
  4. EPI-Hi FRRs, TRRs
- At the end of a review, action items are re-visited, summarized and documented, written inputs from reviewers collected
- Action item materials are posted on the ISIS Wiki

APL / Caltech Action Item Tracking

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- APL has its own tracking systems, which the EPI-Lo team will use for lower-level action items, e.g. peer reviews:
  - Post-review, a memo is circulated to all review participants and ISIS management, which lists all action items
  - At APL, action items are recorded in an Excel spreadsheet and tracked by the EPI-Lo team. This is periodically distributed as work on each action item progresses
  - Action Item Response memos are circulated to all review participants and ISIS management summarizing the disposition of each action item until all have been closed
- APL will use SwRI's PIMS-AIM for higher-level action items, e.g. from PDR, CDR, etc.; it is always available to EPI-Lo as a backup tracking mechanism
- Caltech will use the SwRI action item tracking tools

ISIS Action Items from Meetings

For tracking actions items from SPP-ISIS meetings and internal ISIS meetings:

- Action items arising during meetings are noted in the minutes, and an actionee and due date are assigned
- Progress is tracked during subsequent meetings and noted in the minutes
- Action items remain in the meeting minutes until they are closed
- The SPP Payload Systems Engineer (SE) is responsible for tracking action items arising from SPP-ISIS meetings
- The ISIS SE is responsible for tracking the disposition of ISIS action items from internal meetings

Summary of ISIS Action Item Tracking (1/2)

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Action Items from	SwRI	APL	Caltech
PDR, CDR etc.	PIMS-AIM	PIMS-AIM	PIMS-AIM
Peer reviews	PIMS-AIM	Memos, spreadsheet	PIMS-AIM
I&T	PIMS-AIM	Memos, spreadsheet	PIMS-AIM
FRR, TRR etc.	PIMS-AIM	Memos, spreadsheet	PIMS-AIM
Meetings	Minutes	Minutes	Minutes

Summary of ISIS Action Item Tracking (2/2)

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- SwRI has the tools to track ISIS action items
- Institutional tracking tools will be used by the EPI-Lo team at APL to track lower-level action items (PIMS-AIM is available as a backup tracking system)
- High-level EPI-Lo action items will be tracked with SwRI’s tracking tools
- SwRI’s tools will be used to track all EPI-Hi action items
- Action items arising from meetings are being tracked through meeting minutes
- All ISIS action items are being effectively tracked

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Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

Instrument Development Status

Scott Weidner

ISIS PM (SwRI)

Outline

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- Key Dates
- EPI-Hi EM Schedule
- EPI-Lo EM Schedule
- EPI-Hi FM Schedule
- EPI-Lo EM Schedule
- Critical Path, Reserves, and Slack
- Schedule Threats and Mitigations
- Summary

