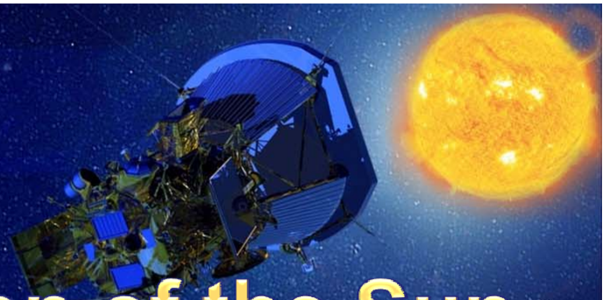
Solar Probe Plus

A NASA Mission to Touch the Sun



Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

Systems Engineering

John Dickinson

ISIS SE (SwRI)

Outline

- 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

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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)

Status Key:
- Started
- Draft: Key Driving
- Draft: Complete
- Preliminary
- Baseline

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

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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

- 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

- 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

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	Energetic Protons/Heavy Ions FOV	ISIS-118	EPI-Lo Instrument Protons/Heavy Ions Field of View	ISIS-218	EPI-Hi 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.		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.
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).		**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.		**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.		**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.

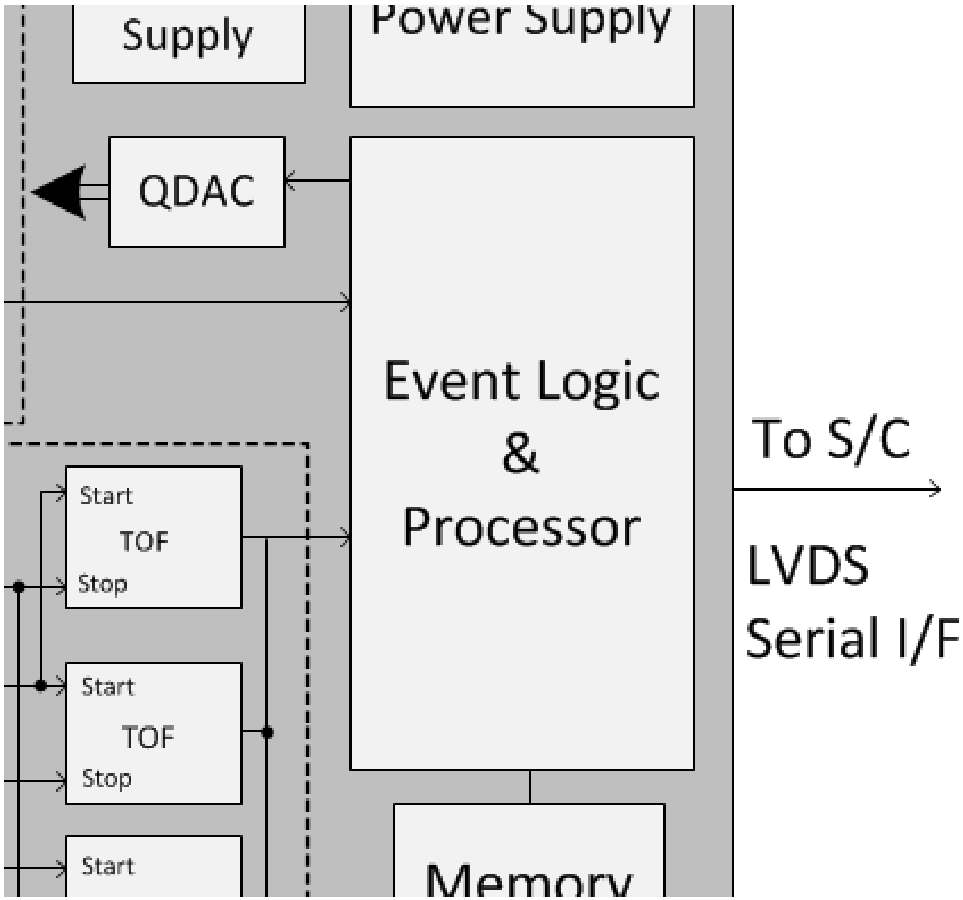
ISIS-118 verification

Verification Method	Verification Activity	Verification Result
Analysis & Test	Analyze obstructions using CAD model and inspect mounting on the spacecraft after integration to verify the accuracy of that analysis.	

ISIS-218 verification

Verification Method	Verification Activity	Verification Result
Analysis & Inspection	Analyze obstructions using CAD model and inspect mounting on the spacecraft after integration to verify the accuracy of that analysis.	

