National Aeronautics and
Space Administration

NASA EUROPA CLIPPER
JOURNEY TO AN OCEAN WORLD

NASA's Europa Clipper Mission: Drawing from the NEPP Knowledge Base

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Jet Propulsion Laboratory, California Institute of Technology

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NASA Electronic Parts and Packaging (NEPP) Program - Electronics Technology Workshop (ETW)

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Thanks to the Europa Clipper Radiation Team

Too many to mention, but big thanks to all the contributors to the Radiation Effects work on the project across JPL, APL and our many partners and suppliers

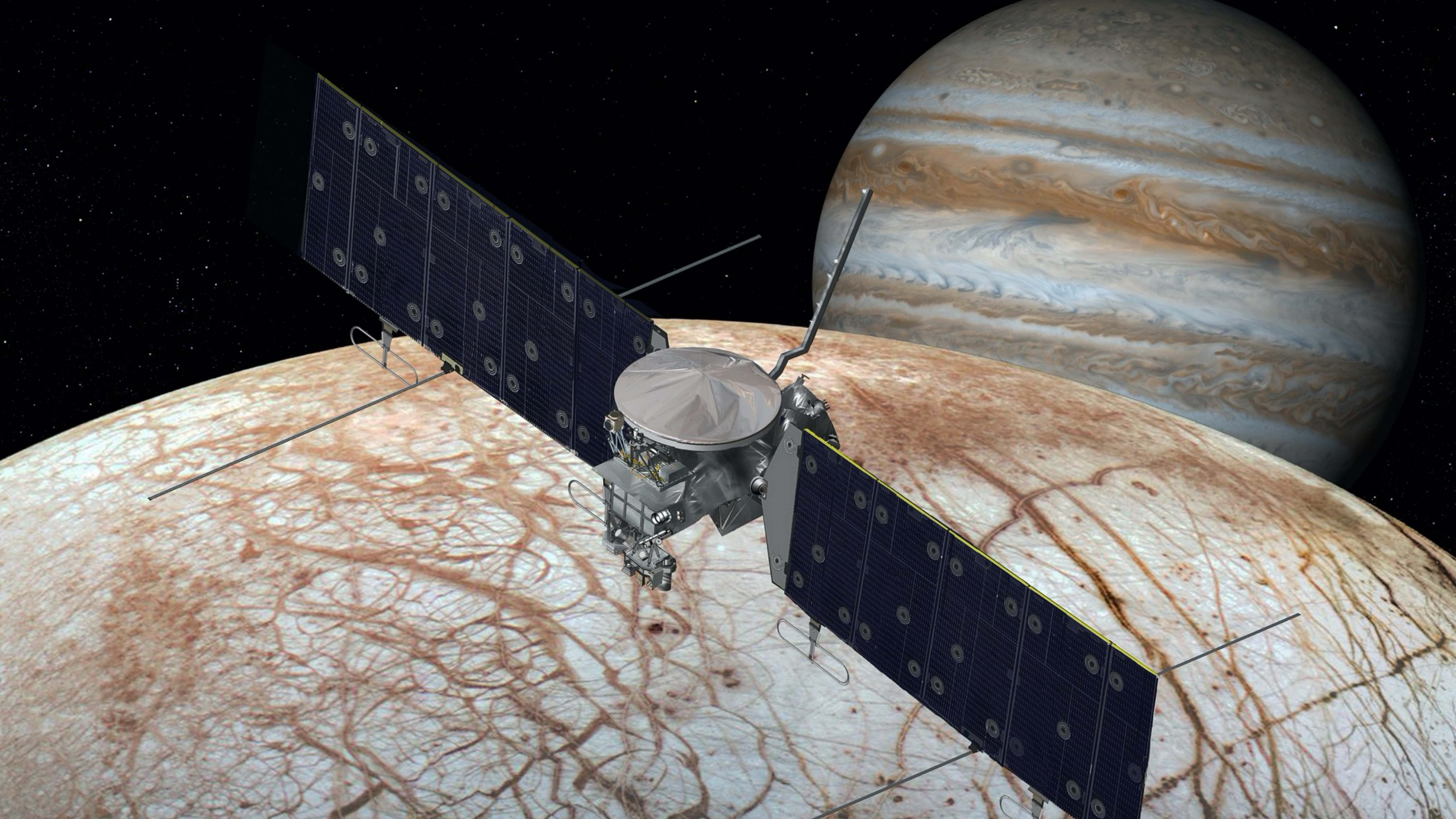
Thanks also to the NEPP project for providing a foundation for our Radiation Program

Overview

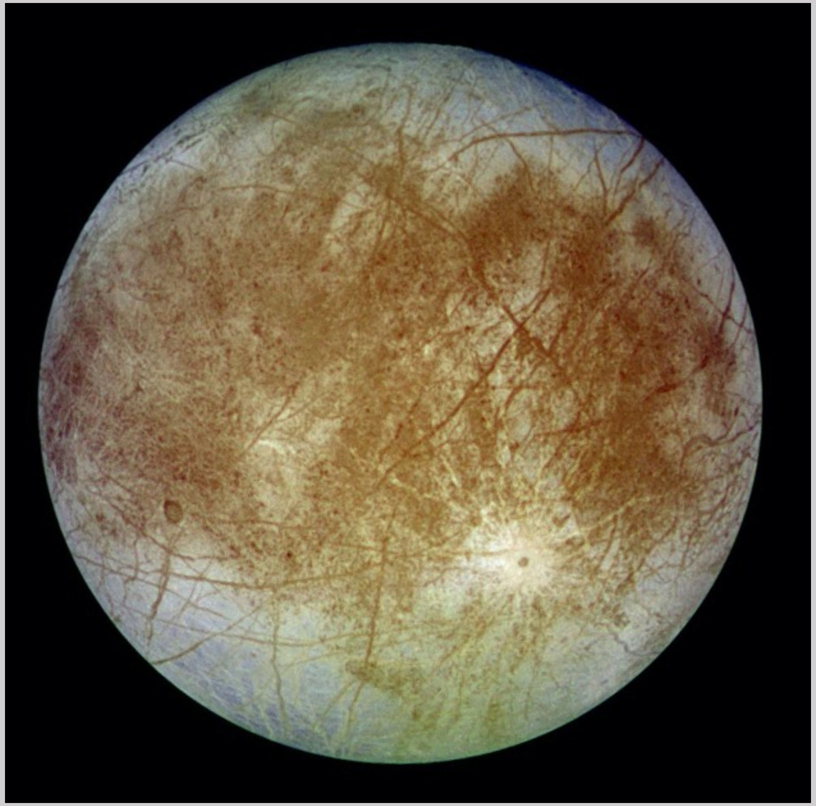
- Science Objectives
- Radiation Environment
- Shielding Approach
- Parts Selection Approach
- Risk Reduction Tasks
- NEPP Program Applicable Work
- Observations and Summary

In Backup Slides

- Radiation Testing Results
- Transport Verification
- Solar Panel Testing
- iESD Mitigation
- Radiation Monitor Subsystem (RadMon)



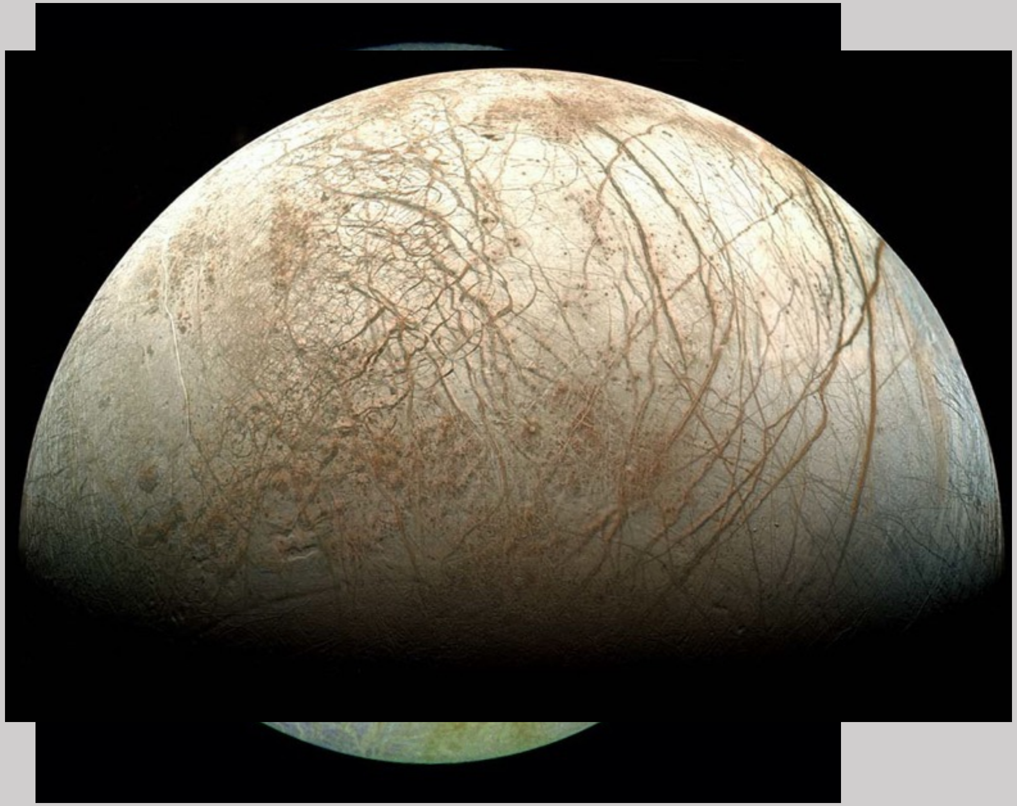
Europa: Key to Icy World Habitability



- **A world of rock, ice, and water the size of Earth's moon**

The Motivation

Europa: Key to Icy World Habitability



- A world of rock, ice, and water the size of Earth's moon
- One of the youngest surfaces in the solar system

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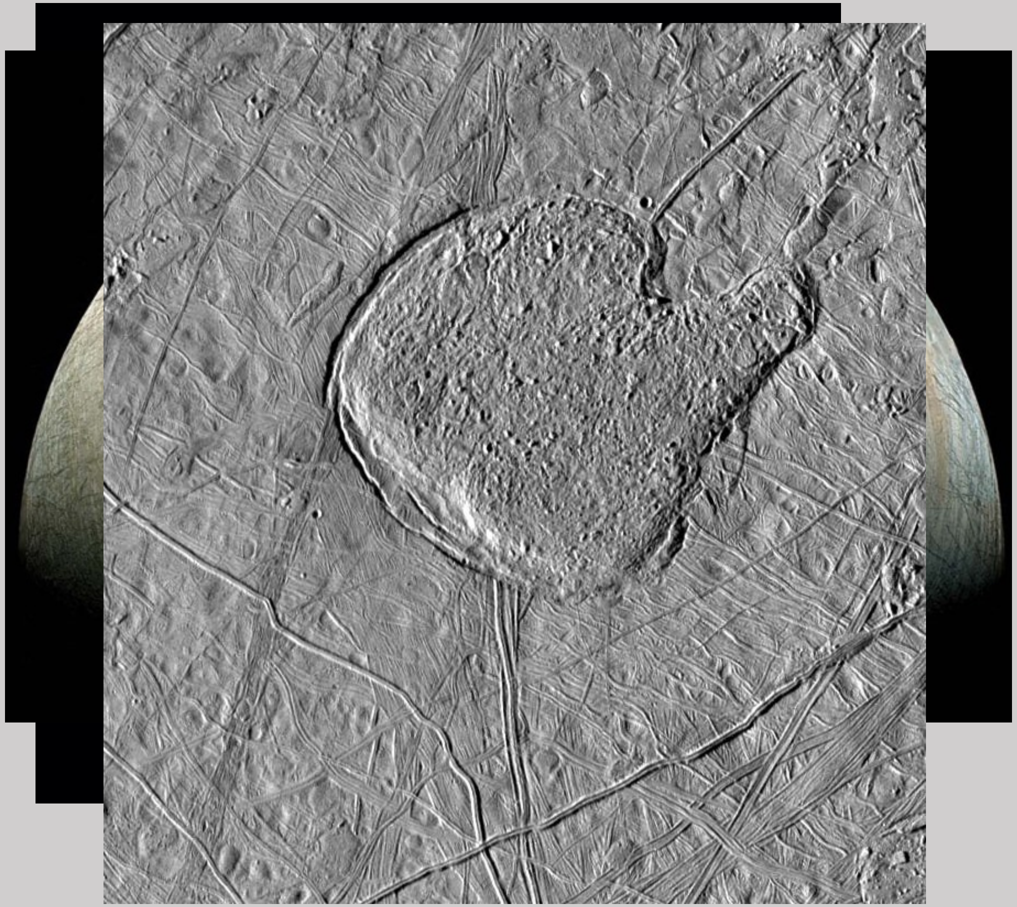

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- Plentiful cryovolcanism

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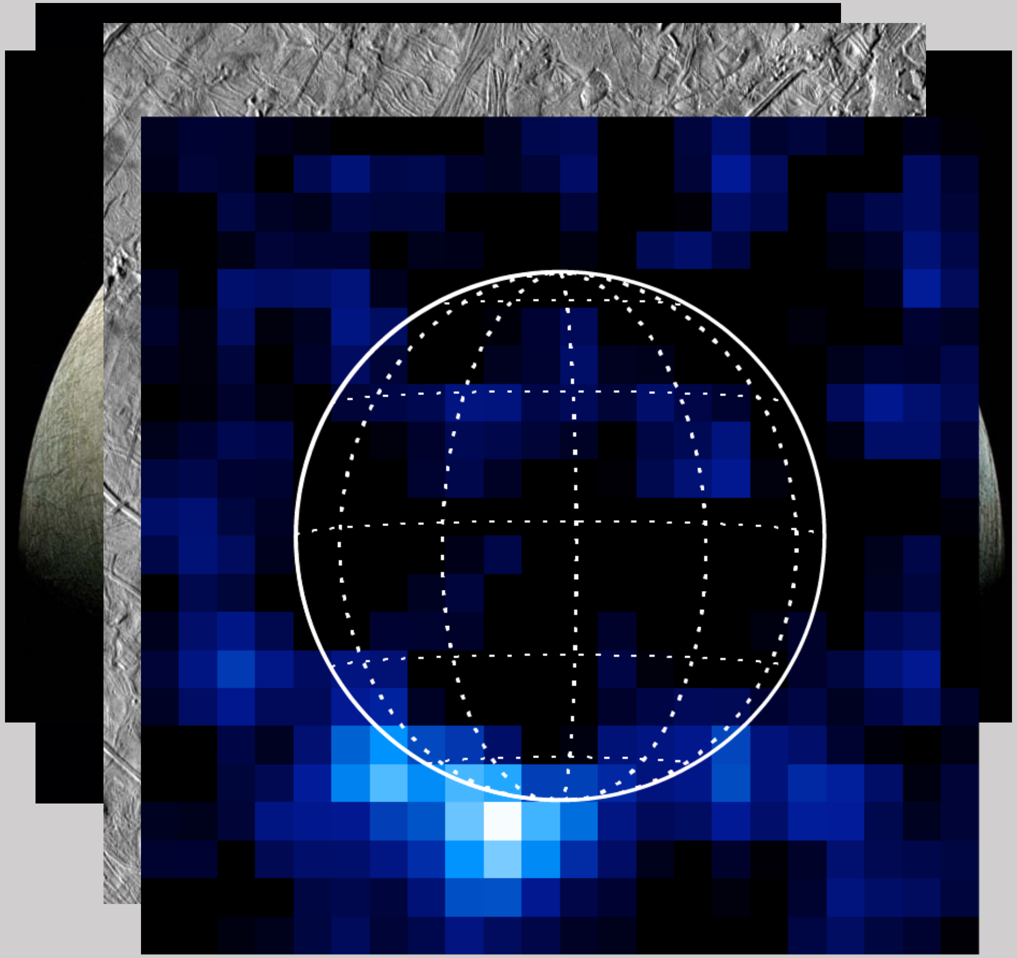

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- Possible geysers and plumes

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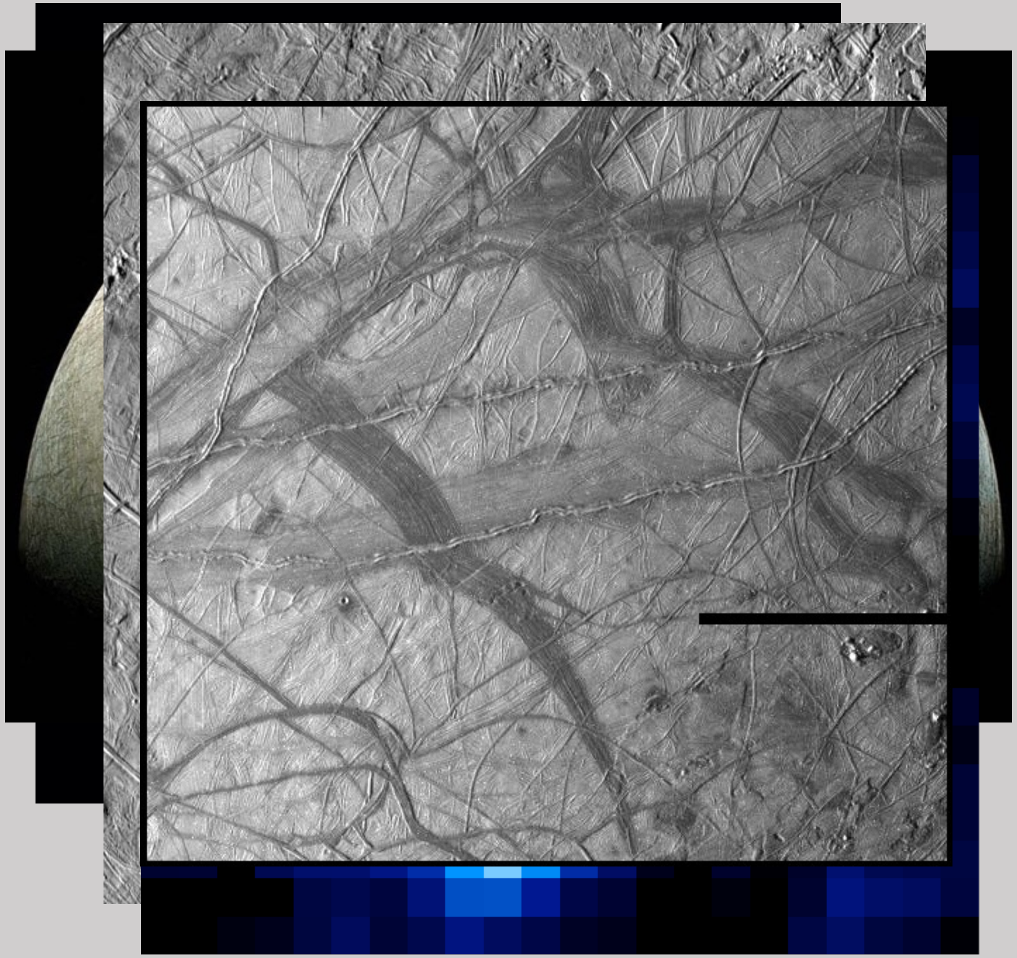

