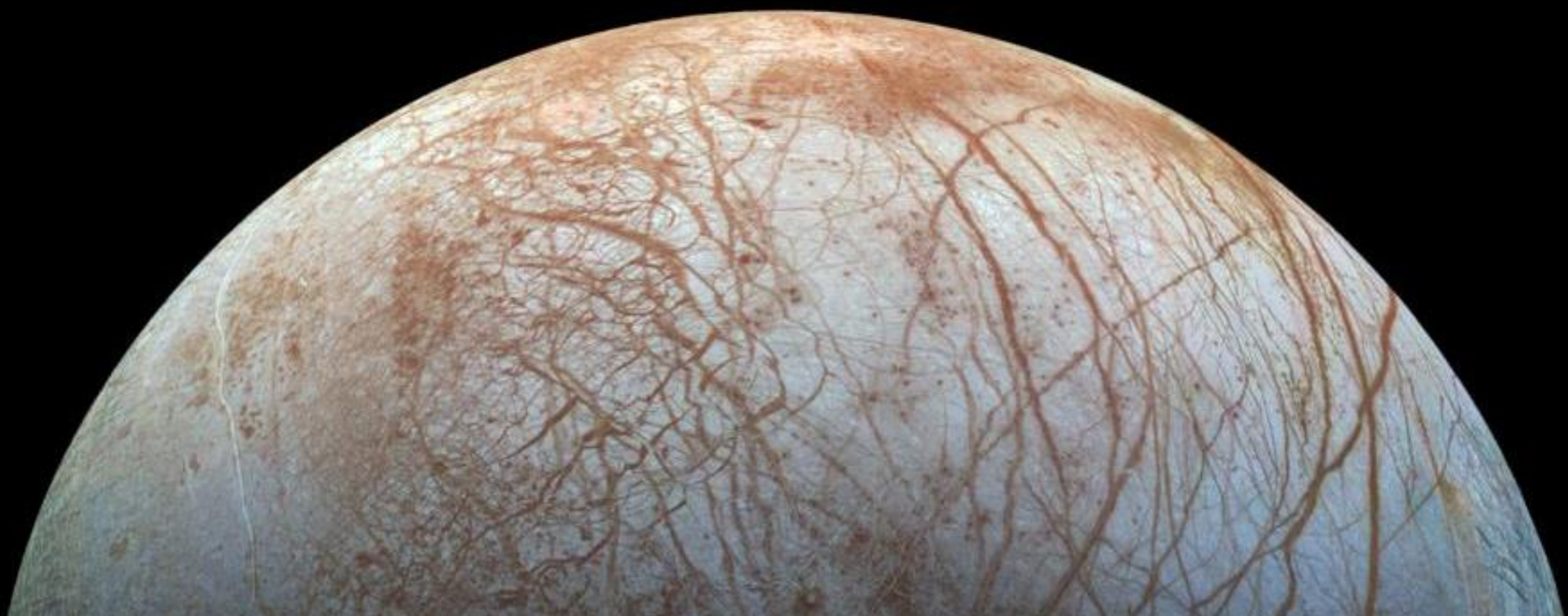
Jet Propulsion Laboratory
California Institute of Technology

Addressing Material Challenges for the Planned Europa Clipper Mission

Presented by Nora Low, Europa Clipper Materials Lead

July 19, 2017



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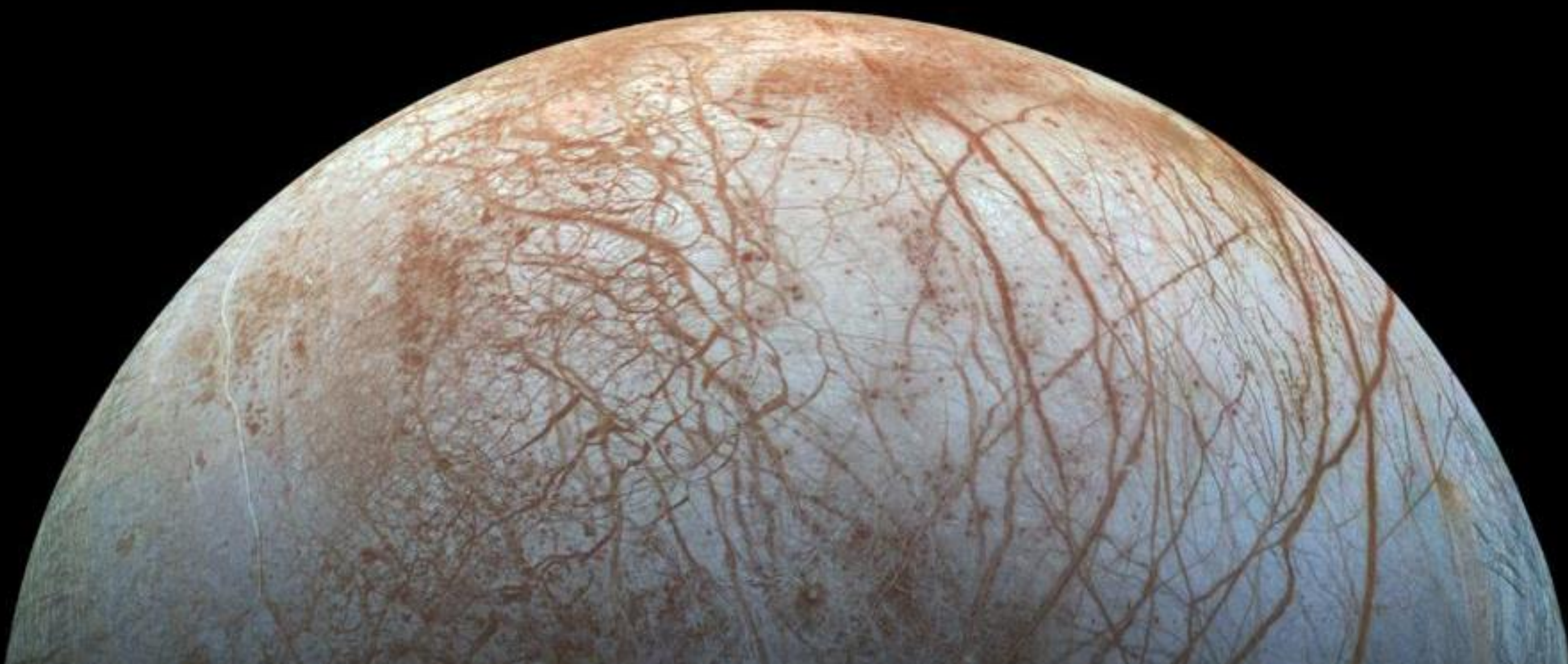
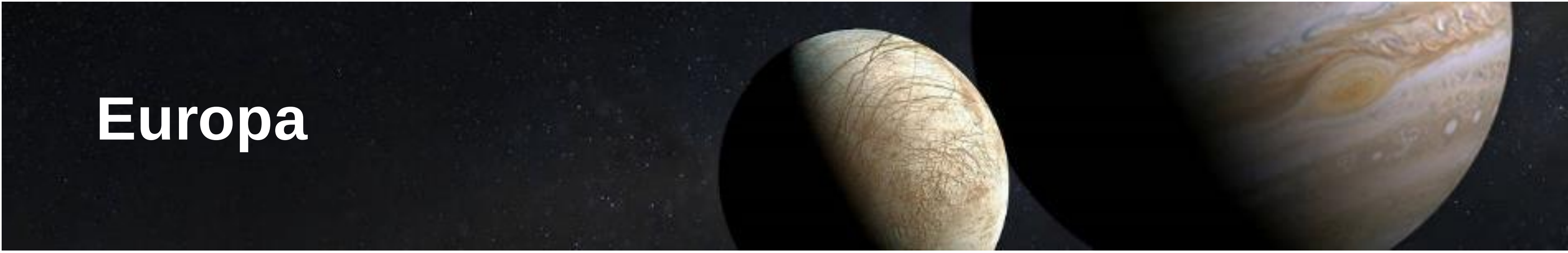
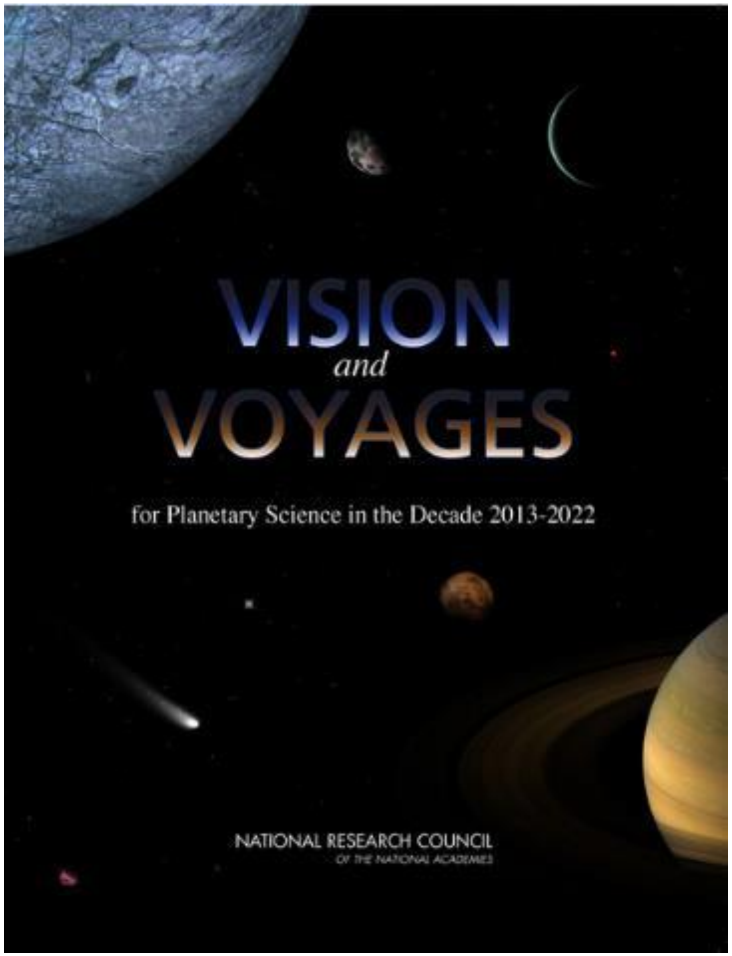


