EUROPA CLIPPER

Selection and Characterization of Electronic Parts and Materials for the Europa Clipper Mission

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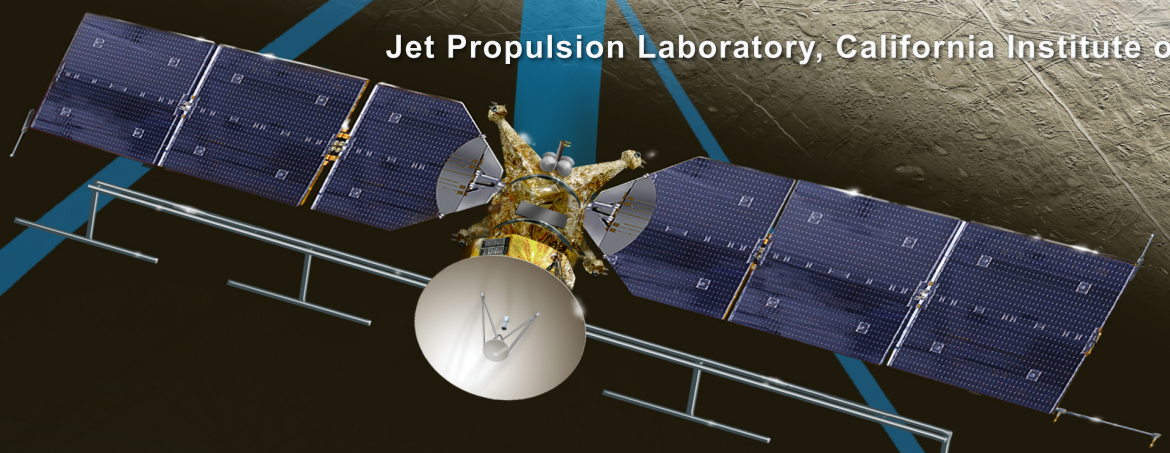
Jet Propulsion Laboratory, California Institute of Technology



International Workshop on Radiation Resistant sensors and Related Technologies for Nuclear Power Plant Decommissioning 2016 (R2SRT2016)

April 19, 2016

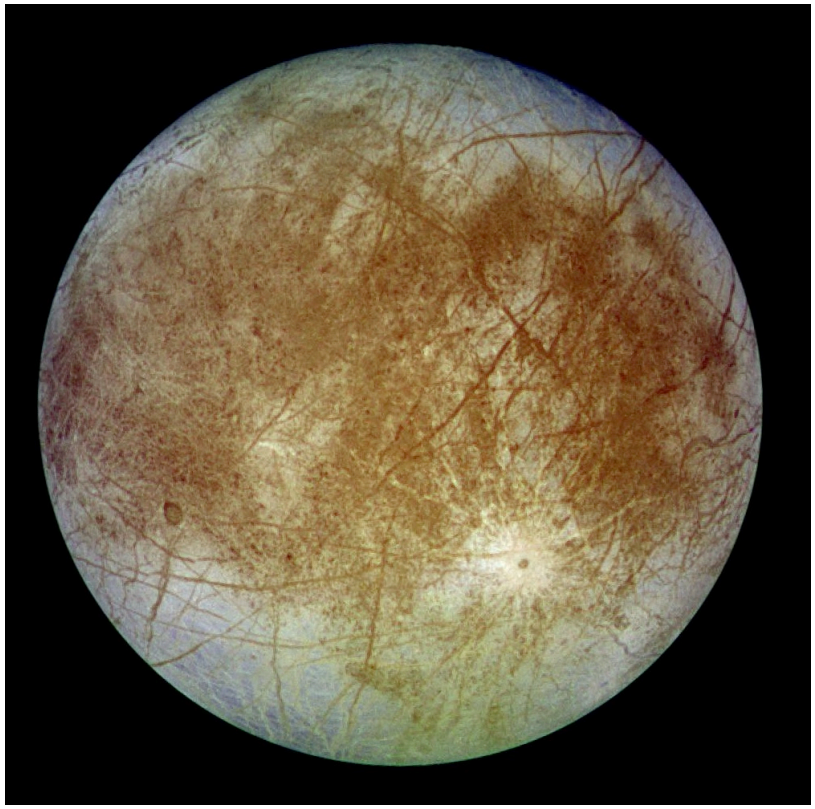
Pre-Decisional Information — For Planning and Discussion Purposes Only

Agenda

- Overview of the planned Europa Mission
- Radiation Environment and Sheilding Approach
- Radiation Hardening and Device/Material Selection Approach
- Radiation Testing Results
- Conclusions

Pre-Decisional Information — For Planning and Discussion Purposes Only

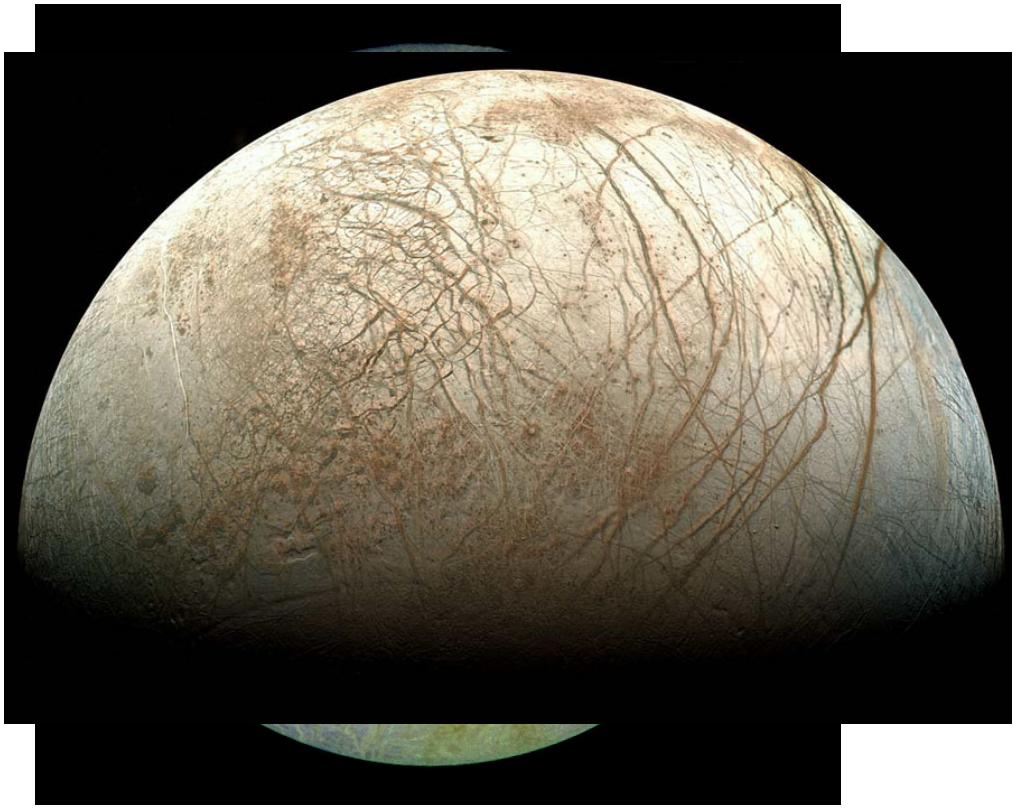
Europa: Key to Icy World Habitability



- **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**

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
- Plentiful cryovolcanism

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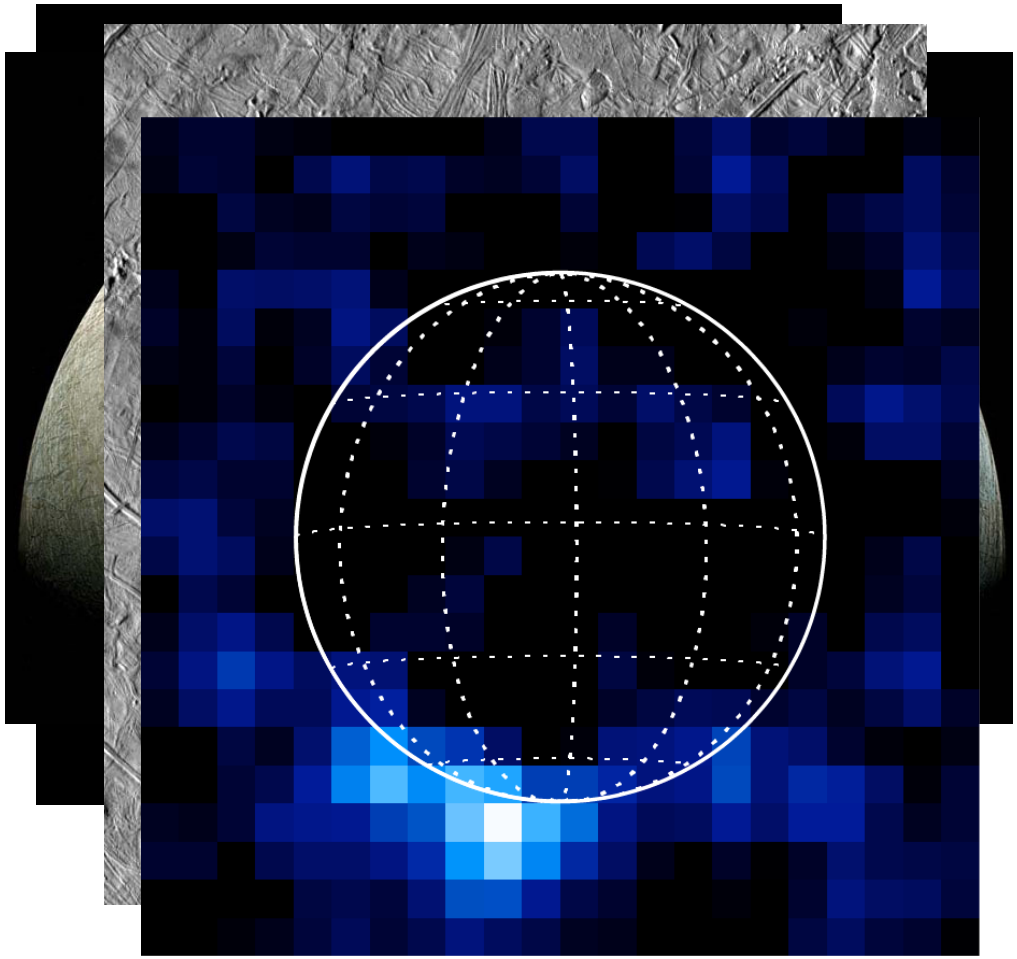

- A world of rock, ice, and water the size of Earth's moon
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- Plentiful cryovolcanism
- Possible geysers and plumes