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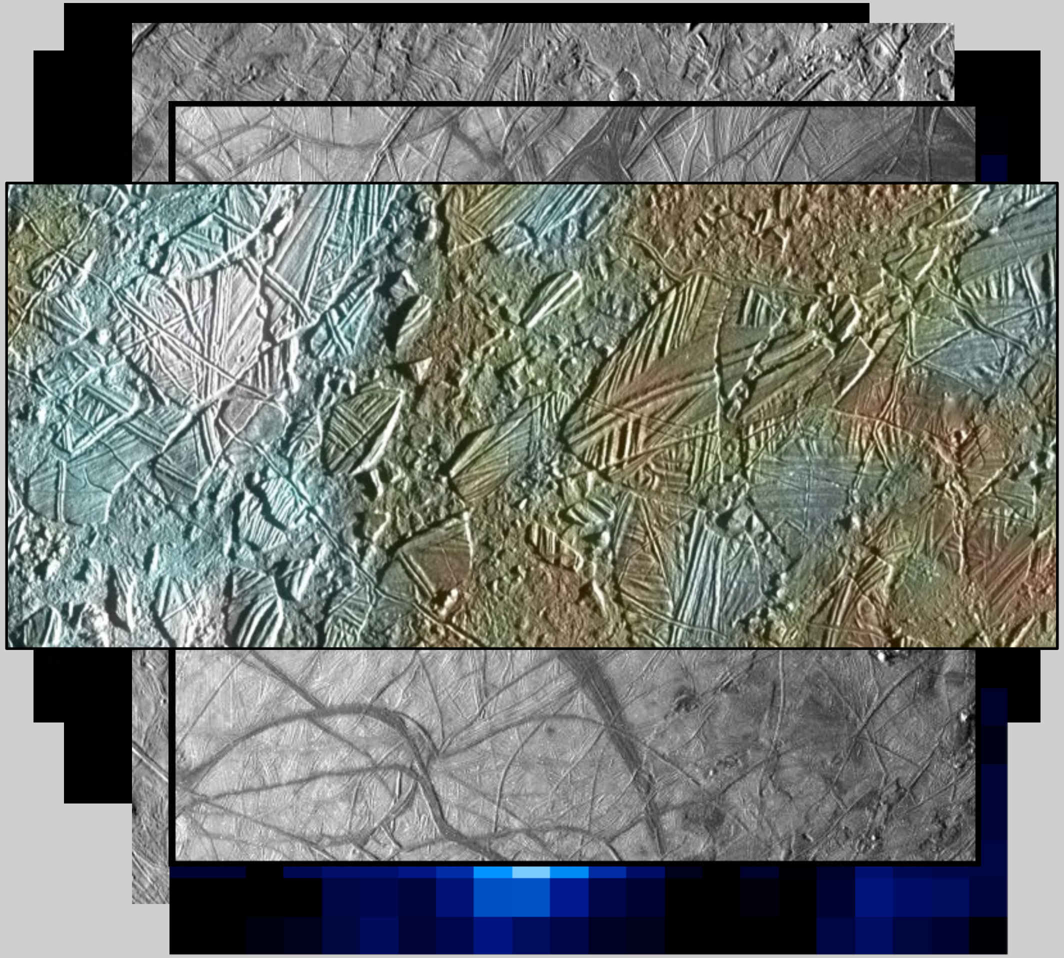

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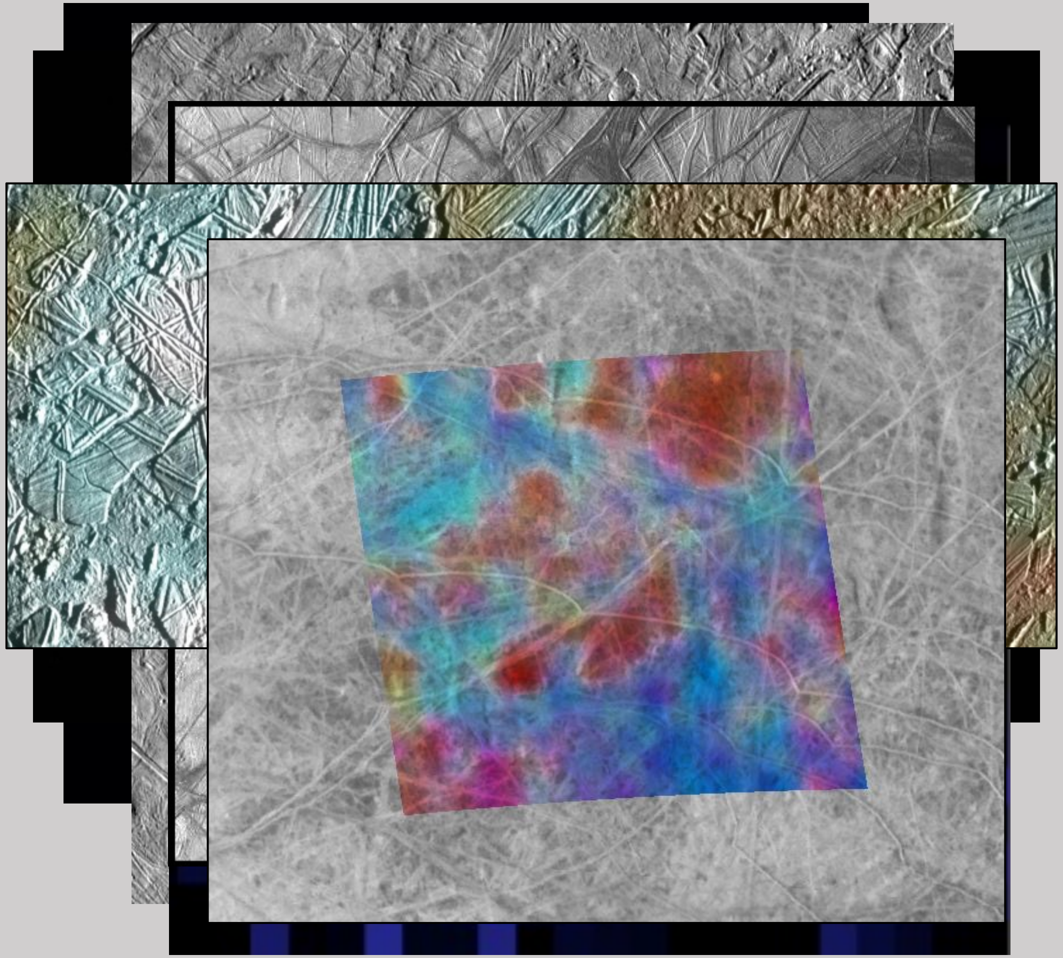

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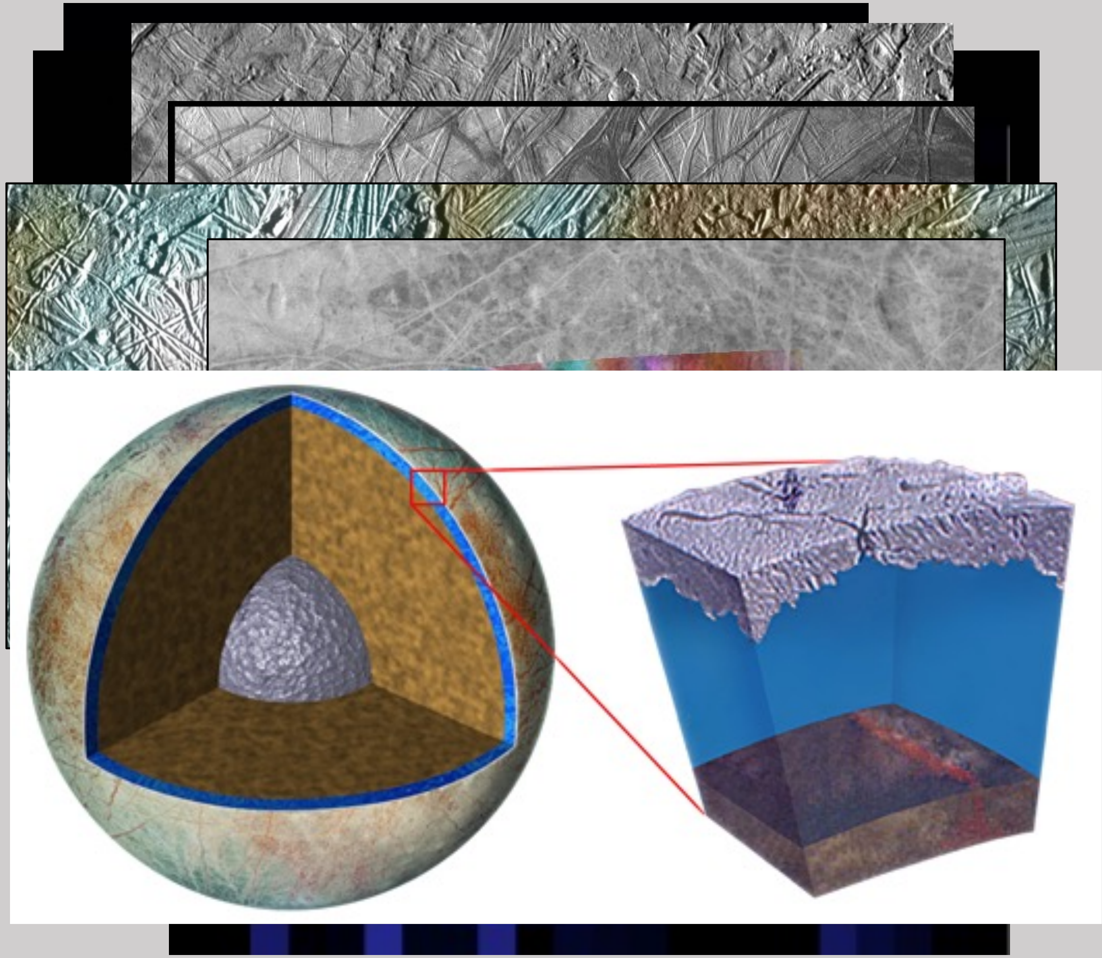

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- Widespread surface disruption
- Surface chemistry of salts and acid
- Subsurface ocean: our Solar System's best chance for extant life beyond Earth?

Habitability: Ingredients for Life

Water:

- **Probable saltwater ocean, implied by surface geology and magnetic field**
- **Possible lakes within the ice shell, produced by local melting**

Chemistry:

- **Ocean in direct contact with mantle rock, promoting chemical leaching**
- **Dark red surface materials contain salts, probably from the ocean**

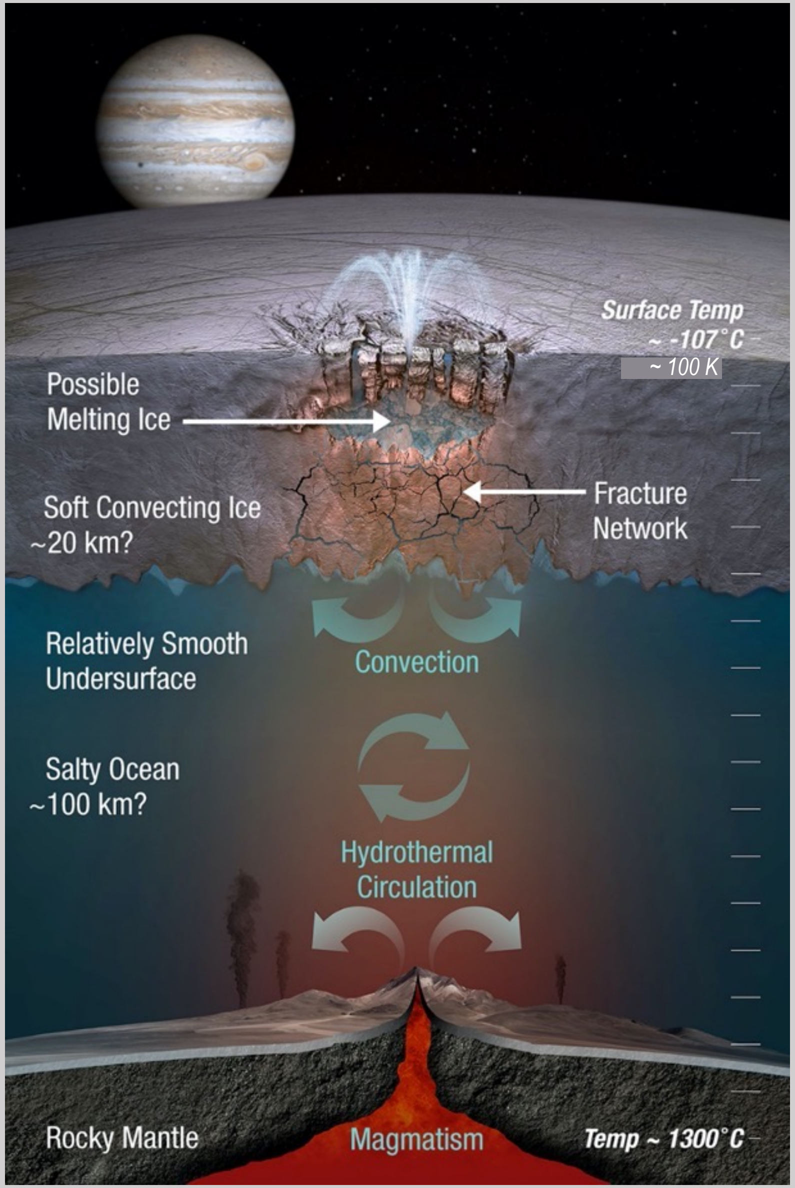
Energy:

- **Chemical energy could sustain life**
- **Surface irradiation creates oxidants**
- **Mantle rock-water reactions could create reductants**

Activity:

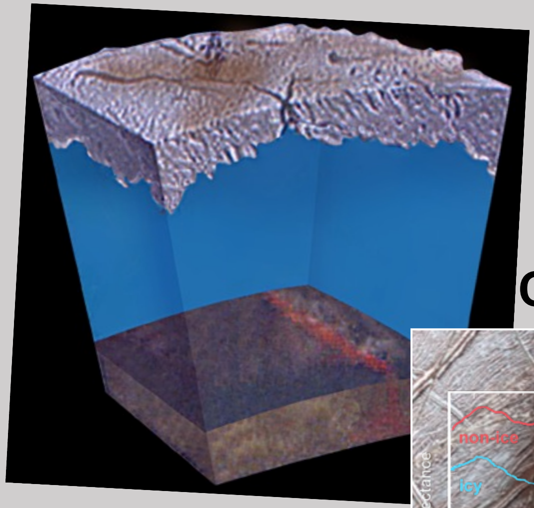
- **Geological activity "stirs the pot"**