Europa

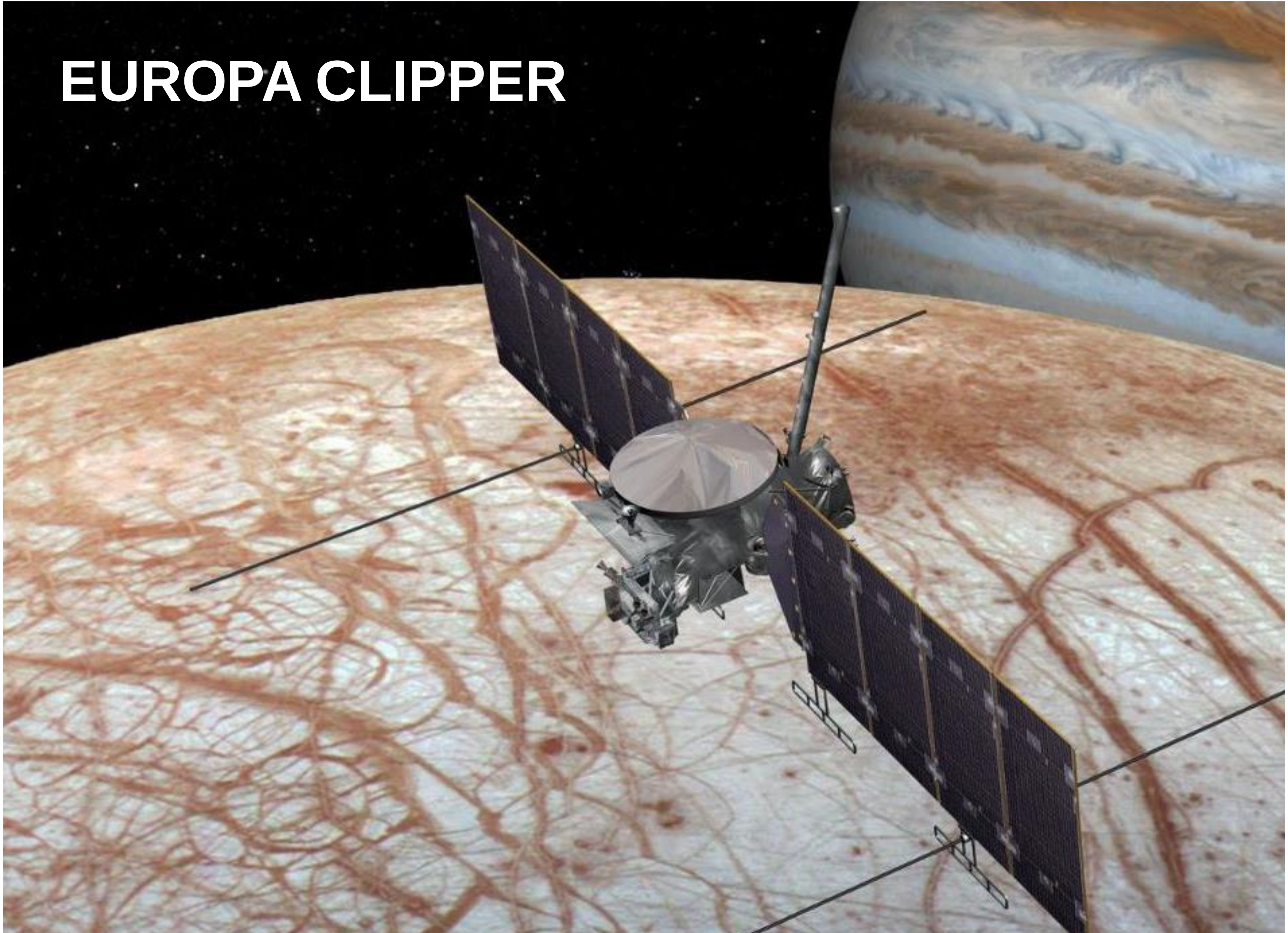


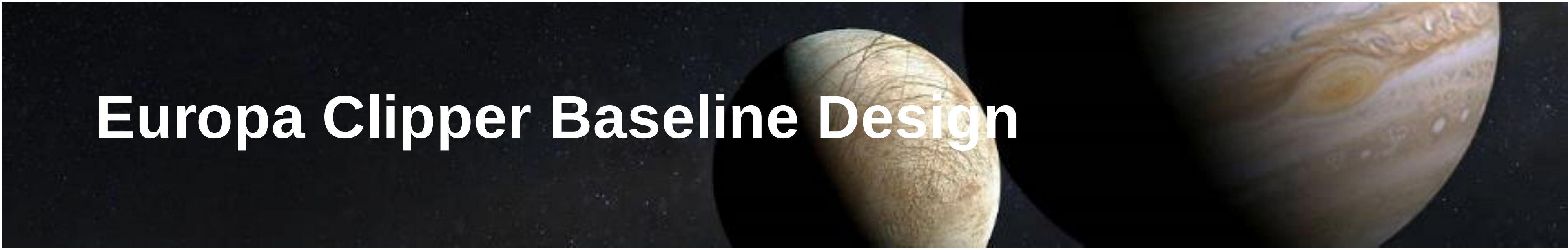


From the 2013-2022 Visions and Voyages for Planetary Science report,

"…Jupiter's icy moon Europa. This moon, with its probable vast subsurface ocean sandwiched between a potentially active silicate interior and a highly dynamic surface ice shell, offers one of the most promising extraterrestrial habitable environments in our solar system…"

EUROPA CLIPPER





Europa Clipper Baseline Design

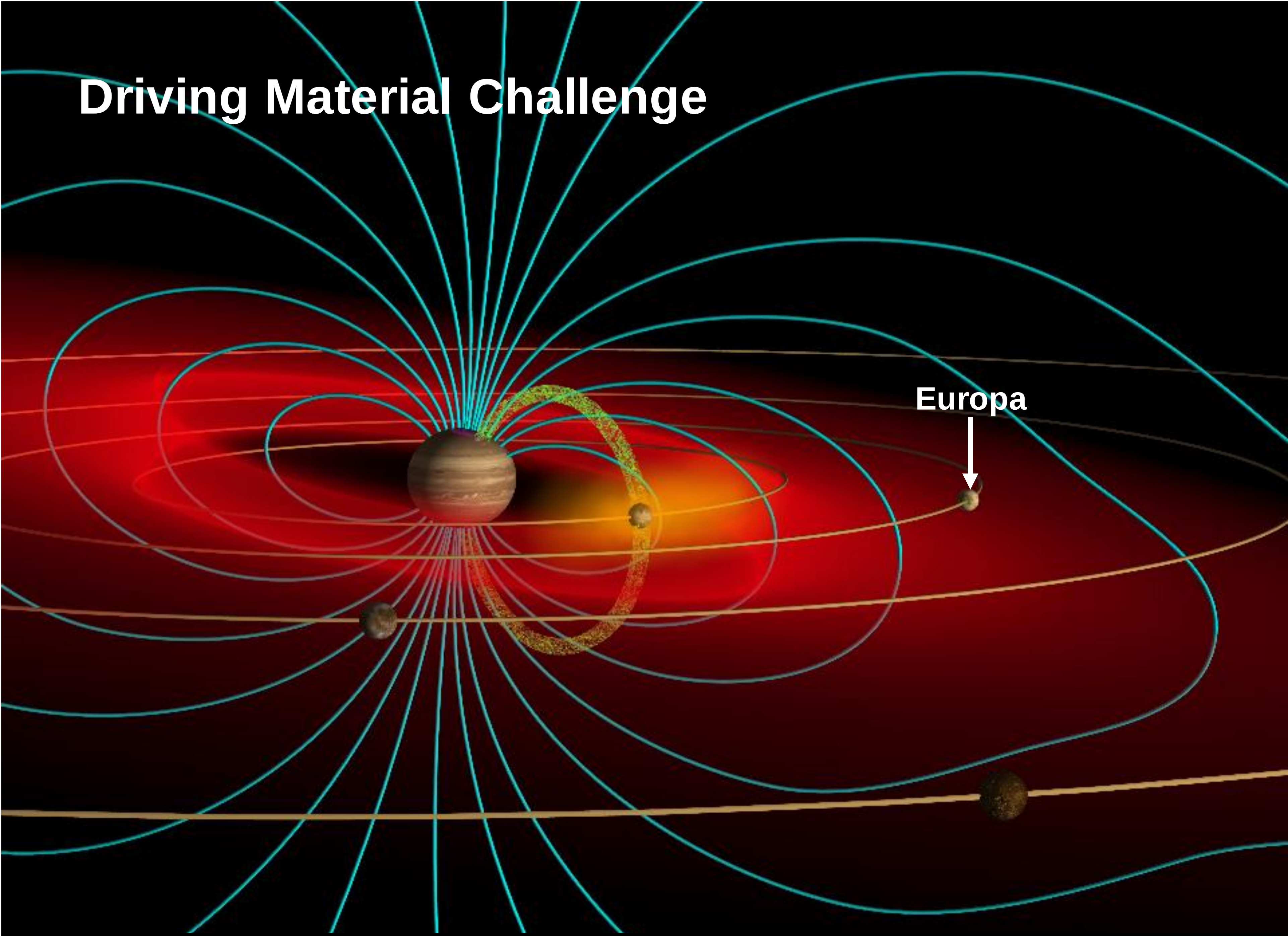
Flyby Mission

- 40-45 Flybys enables nearly global coverage over ~3 years
- 14 day orbit allows for downlink and recharge
- Without Europa Orbit Insertion, propellant saved may be used for radiation shielding
- Minimizes time in the high radiation environment

Science Payload – 9 instruments

- High resolution cameras and spectrometers
- Ice penetrating radar
- Magnetometer
- Thermal Imager

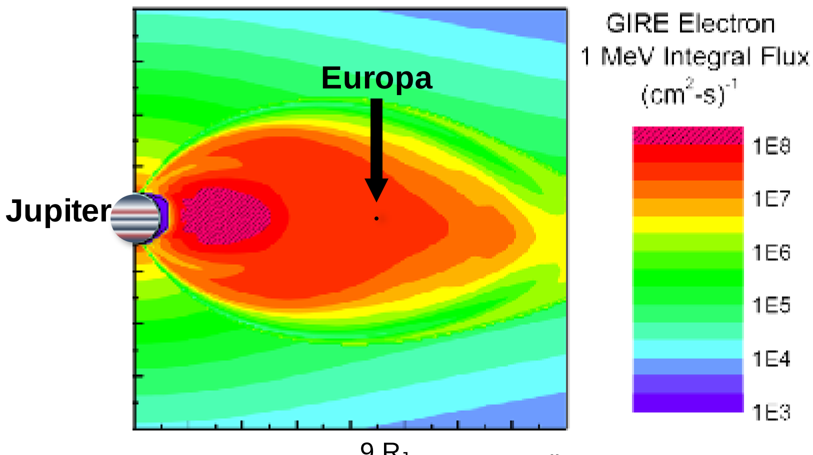
Driving Material Challenge



Driving Material Challenges

Radiation

- While Jupiter is roughly 10 times the size of earth, its magnetic field is 20 times larger than Earth's
- Compared to Earth, the energy and flux levels of trapped particles in the Jovian system can be much higher