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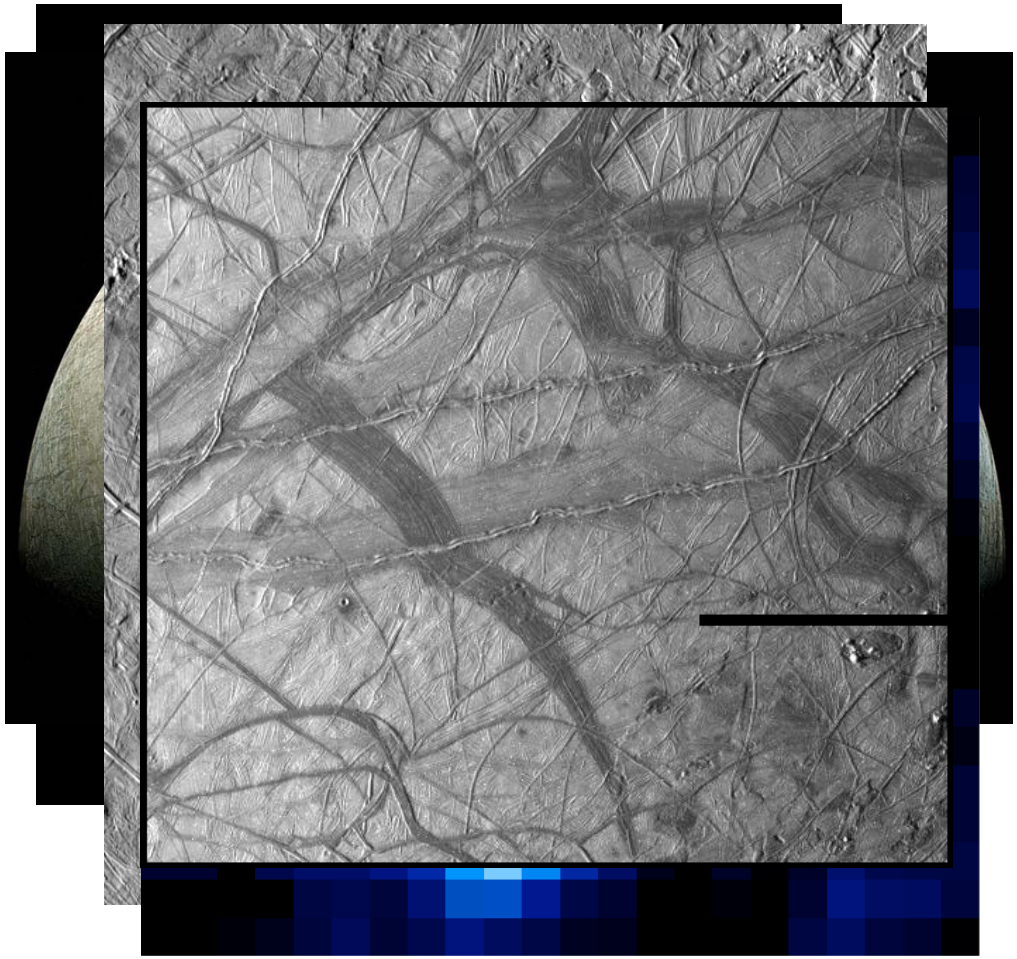

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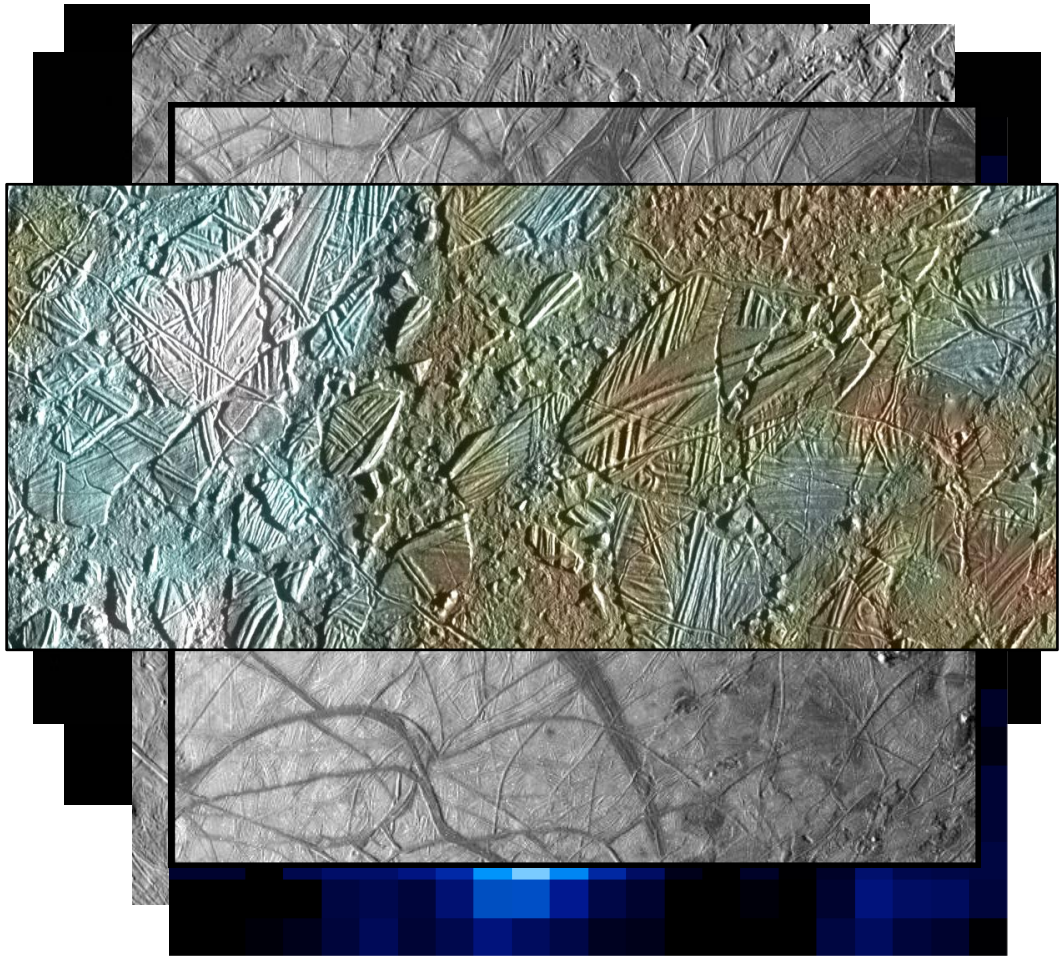

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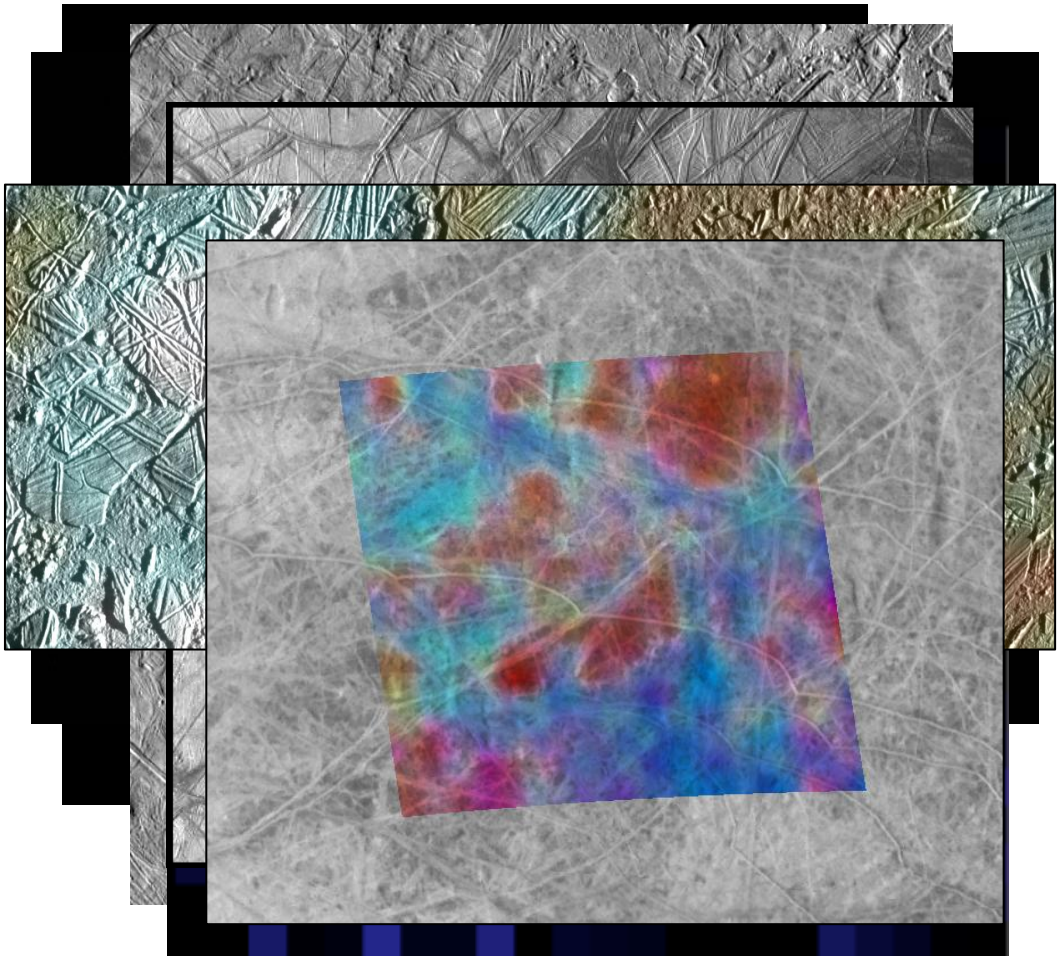