Europa Flyby Mission will verify key* habitability *hypotheses

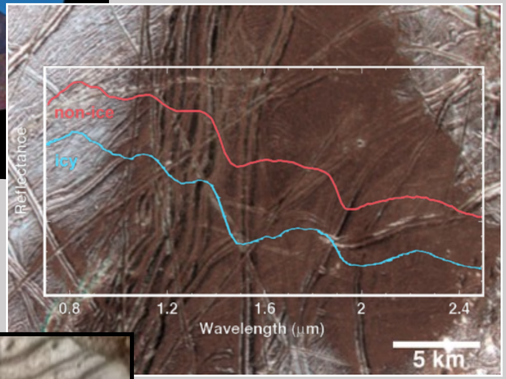


Goal: Explore Europa to investigate its habitability

Ocean & Ice Shell

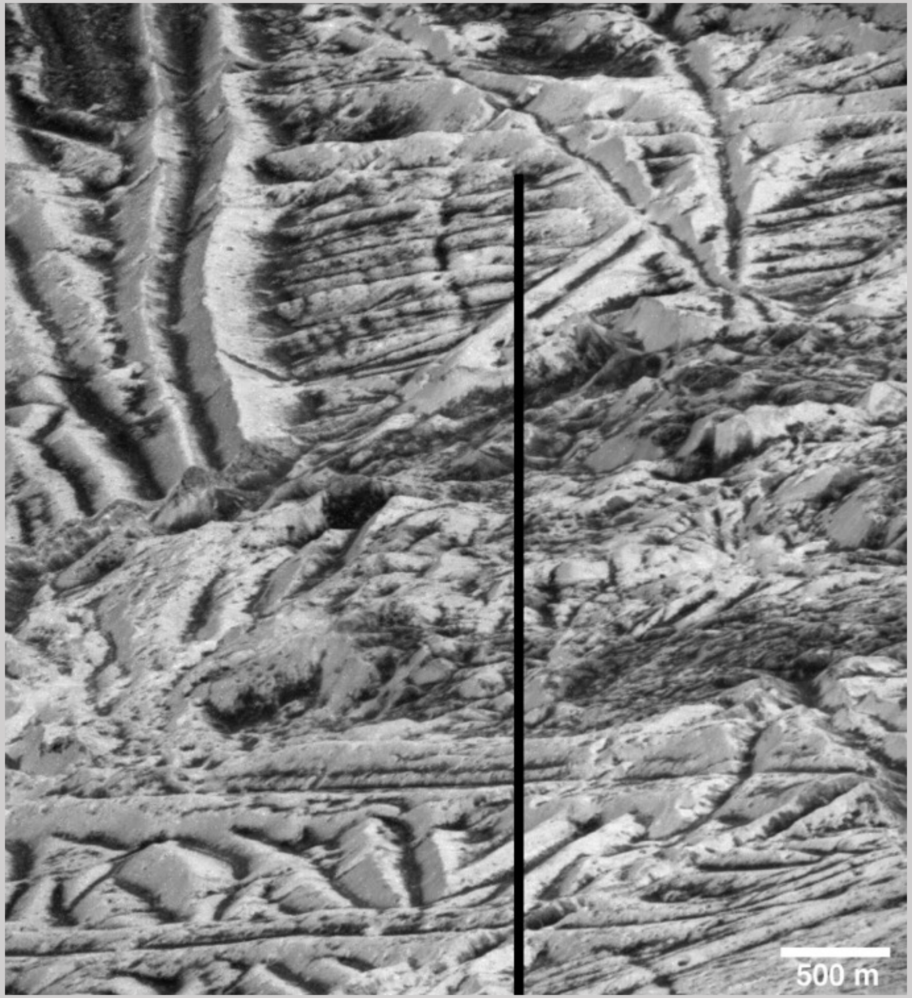


Composition



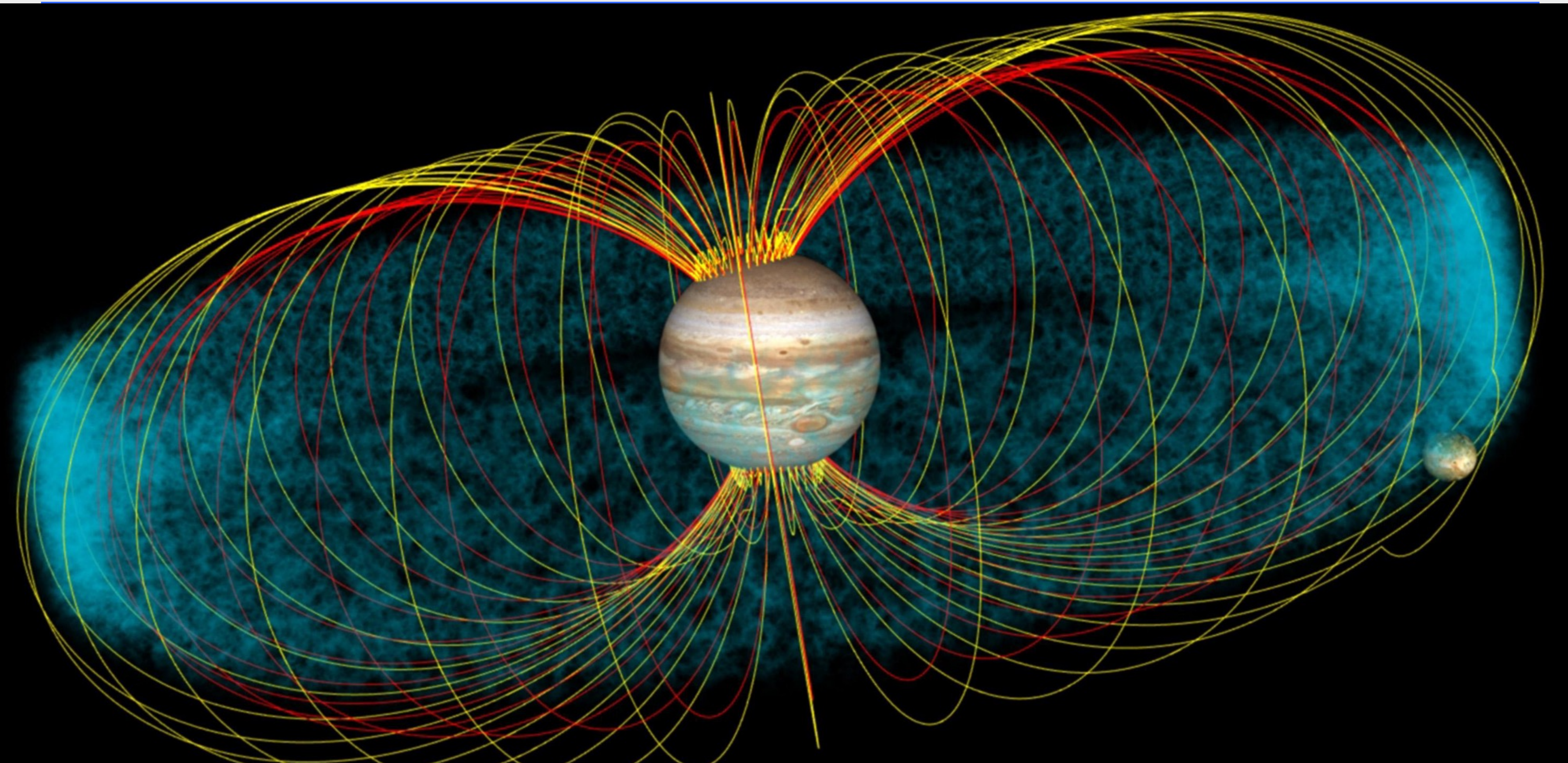
Geology

Reconnaissance

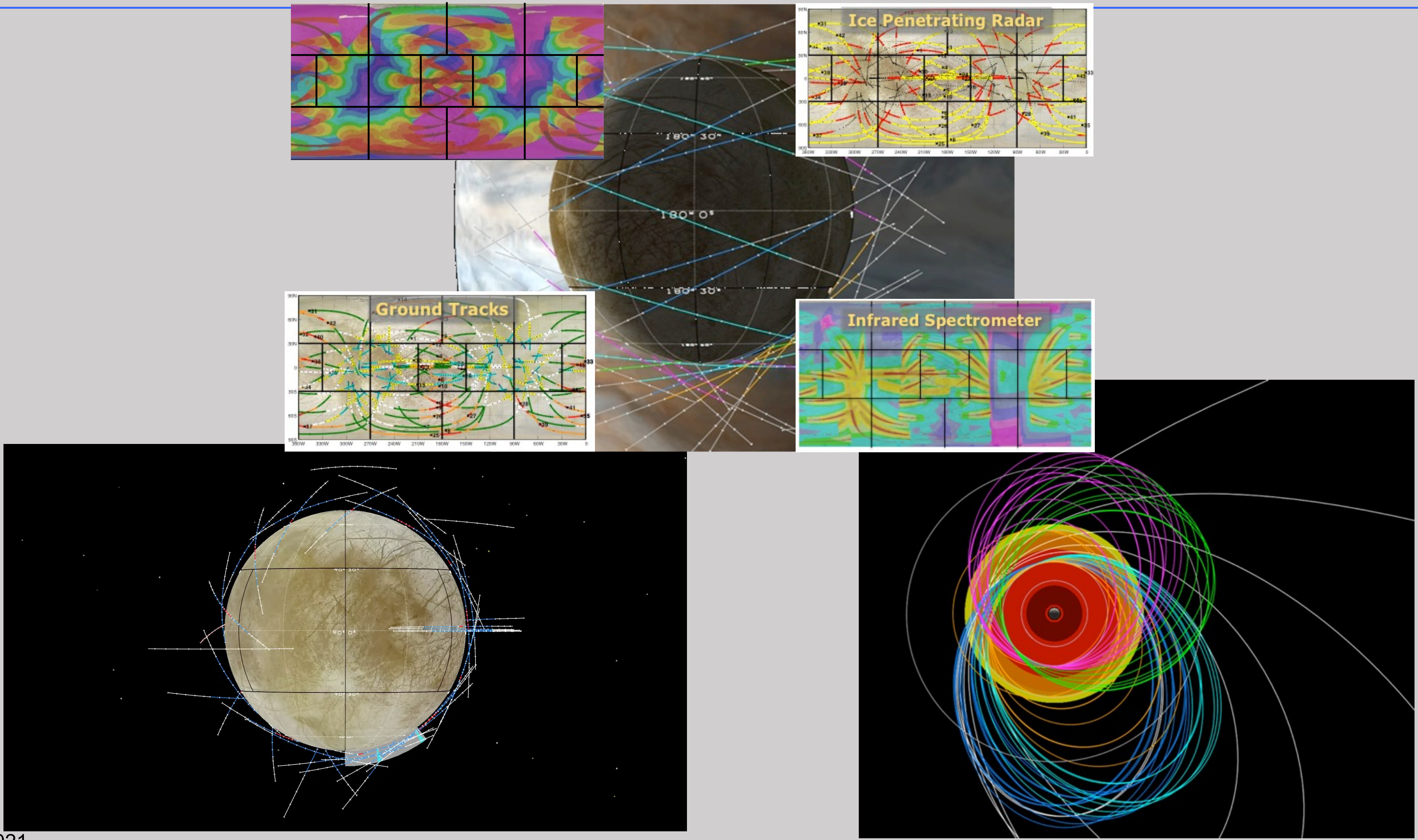



Europa Clipper Investigations
MASPEX
Mass Spectrometer
PI: Jim Burch, SwRI
sniffing atmospheric composition
SUDA
Dust Analyzer
PI: Sascha Kempf: U. Colorado
detecting surface & plume composition
ECM
Magnetometer
TL: Margaret Kivelson, U. Michigan
revealing ocean properties
PIMS
Faraday Cups
PI: Joe Westlake, APL
measuring plasma environment
Europa-UVS
UV Spectrograph
PI: Kurt Retherford, SwRI
seeking plume glow
EIS
Narrow-angle Camera + Wide-angle Camera
PI: Zibi Turtle, APL
mapping alien landscape
MISE
IR Spectrometer
PI: Diana Blaney, JPL
detecting chemical fingerprints
E-THEMIS
Thermal Imager
PI: Phil Christensen, ASU
searching for hot spots
REASON
Ice-Penetrating Radar
PI: Don Blankenship, UTIG
probing the ice shell
G/RS
Doppler Gravity
TL: Erwan Mazarico, GSFC
sensing interior layers
Remote Sensing
In Situ

Jupiter’s Radiation Belts



Innovative Mission Concept



Technical Baseline Jupiter Tour: 19F23_V2

[Comparison with PDR baseline trajectory, 17F12_V2]

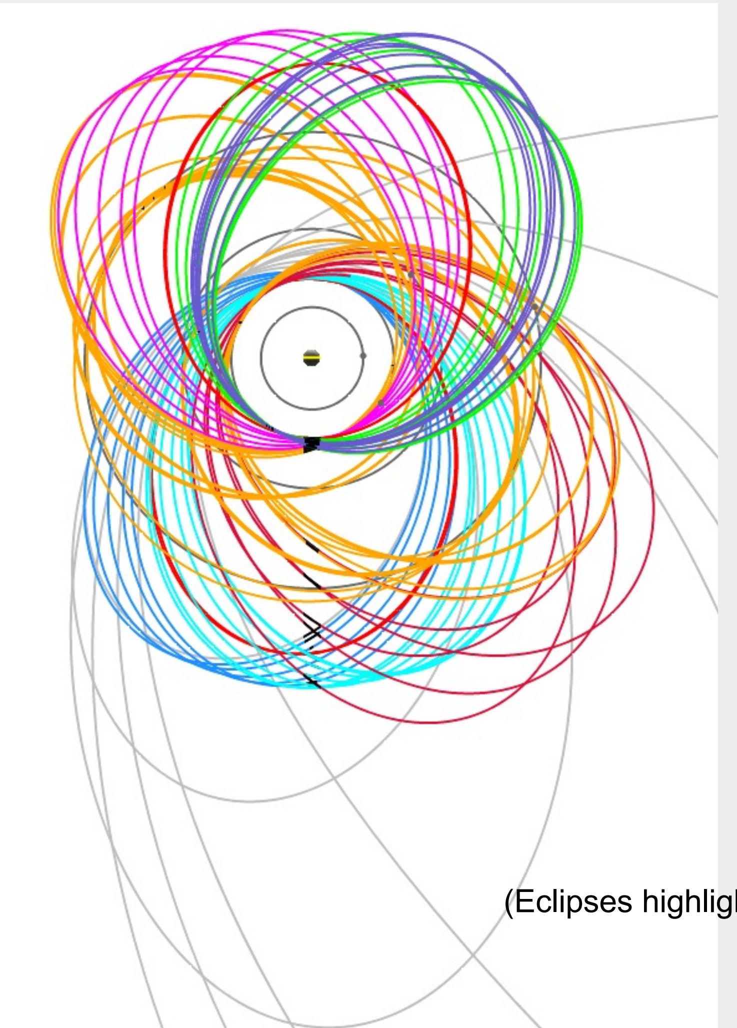
Tour	17F12_V2	19F23_V2
Launch Date	6/4/2022	**11/7/23**
Arrival Date	12/24/2024	**9/29/29**
Interplanetary Trajectory	Direct	**VEEGA**
Tour Duration (years)[1]	3.7	**3.84**
Number of Flybys		
Europa	46	**51**
Ganymede	4	**6**
Callisto	9	**7**
No. of Night Side Europa Flybys	9	**11**
No. of Jupiter Orbits[1]	72	**77**
Time between Flybys (days)		
Maximum (not including capture orbit)	229	**202.5**
Minimum	5.4	**5.7**
Minimum (Europa-to-Europa)	10.1	**10.6**
Deterministic Tour ΔV, post-PRM (m/s)	182	**199**
Maximum Inclination (deg.)	18.9	**21.0**
No. of Solar Eclipses (due to Jupiter)	47	**43**
Maximum Eclipse Duration (hours)	9.15	**9.2**
Total Ionizing Dose (Mrad)[2]	2.50	**2.88**

(1) From **G0** to spacecraft disposal

(2) Calculated using **GRID3** model from **G0** to end of Prime Mission (last Europa flyby); **Si** behind 100 mil **Al**; spherical shell

Baseline for PDR and ΔPDR

17F12_V2



Sun

CDR Technical Reference

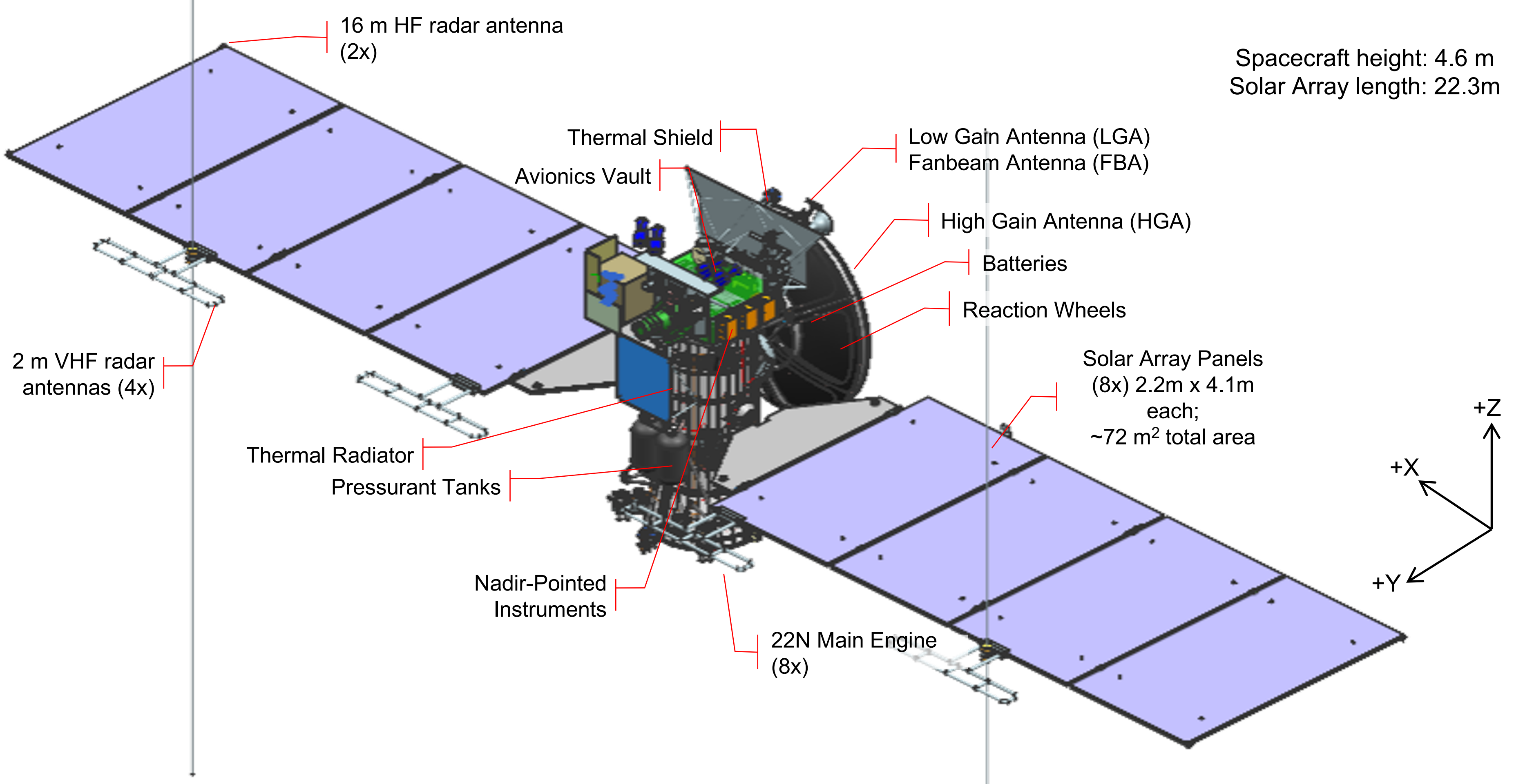
19F23_V2

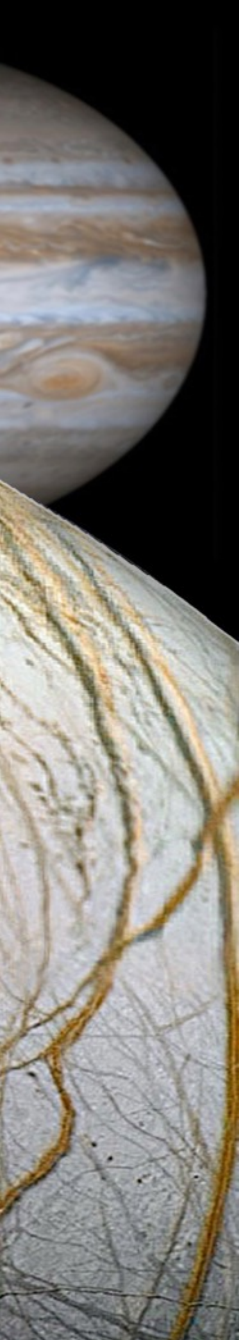
(Eclipses highlighted **black**)

The technical data in this document is controlled under the U.S. Export Regulations; release to foreign persons may require an export authorization.

Europa Clipper Overview

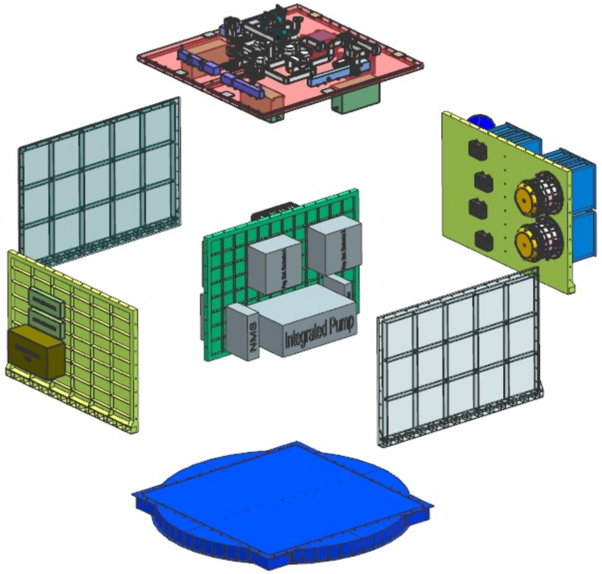
Spacecraft height: 4.6 m
Solar Array length: 22.3m

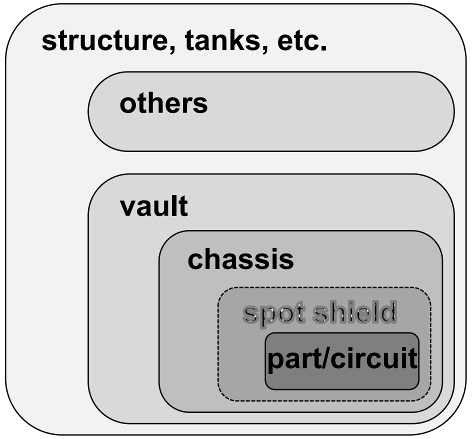




Radiation Management

- Bound mission total dose at 3 Mrad@100 mil Al
- Radiation Design Factor of 2
- Goal: 300 krad electronic parts
- Significant early characterization efforts
- Use of Preferred parts & materials database
- Utilization of radiation vault (shielding)
  - 150 krad environment inside of vault
  - Benefits of packing and self shielding
  - IESD protection
- When needed additional shielding at box level
  - Heritage subsystems
  - Some in the 100 Krad range
- Local shielding as needed
  - Some sensors
  - Few soft critical devices
- Circuit Design Mitigation

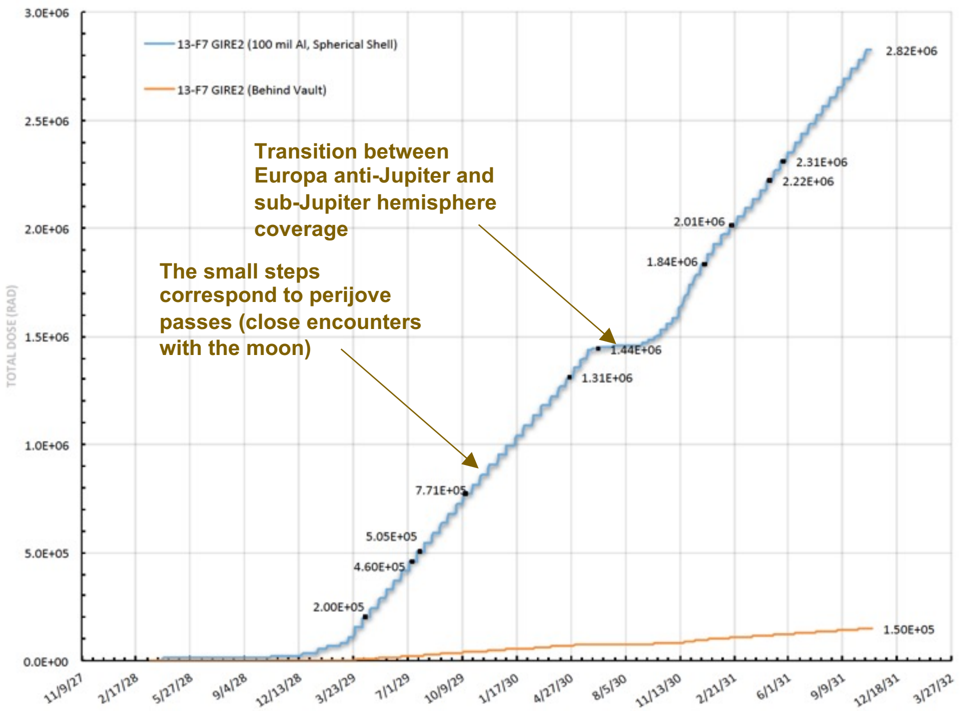




Systems Approach: Mission design, Shielding, Parts Selection, Mitigation

Europa Mission Radiation Environment – TID

- The **total ionizing dose (TID)** is a measure of the energy deposited by energetic electrons and protons in materials
- TID depends on the outside environment, shielding material, and target material
- The moon encounters are the times with the highest dose rate
- The spacecraft holds a heavily shielded box called “vault” (~400 mil thick Al) that contains most sensitive electronics
- The dose inside the “vault” is reduced to 150 krad compared to the 3 Mrad mission dose (behind 100 mil of Al)



Radiation sensitive components shall be shielded to ensure TID exposure of no greater than 50% of their demonstrated tolerance