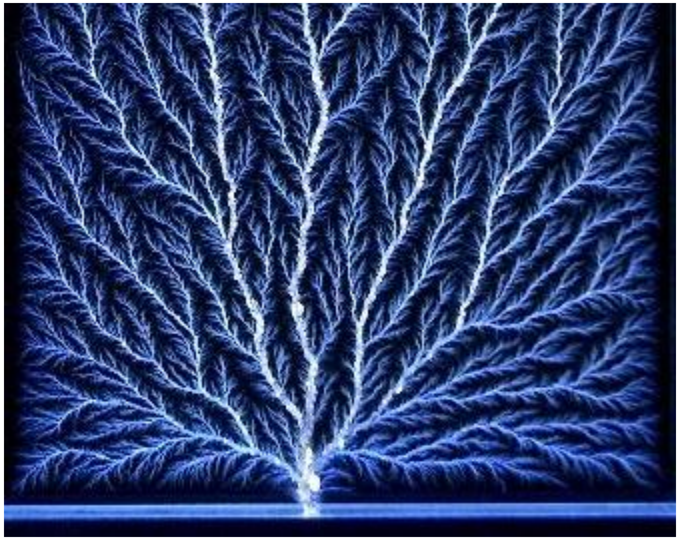
Credit: H. Garrett, JPL

- Spacecraft design to survive and operate in this dangerous environment typically involve shielding of the most sensitive components
- External materials or applications must withstand extreme radiation total dose through the mission life
- Spacecraft charging effects must be understood and risks mitigated

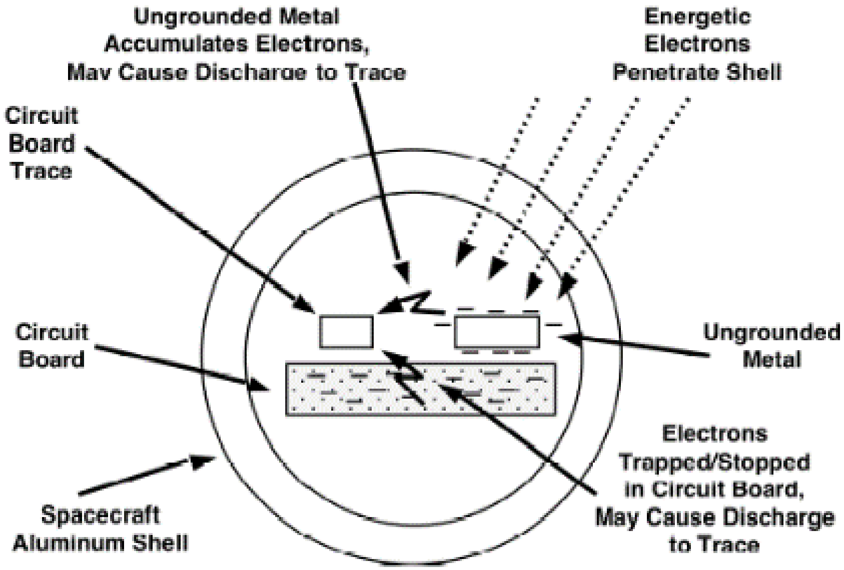
Driving Material Challenges

Radiation

- While the Total Ionizing Dose (TID) will be punishing, the intense charged particle flux may cause Electrostatic Discharge events that can have damaging effects on nearby sensitive electronics
- Internal Electrostatic Discharge (iESD)
  - Results of charged particles embedded in dielectric material



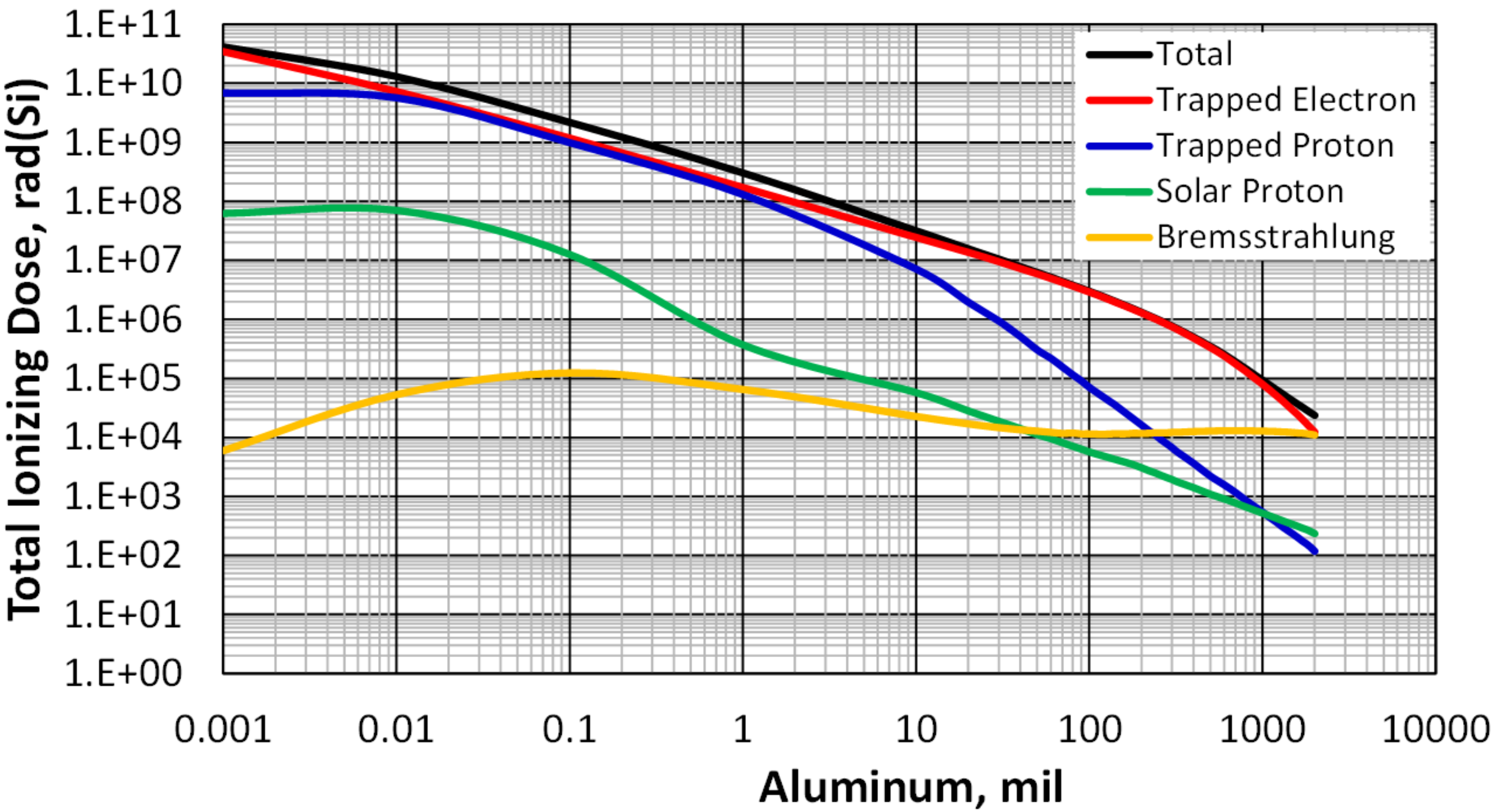
Credit: capturedlightening.com



From NASA-HDBK-4002A
Mitigating in-Space Charging Effects – a Guideline
Hank Garrett and Al Whittlesey