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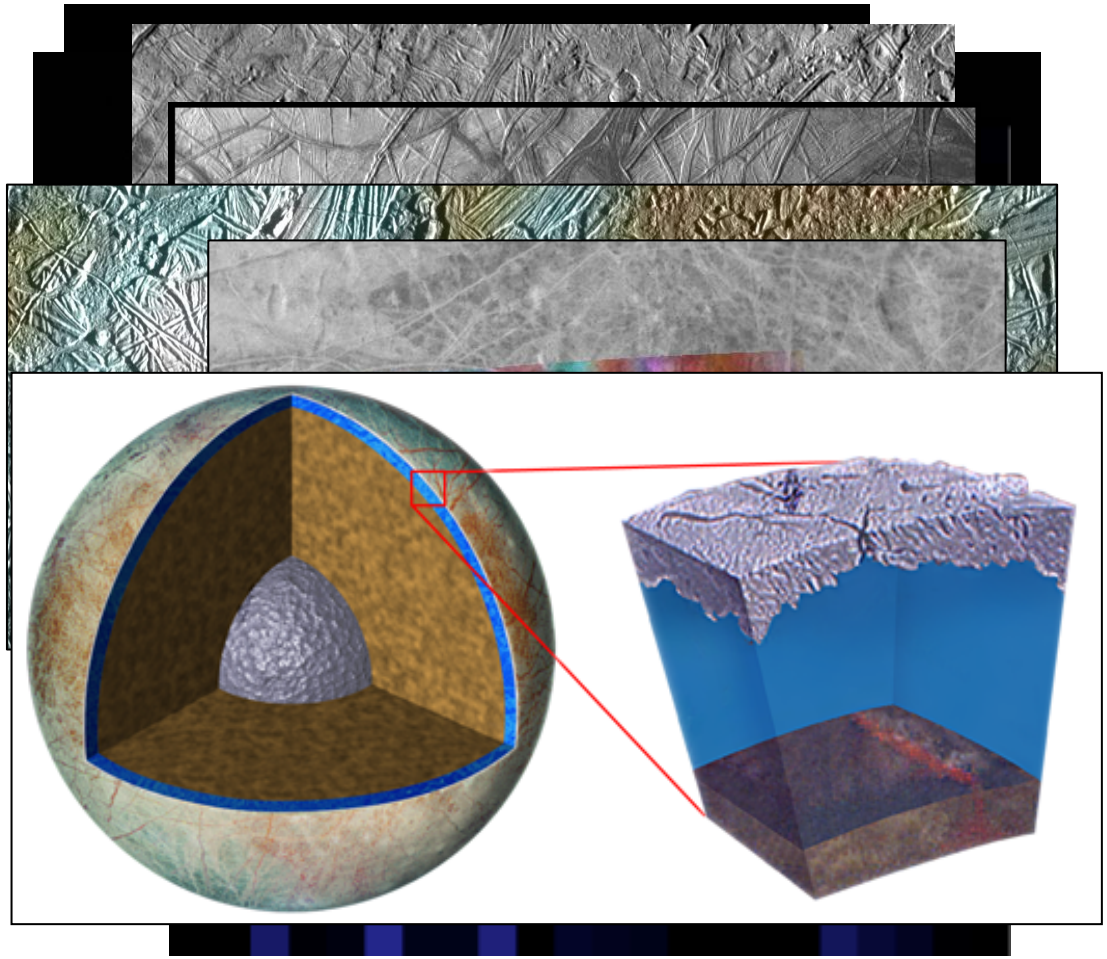

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- Surface chemistry of salts and acid
- Subsurface ocean: our Solar System's best chance for extant life beyond Earth?

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

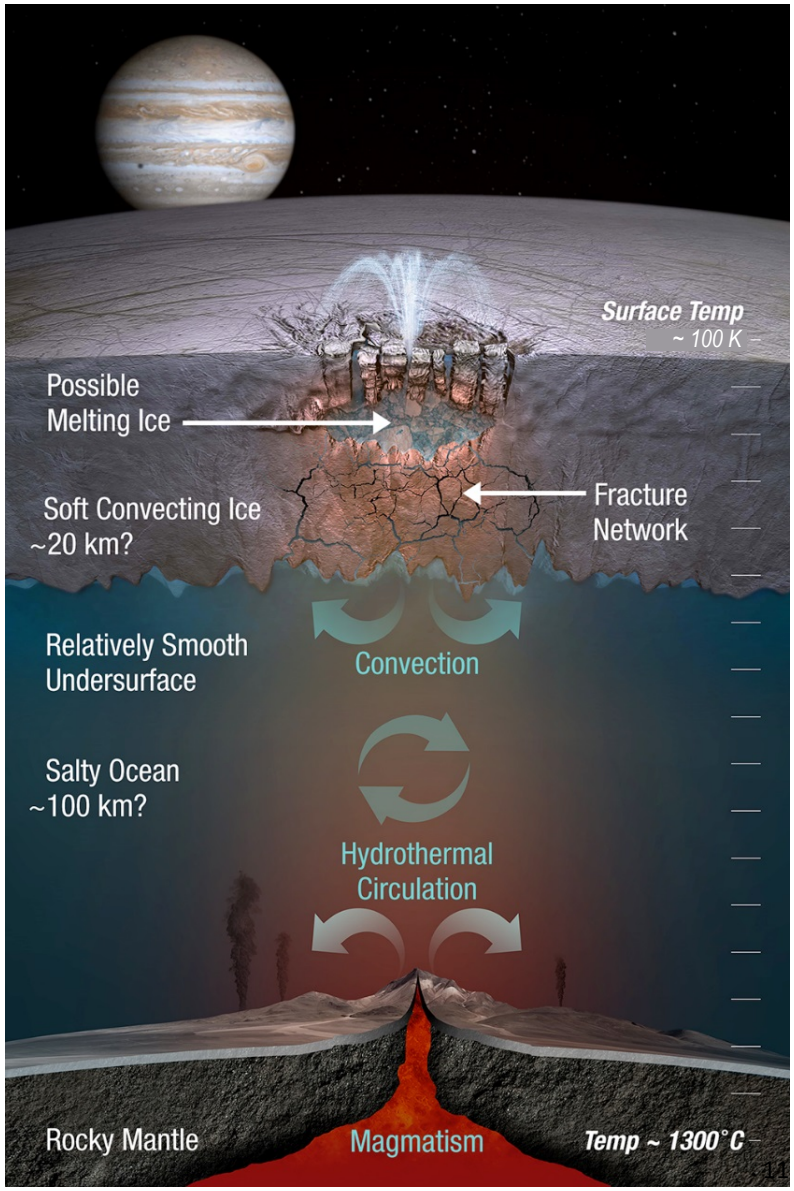
Energy:

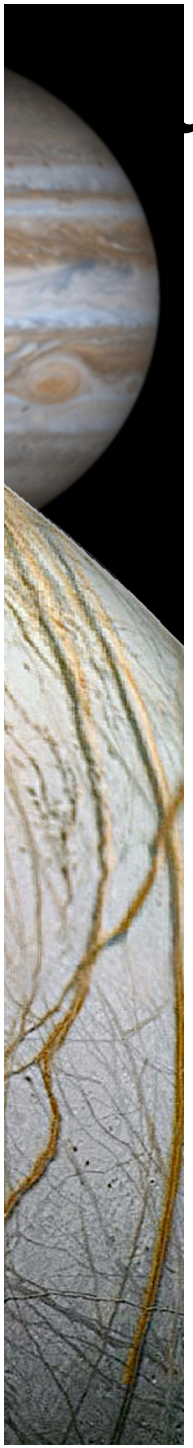
- Chemical energy could sustain life
- Surface irradiation creates oxidants
- Mantle rock-water reactions could create reductants

Activity:

- Geological activity "stirs the pot"

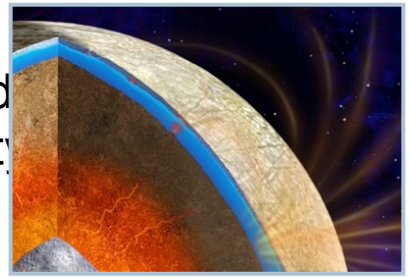
Europa Flyby Mission will verify key* habitability *hypotheses