Mission Dose vs Depth

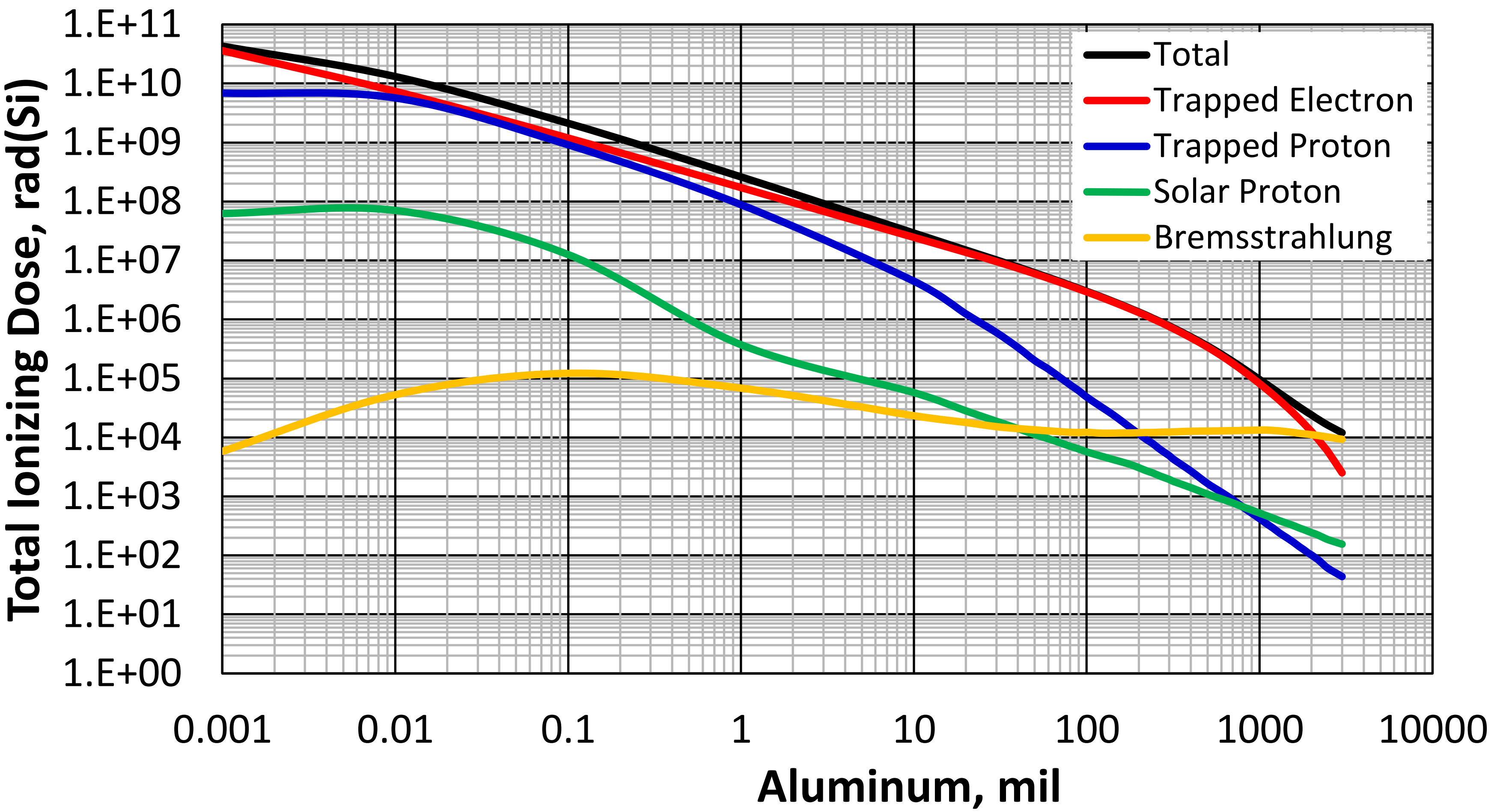
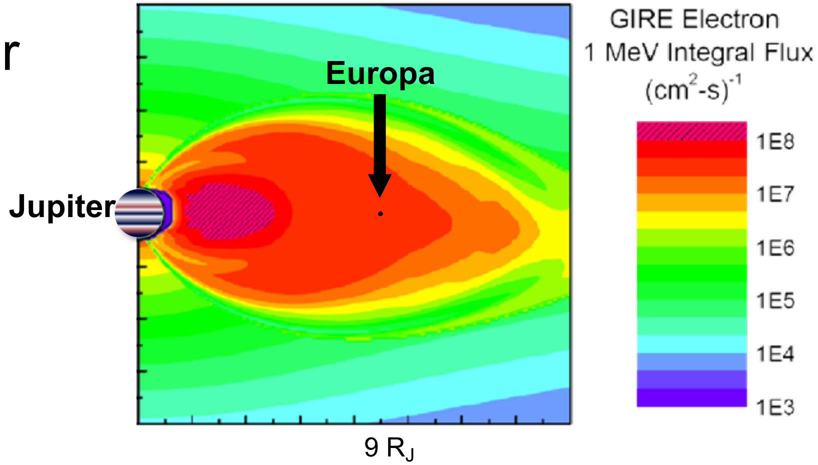
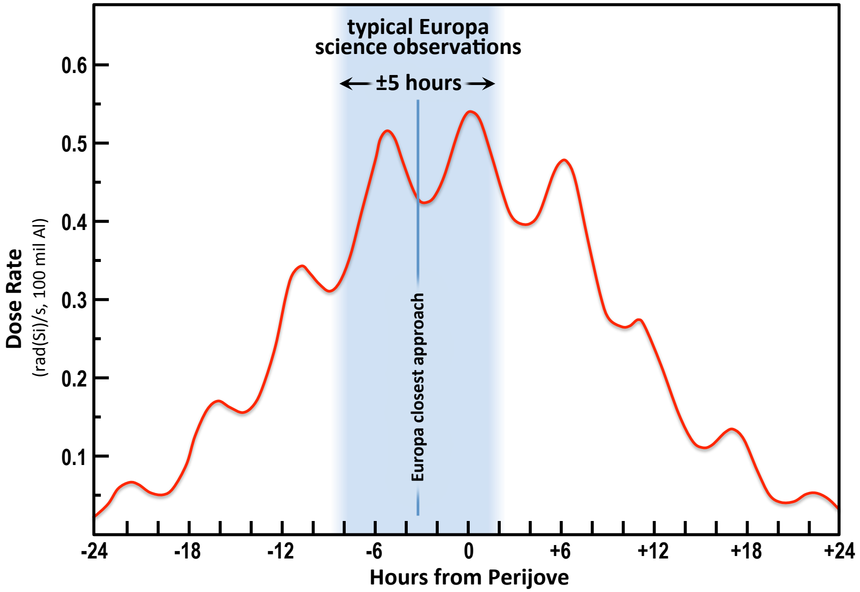


Figure 4.9-3a. Aluminum Spherical Shell TID-Depth Curve for the Design Reference Mission, RDF=1.

Flux Environment at Flyby

- **Flux:** The high flux environment on Clipper is ***comparable*** to prior missions
  - Most noise & ESD events on Voyager and Galileo occurred inside 16 R_J with *very* large fluctuations around the mean





- Clipper will experience peak flux near 9 R_J where Europa science observations occur,
  ←
  but <u>by design</u> most downlinks, calibrations, ΔV maneuvers, etc. occur where flux is low

Dose Rate at Flyby

Average dose rate profiles during the worst-case Europa flyby through various aluminum shielding thicknesses for the Design Reference Mission is shown in Figure 4.9-4. Electronics within well-shielded areas will see typical maximum dose rates of ~150 mrad(Si)/s.

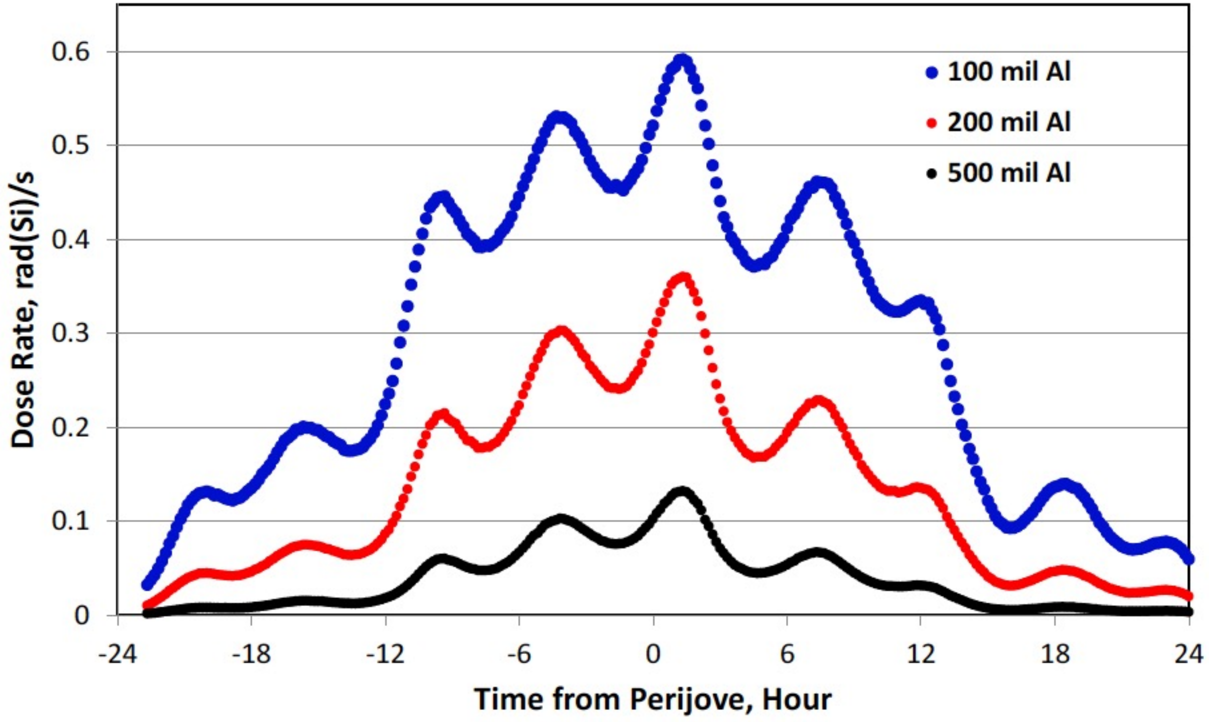
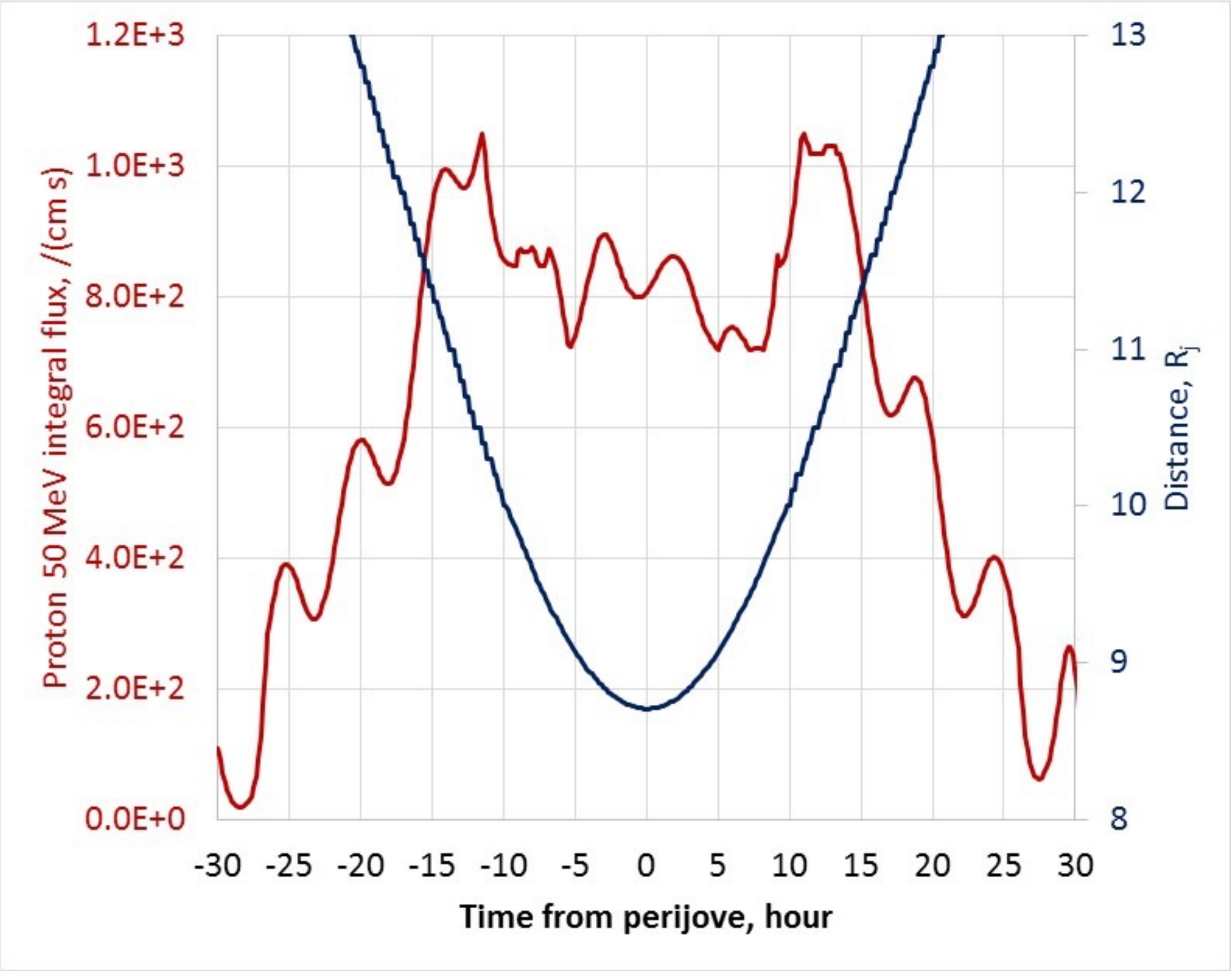


Figure 4.9-4. Average Dose Rate Profile during the Worst-Case Europa Flyby through Various Aluminum Shielding Thicknesses for the Design Reference Mission.

Vault Interior (>500 mil Al eq.)

- Peak proton flux for >50 MeV
- Protons < 50MeV do not penetrate Vault
- 5x flux used in Proton SEE rates
- Proton upset rate during flyby is included in device rate calculations and SEEA analysis



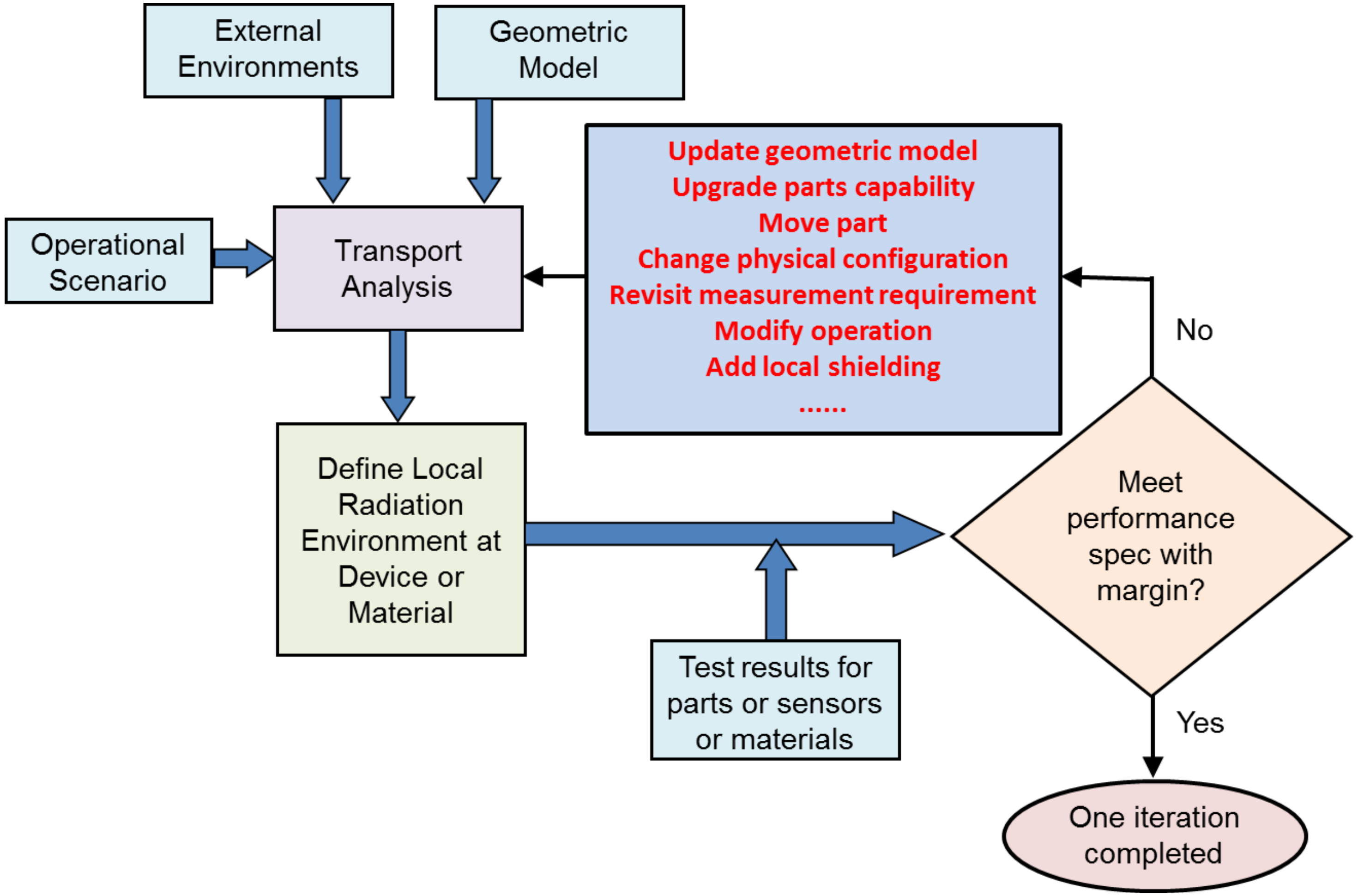
Parts Radiation Requirements

Parts Program Requirements	
Parts Class Requirements	Level 1, Class A mission per JPL PETS
Radiation (TID, ELDRS, DD)	Meets ERD level with RDF of 2. Parametric acceptance based on 99% probability of survival with 90% confidence level.
Radiation (SEE)	SEL: LETth > 75 MeV-cm^2/mg SEGR/SEB: LETth > 37 MeV-cm^2/mg SEU: LETth > 75 MeV-cm^2/mg or < 10^{-10} per bit per day or by analysis verifying no impact to mission requirements SEFI: LETth > 75 MeV-cm^2/mg or < 10^{-3} events/yr or by application analysis SET: LETth > 75 MeV-cm^2/mg or by application analysis

Parts Program Approach

- **Preferred Parts Selection List (PPSL)**
  - Parts with high likelihood to survive TID of 300 Krad(Si) (2x RDF inside vault) and capable of meeting Class A, Level 1 part requirements
  - Can include parts with datasheet/SMD rating <300 Krad, however, generic manufacturer data may be available to higher levels or robustness of process technology well known
  - Working closely with RH manufacturers (ADI, STM, Intersil, TI) to gather data and risk assess likelihood of survival
  - Parts on PPSL with characterization data on one lot out to 2x still require RLAT (flagged as “AC” in PARS)
  - Consistent data for two different lots, indicating part meets spec out to 2x, fully approved without requiring RLAT on flight lot
- Early evaluation of parts radiation hardness (risk reduction and **PPCL → PPSL testing**)
- Non-RH parts characterized and/or RLAT on flight lot required for all applicable environments
- Working closely with users across project to buy from target lots JPL has tested to eliminate need for additional RLAT and reduce costs (requires close collaboration with manufacturers)
- Common Buy across the project to reduce RLAT costs