Driving Material Challenges

TID Dose-Depth Curve (for reference):



Driving Material Challenges

Europa Hardware	Temperature, °C	
	min	max
Spacecraft		
Telecom Subsystem	-230	195
GNC Subsystem	-150	150
Power Subsystem	-35	70
Avionics Subsystem	-35	75
Radiation Monitoring Subsystem		
Thermal Subsystem	-105	370
Propulsion Subsystem	-45	55
Mechanical Subsystem	-165	120
Solar Array Assembly	-238	150
Payload		
EIS	-105	70
E-Themis	-35	70
Europa UVS	-15	55
ICEMAG	-135	120
MASPEX	-35	80
MISE	-195	55
PIMS	-110	145
REASON	-270	600
SUDA	-55	70
Temp Extremes	**-270**	**600**

Driving Material Challenges

Planetary Protection Considerations

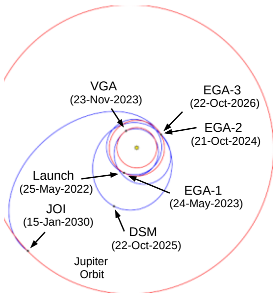
- Inadvertent contamination of a Europa ocean by terrestrial organisms must be avoided, to a probability level of less than 1 in 10,000
- Microbial reduction prior to launch
  - Heat Microbial Reduction (HMR)
  - Alternatives being investigated

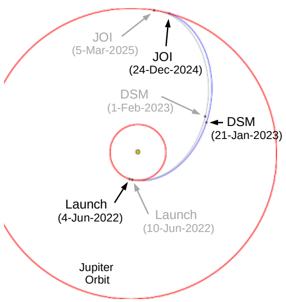
	3-Order Reduction				4-Order Reduction		6-Order Reduction	
	Surface			Encap	Surface	Encap	Surface	Encap
	Dry	Ambient	Uncontrolled					
T (C)	D (hours)							
110	19.42	33.56	97.12	-	140.91	704.56	-	-
116	10.06	15.58	50.30	74.65	116.53	582.64	-	-
125	3.75	4.93	18.75	18.75	88.58	442.88	265.73	1328.63
150	0.28	0.28	1.43	1.43	8.08	40.42	24.25	121.27
200	0.01	0.01	0.05	0.05	0.07	0.34	0.20	1.01