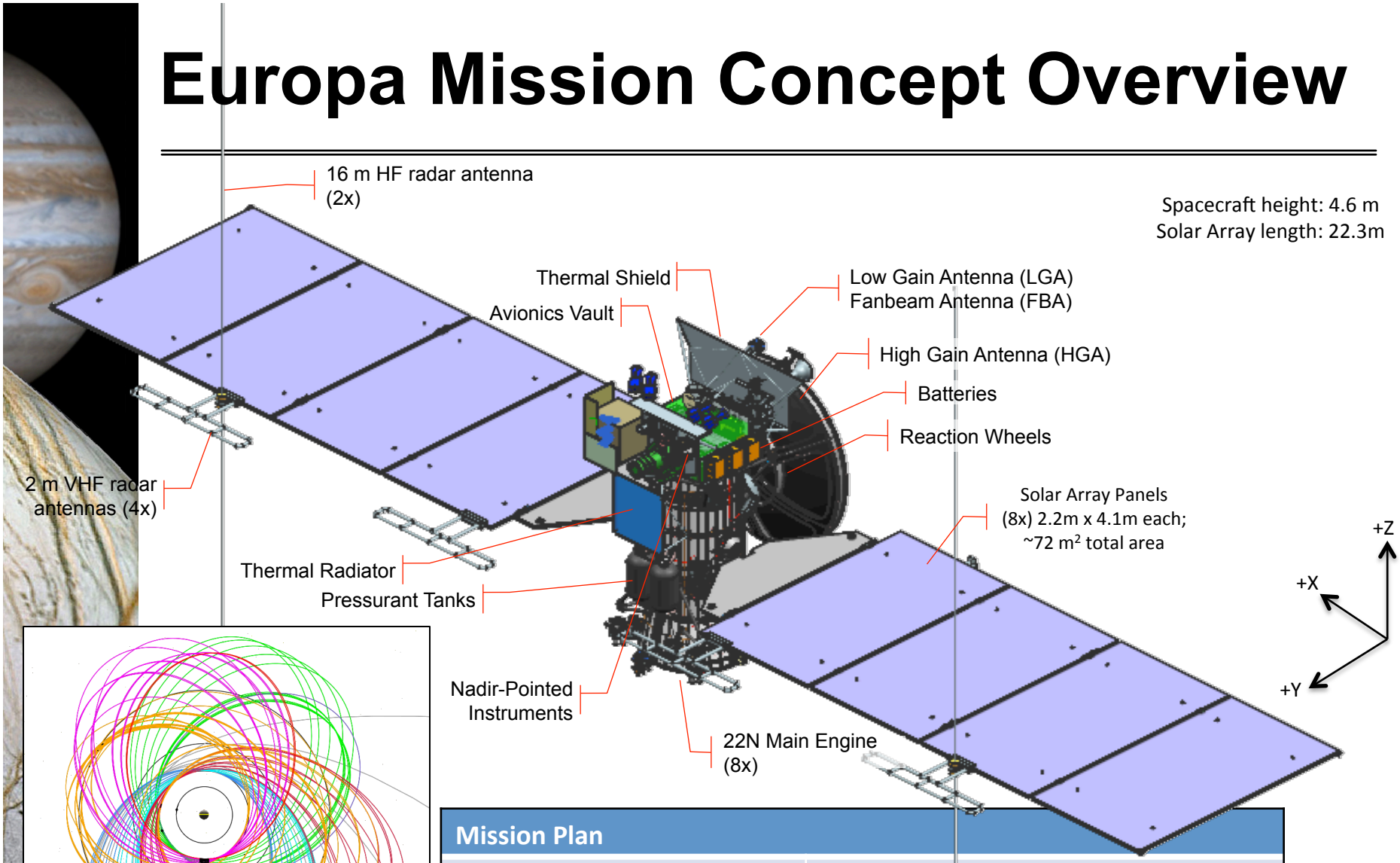


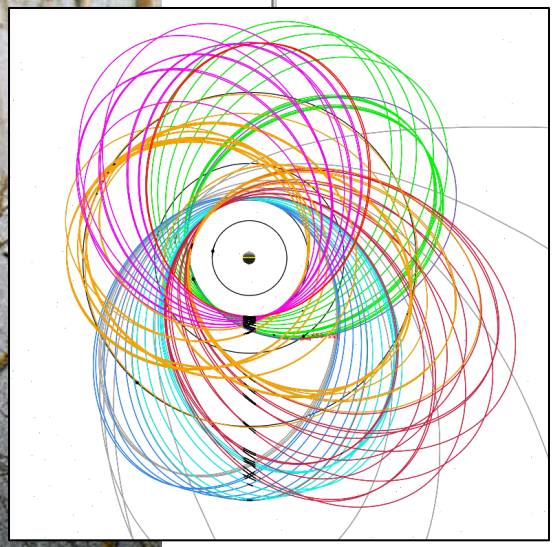
uropa Mission Science Goal & Objectives

- *Goal:* **Explore Europa to investigate its habitability**
- *Objectives:*
  - **Ice Shell & Ocean:** Characterize the ice shell and any subsurface water, including their heterogeneit ocean properties, and the nature of surface-ice-ocean exchange
  - **Composition:** Understand the habitability of Europa's ocean through composition and chemistry
  - **Geology:** Understand the formation of surface features, including sites of recent or current activ and characterize high science interest localities



Europa Mission Concept Overview





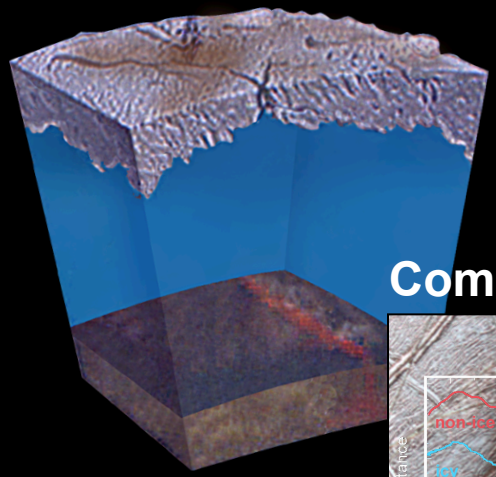
Mission Plan	
Earliest potential launch date	6 June 2022
Earliest Jupiter Arrival	5 Mar 2025 (if SLS launch)
Science Tour	~42 Europa Flybys in prime mission
Primary Mission End	6 Dec 2028 (Ganymede Impact)