General Radiation Hardening Process Flow

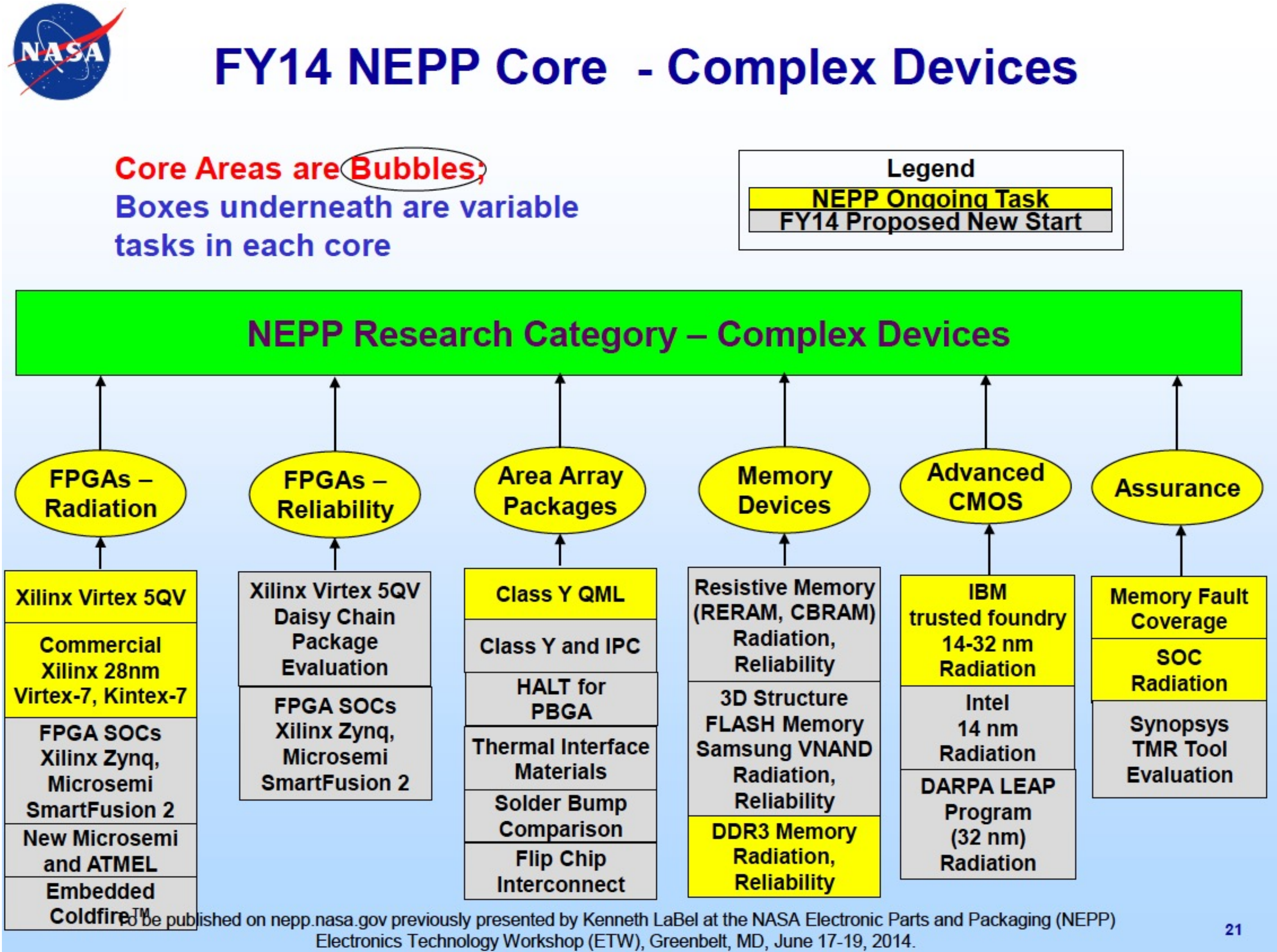


Radiation Hardening of Spacecraft for High Radiation Environments is an Iterative Process

Early Risk Reduction Efforts

- Volatile Memory
- Non-Volatile Memory
- Power Subsystem devices
- Other Avionics devices
- Optocouplers
- ELDRS Testing
- Field Programmable Gate Arrays
- Materials

NEPP – Tasks Around the Time of Our Start

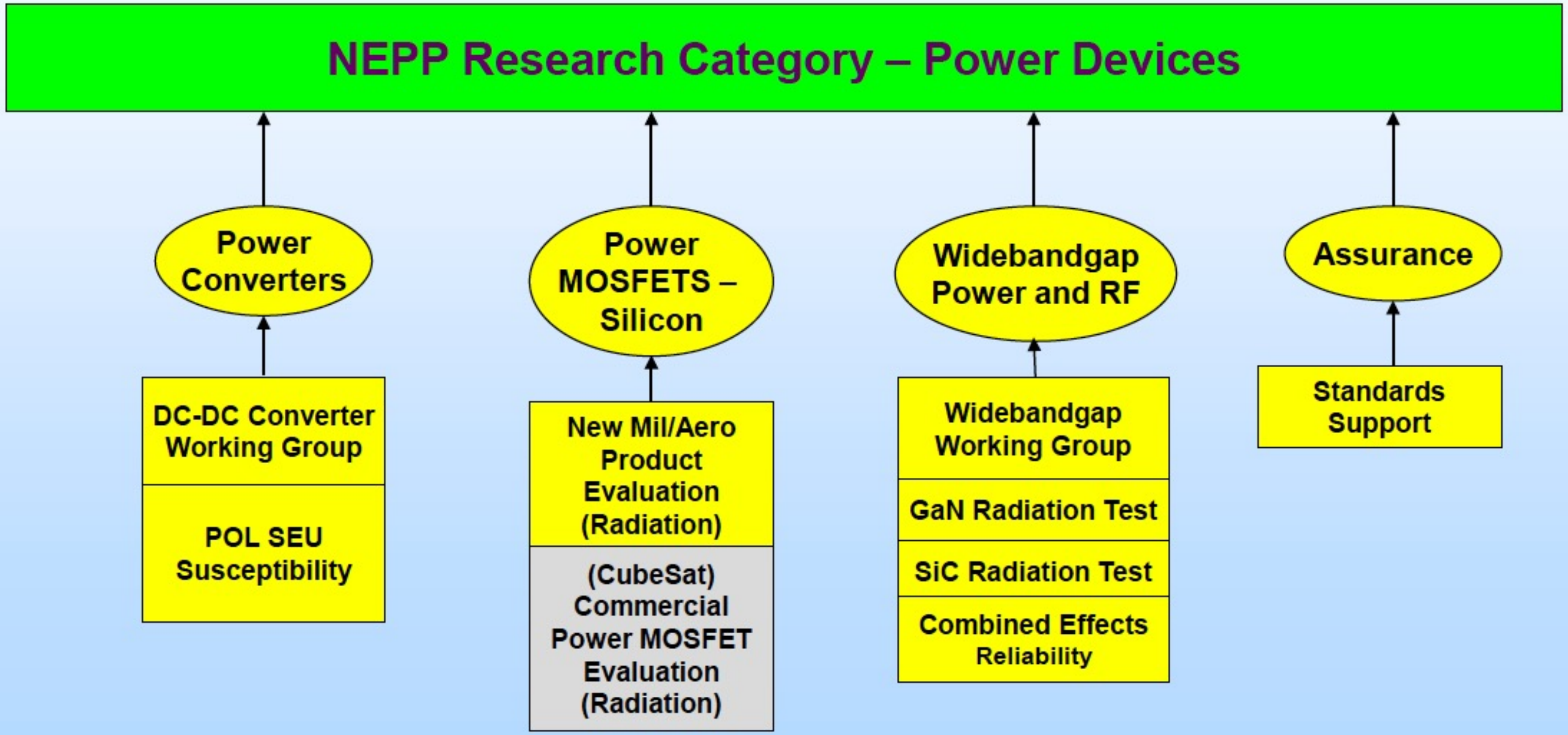


NEPP – Tasks Around the Time of Our Start

FY14 NEPP Core - Power Devices

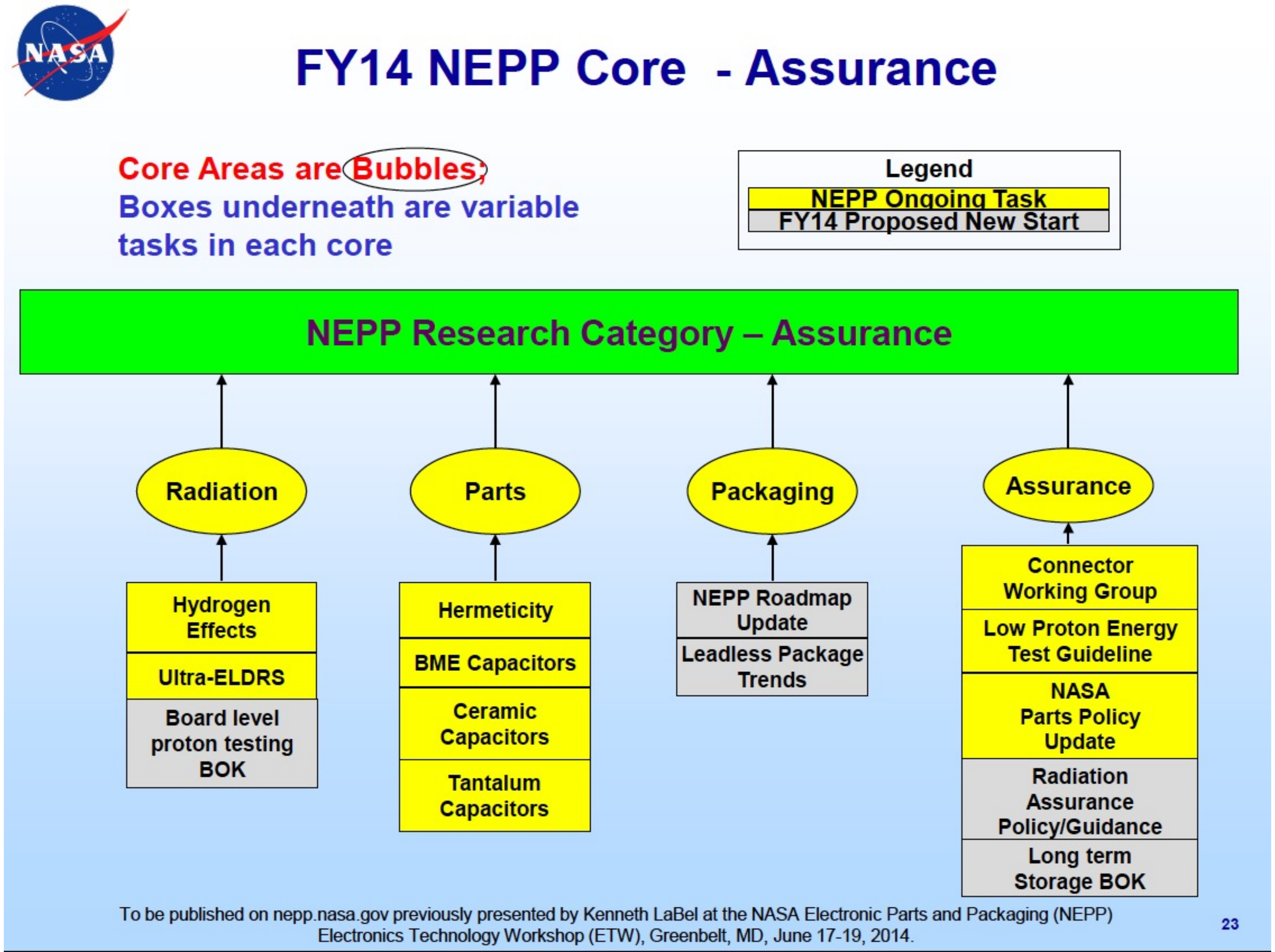
Core Areas are Bubbles;
Boxes underneath are variable tasks in each core

Legend
- NEPP Ongoing Task
- FY14 Proposed New Start



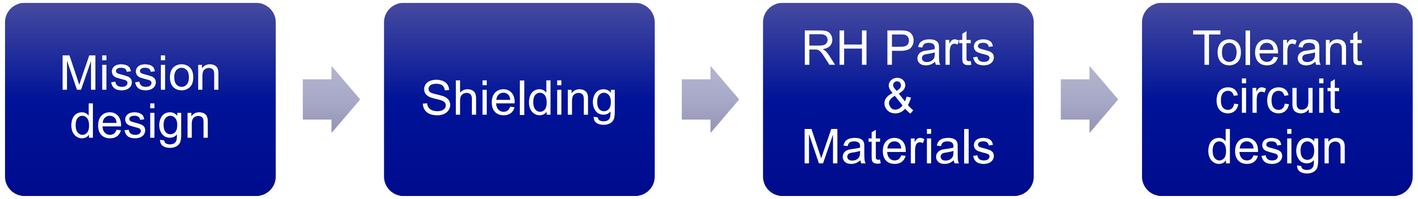
To be published on nepp.nasa.gov previously presented by Kenneth LaBel at the NASA Electronic Parts and Packaging (NEPP) Electronics Technology Workshop (ETW), Greenbelt, MD, June 17-19, 2014. 22

NEPP – Tasks Around the Time of Our Start

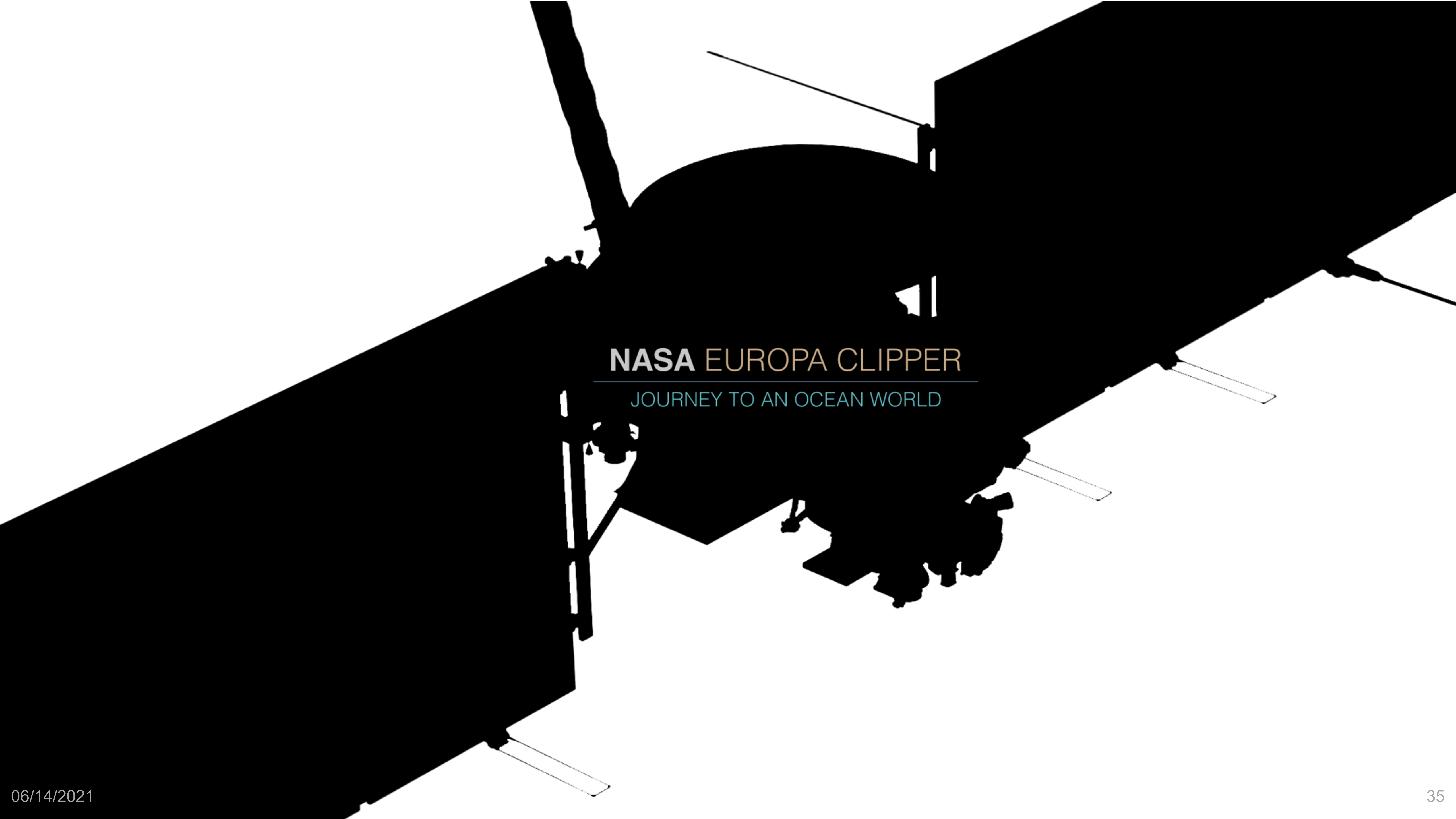


Summary

- System level approach to surviving radiation
  - Mission design limits total dose to 3 Mrad @ 100mil Al eq.
  - Shielding vault for a majority of electronic systems
  - Subsystem and local shield as required
  - Characterization of parts and materials
  - Use of approved parts and materials lists
  - Selection of parts and materials for radiation tolerance



- Thanks for Your Attention
- Thanks to the NEPP Program for providing a foundation
- There is more detail provided in the backup slides
- Open for questions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Backup Slides

Volatile Memory - Significant Findings

- SDRAM
  - Performance of all known devices is limited to 100 Krad or less
  - Vendor “100 Krad guaranteed” devices likely do not meet vendor spec when tested in worst case condition (refresh on)
  - Tests continuing to bound performance
- DDR2
  - Existing data sufficient to validate capability to 200 to 300 Krad but will require RLAT
- DDR3
  - Test results support TID capability to 200 to 300 krad

- All devices are prone to SEFI/SEU events and require mitigation, though none latch
- Most if not all, prone to stuck bits due to localized displacement damage

Part#	Supplier	Size (GB)	Width	TID (krad)	Comments
DDR3					
MT41J128M8JP	Micron	1	x8	>200	Functional >300 krad with stuck bits
K4B1G0446G	Samsung	1	x4	>250	Functional >300 krad with stuck bits
DDR2					
IMXS108D2DEBG	Intelligent Memory	TBD	x8	TBD	
IS43DR81280	3DPlus-ISSI	1	x8	>300	Functional >300 krad with stuck bits
SDRAM					
IS42S86400B	ISSI	0.5	x8	80	100 with stuck bits, refresh ”on” is worst case
EDS5104ABTA	3DPlus-ISSI	0.5	x4	50	Used on Juno
UT8SDMQ64M48	Aeroflex	3	x48	100	Actual performance in refresh mode may be less

SDRAM limited to < 100 krad – DDR2/3 ~ 300 krad

Non-Volatile Memory

- Spacecraft requires 1 Tb memory storage
  - Driven by science data requirements
- Need to hold data until opportunity to transmit
- No radiation hardened devices large enough
- Commercial devices were evaluated
- A single device was found suitable (with mitigation) for the mission
  - Samsung 8Gb SLC Version M NAND flash, 3D-Plus stacks

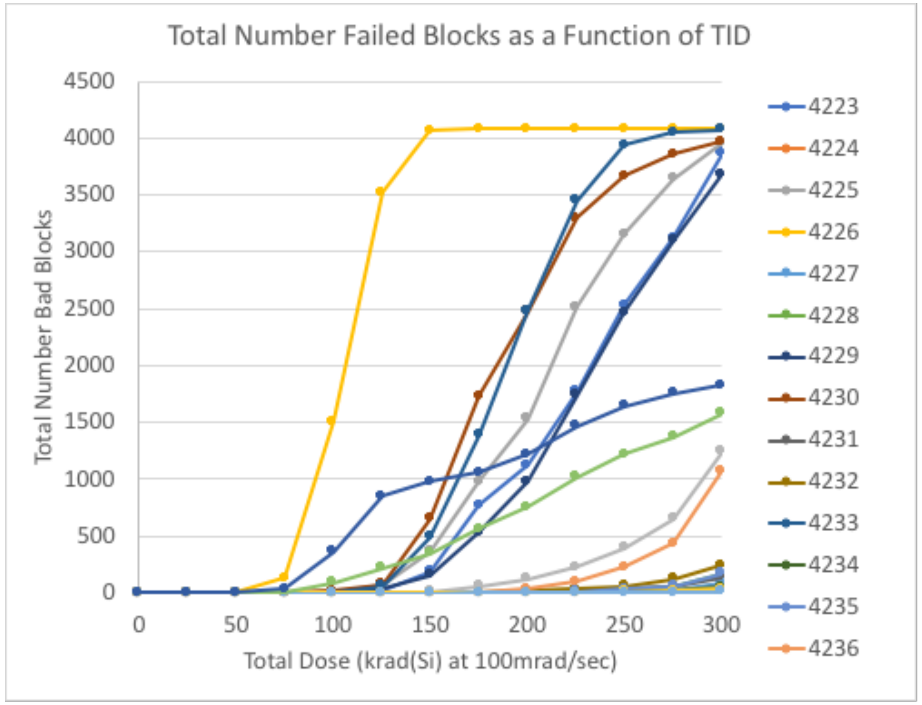
This device will still require Erase/Rewrite every 25 Krad to meet mission requirements