ISIS Schedule Key Dates

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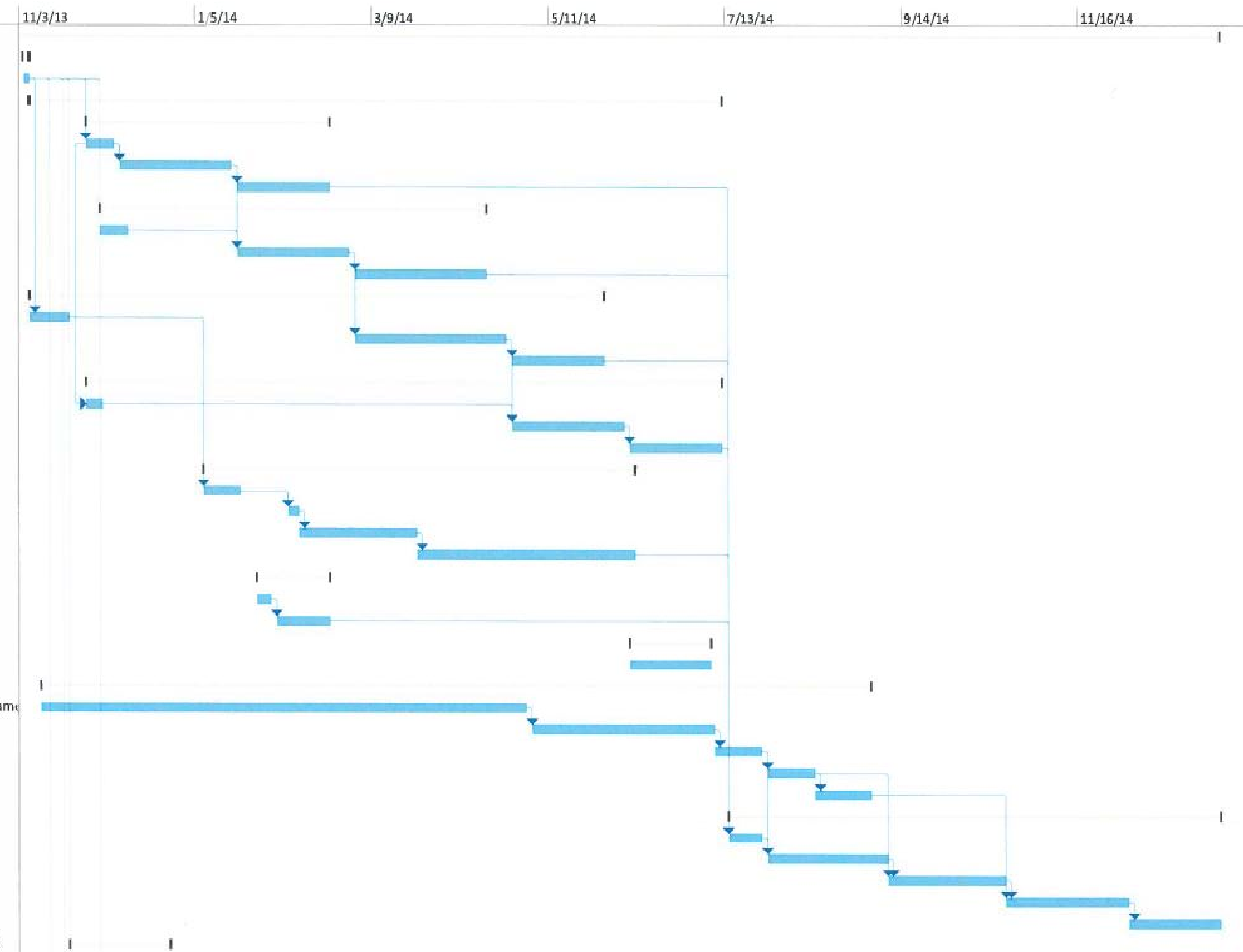
Q3 '13 | Q1 '14 | Q3 '14 | Q1 '15 | Q3 '15 | Q1 '16 | Q3 '16 | Q1 '17 | Q3 '17 | Q1 '18 | Q3 '18

Task Name	Date
Solar Probe Plus	
Mission Level Milestones	
Preliminary Design Review (PDR)	1/8
Critical Design Review (P-CDR)	3/4
System Integration Review (SIR)	6/3
Pre-Environmental Review (PER)	10/6
Pre-Ship Review (PSR)	2/22
Launch Readiness Review (LRR)	7/31
Mission Phases	
Phase B	
Phase C	
Phase D	
Phase E Start (Ends 9/1/25)	
Instruments	
ISIS Milestones	
ISIS PDR	11/5
ISIS CDR (13/14 January 2015)	1/13
EPI-Lo PER	2/5
EPI-Hi PER	2/8
EPI-Lo Mandatory Schedule Reserve (65 days)	
EPI-Hi Mandatory Schedule Reserve (65 days)	
EPI-Lo PSR	2/16
EPI-Hi PSR	2/17
EPI-Lo Mandatory Ship Date (3/08/17)	3/7
EPI-Hi Mandatory Ship Date (3/08/17)	3/7