Pre-Decisional Information — For Planning and Discussion Purposes Only

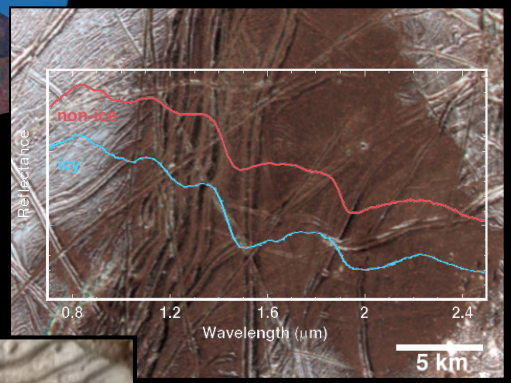
Europa Mission Science

- *Goal:* Explore Europa to investigate its habitability

Ocean & Ice Shell

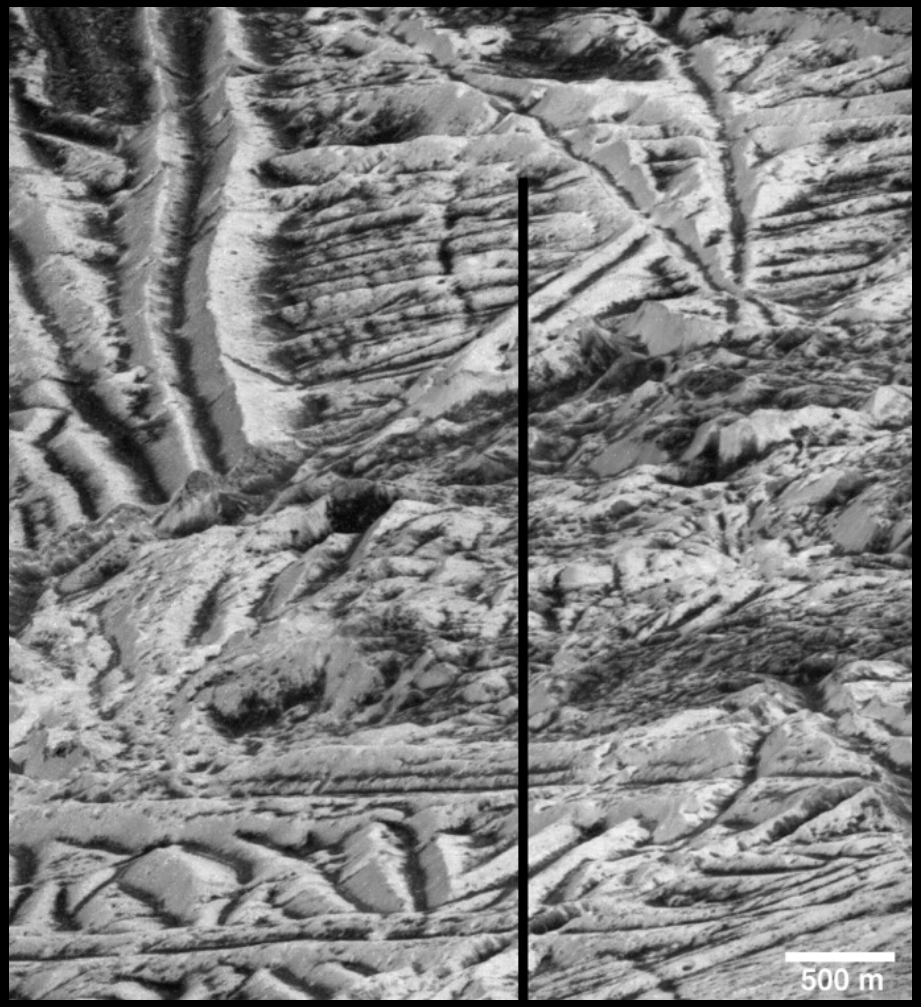


Composition



Geology

Reconnaissance



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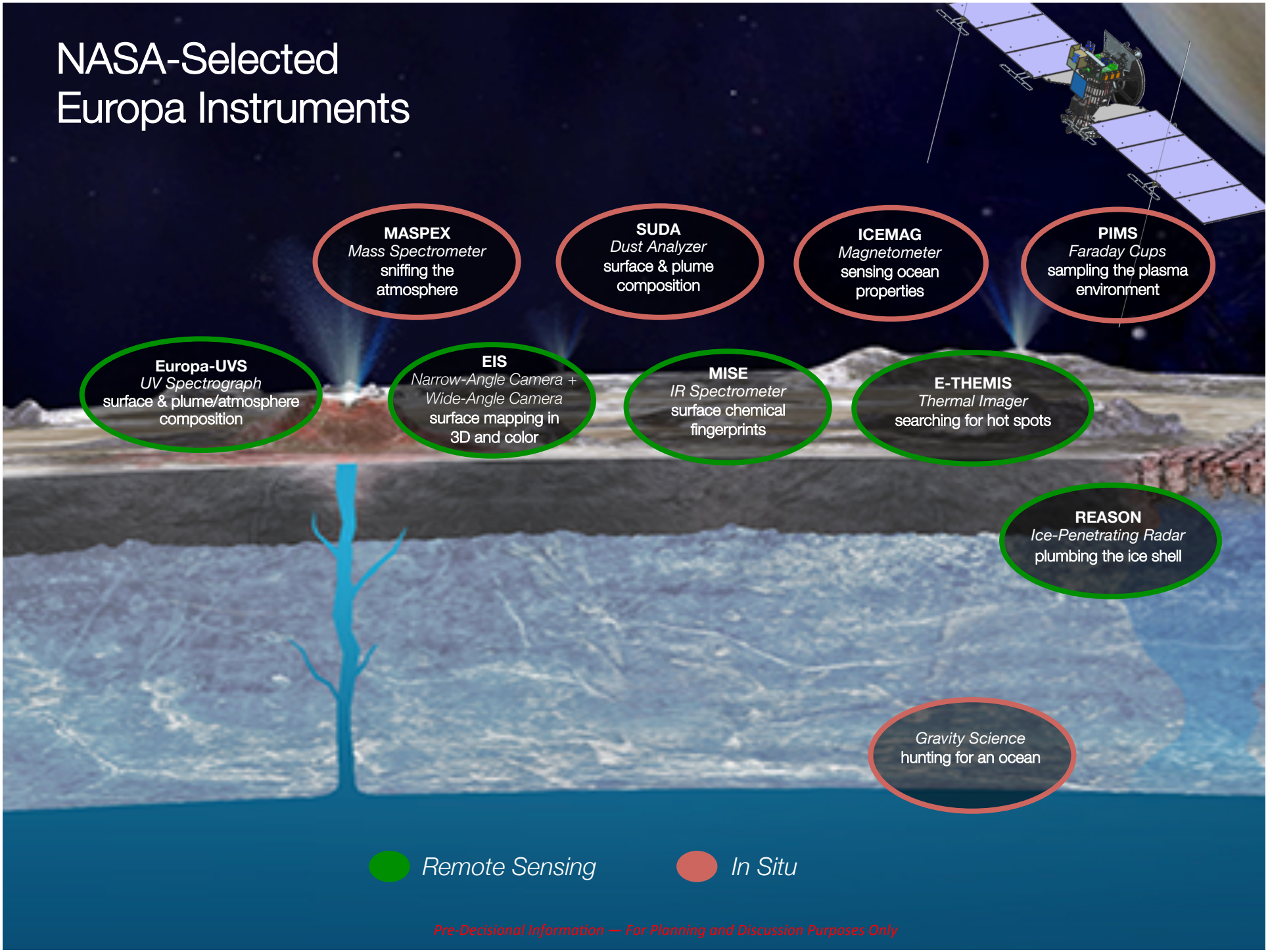
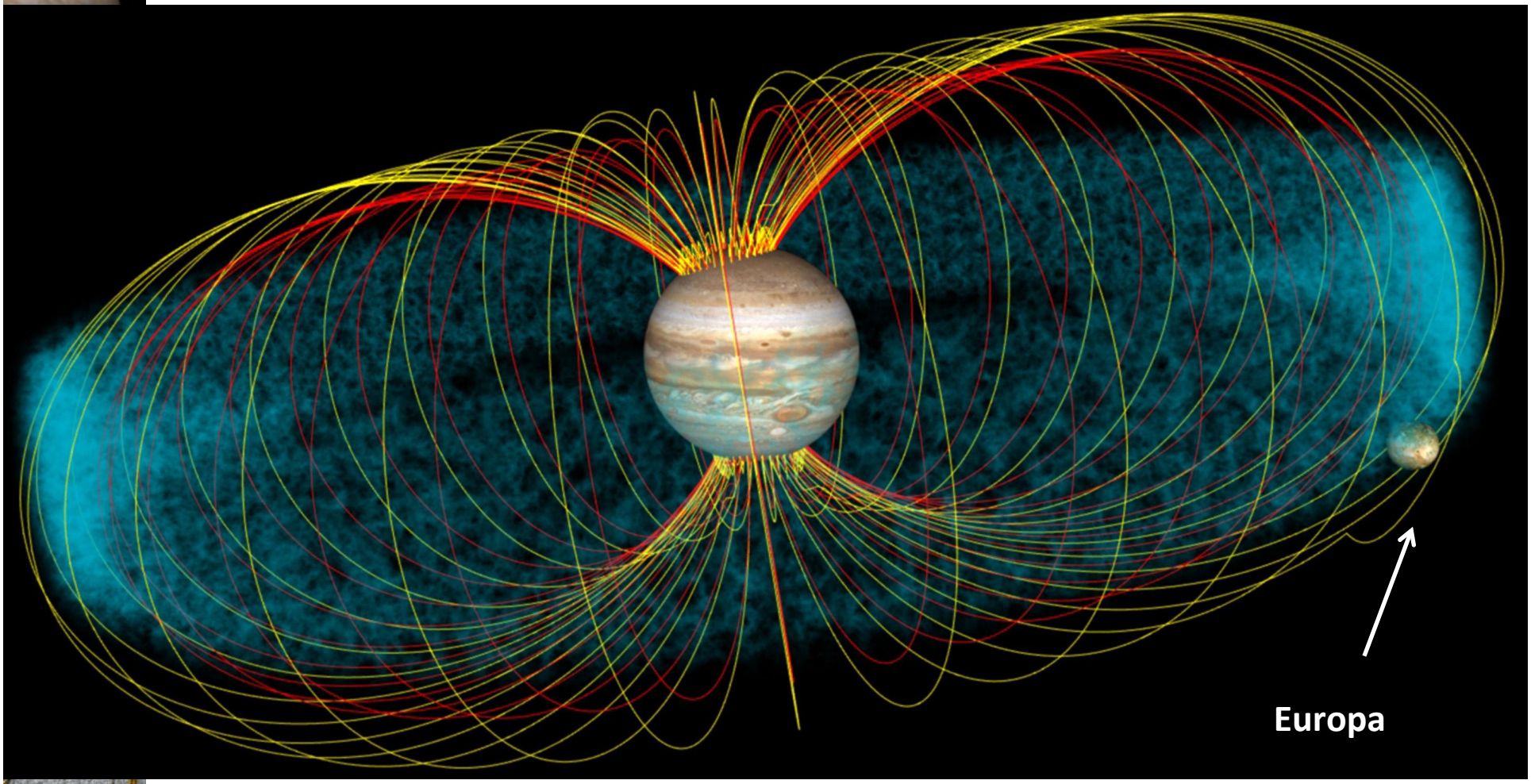
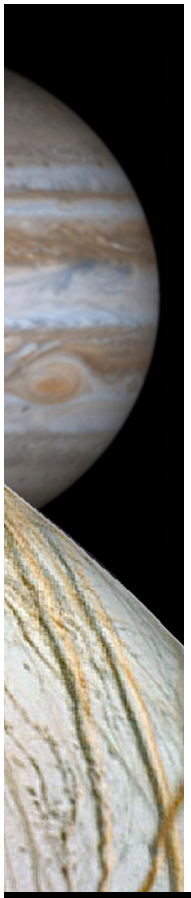
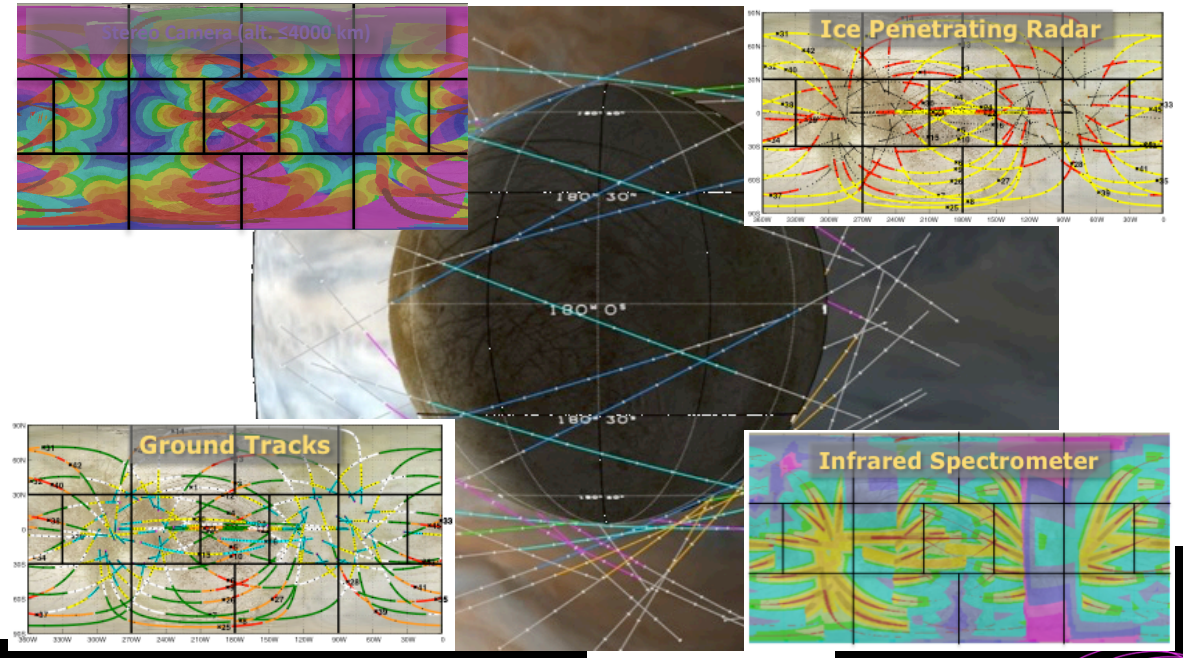

NASA-Selected
Europa Instruments
MASPEX
Mass Spectrometer
sniffing the atmosphere
SUDA
Dust Analyzer
surface & plume composition
ICEMAG
Magnetometer
sensing ocean properties
PIMS
Faraday Cups
sampling the plasma environment
Europa-UVS
UV Spectrograph
surface & plume/atmosphere composition
EIS
Narrow-Angle Camera +
Wide-Angle Camera
surface mapping in 3D and color
MISE
IR Spectrometer
surface chemical fingerprints
E-THEMIS
Thermal Imager
searching for hot spots
REASON
Ice-Penetrating Radar
plumbing the ice shell
Gravity Science
hunting for an ocean
Remote Sensing
In Situ
Pre-Decisional Information — For Planning and Discussion Purposes Only