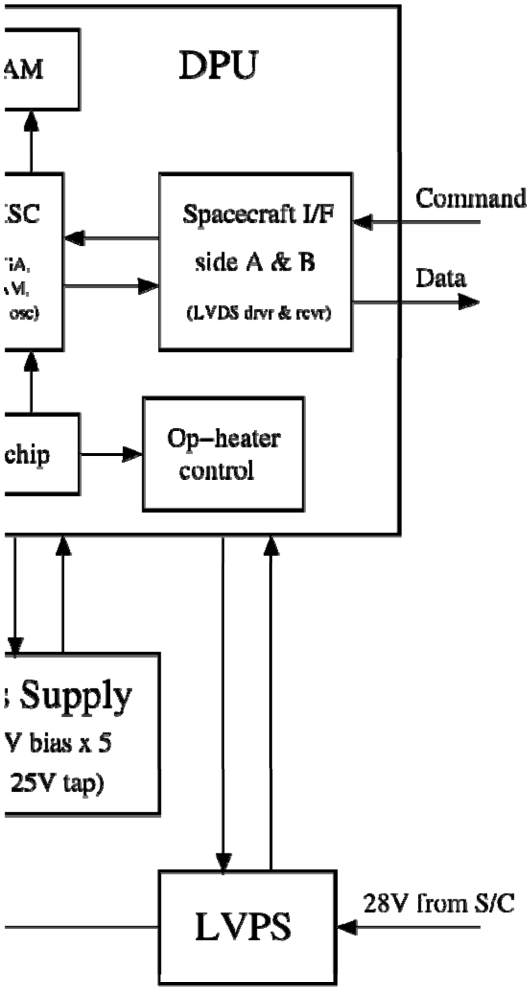
EPI-Lo Spacecraft Interfaces



- 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

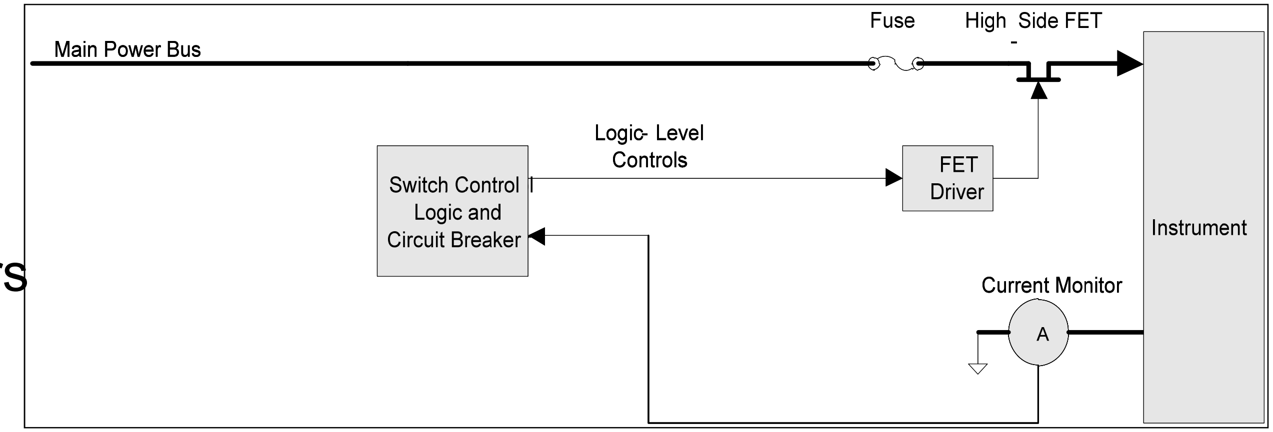


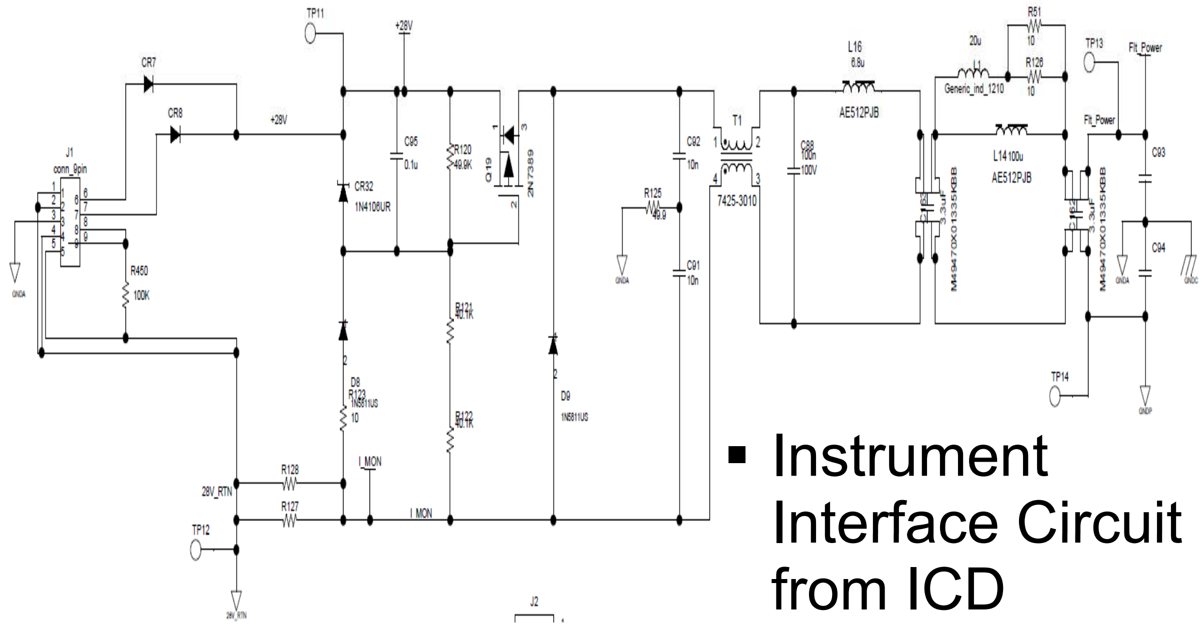
- Unique EPI-Hi-to-spacecraft Interfaces include:
  - Spacecraft power
  - Command/Telemetry
  - Survival Heaters
  - Spacecraft Temperature Sensors