Non-Volatile Memory Radiation Tests

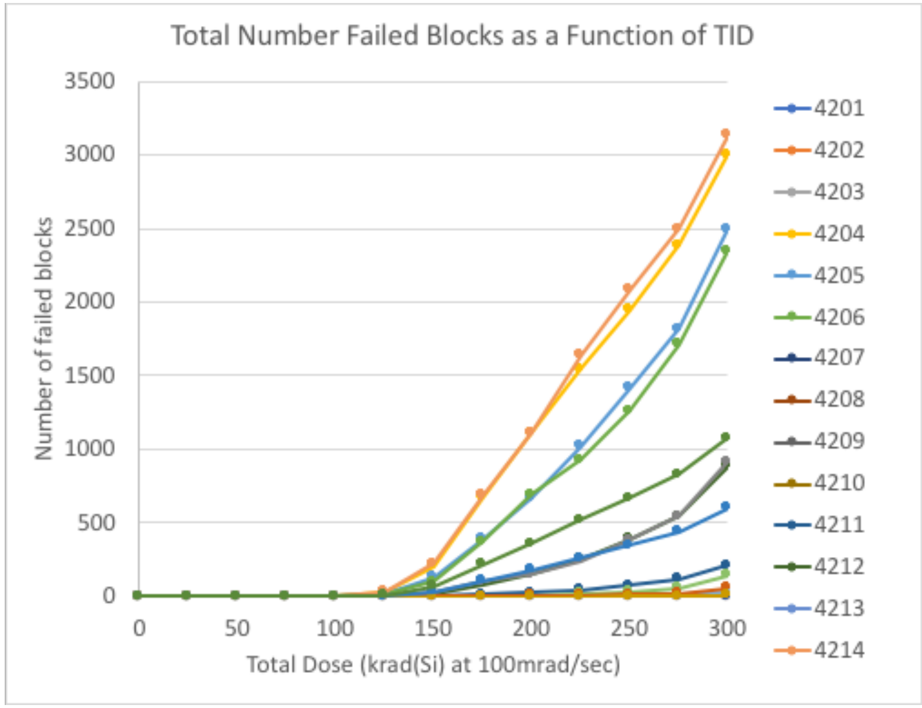
Device	TID/DD (krad)	Comments
Micron 4Gb	<100	Not recommended for Europa 3/8 DUT non-functional after 100krad
Micron 32Gb	55	Not recommended for Europa 3/5 DUTs fail to erase
Micron 32Gb eNAND	10	Not recommended for Europa Non functional at 50 krad
Samsung 8Gb Rev A	>200	1% BER at 40krad Erase still possible after 600krad Not an ECM candidate due to SEE
Samsung 8Gb Rev M	>200	5E-5 BER @ 50krad, 10% BER at 200krad, write-able. Test to 300 krad with Erase/Rewrite in 25 krad steps Primary NVM for ECM
Samsung 8Gb Rev D	>200	
Samsung 8Gb Rev E	<100	Not recommended for Europa Unrecoverable page errors at 100krad
Samsung V-NAND 128 Gb	~ 20 krad (~200 krads array)	Control circuitry – limiting factor

Bad Block Problem TID

Lot 0320



Lot 0308



Demonstrating the dangers of lot to lot variation and and inadequate initial characterization and evaluations

Samsung NAND Flash "Summary"

<table>
<tr><th>Effect</th><th>Definition</th><th>Detection</th><th>Recovery</th><th>Rate/Dose-Level</th><th>Report</th></tr>
<tr><td>Bit-Flip</td><td>An erroneous value is read from the stored state on the floating gate. This can be due to radiation induced leakage (reduced retention), single ion strikes, and control circuitry degradation. Bit flips are a function of both TID and SEE. Somewhat LOT dependent, extreme sample variation. Effect is reduced when powered off.</td><td>Error Correction Code (ECC) or Error Detection and Correction (EDAC). Errors may be transient in nature, e.g. errors may be observed during one read operation, but not the next.</td><td>Reprogram operations will correct most errors, however new or residual errors may persist, especially at higher dose levels.</td><td>30040 absolute maximum bit errors per device at 300krad(Si), or 3.39×10^{-4}% of the device, LOT 320.

21227 absolute maximum bit errors per device at 300krad(Si), or 2.34×10^{-4}% of the device, LOT 308.</td><td>(11)</td></tr>
<tr><td>Single-Event Functional Interrupt (SEFI)</td><td>A single ion strike induces errors in the control logic of the memory, e.g. address decoding, and results in gross errors throughout the device. This SEFI is a function of SEE, independent of TID. Independent of LOT. Only occurs in powered-on state.</td><td>Persistent errors across large portions of the device. May manifest as read errors in whole pages or blocks, sudden halts to operation, operational changes, and other gross general error modes.</td><td>Device power cycle</td><td><table>
<tr><th>Shield Thickness (mils of Al)</th><th>Upper Bound Rate (1/device-day)</th><th>Best Estimate Rate (1/device-day)</th></tr>
<tr><td>100</td><td>2.7×10^{-5}</td><td>9.6×10^{-6}</td></tr>
<tr><td>400</td><td>2.0×10^{-5}</td><td>7.2×10^{-6}</td></tr>
<tr><td>663</td><td>1.7×10^{-5}</td><td>5.9×10^{-6}</td></tr>
<tr><td>1,000</td><td>1.4×10^{-5}</td><td>4.3×10^{-6}</td></tr>
</table></td><td>(15)</td></tr>
<tr><td>Destructive Single-Event Effect</td><td>A single ion strike to the charge pump circuitry results in various levels of full device failure. This event is a function of SEE, independent of TID. Independent of LOT. Only occurs in powered-on state.</td><td>Manifests as failure to read, program, and/or erase. A high-current spike of varying amplitude lasting several hundred milliseconds always precedes the event. Read failures will be observed as large amounts of errors not correctable by a power cycle (from SEFI), program/erase failures should be denoted from the status register.</td><td><u>NONE.</u></td><td><table>
<tr><th>Shield Thickness (mils of Al)</th><th>Upper Bound Rate (1/device-day)</th><th>Best Estimate Rate (1/device-day)</th></tr>
<tr><td>100</td><td>1.2×10^{-6}</td><td>3.1×10^{-7}</td></tr>
<tr><td>400</td><td>9.2×10^{-7}</td><td>2.3×10^{-7}</td></tr>
<tr><td>663</td><td>7.9×10^{-7}</td><td>1.9×10^{-7}</td></tr>
<tr><td>1,000</td><td>6.2×10^{-7}</td><td>1.4×10^{-7}</td></tr>
</table></td><td>(11)</td></tr>
<tr><td>Bad Blocks</td><td>A program failure was defined for this test as an asserted fail in the status register after the operation (These failures only occurred in the biased, refresh test case only). If an operational failure occurs, the entire block is disregarded. Bad blocks are a function of TID only. Highly LOT/DC dependent. Effect is significantly reduced when powered off.</td><td>Status register read after erase/program operation (see Figure 4 Program Operation flow chart from datasheet [2]).</td><td>Application dependent. Block replacement is recommended. Repeated operations will eventually lead to successful operation.</td><td><table>
<tr><th>LOT</th><th>TID (krad)</th><th>Mean # Bad blocks/dev</th><th>Mean % Bad blocks/dev</th></tr>
<tr><td rowspan="4">308</td><td>250</td><td>545</td><td>13.3</td></tr>
<tr><td>200</td><td>314</td><td>7.67</td></tr>
<tr><td>150</td><td>53.2</td><td>1.30</td></tr>
<tr><td>100</td><td>0.976</td><td>0.0238</td></tr>
<tr><td rowspan="5">320</td><td>300</td><td>2250</td><td>54.9</td></tr>
<tr><td>250</td><td>1820</td><td>44.4</td></tr>
<tr><td>200</td><td>1050</td><td>25.6</td></tr>
<tr><td>150</td><td>753</td><td>18.4</td></tr>
<tr><td>100</td><td>277</td><td>6.76</td></tr>
</table></td><td>(12)
(14)</td></tr>
<tr><td>Standby Leakage Current Parametric Shift</td><td>Slow parametric increase in leakage current and is a function of TID alone. Effect is reduced when powered off. No other AC (timing) or DC parameter exhibited specified limit failures to the dose levels tested.</td><td>Current measurements (I_{CC}) via spacecraft telemetry as available.</td><td>Device annealing (increased temperature) if required.</td><td>99-90 data sheet specified limit failure between 75krad(Si) and 100krad(Si) for both LOTs 308 and 320.
Maximum 99-90 leakage of 121.3uA and 91.66uA for LOTs 308 and 320 respectively.</td><td>(12)
(13)</td></tr>
</table>

Optocoupler Displacement Damage Tests

Device **c**	**Equivalent Neutron (1 MeV) Fluence**	**Comments**
Isolink OLH249	<5E11	CTR<20%, Not ECM Candidate
Isocom IS49	>2E12	CTR ~60% Candidate for Europa
Isocom CSM141A	>2E12	CTR ~70% Candidate for Europa
Isolink OLS049	<5E11	CTR<20%, Not ECM Candidate
Avago HCPL-5700	>2E12	CTR ~80% Candidate for Europa
Micropac 66179	<2E12	CTR<40%
Micropac 66296	<2E12	CTR~60%
Micropac 66294	>2E12	CTR ~75% Candidate for Europa

Several acceptable to Europa Displacement Damage Levels

Power Device Radiation Test

Part#	Supplier	Function	TID (krad)	Comments
MSK5063RH	**MSK**	Buck Regulator: Rad Hard High Voltage Synchronous Switching Regulator (w/FET)	300	@ 0.100 rad(Si)/s
MSK5055RH	**MSK**	Buck Regulator: Rad-Hard Regulator Controller, Switching, High Voltage, Synchronous	300	@ 0.100 rad(Si)/s
MSK196RH	**MSK**	Rad Hard Current Sense Amplifier	In work	Alternate parts being reviewed
MSK6000RH	**MSK**	Current limiting switch: Dual Rad Hard High Side Driver with Current Sense	300	@ 0.100 rad(Si)/s
MSK5800RH	**MSK**	Linear Regulator w/ adjustable output	In planning	Alternate parts being reviewed
DAC121S101QM	**Texas Instr.**	12-bit Digital-to-Analog Converter	In Work	Will be tested at low rate to take advantage of annealing
LTC2977	**LTC**	PMBus Controller	Non functional at 20 krad(Si)	

- Power distribution is required throughout the SC
- Vast Majority of commerical devices fail at low dose levels
- Selected RH power devices can meet 300 krad

Avionics Device Testing

Part	Manufacturer	TID (Krad)	Comments
Isolator IL611	NVE	300	Likely Immune
Isolator IL715T	NVE	300	Likely Immune
SRAM UT8ER512K32	Aeroflex	300	Tested at 0.1 R/s
SRAM UT8R4M39	Aeroflex	300	Tested at 0.1 R/s
Spacewire	Aeroflex	>450	Tested at 0.1 R/s

SRAMS/Spacewire were 100 Krad Vendor rated - Functional to 300 Krad when tested at 0.1 R/s

FPGA Radiation Tests

Device	Manufacturer	TID/DD (krad)	Comments
Virtex V4QV	Xilinx	>300	
Virtex V5	Xilinx	>500	
Virtex V5QV	Xilinx	>1000	Candidate for Europa
Virtex 7-series	Xilinx	Not Tested	Not recommended for Europa
RTAX 250/1000/ 2000/4000	Microsemi	200/300	Candidate for Europa Static current increases, rise/file time degrades at 300 Krad
Aeroflex UT6325	Cobham/ Aeroflex	300	Candidate for Europa Following packages are qualified: 208 CQFP, 288 CQPF, 484 CLGA and 484 CCGA
Microsemi RTG4	Microsemi	150	Device will be rated to 100 krad

V5QV, RTAX, UT6325 found acceptable to 300 krad
owever – Commercial devices exceed 300 Krad as we

ELDRS Test Method – Parts Tested

Parts	Description	Test type @300krad	Manuf.	Functional fail	Fail specs	comments	Recommended for Europa
LM124	Operational Amplifier	10 mRad/s 80 mRad/s 25 Rad/s Flight-like	TI	No	Yes	LM124 do not fail functionally @300krad Need to work on spec limits No dose rate effects and no non-linearities	Yes
LM2941	Linear Regulator	10 mRad/s 80 mRad/s 25 Rad/s Flight-like	TI	No	Yes	RM2941 do not fail functionally @300 krad Need to work on spec limits Degradation trends show a slight dose rate effect	Yes
LM136	2.5 Voltage reference	10 mRad/s 80 mRad/s 25 Rad/s Flight-like	TI	No	Yes	LM136 do not fail functionally @300 krad Dynamic Z out of spec <125 krad LDR Degradation show a dose rate effect	Yes
LM139	Comparator	10 mRad/s 80 mRad/s 25 Rad/s Flight-like	TI	No	Yes	LM139 do not fail functionally @300krad Ib, Vos goes out of spec < 150krad No dose rate effects and no non-linearities	Yes
REF05	5V voltage reference	10 mRad/s 80 mRad/s 25 Rad/s Flight-like	AD	No	Yes	REF-05 do not fail functionally @300 krad Vref, Vload and Vline, Isource, Isink, Ishort-circuit go out of spec <125 krad LDR Dose rate effects and circuit effects	Maybe
PM139	Comparator	10 mRad/s 80 mRad/s 25 Rad/s Flight-like	AD	No	Yes	PM139 do not fail functionally @300krad Ib, Isink goes out of spec < 200krad No dose rate effects and no non-linearities	Yes
RH117	Linear regulator	10 mRad/s 80 mRad/s 25 Rad/s Flight-like	LT	Yes	Yes	RH117 Fails functionally @125 kRad(Si) (LDR) VRline, Vrload, Vout, Dropout, IADJ and Vref go out of spec < 125 krad (LDR) Severe dose rate effects	No
RH1014	Operational amplifier	10 mRad/s 80 mRad/s 25 Rad/s Flight-like	LT	No	Yes	RH1014 do not fail functionally @300 krad Voffset and Ib go out of spec < 70 krad No dose rate effects and no non-linearities in degradation trends	Yes
RH1009	2.5V Reference	10 mRad/s 80 mRad/s 25 Rad/s Flight-like	LT	No	Yes	RH1009 do not fail functionally @300 krad Vref, Load Reg and Dynamic impedance goes out of specs below 150 krad (LDR) Dose rate effects	Yes

Accelerated ELDRS test developed – Test Duration ~100 days

Radiation Data Sharing: JPL EEE Parts Sharepoint

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Name	Modified	Modified By
ECM_TestMasterList.20180328	Yesterday at 5:53 PM	Zajac, Stephanie A (5144)
Instrument Radiation Test Plans	6 days ago	Sundgaard, Mitch (5143)

Europa ID	Generic	Flight PN	SUDA	UVS	E-Themis - Ball	E-Themis - RVS	MISE	REASON	ICEMAG	MASPEX	Plan Forward
8	MSK 5055-2	5962F1422302KYC						X			
8.21	VRG8663	TBD		X							
8.21	VRG8662	5962R0920701KXC	X								
12.06	2N4858	L741-30591-01						X			
08.01-004	RHF1201							X			
08.01-005	RHF1401	5962F0626001VXC	X		X						
08.01-009	ADC12D1600	ADC12D1600CCMLS	X								
08.01-013	ADC128S102QML-SP	5962R0722701VZA	X	X	X	X	X	X			Europa Power is paying for RLAT
08.03-040	LT1499MW	5962R1325101VDA		X							
08.03-048	MSK196	MSK196VRH		X							Part will likely not be used.
08.03-052	ISL70417SEH	5962F1222801VXC	X	X	X						SUDA planning test for LDR
08.21-005	RHFL4913	5962F0252401VXC	X	X		X	X		X		
08.03-050	ISL70444SEH	5962F1321401VXC			X	X					
08.03-051	ISL70244SEH	5962F1324801VXC	X				X				
08.04-002	8CR512K32	5962F0422701VXC	X	X							
08.09-005	DAC121S101	5962R0722601VZA	X	X							Europa Power is performing testing. UVS is fine for 100k SUDA may piggy back on JPL testing.
08.10-002	XQR5V		X		X	X		X			
08.10-003	RTAX250SL			X			X				
08.10-005	RTAX2000SL			X			X		X		

Teams across the project can post TRR packages, test plans, test status, final reports, etc.

JPL Pars – Parts Approval Documentation

Parts search in PARS returns all prior instances of use. Radiation test reports attached to parts record as well as tracking of tested lot for RLAT.