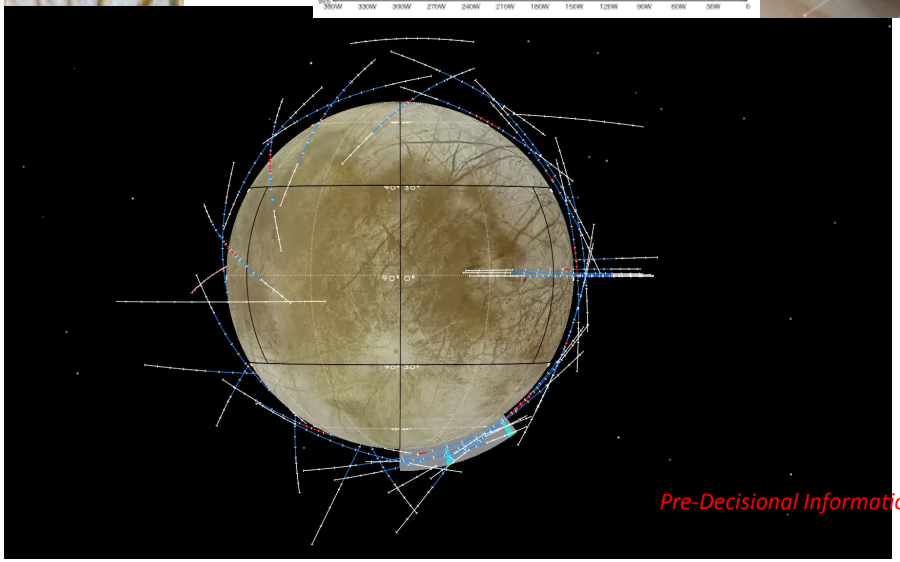
Jupiter's Radiation Belts

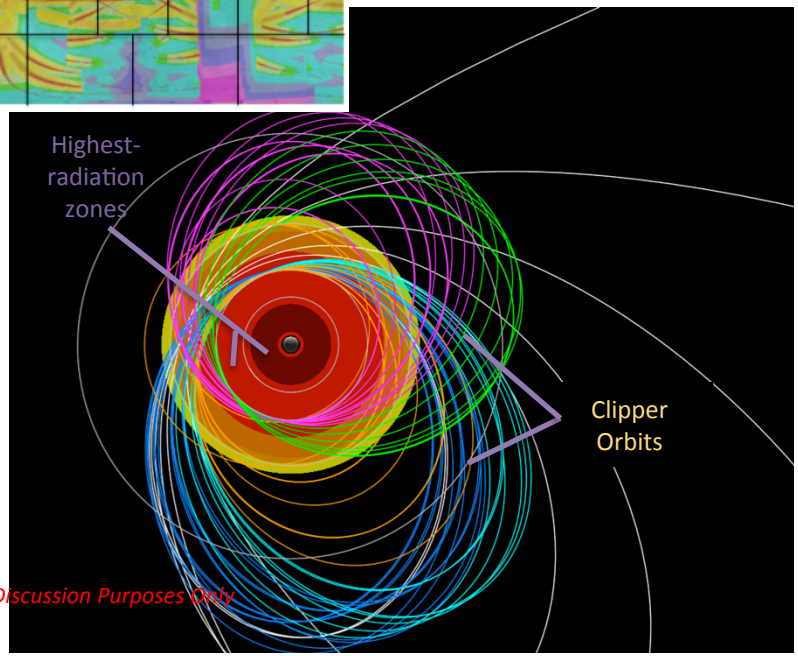


Innovative Mission Concept





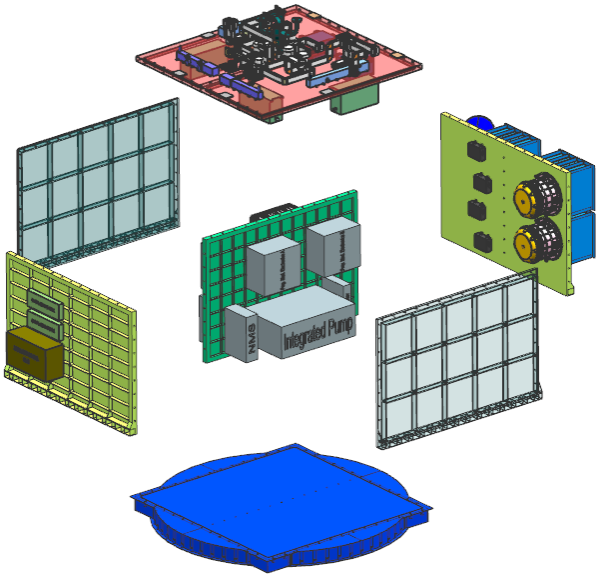


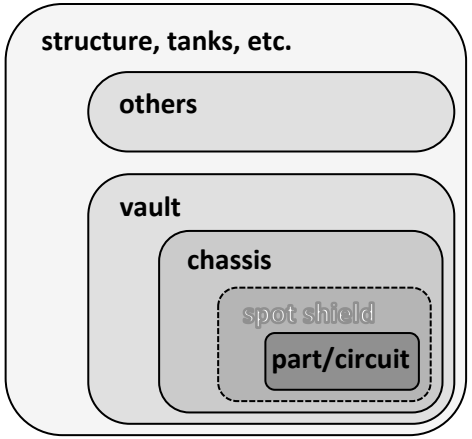


Pre-Decisional Information — For Planning and Discussion Purposes Only

Radiation Management

- Bound total dose at 3 Mrad@100 mil Al
- Radiation Design Factor of 2
- Goal: 300 krad electronic parts
- Testing, testing, testing…
- Preferred parts & materials database
- Utilize radiation vault
  - 150 krad environment inside of vault
  - Benefits of packing and self shielding
  - Micro Meteoroid and Orbit Debris protection
  - IESD protection
- Juno IESD approach
  - Protection circuitry
  - Cable overwrap, minimize floating metal
- Accommodation Work
  - In/outside the vault decision
  - IESD approach
  - Vault radiation transport analysis

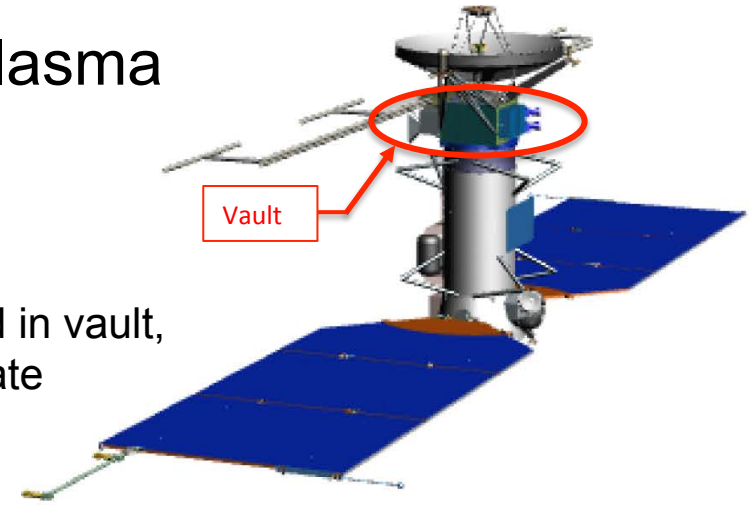


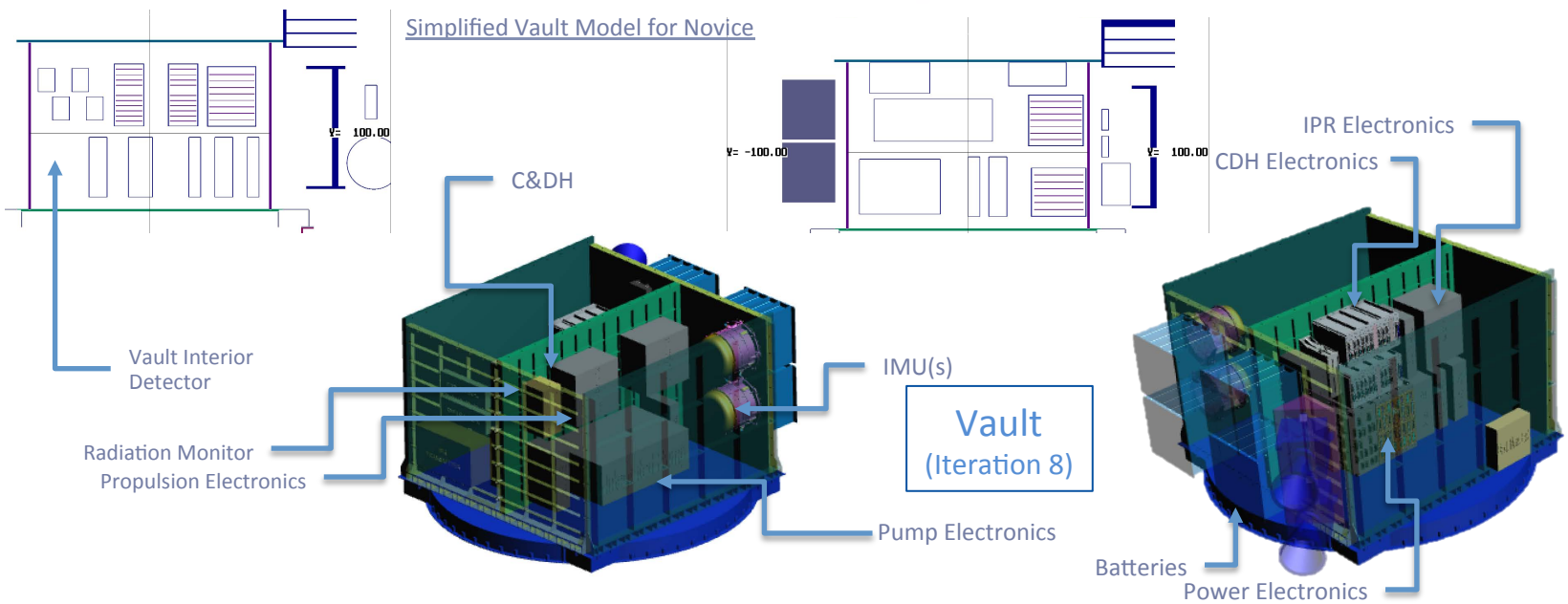


Radiation Vault: Shielding Sum is Greater than the Parts

Europa Radiation Environment Mitigation

- Primary concern is radiation/plasma environment
  - Approach for flight systems is to place a majority of electronics in a radiation "Vault"
  - Instrument main electronics accommodated in vault, with detector/proximity electronics in separate shielded enclosures external to vault