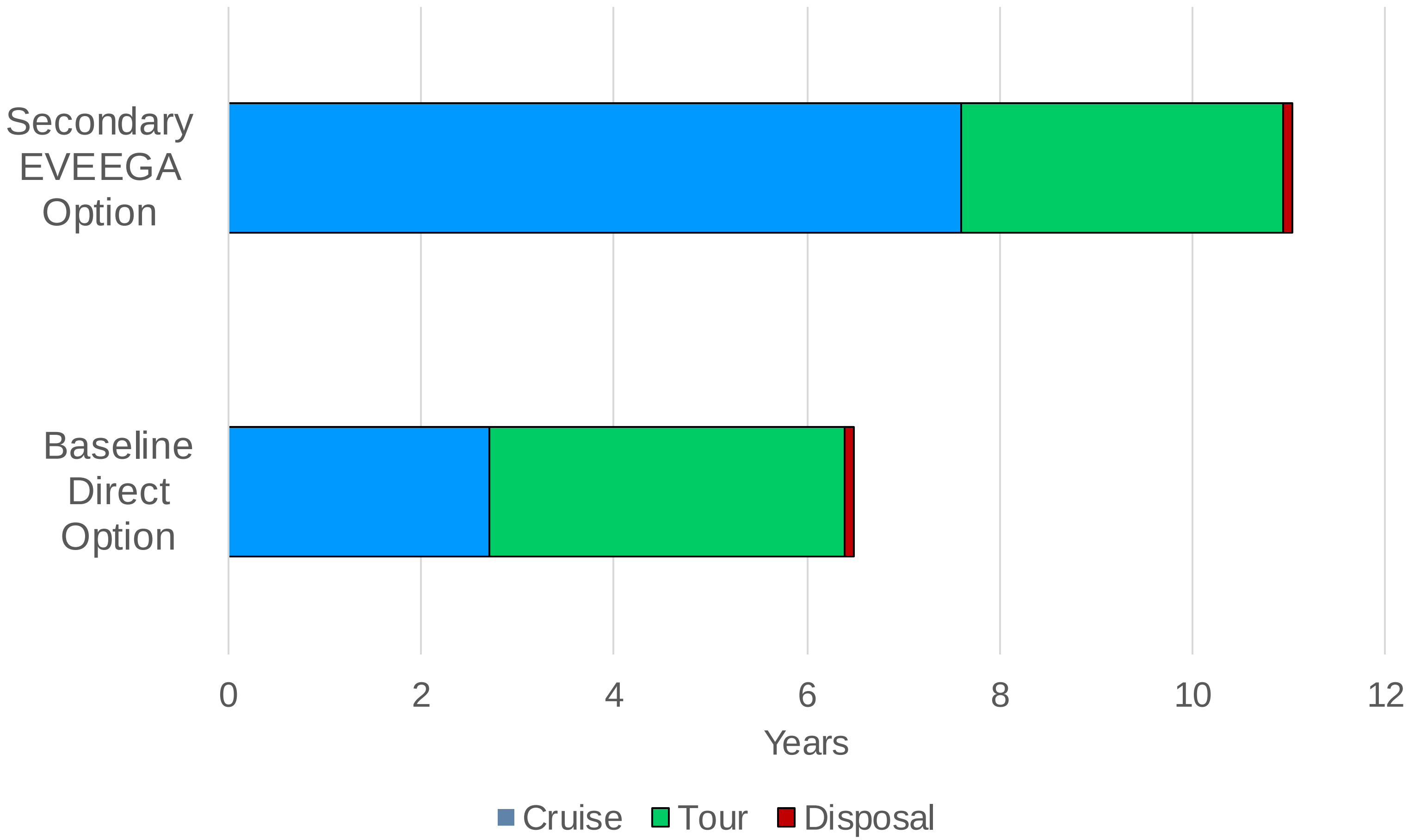
To be incorporated in NPR 8020.12

Driving Material Challenges

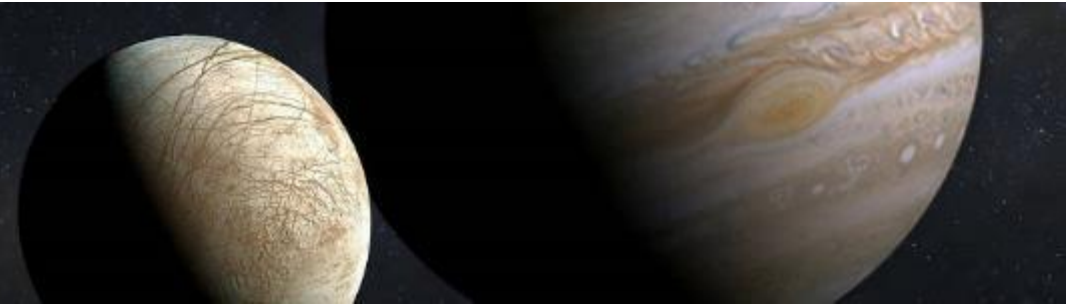
Mission Life Considerations







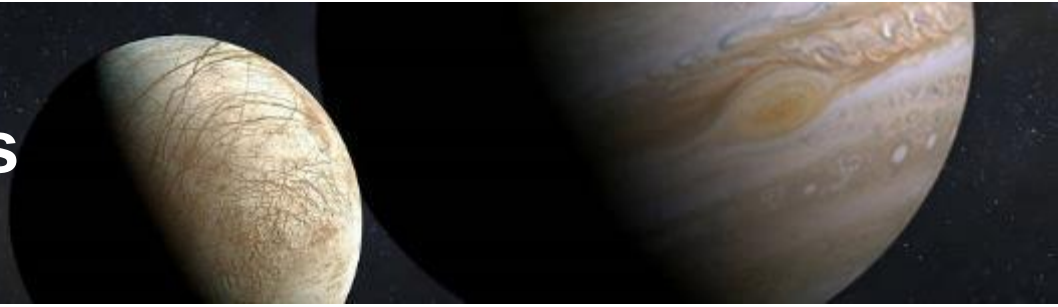
Materials Testing



Europa Materials Test program is underway to address radiation survivability and PP HMR compatibility of common spacecraft material applications including the following:

- Electrical Connectors
- Wire Harness
- Adhesives
- Thermal Control Coatings
- Multilayer Insulation
- Heaters / PRTs
- Composite Overwrap Pressure Vessels

Electrical Connectors



Purpose

- Evaluate candidate connectors for radiation effects (iESD and TID)

Test Approach

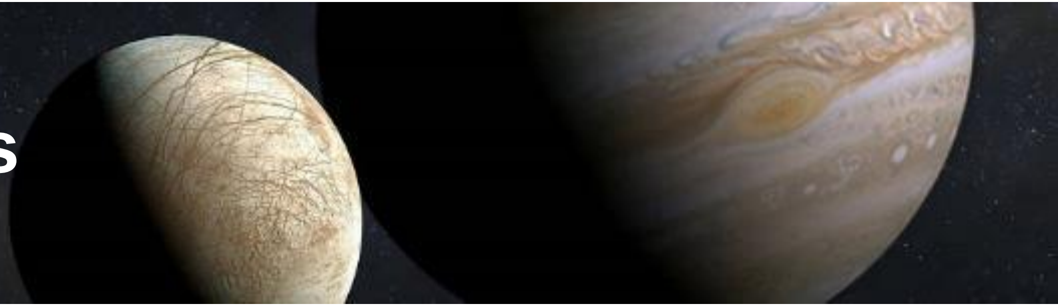
- Connector manufacturers use a variety of materials and construction schemes