PARS

Search Result

Match: AL

Searched By

Partnumber: rh1

Part Status: AL

[Export]

Project Name	Part List	Generic	Description	D	PartNum	Procu
Europa Clipper	EEE Parts - Part Removals and Deletions	RH1013	IC, Dual op amp	21	RH1013MW	RH101
Europa Clipper	Spacecraft - Thermal Pump	RH1013	Microcircuit, Linear, Dual Op ...	21	RH1013MJ8	RH101
Europa Clipper	EEE Parts - Europa Clipper Preferred Parts Selection List (PPSL)	RH1013MW	Microcircuit, Linear, Operat...	21	5962R8876003VHA	5962R
Europa Clipper	Payload - MASPEX - EEE Parts List	RH1013MW	Microcircuit, Linear, Operat...	21	5962R8876003VHA	5962R
Europa Jupiter Orbiter	All EEE Parts	RH1013	IC, Dual op amp	21	RH1013MW	RH101
GRACE FO	MWA	RH1013	Microcircuit, Linear, Chip, ...	21	RH1013DICE	RH101
GRAIL	MWA	RH1013	MICROCIRCUIT, CHIP, LINEAR, DU...	21	RH1013BKK	RH101
GRAIL	DRO	RH1013	MICROCIRCUIT, LINEAR, CHIP, ...	21	RH1013DICE	RH101
InSight	Payload Auxiliary Electronics EEE Parts	RH1013	Microcircuit, Analog,	21	RH1013MH	RH101
			LINEAR TECH			

Part Review Details

[Search] [Close] [Edit]

Hardware: [Europa Clipper (EC)]-[Spacecraft (S/C)]-[Telecommunications (TEL)]

Generic: 66212 **PID:** ECLIWE

Part Num: 66212-300
Make from Part Num:
Procurement Num:
PETS Reliability:
Max TID Level (krad):
PPL Candidate:
PCB:
PCB Comment:

Descriptor: B
Manufacturer: TBD
SubContractor Part:
PETS Radiation:
Package Type: TBD
PPL Part:
Project Num: TBD

Description: Optocoupler
Comments:

Eval: TID/ELDRS **Authorized:** 03/29/2017 **Mod:** 07/30/2018 **Closed:** 07/30/2018 **Procure Status:** Not Approved to Buy

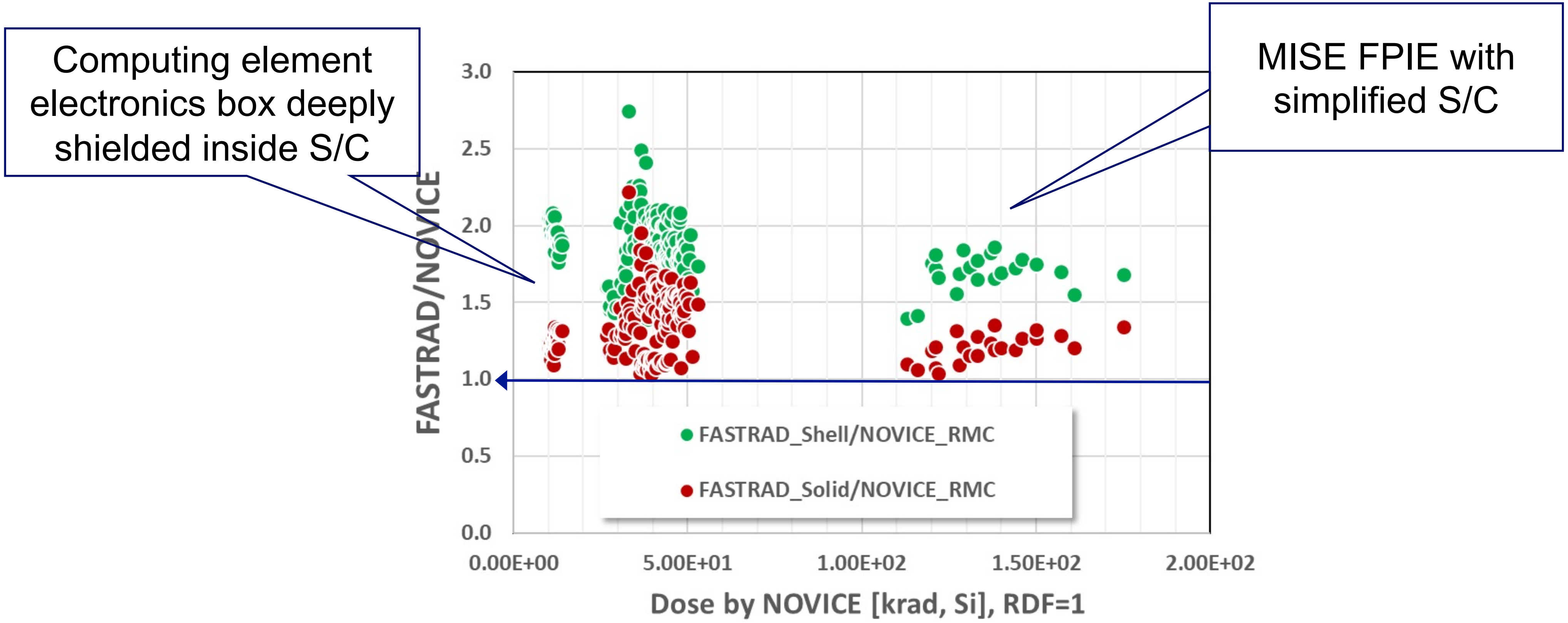
Search Part to Clone

Authorized: Yes
Specialist: Amanda N Bozovich
IOMs/IOM Findings:
References:
Waiver No:
Specialist Comments: Flight lot (E35053A1/1) was TID RLAT at HDR and LDR to 100 krad. All parameters meet spec limits pre- and post-radiation up to and including 100 krad. Per attached RLAT report, lot E35053A1/1 is accepted for use in the Frontier Radio flight build as it meets the 2x RDF per the project requirements.
PIE Comments:
Subcontractor Comments:
NSPAR:
NSPAR#:
Basis of Approval:
GIDEP Check?: Yes No
Applicable GIDEPs:
Schematic No:
Attachments: 1. SER-18-045 Micropac 66212 Radiation Lot Acceptance Test (RLAT) Results f....pdf
Alternate Part Recommendation:
Status: Approved

History

Radiation Transport Tool Validation

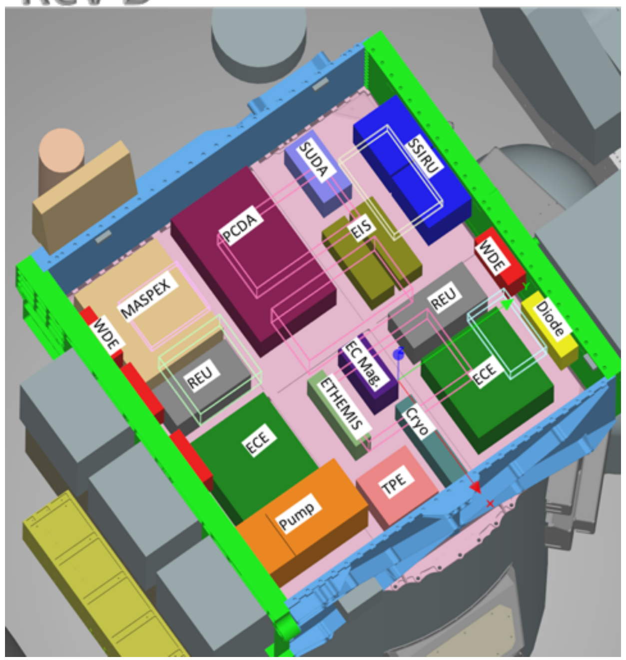
- Radiation Transport tools validated over a range of geometries and shielding depths



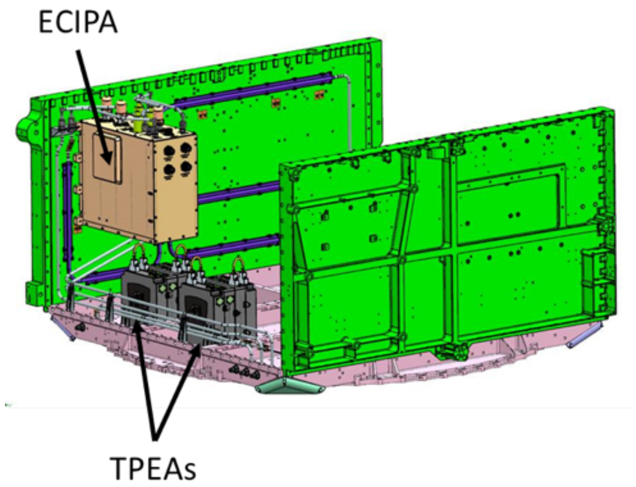
Vault Transport – Rev D Update

- Vault transport updated for S/C config Rev. D
- Individual units subject to detailed analysis

Rev D



Work-to-go: Incorporate ECR-19157 for 4-pump ECIPA with 2 TPEs in vault.



Detector Location >>	Lowest 1 of 9	Center Location	Worst 1 of 9
S/C Configuration>>	Rev D	Rev D	Rev D
Electronics Assembly	TID (rad, Si, RDF =1)	TID (rad, Si, RDF =1)	TID (rad, Si, RDF =1)
MASPEX	7.85E+04	9.63E+04	1.50E+05
Integrated Pump	7.29E+04	7.39E+04	1.58E+05
EIS 1 (WAC)	9.29E+04	1.08E+05	1.35E+05
EIS 2 (NAC)	8.37E+04	8.37E+04	1.10E+05
CDH 1	9.10E+04	9.10E+04	1.57E+05
CDH 2	6.96E+04	6.96E+04	1.22E+05
E-THEMIS	7.52E+04	7.52E+04	1.12E+05
PCDA	7.41E+04	7.41E+04	1.35E+05
MISE-DPE	1.09E+05	1.19E+05	1.58E+05
SUDA	1.08E+05	1.10E+05	1.48E+05
ICEMAG	8.35E+04	8.35E+04	1.15E+05
REU 1	9.00E+04	9.00E+04	1.29E+05
REU 2	6.90E+04	6.90E+04	9.99E+04
MISE-CEU	8.35E+04	8.35E+04	1.44E+05
REASON-VHF	1.02E+05	1.23E+05	1.56E+05
REASON-HF	9.84E+04	1.16E+05	1.45E+05
REASON-DES	8.20E+04	8.20E+04	1.22E+05
SRU (16 mm wall)	3.59E+04	4.17E+04	4.17E+04
SIRU 1	5.47E+04	5.47E+04	1.12E+05
SIRU 2	6.34E+04	6.34E+04	1.40E+05
WDE 1	8.87E+04	8.87E+04	1.35E+05
WDE 2	6.14E+04	7.51E+04	1.13E+05
WDE 3	5.73E+04	5.73E+04	9.57E+04
WDE 4	5.64E+04	5.64E+04	9.01E+04
TPE	1.06E+05	1.06E+05	1.41E+05
DSS	1.03E+05	1.17E+05	1.40E+05
AVERAGE	8.04E+04	8.50E+04	1.27E+05

Vault wall thickness established - four units slightly exceed 150 krad target (not an issue)

Detailed Radiation Transport Status

	Subsystem/Assembly/Instrument	Transport Status	Design To (Krad, RDF=2)	Locally Shielded (Krad, RDF=2)
Avionics/Command & Data Handling (CDH)	Europa Compute Element (ECE)	C	200	NAND - 66 EIO (Osc) - 100
	Remote Engineering Unit (REU)	C	300	
Guidance Navigation and Control (GNC)	Stellar Reference Unit (SRU) Optical Head & Baffles	P-I	40	
	Stellar Reference Unit (SRU) Electronics	P-I	100	
	Scalable Space Inertial Reference Unit (SSIRU)	P-I	300	QA3000 - 25
	Reaction Wheel Unit-Isolation	C	300	Hall Effect - 70
	Reaction Wheel Drive Electronics (WDE)	C	300	See Analysis
	Digital Sun Sensor Assembly (DSS)Optical Head	C	100	
	Digital Sun Sensor Assembly (DSS)Electronics	C	300	
Power	Power Control and Distribution Assembly (PCDA)	C	300	
	Filter Box	C	300	
	Li-Ion Small Cell Battery	C	10,000	
Propulsion Module (PM)	Propulsion Module Electronics (PME)	C	100	
	SADA/HDRM Power Converter (SHPC)	P-I	100	
	Diode Box	P-I	300	
	Radiation Monitor ***	P-I		
	Propulsion System Pressure Transducers	P-I	300	170
Telecom	Frontier Radio A and B	C	100	
	Ka-Band antenna and subsystem (EPC)	C	100	
	X-Band antenna and subsystem (EPC)	C	100	
	RF Switches diodes	P-I	300	
Thermal	Integrated Pump Assembly (IPA)*			Hall Effect - 70
	Thermal Pump Electronics	P-I	300	DC-DC – 100
Facility Instrument	Europa Clipper Magnetometer (ECM) Flux Gate (FG)	C		
	Europa Clipper Magnetometer (ECM) Electronic Unit	C	300	DC-DC – 100

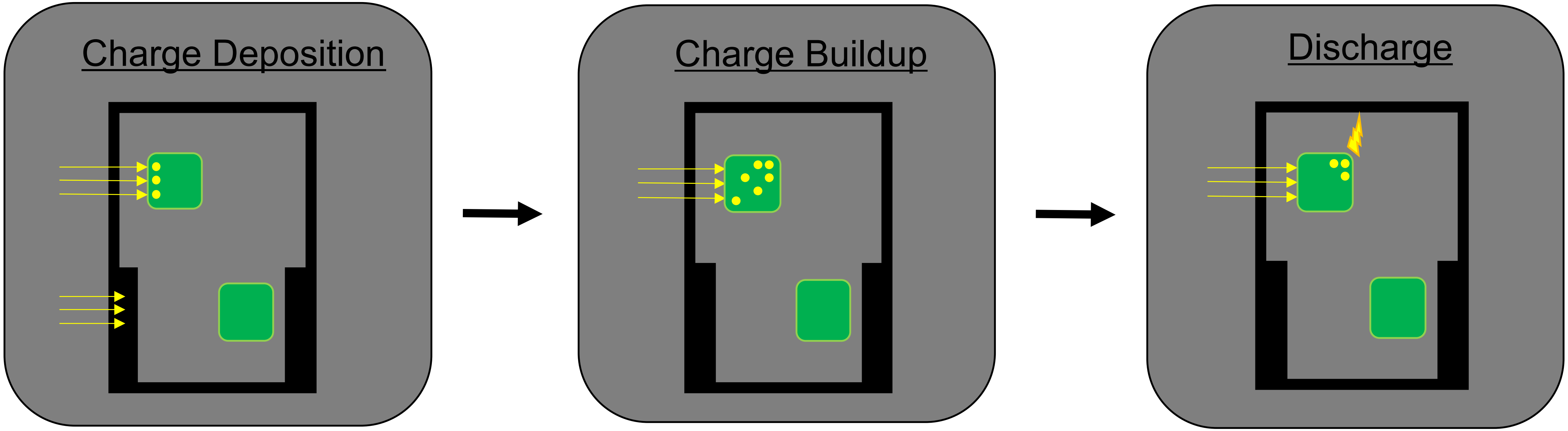
	Subsystem/Assembly/Instrument	Transport Status	Design To (Krad, RDF=2)	Locally Shielded (Krad, RDF=2)
Payload	EIS NAC Telescope & Gimbal Assembly	P-I	300	200
	EIS NAC Data Processing Unit (JPL)*		300	
	EIS NAC , (DE 1)	P-I	300	
	EIS WAC Telescope Assembly	P-I	300	200
	EIS WAC Data Processing Unit (JPL)*		300	
	EIS WAC (DE 2)	P-I	300	
	E-THEMIS (Europa Thermal Emission Imaging System)Sensor	C		
	E-THEMIS (Europa Thermal Emission Imaging System)Electronics	C	300	
	MASPEX Electronics Box	P-U	200	100 (see analysis)
	MASPEX Mass Spectrometer (MS) Gas-Inlet System (GIS) Assembly	P-U	TBD	
	MISE (Data Processing Unit (DPU)	P-I	300	RTAX 200
	MISE Cryocooler Electronics Unit (CEU)**	C	300	MOSFET 150
	MISE Focal Plane Interface Electronics (FPIE)	C	100	
	PIMS Upper Sensor Assembly	C	300	FPGA – 200
	PIMS Lower Sensor Assembly	C	300	FPGA – 200
	REASON Digital/Synthesizer Electronics Stack (DES)	C	300	
	REASON Very High Frequency (VHF) Electronics Stack	C	300	
	REASON High Frequency (HF) Electronics Stack	C	300	
	REASON Matching Network	P-I	TBD	
	REASON VHF Antenna Assembly	C	TBD	
	REASON HF Antenna Assembly	C	TBD	
	SUDA Sensor Head	C	1000	
	SUDA Remote Electronics Box (REB)	C	300	NAND 150
	UVS (Ultraviolet Spectrograph)	P-I	100	

*covered by Vault transport analysis IOM, **preliminary analysis with A9 and 100 mils box, *** no distributed sensors

All subsystems/instruments are expected to comply with TID RDF=2 requirement
(pending final RLATs and MASPEX transport update)

Internal Electrostatic Discharge (IESD)

- High energy electrons penetrate spacecraft and deposit internal to materials
- Dielectric materials with high resistivity and metals without a static bleed path accumulate charge over time
- As charge accumulates, high electric fields develop, and discharges can occur
- **Current arcs can damage electronics and generate noise, coupled both conductively and radiatively**



General Mitigation Methods

- Increase shielding
  - Decrease charging flux
- Ground floating conductors
- Limit the size of dielectrics
- Minimize exposed dielectric surface areas
- Change to more conductive material
- Harden the electronics affected by discharges
- Block conducted discharges with a filter

General Approach to Mitigating iESD Risk

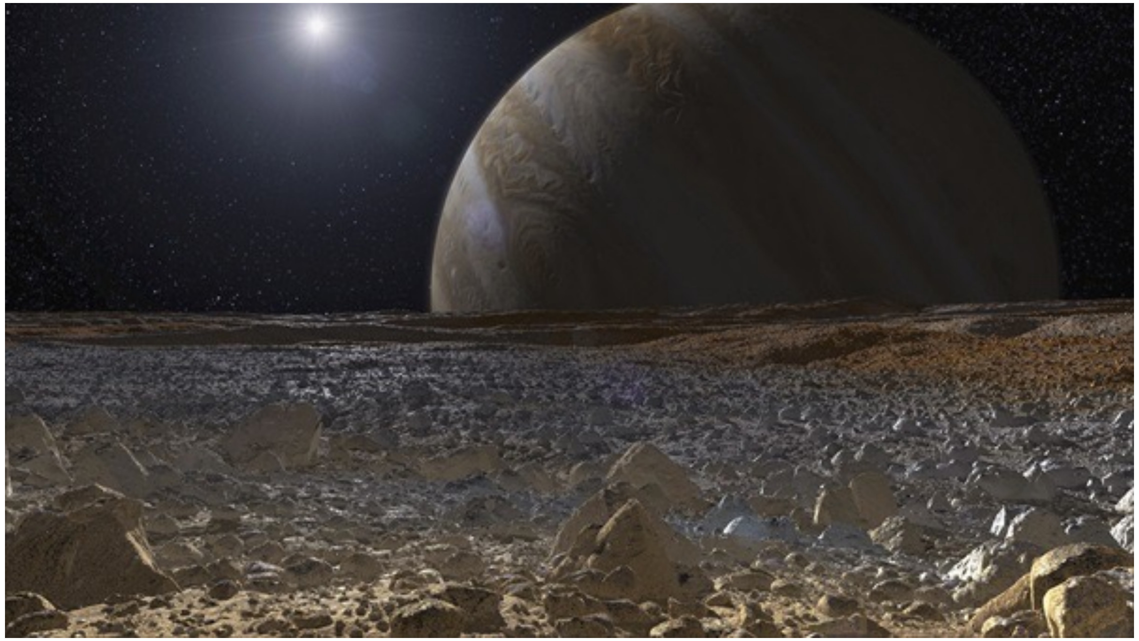
- Limit the usage of very resistive materials (bulk resistivity > 10^{19} Ω·cm at operation temperature)
- No discharges inside of the vault
  - Place the sensitive electronics inside of the vault
- Follow the ESD Control Plan (D-80301)
  - Wrap the harnesses external to the vault with ESD conductive tapes providing 100% visual coverage
  - Filter the discharge pulses conducted through cables
  - Ground the most of floating conductors
  - Minimize the dielectric usage
  - Make most, if not all, external surface ESD conductive.
- The probability of not having discharges inside of the vault is at least 95 %.
  - If Europa Clipper mission is repeated 100 times, there will be no discharges inside of vault for 95 times. For 5 times, there might be discharges for one or few orbits which might or might not damage the electronics.