ISIS Schedule: EPI-Hi EM

ID	Task Name
1	**Instruments**
2	**ISIS Milestones**
3	*ISIS iPDR and SOC iPDR (11/5&6)*
4	**EPI-Hi EM Electronics Development**
5	**EPI-Hi EM LET 1 Board**
6	Prepare and kit parts LET 1
7	Assemble EM LET 1
8	Test/Rework/Document EM LET 1
9	**EPI-Hi EM DPU Board**
10	Prepare and kit parts DPU
11	Assemble EM DPU
12	Test/Rework/Document EM DPU
13	**EPI-Hi EM LET 2 Board**
14	Prepare and kit parts LET 2
15	Assemble EM LET 2
16	Test/Rework/Document EM LET 2
17	**EPI-Hi EM HET Board**
18	Prepare and kit parts HET
19	Assemble EM HET
20	Test/Rework/Document EM HET
21	**EPI-Hi EM SSD Bias Supply**
22	Prepare and kit parts SSD Bias
23	Receive/Inspect SSD Bias EM PCB
24	Assemble EM SSD Bias
25	Prepare/Test/Rework/Document EM
26	**EPI-Hi EM LVPS**
27	Receive/inspect/doc EM board
28	Test/Rework/Document EM LVPS
29	**Detectors**
30	Detector selection
31	**EPI-Hi EM Mechanical Development**
32	Iterate Stress analyses mounts/board frame
33	E-Box machine and deliver
34	LET1 telescope machine and deliver
35	LET2 telescope delivery
36	HET telescope delivered
37	**EPI-Hi EM Integration and Testing**
38	Integrate EM boards with E-Box
39	Integrate & Test LET 1
40	Integrate and Test LET 2
41	Integrate and Test HET
42	Fully integrated unit test
43	**LVPS for EPI-Hi Engineering Development**