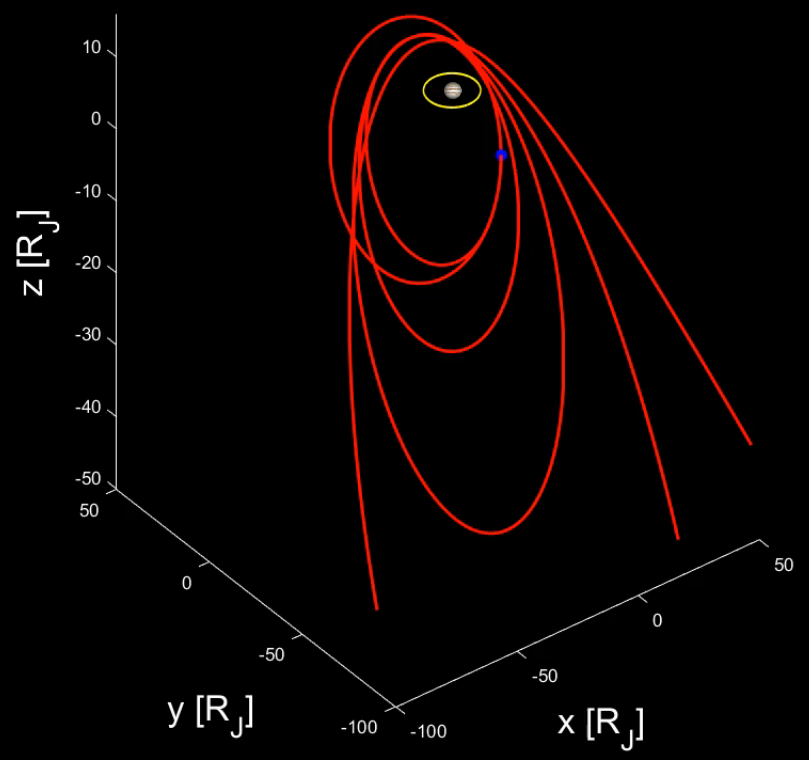


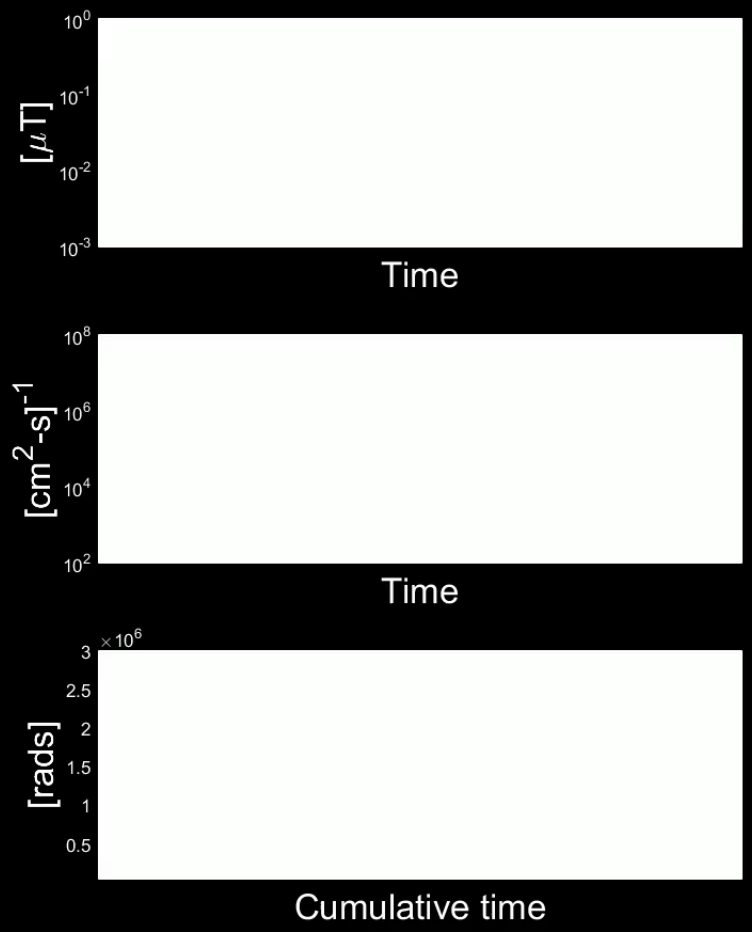
Europa Mission Radiation Environment

Jet Propulsion Laboratory
California Institute of Technology

Environment along the Europa orbit (13-F7)

2029FEB25



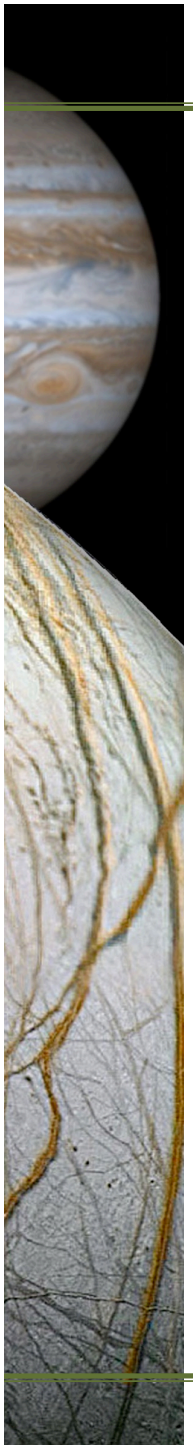


Magnetic field at spacecraft

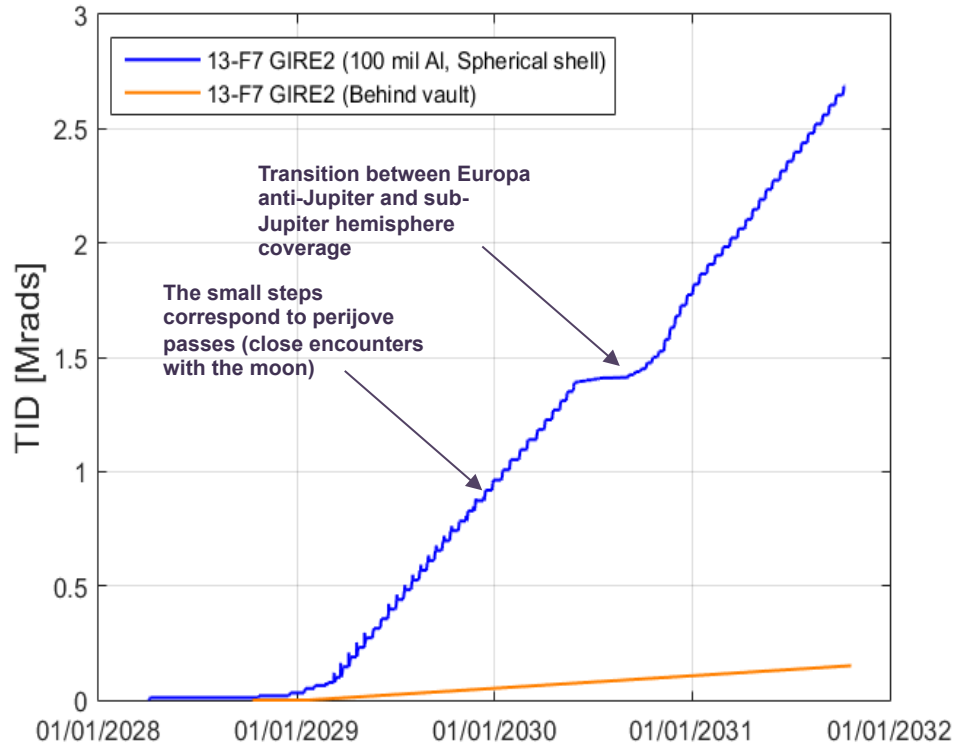
>1 MeV electron flux

Total dose

Europa Mission Radiation Environment – TID

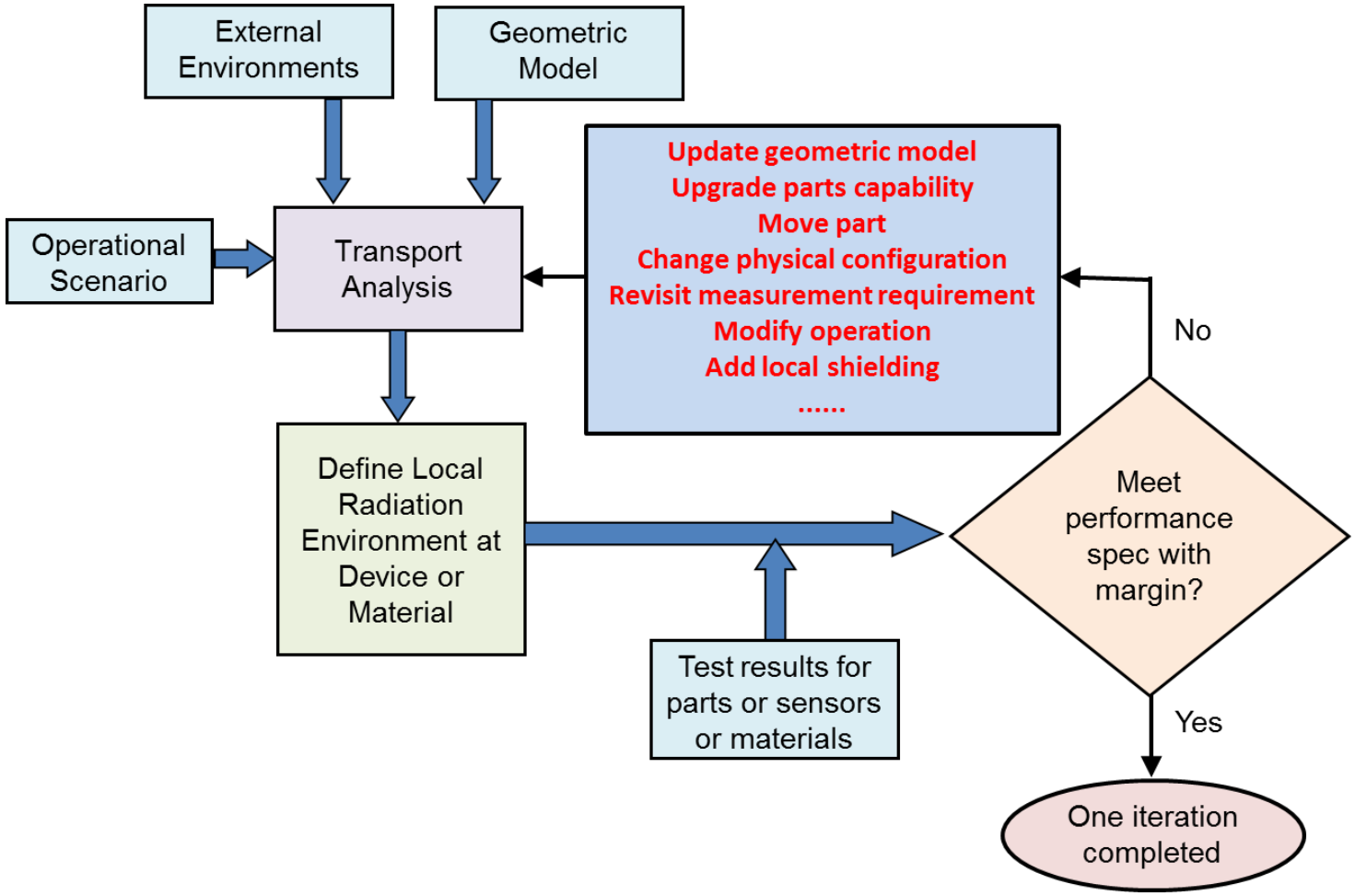


- The **total ionizing dose (TID)** is a measure of the energy deposited by energetic electrons and protons in materials
- TID depends on the outside environment, shielding material, and target material
- The moon encounters are the times with the highest dose rate
- The spacecraft holds a heavily shielded 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 cap (behind 100 mil of Al)



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

General Radiation Hardening Process Flow for Spacecraft



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

Europa Radiation Effects Evaluations

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

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

Volatile Memory Radiation Test Status

Type	MFR	Part Number	Size (Gb)	Width	TID (krad[Si])	SEL	SEE (σ[cm2/bit])	SEFI (σ[cm2/device])	Notes
DDR3	Micron	MT41J128M8JP-15E IT:G	1	x8	200 (300 w/stuck bits)	>75 LET	TBD	TBD	All tests complete
DDR3	Samsung	K4B1G0446G-BCH9000	1	x4	250 (300 w/stuck bits)	>75 LET	TBD	TBD	All tests complete
DDR2	I'M	IMX5108D2DEBG	TBD	x8	TBD	TBD	TBD	TBD	
DDR2	3DPlus ISSI	IS43DR81280	1	x8	(3DPlus: >200)	>75 LET	~1e-12	~1e-5	(have samples) HDR is next on list; SBU threshold ~LET 10, SEFI at LET 3 (~3e-7cm2).
SDRAM	ISSI	IS42S86400B-7TLI	0.5	x8	80 (100 w/stuck bits)	>75 LET (M2020)	<4e-10	<4e-5	130k is not tested with device refresh enabled.
SDRAM	3DPlus Elpida	EDS5104ABTA	0.5	x4	50	>75 LET (Juno)	<2e-9	<6e-4	Not a Candidate
SDRAM	Aeroflex	UT8SDMQ64M48	3	x48	100	>111 LET	TBD	TBD	SEE/SEFI given in GEO only; expect same TID problems as above
SDRAM	3DPlus ISSI	IS42S86400B-7TLI	0.5	x8	80 (~20 stucks) / 100 (~300 stucks)	>75 LET (M2020)	<4e-10	<4e-5	3D Plus - LDC tracking,and upscreening provided