EPI-Hi mounted to shared ISIS Bracket

Spacecraft Electrical Interfaces

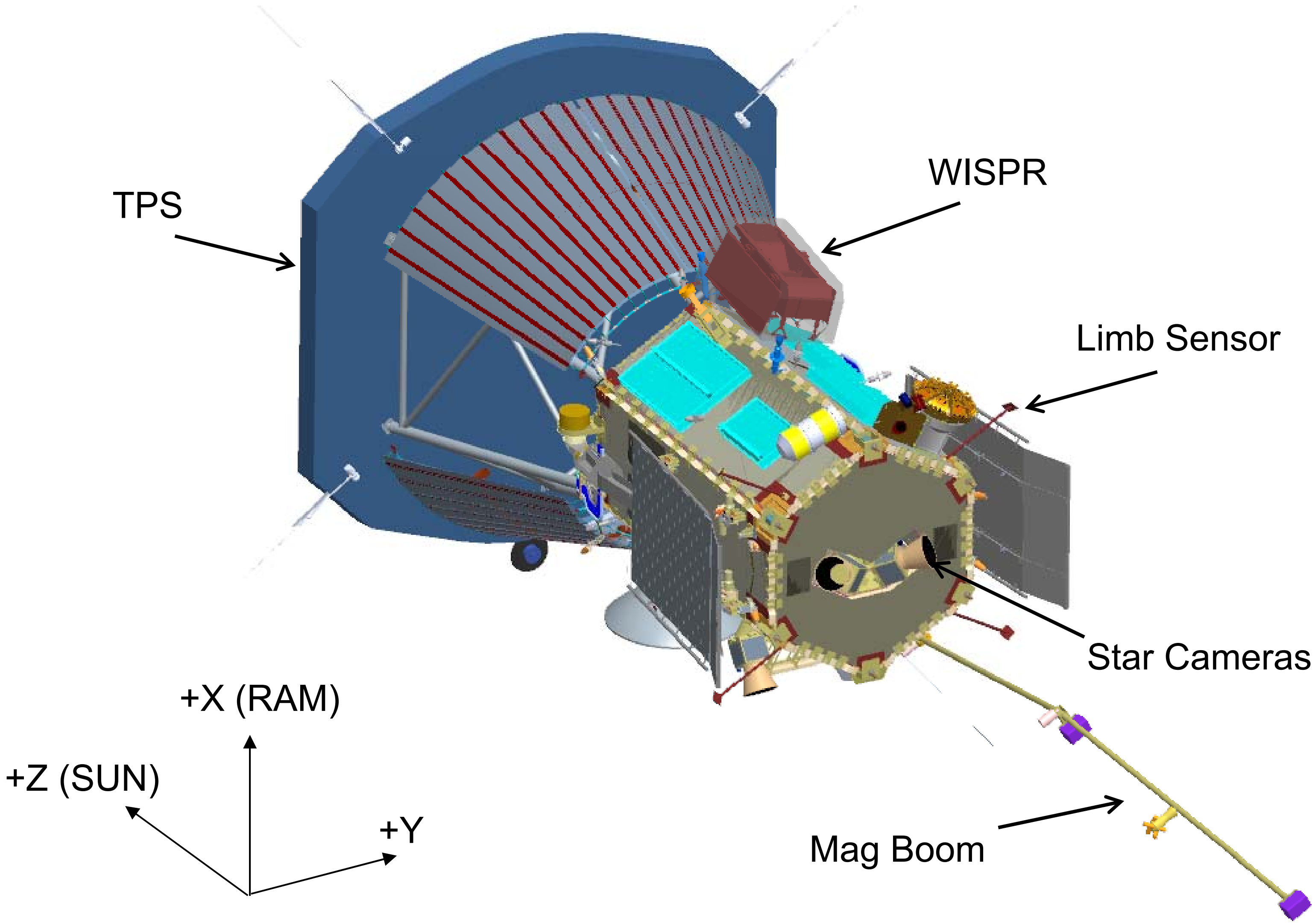
- Power
  - Main Instrument Power
  - Survival Heaters
  - Operational Heaters (EPI-Hi)
- Command & Telemetry
  - Side A/B LVDS UART
- Grounding
  - Chassis Ground to Bracket, thermally isolated
- Thermal
  - Heaters
  - Temperature Sensors
- Captured in GI and SPP-ISIS ICDs