- Connector selection strategy
  - Prioritize common connector types and those typically used in external spacecraft applications with minimal shielding
  - Prioritize testing of connectors with applicability across connector families connector types

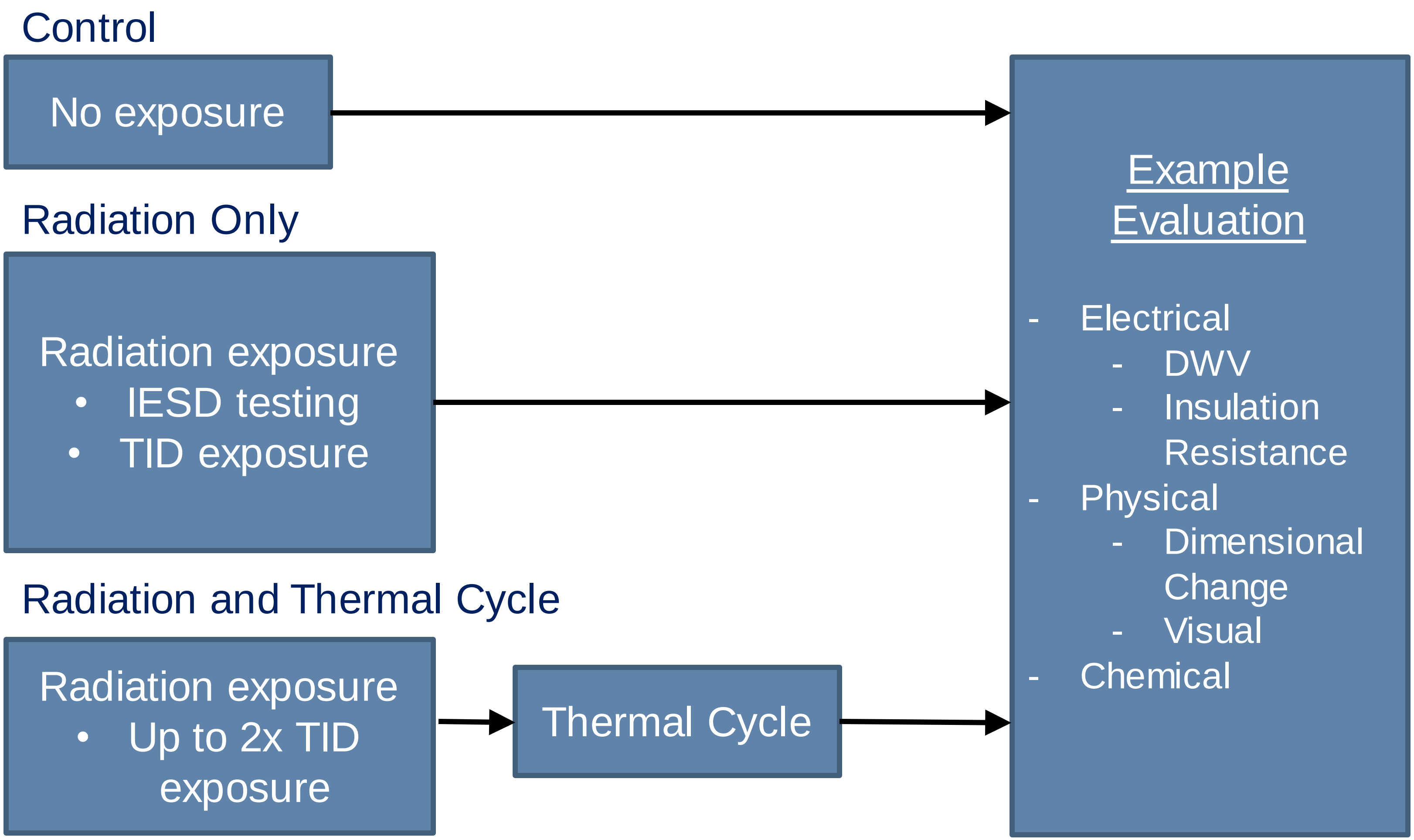
Electrical Connectors

Candidate Selection

Connector Type	Insert matl	Shell matl	Approx Eq Al Shell thickness (min) inches	dielectric thickness (max) inches
Micro-D	PPS	Aluminum	0.025	0.09
Micro-D	LCP	Aluminum	0.03	0.08
Micro Circular	FG Epoxy	Titanium	0.013	0.075
Micro Circular	PEEK	Aluminum	0.022	0.076
Heritage Circular Metal Clip	PAI PPS	Aluminum	0.03	0.09
Heritage Circular Plastic Retention	FG Epoxy	Aluminum	0.03	0.09
Dsub Standard Density	PBT	Brass	0.045	0.02
Dsub High Density	PBT/PPS	Brass	0.045	0.02