ISIS Schedule: EPI-Lo EM and Bracket

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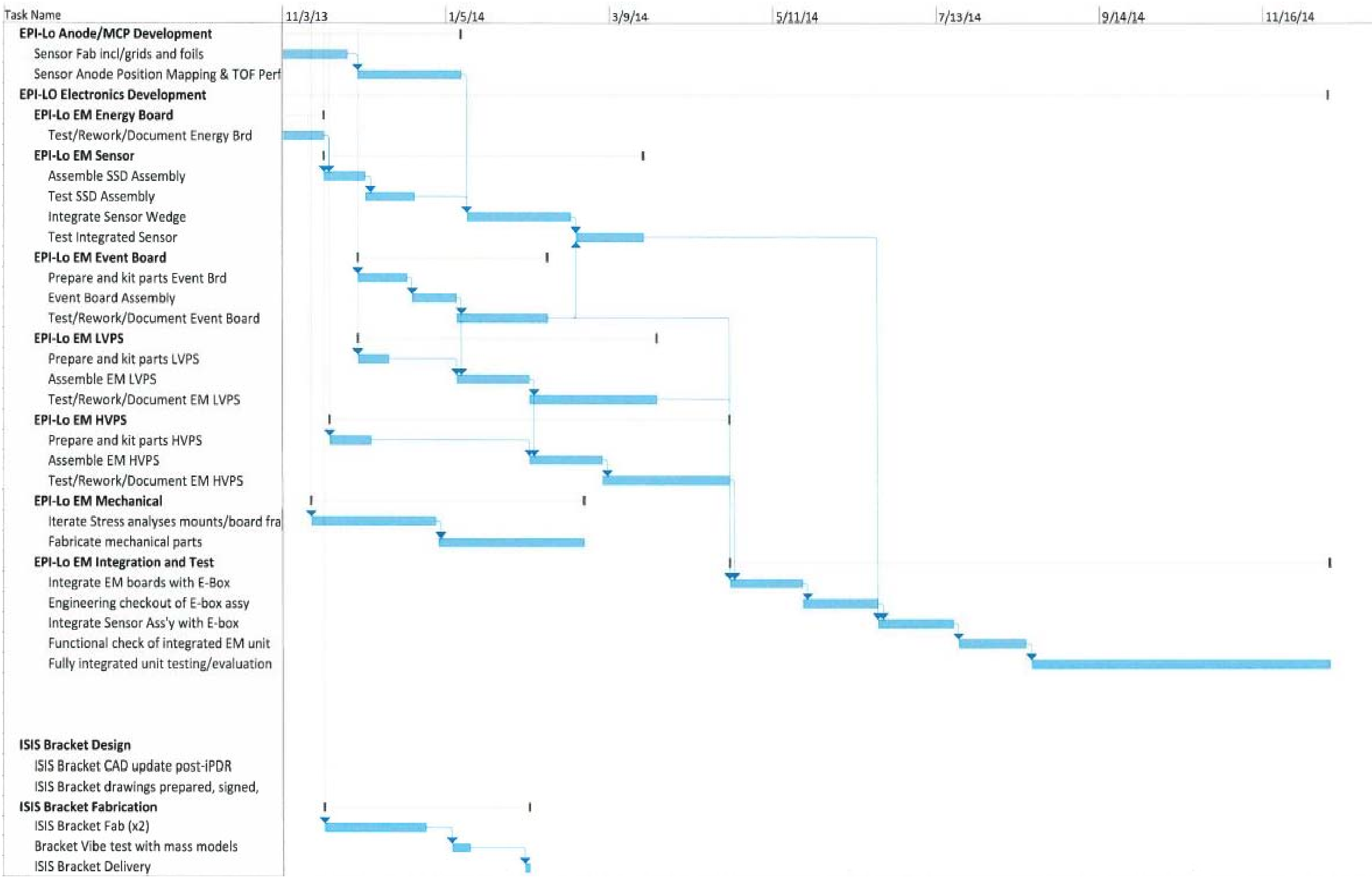