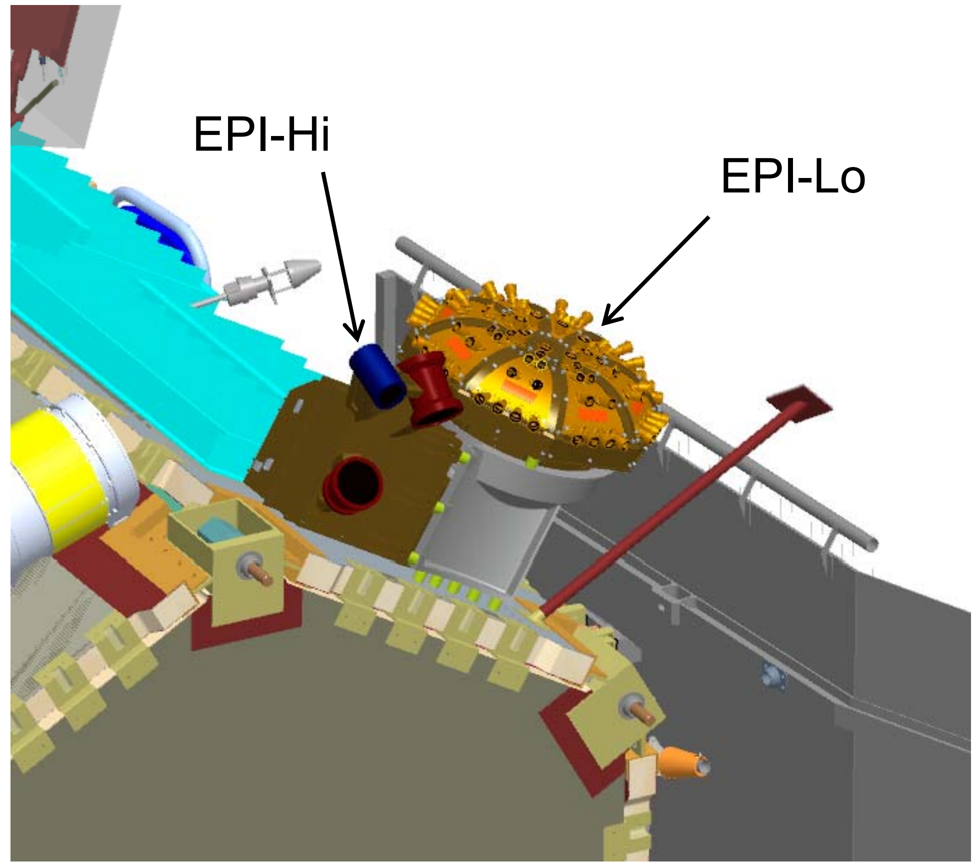
- Instrument Interface Circuit from ICD

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