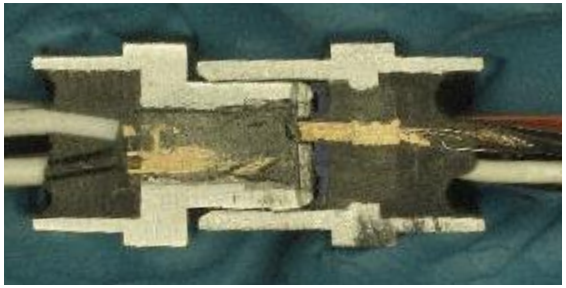
Electrical Connectors

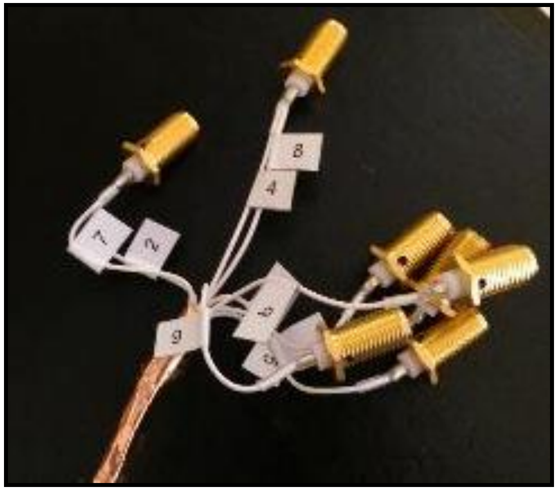




Electrical Connectors

- Micro-D iESD Testing
  - Charge deposition rates were determined for the connector harness under test
  - Beam energy and flux rates were selected to closely match the charging rate
  - Connectors exposed to >4x flux condition relative to Europa iESD design environment
  - Connector pin leads were grouped to monitor for discharges during irradiation