ISIS Schedule: EPI-Hi FM

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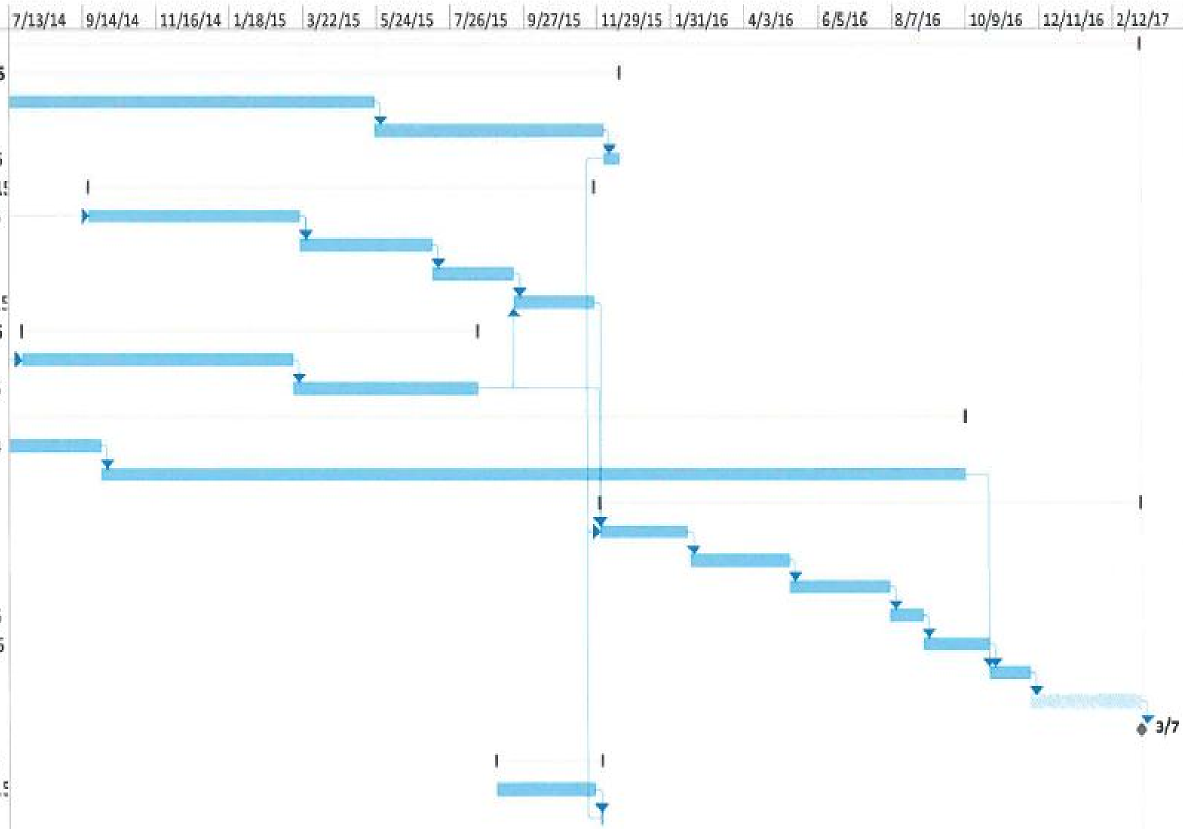
ID	Task Name	Duration	Start	Finish
97	**EPI-Hi Flight Model**	**766 days**	**Thu 2/27/14**	**Tue 3/7/17**
98	**Detectors**	**395 days**	**Wed 5/28/14**	**Thu 12/17/15**
99	Flight Detector Process/Mount/Test	250 days	Wed 5/28/14	Thu 5/21/15
100	Detector Environmental Tests	135 days	Fri 5/22/15	Thu 12/3/15
101	Select FM Detectors for Flight Unit	10 days	Fri 12/4/15	Thu 12/17/15
102	**Electronics Module**	**301 days**	**Fri 9/19/14**	**Wed 11/25/15**
103	Electronics Boards Design Update/Modify	124 days	Fri 9/19/14	Wed 3/18/15
104	Electronics Boards Fab	79 days	Thu 3/19/15	Thu 7/9/15
105	Electronics Boards Test	49 days	Fri 7/10/15	Thu 9/17/15
106	Electronics Boards Integrate	49 days	Fri 9/18/15	Wed 11/25/15
107	**Mechanical**	**270 days**	**Thu 7/24/14**	**Mon 8/17/15**
108	Mechanical Design Update/Modify	160 days	Thu 7/24/14	Thu 3/12/15
109	Mechanical Fabrication	110 days	Fri 3/13/15	Mon 8/17/15
110	**Firmware/Software**	**664 days**	**Thu 2/27/14**	**Fri 10/7/16**
111	Firmware/Software Implementation	150 days	Thu 2/27/14	Mon 9/29/14
112	Firmware/Software Validation/Test	514 days	Tue 9/30/14	Fri 10/7/16
113	**EPI-Hi FM Unit Assy/Calibration/Test**	**322 days**	**Mon 11/30/15**	**Tue 3/7/17**
114	Assembly	53 days	Mon 11/30/15	Fri 2/12/16
115	Test	61 days	Mon 2/15/16	Mon 5/9/16
116	Calibration	60 days	Tue 5/10/16	Wed 8/3/16
117	Disassemble, Stake, Coat, Reassemble	20 days	Thu 8/4/16	Wed 8/31/16
118	Environmental Test	40 days	Thu 9/1/16	Thu 10/27/16
119	Final Calibration	23 days	Fri 10/28/16	Thu 12/1/16
120	ISIS Schedule Reserve (65 days)	65 days	Fri 12/2/16	Mon 3/6/17
121	Mandatory Ship Date	0 days	Tue 3/7/17	Tue 3/7/17
122	**ISIS FM Bracket Fabrication**	**62 days**	**Wed 9/2/15**	**Tue 12/1/15**
123	ISIS Bracket Fab (x2)	60 days	Wed 9/2/15	Wed 11/25/15
124	ISIS Bracket Delivery to FM Integration	2 days	Mon 11/30/15	Tue 12/1/15