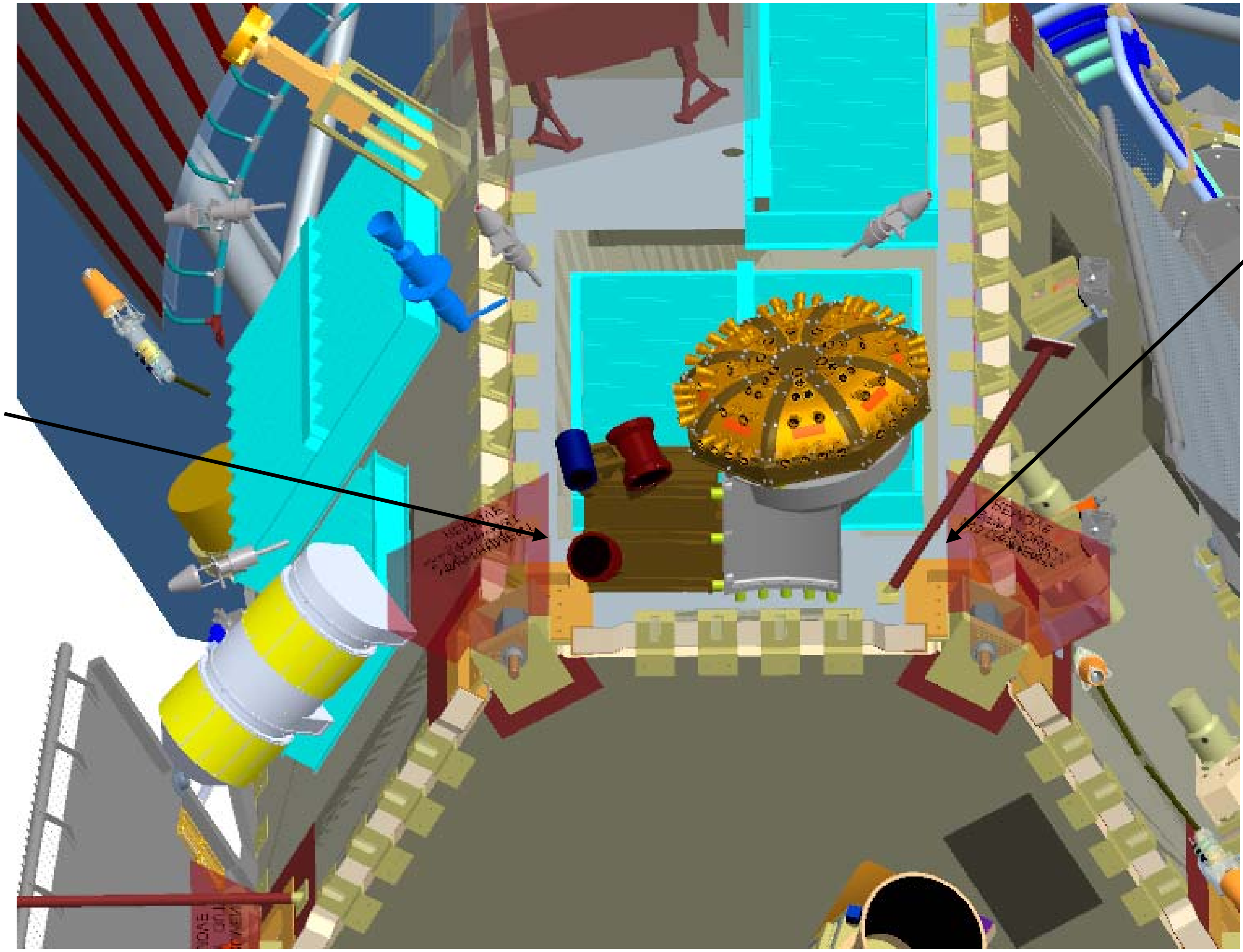
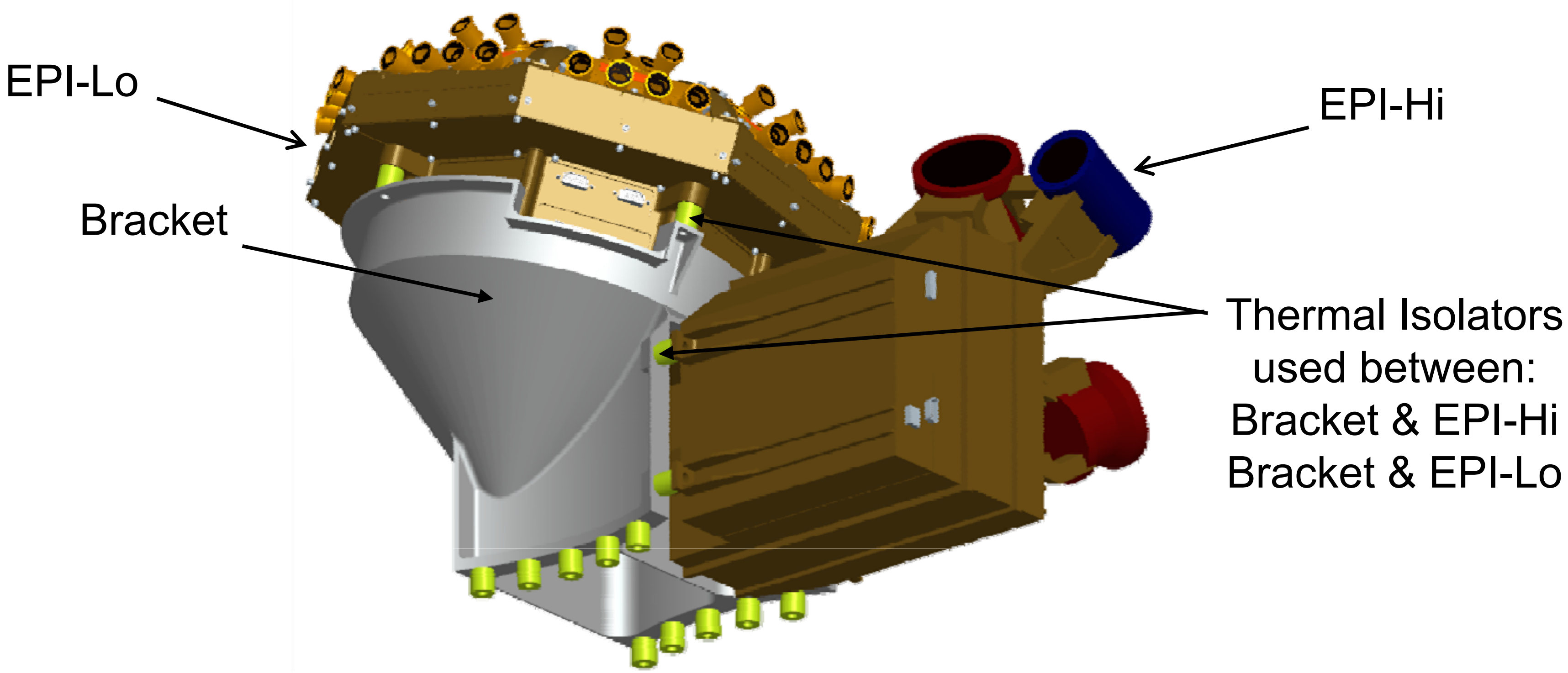
EPI-Hi to S/C Sep Conn. is ~2 cm