Pre-Decisional Information — For Planning and Discussion Purposes Only

Volatile Memory Radiation Plans

- **DDR2 HDR TID**
  - 200 krad (no stuck bits)
  - May need LDR to reach 300 krad with no stucks
- **Planned Tests/Priority**
  - SDRAM: 3D ISSI
    - LDR – to determine if performance can be extended
    - SEE
  - DDR2: 3D ISSI
    - HDR; LDR (if necessary);
    - Proton test is not considered necessary – cross sections very low at LET 3 MeV-cm2/mg)
  - Intelligent Memory DDR2 is lower priority but will do as equipment/cell available
  - DDR3 effort ended – not presently considered for design

Non-Volatile Memory Status

- A single device was found suitable for the mission - Samsung 8Gb SLC Version M NAND flash for EC mission
- Selected and procured from 3D-Plus – Single wafer lot of 1800
- Complete part number is K9F8G08U0M
- 100 units of this lot received from 3DPlus

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

Non-Volatile Memory Radiation Test Status

Device	TID/DD (krad)	Comments
Micron 4Gb	100krad	Not recommended for Europa 3/8 DUT non-functional after 100krad
Micron 32Gb	3/5 DUTs fail to erase 55-100krad	Not recommended for Europa
Micron 32Gb eNAND	Pass at 10krad, nonfunctional at 50krad	Not recommended for Europa
Samsung 8Gb Rev A	1% BER at 40krad	Erase still possible after 600krad Not an ECM candidate due to SEE
Samsung 8Gb Rev M	5e-5 BER @ 50krad, 10% BER at 200krad, write-able	3D Plus contract in place. Test to 300 krad with Erase/Rewrite Primary NVM for ECM
Samsung 8Gb Rev D	7e-3 BER at 300krad	Hold for 3D Plus negotiation. Test with Rev M parts
Samsung 8Gb Rev E	17% bit fails at 100krad	Not recommended for Europa Unrecoverable page errors at 100krad
Samsung V-NAND 128 Gb	~200 krads no errors	Closed, parts not procurable

Optocoupler Displacement Damage Tests

Device	TID/DD (krad)	Comments
Isolink OLH249	Complete <5E11	CTR<20%, Not ECM Candidate
Isocom IS49	Complete >2E12	CTR ~60% Candidate for Europa
Isocom CSM141A	Complete >2E12	CTR ~70% Candidate for Europa
Isolink OLS049	Complete <5E11	CTR<20%, Not ECM Candidate
Avago HCPL-5700	Complete >2E12	CTR ~80% Candidate for Europa
Micropac 66179	Complete <2E12 report in work	CTR<40%
Micropac 66296	Complete <2E12	CTR~60%
Micropac 66294	Complete >2E12	CTR ~75% Candidate for Europa

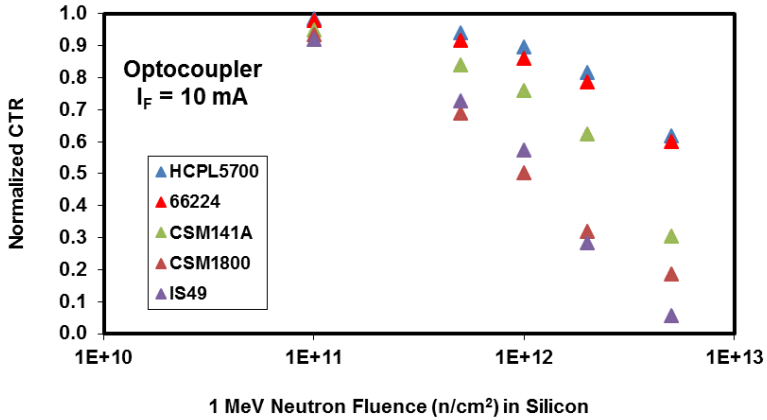
Several Devices found acceptable to Europa Displacement Damage Levels

Pre-Decisional Information — For Planning and Discussion Purposes Only

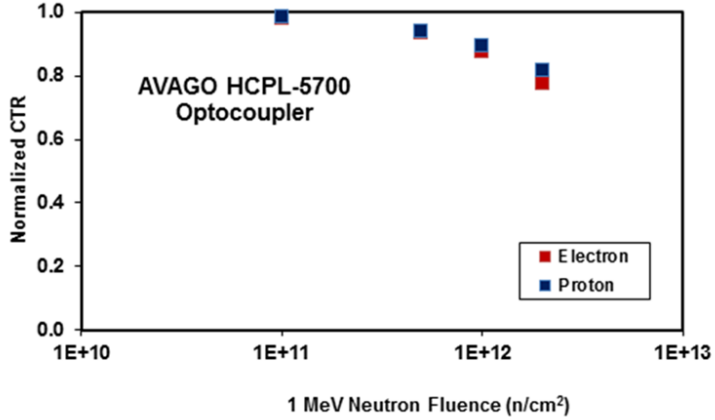
Significant Results

- Several devices found to be usable for Europa (with worst case degradation accounted for)
- Electron DD measurements were performed at BNL ATF facility on HCPL-5700 and Isolink OLS049 show no significant difference in comparison with Proton degradation

Proton Tests



Electron- Proton Comparison



Power System Radiation Test Status

Part#	Supplier	Function	TID Results	SEE Results	Comments
LT8705	**Linear Technology**	Buck/Boost Power Converter: 80V VIN and VOUT Synchronous 4-Switch Buck-Boost DC/DC Controller	Not planned	Destuctive SEE at 87 MeV.cm2/mg	No RH version at LTC - Part not approved as is
LT8710	**Linear Technology**	Buck/Boost Power Converter: 80V VIN and VOUT Synchronous 4-Switch Buck-Boost DC/DC Controller	Not planned	Destuctive SEE at 87 MeV.cm2/mg	No RH version at LTC - Part not approved as is
LT3752	**Linear Technology**	Buck/Boost Power Converter: 80V VIN and VOUT Synchronous 4-Switch Buck-Boost DC/DC Controller	Not planned	No SEE at 87 MeV.cm2/mg	No RH version at LTC - Part not approved as is
MSK5063RH	**MSK**	Buck Regulator: Rad Hard High Voltage Synchronous Switching Regulator (w/FET)	Functional at 300 krad(Si) @ 0.100 rad(Si)/s	Destuctive SEE at Vin > 40 V	Moved to candidate list
MSK5055RH	**MSK**	Buck Regulator: Rad-Hard Regulator Controller, Switching, High Voltage, Synchronous	Functional at 300 krad(Si) @ 0.100 rad(Si)/s	In planning	Report in review - Moved to candidate list
MSK196RH	**MSK**	Rad Hard Current Sense Amplifier	In planning	Not planned	Alternate parts being reviewed
MSK6000RH	**MSK**	Current limiting switch: Dual Rad Hard High Side Driver with Current Sense	Functional at 300 krad(Si) @ 0.010 rad(Si)/s	Not planned	Moved to candidate list
MSK5800RH	**MSK**	Linear Regulator w/ adjustable output	In planning	Not planned	Alternate parts being reviewed
DAC121S101QM	**Texas Instruments**	12-bit Digital-to-Analog Converter	Scheduled to start Feb 2016	Pending data review	
LTC2977	**LTC**	PMBus Controller	Non functional at 20 krad(Si)	SEL at 4 MeV.cm2/mg	No RH version at LTC - Part not approved as is
LM25066	**NSC**	System Power Management and Protection IC With PMBus	Not planned	SEL at 4 MeV.cm2/mg	No RH version at NSC - Part not approved as is
LTC3891	**Linear Technology**	step-down switching regulator DC/DC controller	Not planned	SEL at 15 MeV.cm2/mg	No RH version at LTC - Part not approved as is

Pre-Decisional Information — For Planning and Discussion Purposes Only

Power Device Plans

- TID testing of MSK196RH, MSK5800RH, DAC121S101QM
- MSK5055 (SEE)
- Looking for RHA alternates for some parts
  - Vetting some power device from International Rectifier

Pre-Decisional Information — For Planning and Discussion Purposes Only

Avionics Device Testing

Part	Manufacturer	TID (Krad)	Comments
Isolator IL611	NVE	300	Candidate
Isolator IL715T	NVE	300	Candidate
ADC AD9283S	Analog Devices		
Isolator Si8642EA	Silicon Lab		
Isolator Si8600AB	Silicon Lab		
SRAM UT8ER512K32	Aeroflex	300	Candidate – tested at low dose rate
SRAM UT8R4M39	Aeroflex	300	Candidate – tested at low dose rate

Pre-Decisional Information — For Planning and Discussion Purposes Only

Significant Results

- Isolators NVE IL611 & IL715T are latchup immune and showed very little degradation up to 300 krad
- Both Aeroflex SRAMs are only guaranteed to 100 Krad
  - When tested at high dose rate both fail with high leakage current
  - When tested at 100 mrad/s both passed tested paramters to 300 krad
  - This was a small sample test without complete parametrics so complete characterization/RLAT is required

FPGA Radiation Test Status

No Changes – Task Complete

Device	SEL (MeVcm2/mg)	SEU/SEFI	TID/DD (krad)	Rel Test	RLAT	Comments
Xilinx V4QV	> 109	Complete*	>300	Needs Kyocera qual/ JPL CGA	TBD	
Xilinx V5	> 79.9	Complete*	>500	FCBGA RoHS	N/A	
Xilinx V5QV	>125	Complete*	>1000	Needs Kyocera qual/ JPL CGA	Not Required	Candidate for Europa
Xilinx 7-series	< 15	Static SEU Complete*	Not Tested	Needs Qual	NA	Not recommended for Europa
Microsemi RTAX 250/1000/ 2000/4000	>117.2	Complete*	200/300	Qualified CGA	TBD	Candidate for Europa Static current increases, rise/file time decreases at 300 Krad
Aeroflex UT6325	>120	Complete*	300	Qualified	Not Required	Candidate for Europa Following packages are qualified: 208 CQFP, 288 CQPF, 484 CLGA and 484 CCGA

V5QV, RTAX, UT6325 found acceptable to 300 krad
However – Commercial devices exceed 300 Krad as well

Conclusions

- Hardening of the electronics for Europa is done by
  - Early evaluation of electronic part
  - Use of approved/tested devices
  - Thorough design mitigation and verification