ISIS Schedule: EPI-Lo FM and Bracket

ID	Task Name	Duration	Start	Finish
97	**EPI-Hi Flight Model**	**766 days**	**Thu 2/27/14**	**Tue 3/7/17**
98	**Detectors**	**395 days**	**Wed 5/28/14**	**Thu 12/17/15**
99	Flight Detector Process/Mount/Test	250 days	Wed 5/28/14	Thu 5/21/15
100	Detector Environmental Tests	135 days	Fri 5/22/15	Thu 12/3/15
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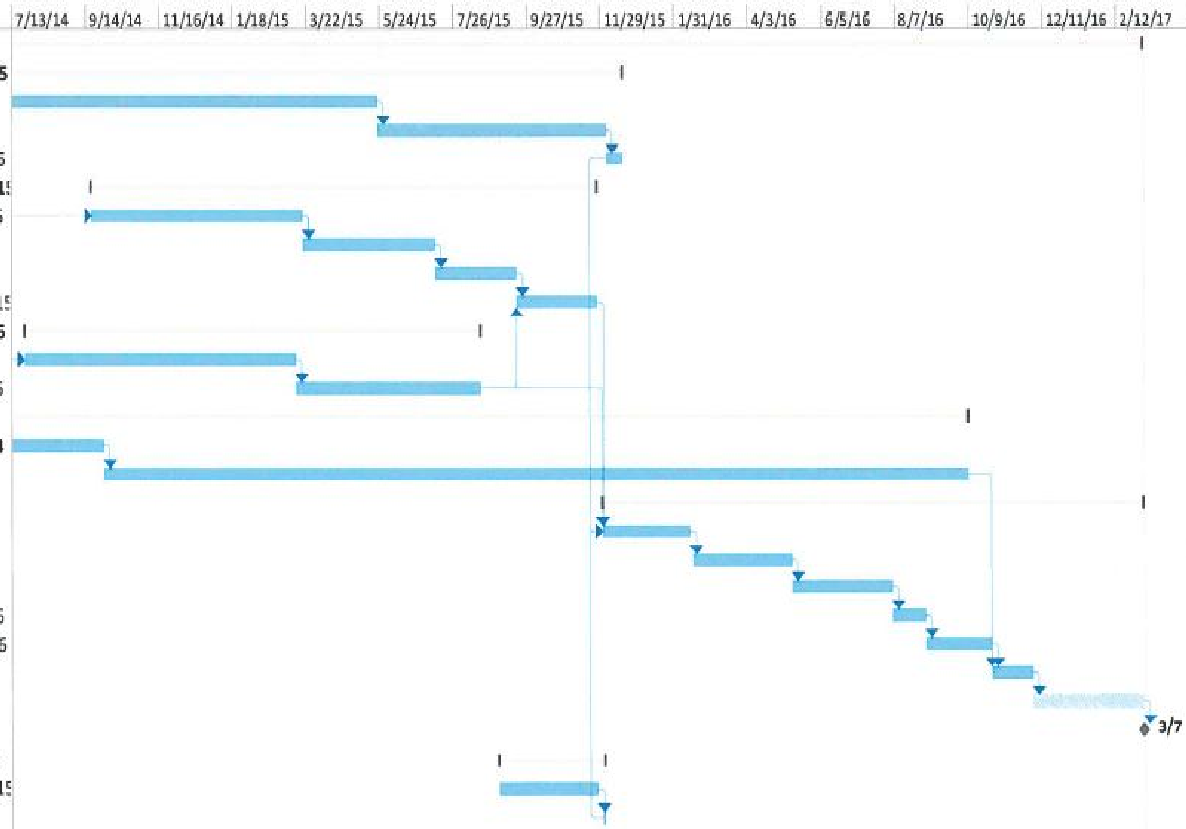
107	**Mechanical**	**270 days**	**Thu 7/24/14**	**Mon 8/17/15**
108	Mechanical Design Update/Modify	160 days	Thu 7/24/14	Thu 3/12/15
109	Mechanical Fabrication	110 days	Fri 3/13/15	Mon 8/17/15
110	**Firmware/Software**	**664 days**	**Thu 2/27/14**	**Fri 10/7/16**
111	Firmware/Software Implementation	150 days	Thu 2/27/14	Mon 9/29/14
112	Firmware/Software Validation/Test	514 days	Tue 9/30/14	Fri 10/7/16
113	**EPI-Hi FM Unit Assy/Calibration/Test**	**322 days**	**Mon 11/30/15**	**Tue 3/7/17**
114	Assembly	53 days	Mon 11/30/15	Fri 2/12/16
115	Test	61 days	Mon 2/15/16	Mon 5/9/16
116	Calibration	60 days	Tue 5/10/16	Wed 8/3/16
117	Disassemble, Stake, Coat, Reassemble	20 days	Thu 8/4/16	Wed 8/31/16
118	Environmental Test	40 days	Thu 9/1/16	Thu 10/27/16
119	Final Calibration	23 days	Fri 10/28/16	Thu 12/1/16
120	ISIS Schedule Reserve (65 days)	65 days	Fri 12/2/16	Mon 3/6/17
121	Mandatory Ship Date	0 days	Tue 3/7/17	Tue 3/7/17
122	**ISIS FM Bracket Fabrication**	**62 days**	**Wed 9/2/15**	**Tue 12/1/15**
123	ISIS Bracket Fab (x2)	60 days	Wed 9/2/15	Wed 11/25/15
124	ISIS Bracket Delivery to FM Integration	2 days	Mon 11/30/15	Tue 12/1/15