Ample clearance between EPI-Lo and S/C

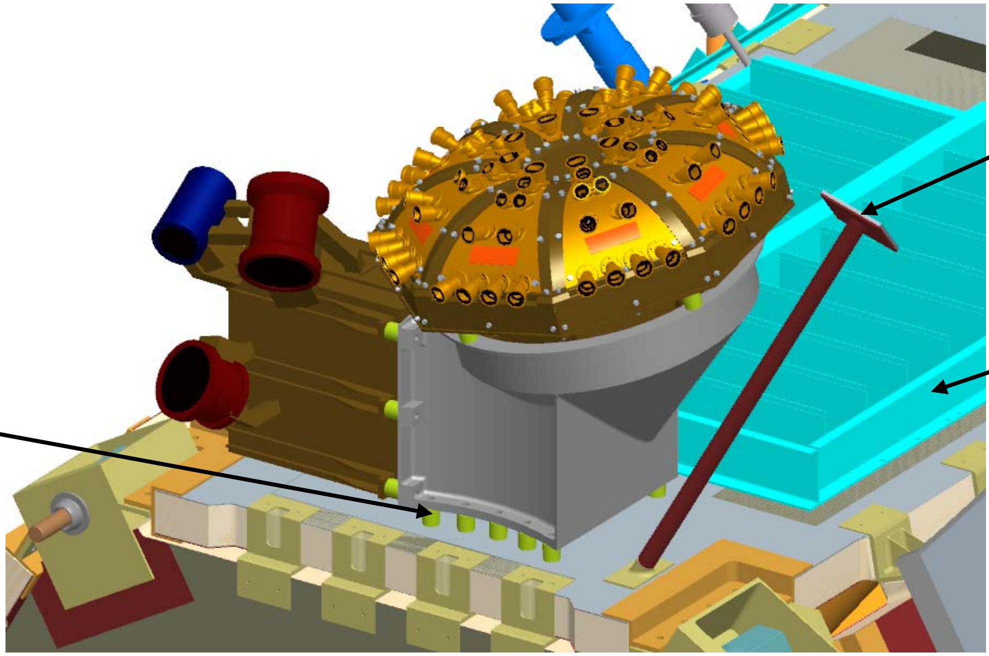
ISIS Instrument Mounting to Bracket

- 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

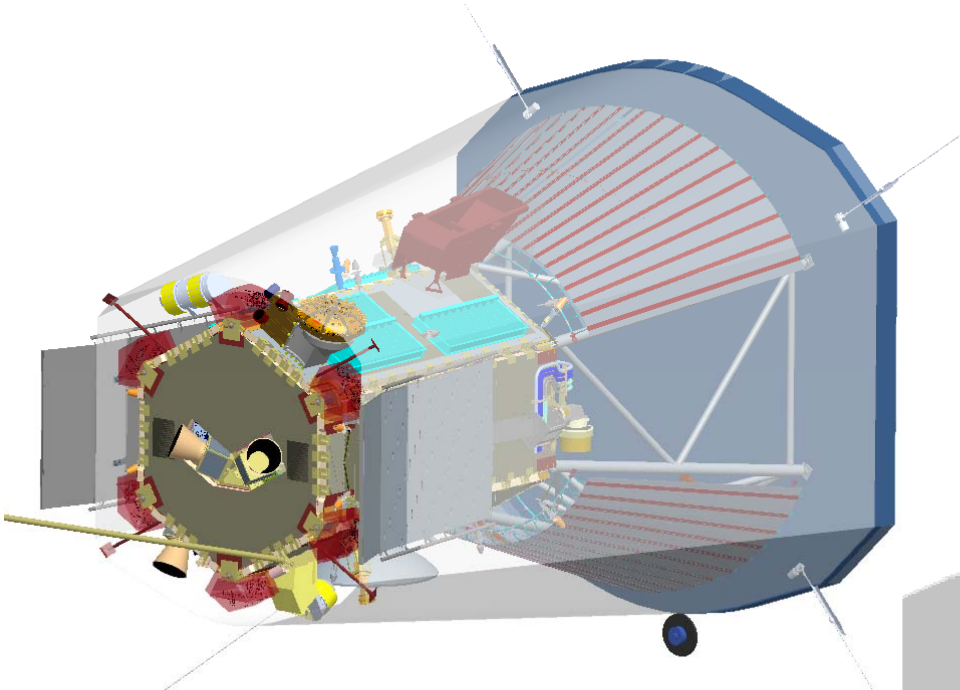


ISIS Mounting to Spacecraft Deck

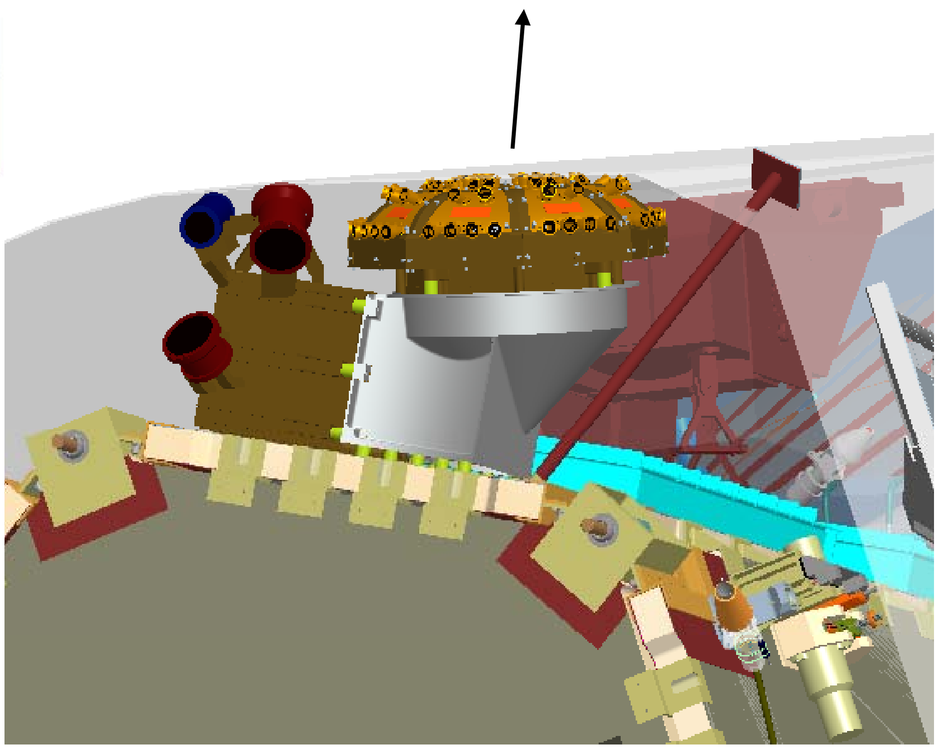
- ISIS bracket mounts on a very small footprint, keeping away from spacecraft structural elements and other deck-mounted components
- ISIS bracket allows for flexibility in mounting order of EPI-Hi and EPI-Lo, and accommodates easy access to EPI-Hi and EPI-Lo mounting interfaces and spacecraft interfaces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