Europa Clipper IESD Design/Mitigation Process

- Many items fall within the guidelines and can be confirmed IESD-compliant with minimal effort
- However, many items also do not fall within the guidelines and require detailed analysis and test to resolve
  - When found late, these can require risky rework or mitigations
    - Hand soldering
    - Copper tape on parts in electronics boxes
    - Introducing filtering
    - Increasing shielding

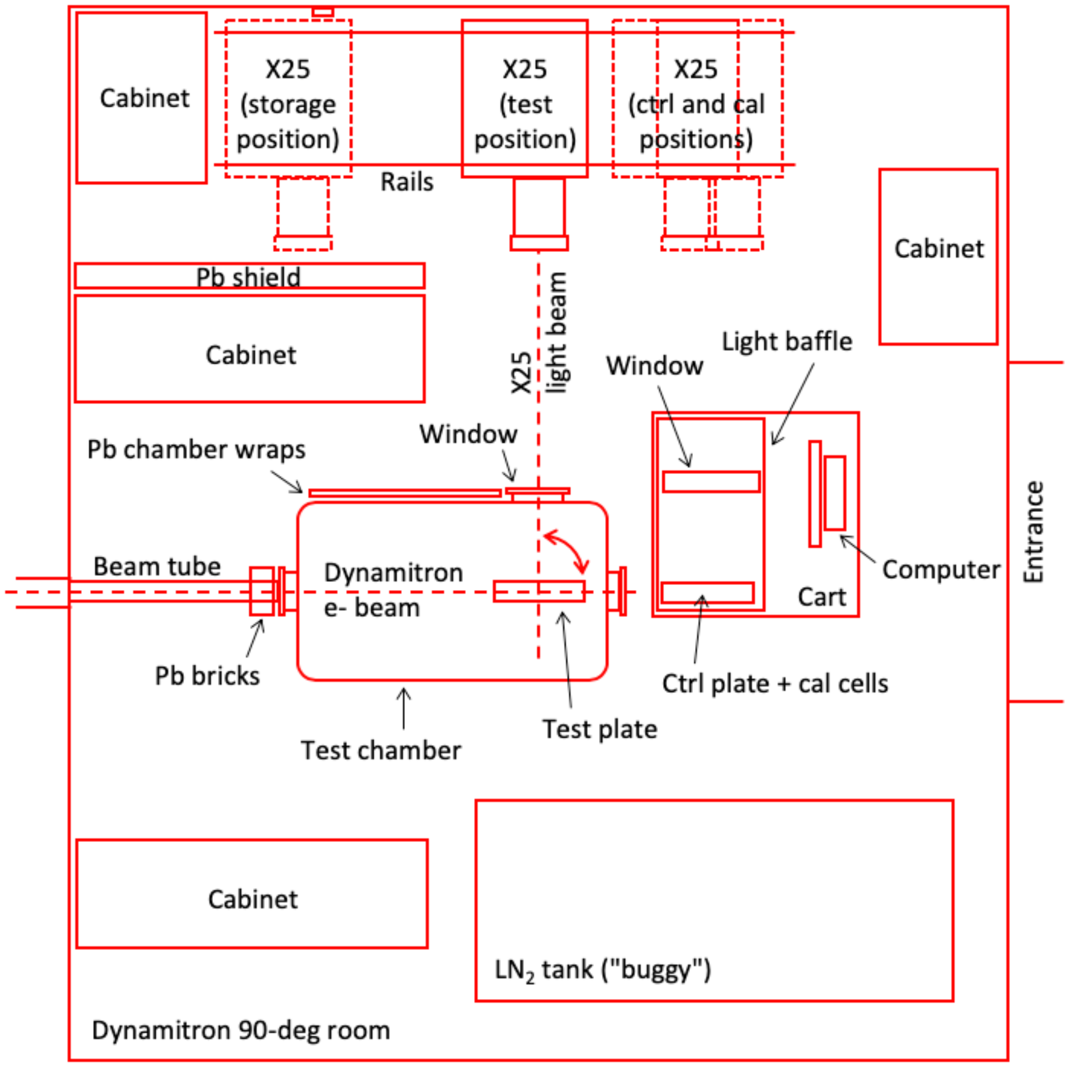
Solar Array LILT

- At Jupiter – Low Illumination and Low Temperature
- Temperature ~ - 140 C
- Illumination ~ 4% compared to Earth

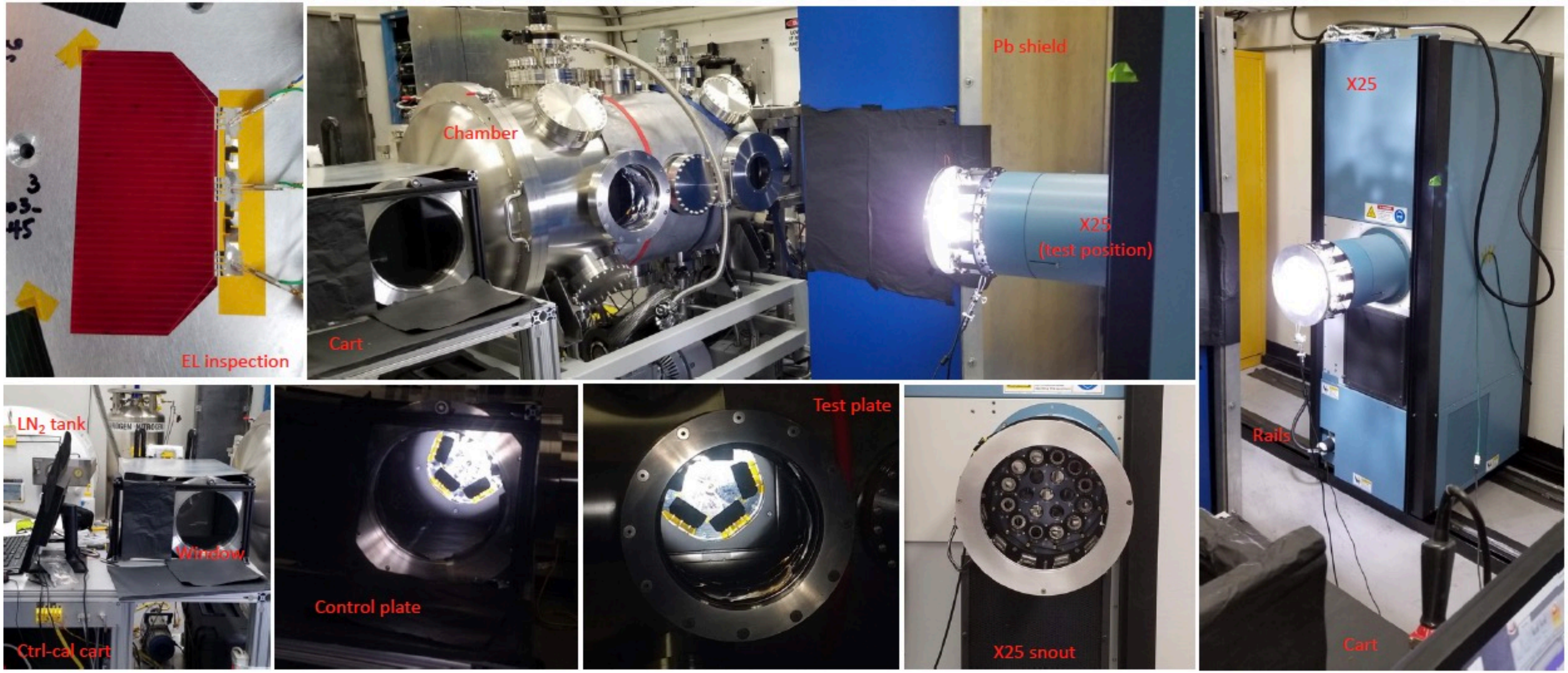


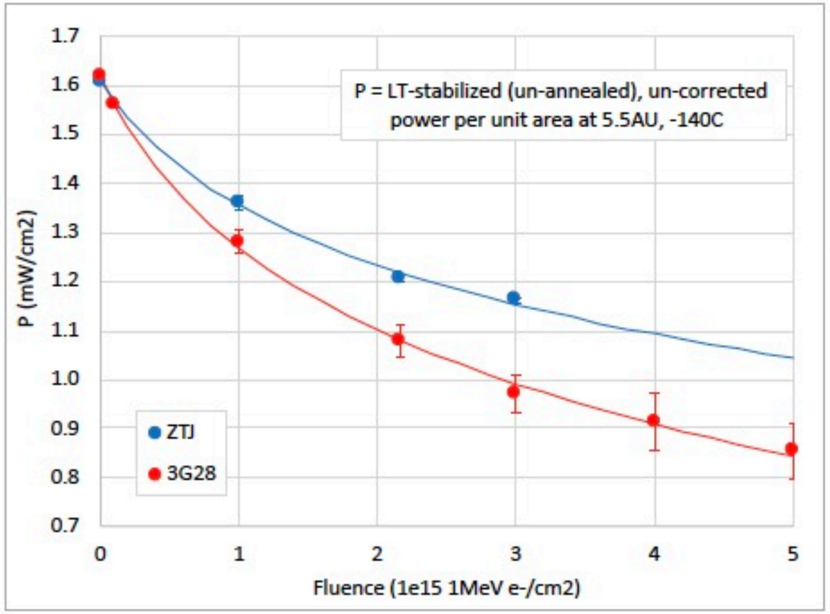
Solar Array LILT – Dynamitron Facility

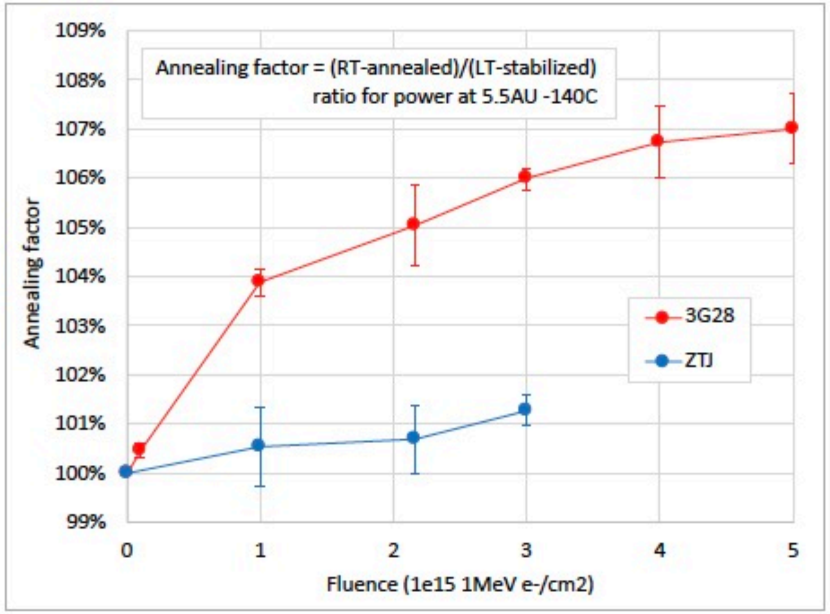
- JPL Dynamitron 90-deg room
- E-beam travels from 0-deg room through beam tube into target/test chamber
- Chamber holds test article plate at controlled temperature
  - Differential pressure LN2-cooled fixture in 100 Torr GN2
  - Temperature: -140°C for radiation, -140 to +28°C for test
- X25 solar simulator is light source for cell characterization
  - Calibrated to AM0 color balance, 1-5.5AU irradiance
  - Four positions: calibration, control, test and storage
- Control-calibration cart holds cal standards, spectroradiometer, unirradiated control plate, data acquisition electronics
  - Two positions: control-calibration and storage (out of room)
  - Control plate is nominally identical to test plate
- Test plate is oriented to face either e-beam or X25 light beam

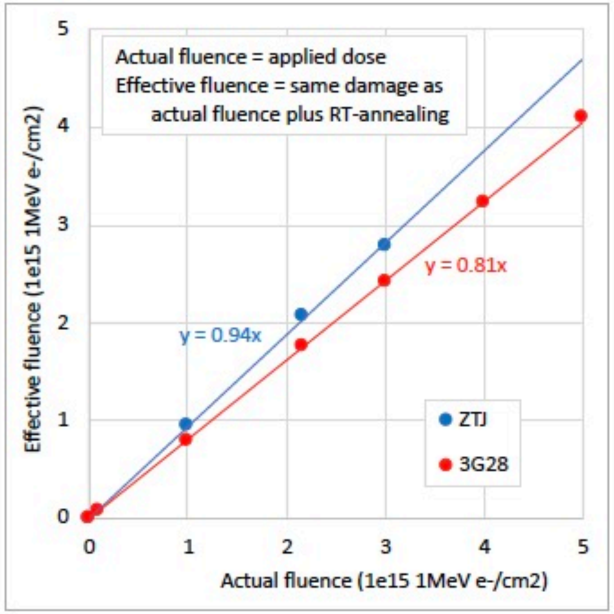


JPL Dynamitron – X25 Facility









Effect of room temperature annealing test artifact is equivalent to a fractional reduction in applied radiation fluence

Radiation Monitor (RadMon)

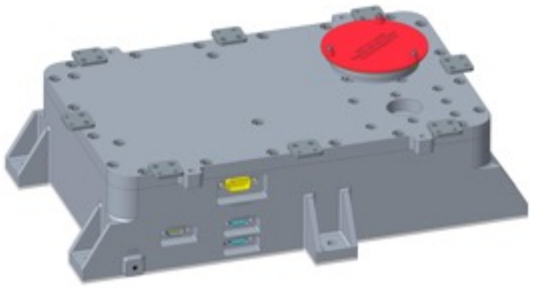
- The Radiation Monitor is a spacecraft resource for characterizing key elements of the radiation environment
  - TID for electronics lifetime
    - Different shielding levels
    - Distributed TID monitoring at multiple locations on spacecraft
  - Charge environment for linking anomalies to iESD events

- Radiation Monitor data will be used to inform decisions on spacecraft health and aging from a radiation perspective
  - This data will not be used for spacecraft autonomy – ground processing only

RadMon Overview

The Radiation Monitor consists of multiple components

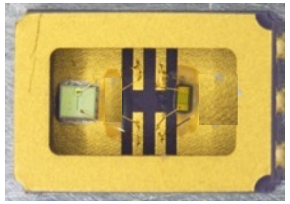
- Sensor Assembly
  - Single unit mounted on exterior of avionics vault
  - Measures both TID and charging
  - Redundant connectivity to Avionics Compute Element



- Distributed TID Units
  - Small, simple assemblies containing two RadFET Hybrids and two PRTs
  - Eight units at various locations in the spacecraft
  - Read out via the REU
  - No connectivity to the Sensor Assembly

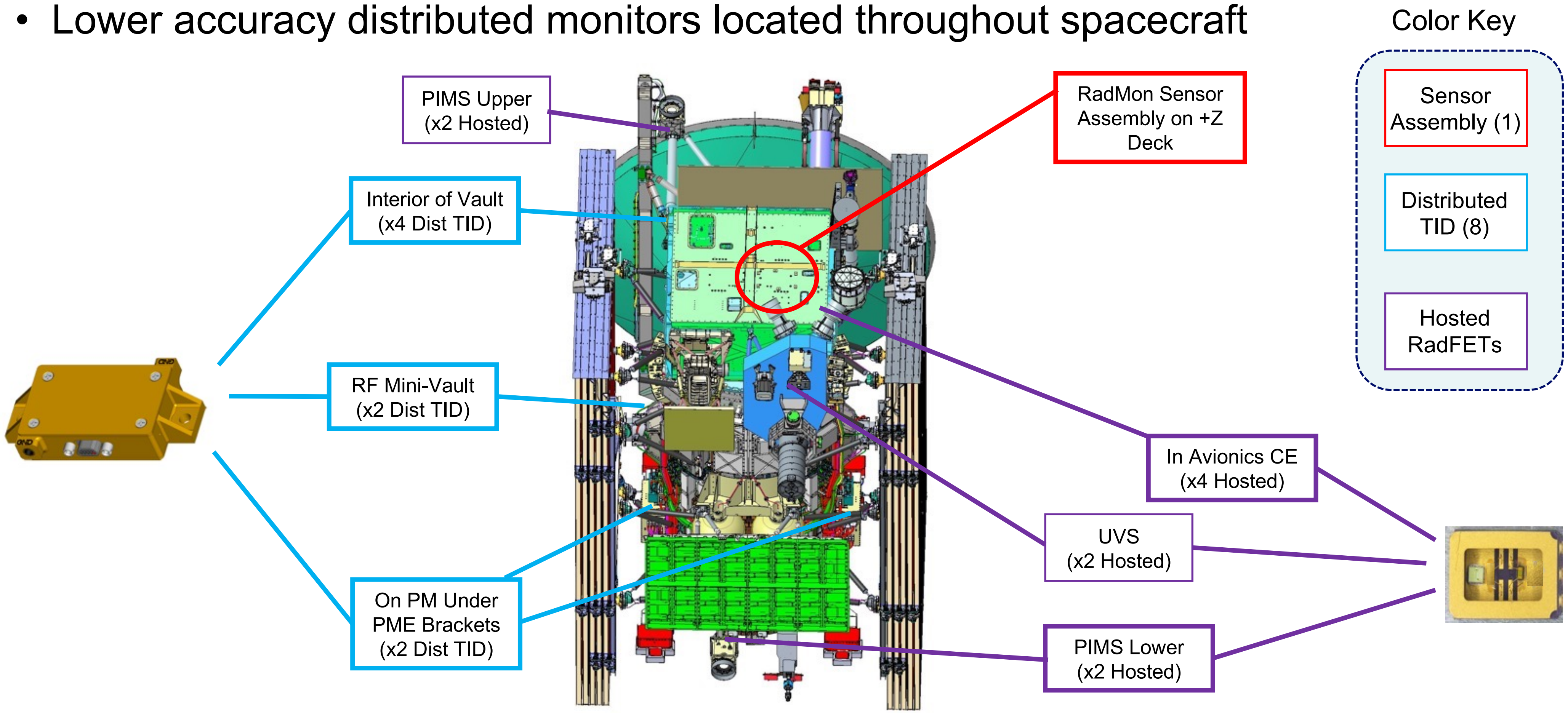
Pictures not to same scale

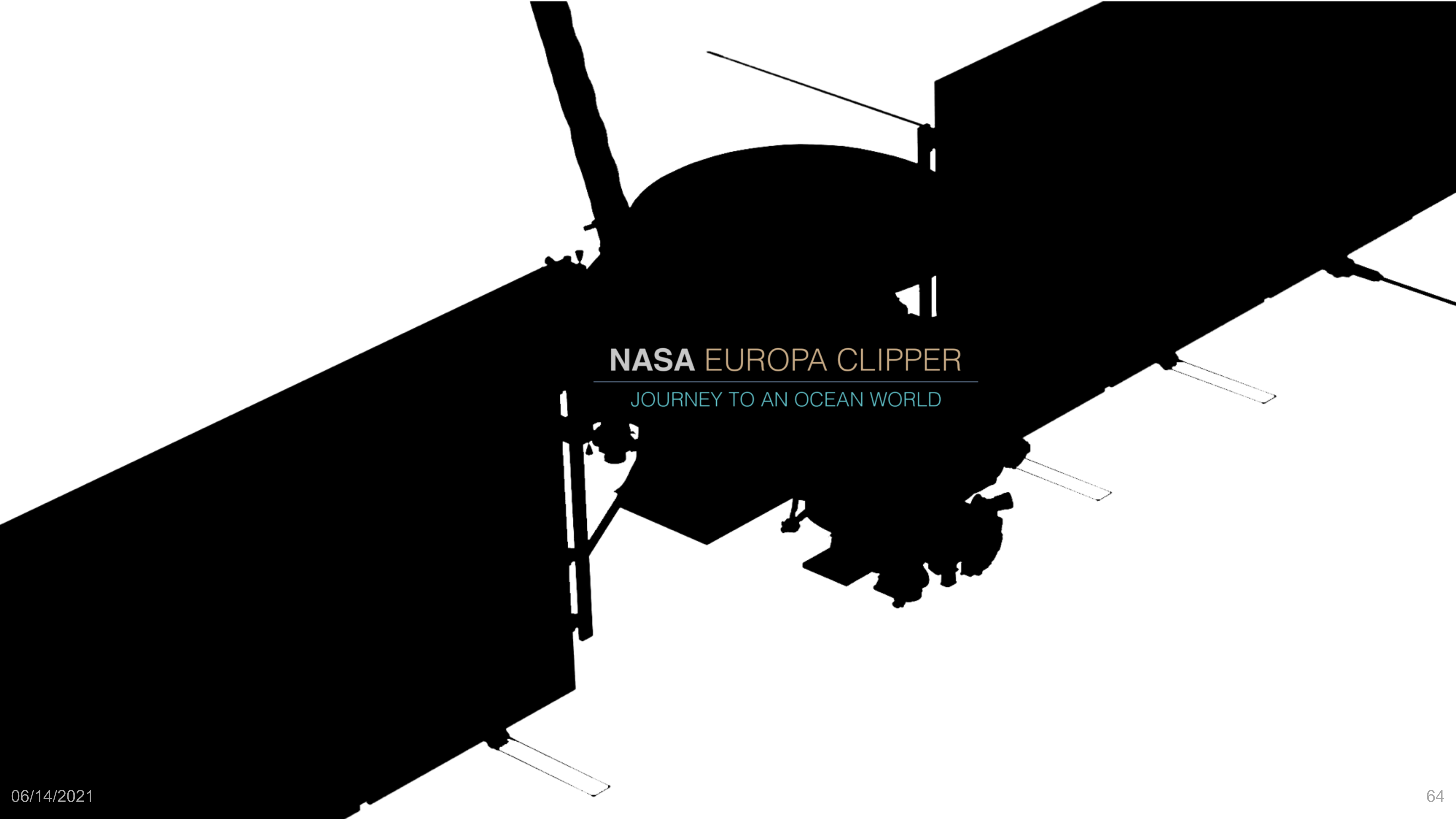
- RadFET Hybrids
  - Small hybrid with a TID sensing RadFET and ESD protection
  - Used for TID measurements in both Sensor Assembly and Distributed TID Units
  - Also delivered as EEE Parts to instruments/subsystems as “hosted” TID sensors
  - Hosted sensors are read by host instrument/subsystem and have no connectivity to the Sensor Assembly
  - RadFET locations: Avionics (4), PIMS instrument (2 per assembly), UVS instrument (1)



RadMon Locations

- Primary data collection point is on +Z deck of avionics vault
- Lower accuracy distributed monitors located throughout spacecraft





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