Critical Path, Reserves, and Slack

- The ISIS Critical Path goes through EPI-Hi Mechanical development
  - Detectors => Telescopes => Assembly => Test
- 65 days of Reserves in-line with month/year reserves to delivery
- Within the schedule, there is slack between tasks to keep schedule pushed to the left even beyond the Reserves
- Earned Value already in use during Phase B to help keep a realistic picture of progress being made and provide early warning

Schedule Threats and Mitigations

- Schedule Threats
  - TRL6 development and other Phase B work eliminated the most serious schedule threats
    - New detectors, new ASIC designs
  - Long-lead parts always need to be watched
    - So far we've had excellent performance from Micron Semiconductor
  - Interfaces between institutions require extra attention
    - GSFC to Caltech with Mechanical and Detector Deliveries
    - JHU/APL to Caltech with LVPS Deliveries
- Mitigations
  - Planner provides weekly Look-Ahead List to the ISIS team
  - Weekly coordination meetings with all institutions
  - EM testing used to mitigate FM schedule risks
  - Earned Value Management provides early warning
  - Planner provides detailed analysis and coordinates with SPP

Summary

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- ISIS Team has performed well during Phase B

- TRL 6 Achieved for all of the ISIS Technology Development
- New design elements have been prototyped and tested
- Requirements Defined
  - Baseline of ICDs and Requirements Documents
- Detailed Preliminary Design completed
  - Schematics and mechanical designs Peer Reviewed
- Preliminary analyses show good margins
- Trade studies in Phase B have reduced risk

- ISIS is on track to proceed into Phase C on schedule

Solar Probe Plus

A NASA Mission to Touch the Sun

Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

Review Board Debrief

Chris Hersman

Review Board Chairman

Outline

- Review of Action Items
- Review Board Comments and Summary