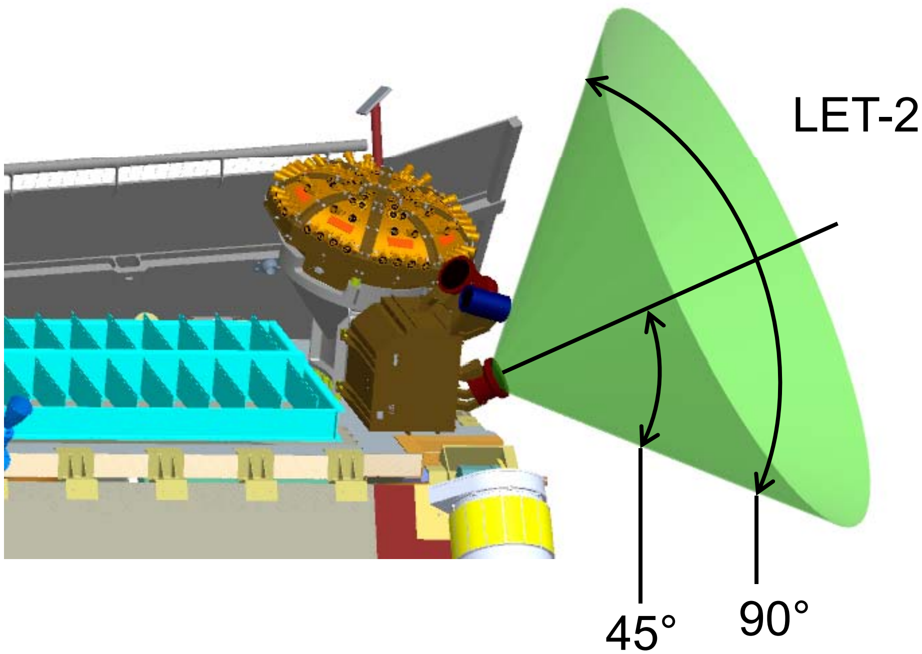
Relationship of ISIS to TPS Umbra

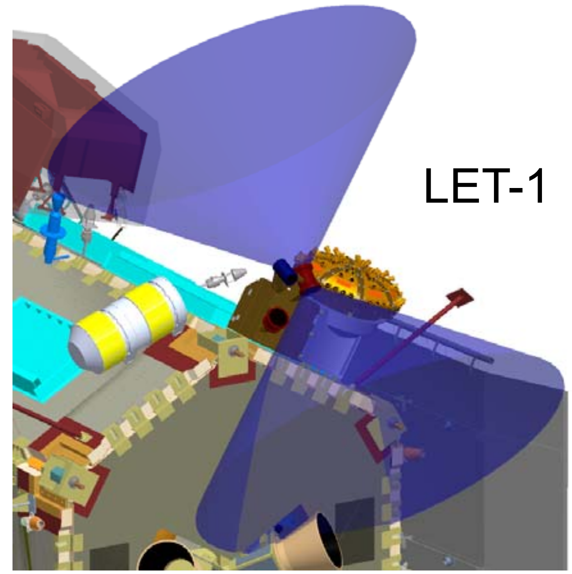


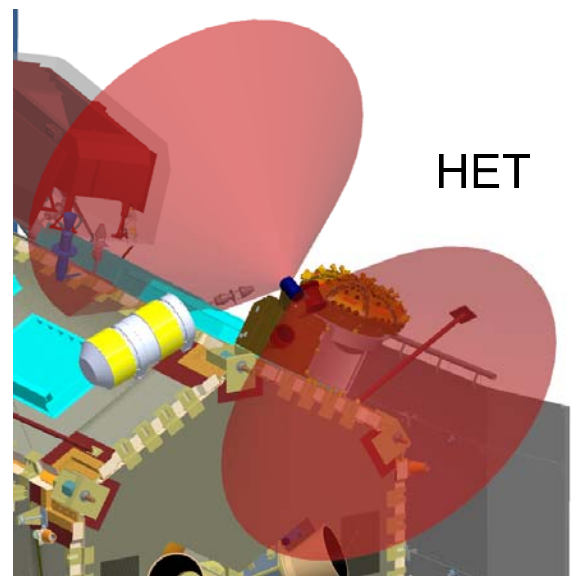
Bracket height can increase in the event of a late TPS shift (Direction of motion shown)



EPI-Hi Field Of View



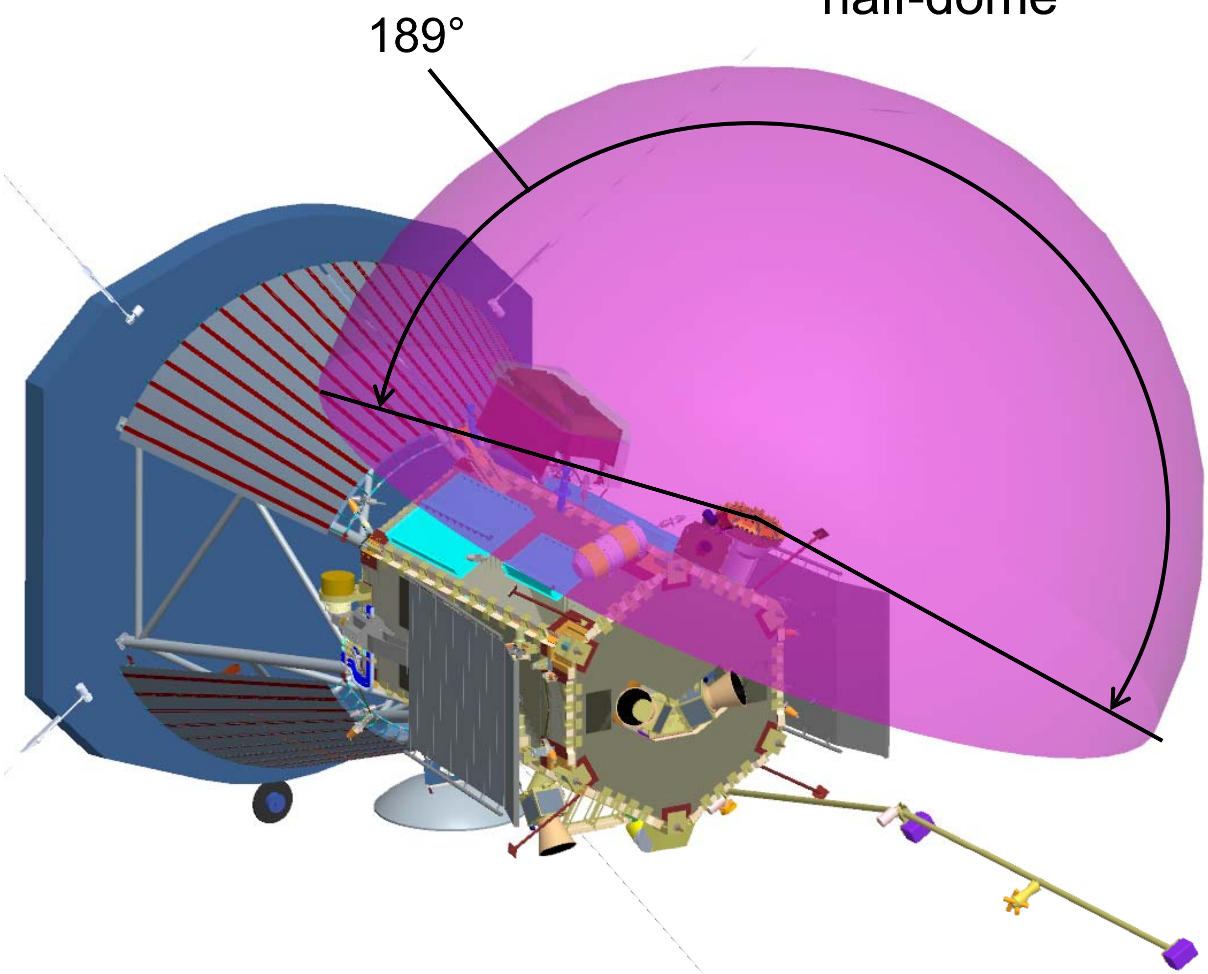


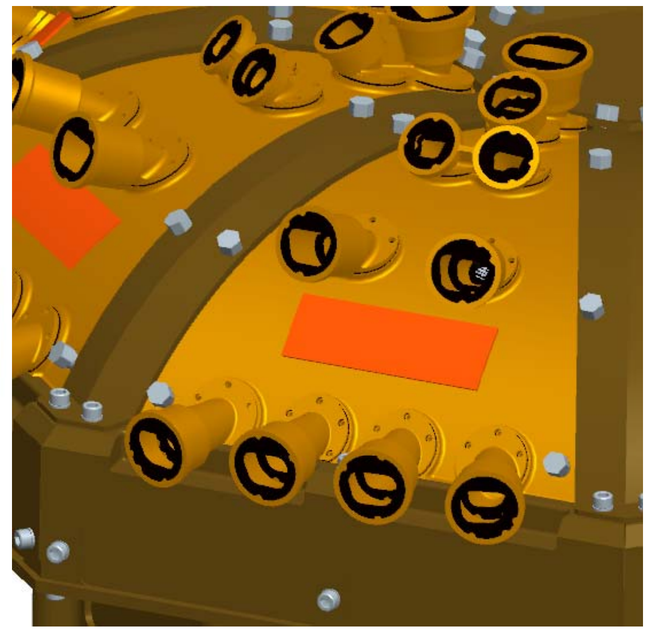


- All EPI-Hi telescopes have the same FOV shape as dimensioned in LET-2

EPI-Lo Field Of View

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





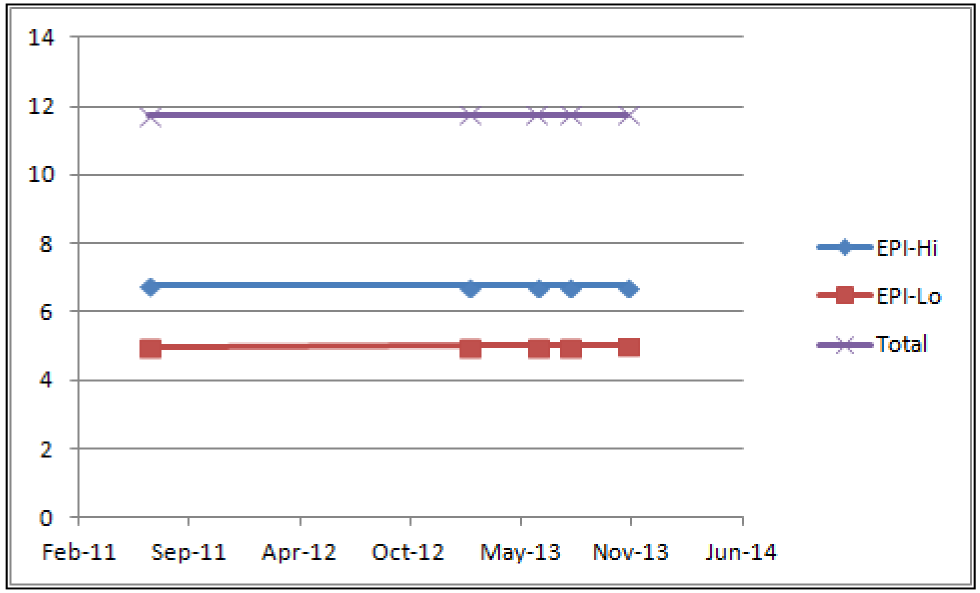
Thermal Interfaces

- 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**		

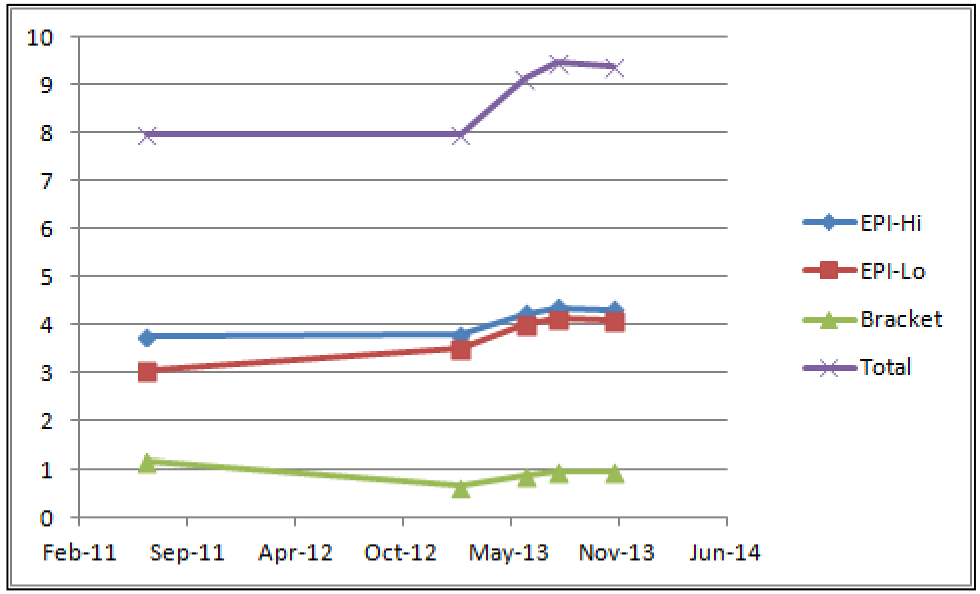


- ISIS Current Best Estimates and Uncertainties
- During Survival, heater power is duty cycled to ensure instrument stays above survival temperature
- During Warm-up, heater has a 100% duty cycle to warm the instrument prior to normal operations (Encounter Mode)
- Because all resources on SPP are tightly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

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

- 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

		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

		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

		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

		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

		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

- 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

Solar Probe Plus
A NASA Mission to Touch the Sun

- 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)