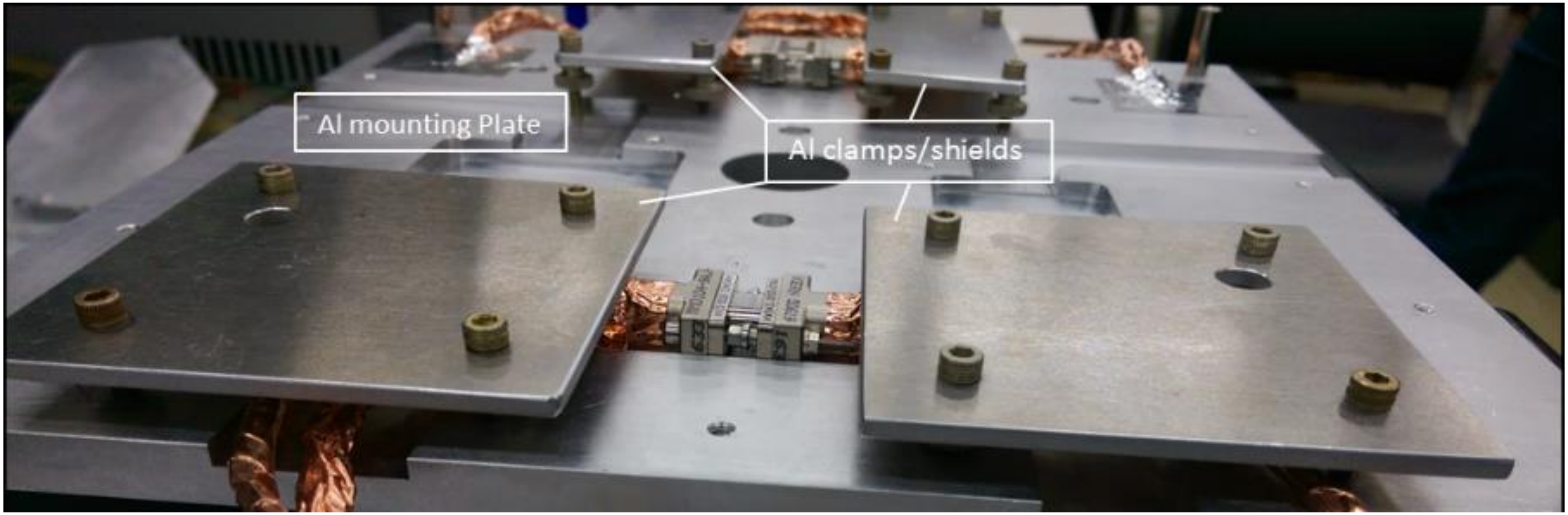




Credit: J. Chinn, JPL

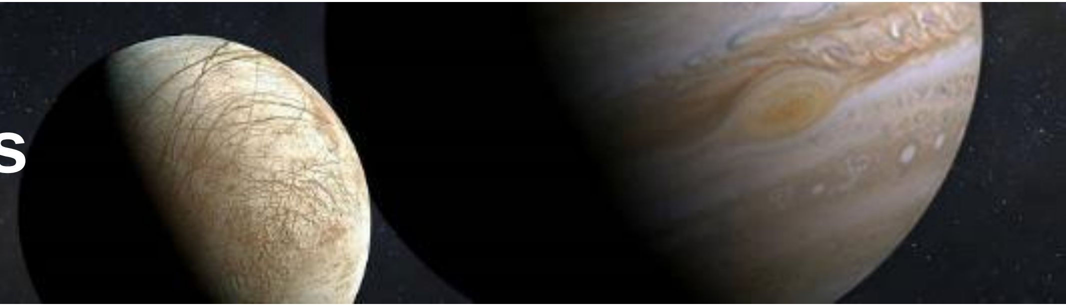
Electrical Connectors

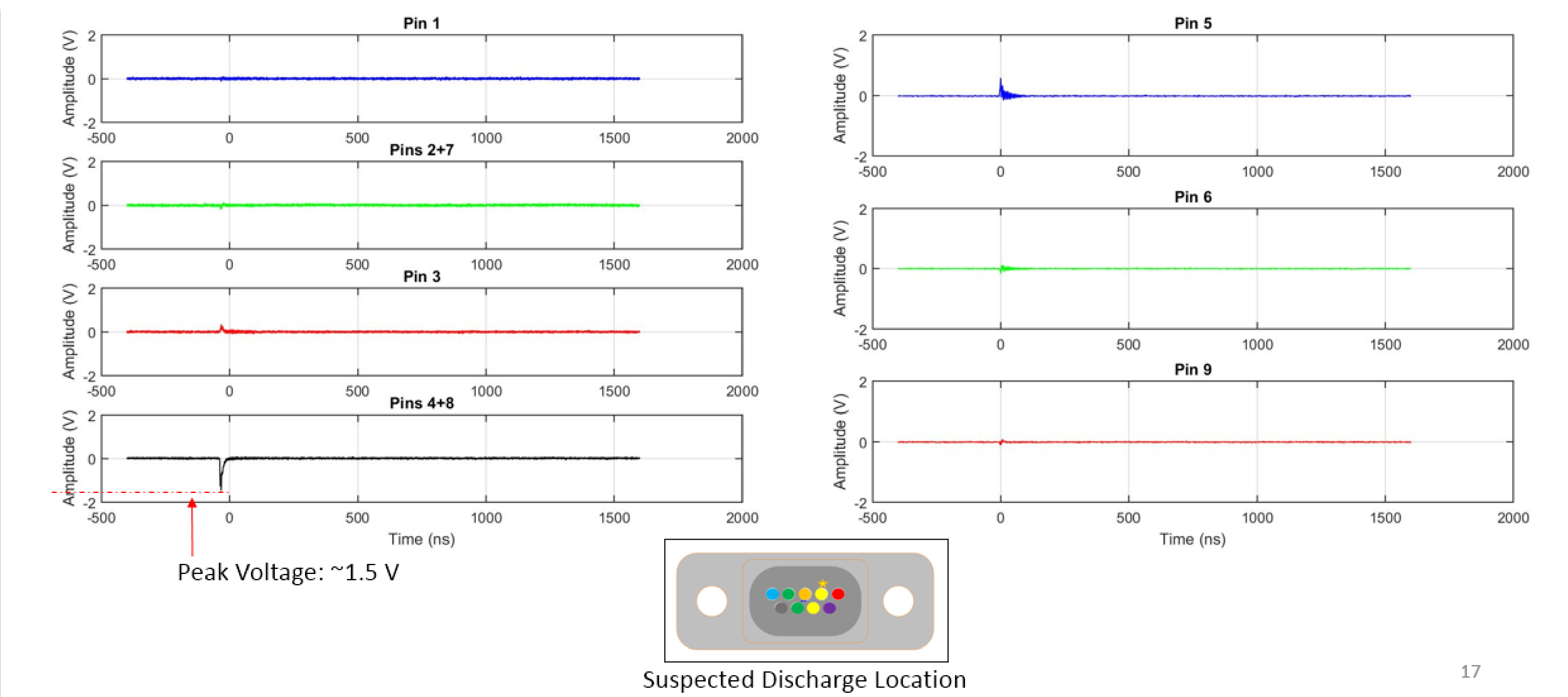
- Micro-D iESD Testing
  - Evaluation includes worst case Connector manufacturer insert arrangement
  - Harness fabrication materials are documented and controlled
    - Potting compound
    - Harness tape
    - Shielding materials



Credit: J. Chinn, JPL

Electrical Connectors

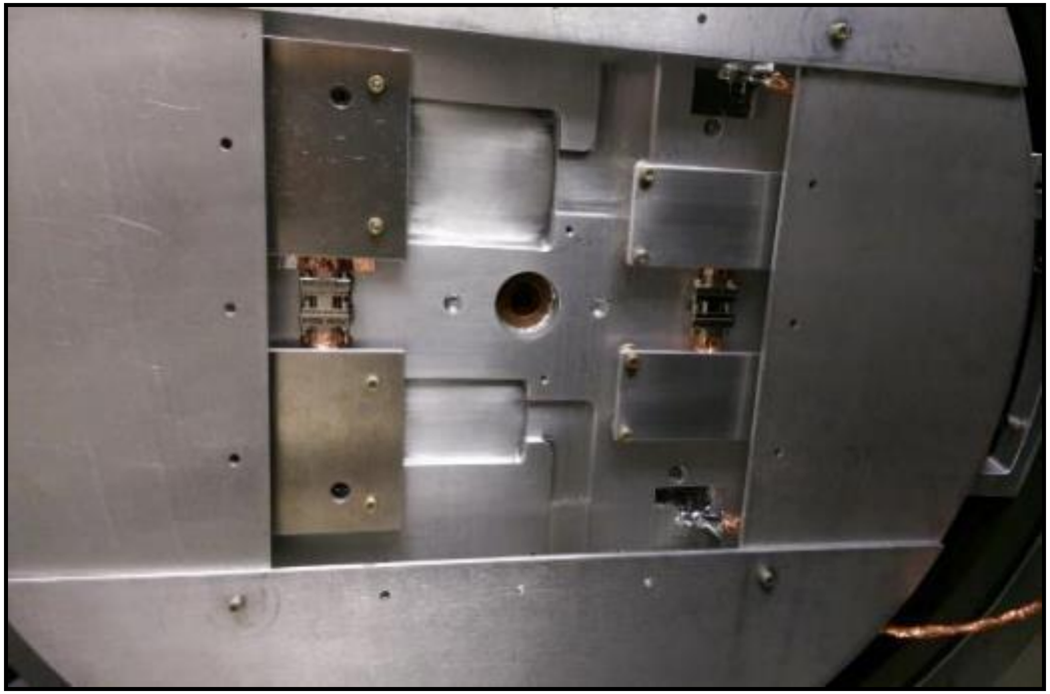




Credit: J. Chinn, JPL

Electrical Connectors

- Micro-D iESD Test Results
  - Testing of Micro-D harnesses determined to safely interface with HBM Class 1A rated electronics
  - Consistent with project circuit design requirements



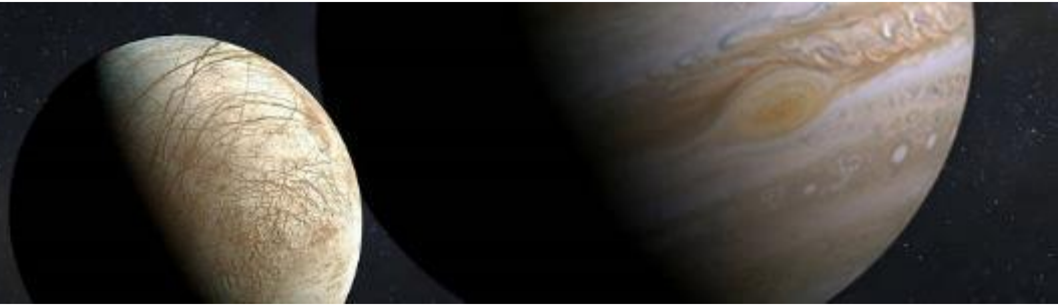
Credit: J. Chinn, JPL

Electrical Connectors

Forward Plans

- Micro-D Connector testing continues
  - TID/Thermal cycle test planning
- Evaluate additional connector types for materials and shielding schemes
  - Follow up with iESD and TID/Thermal cycle exposure as appropriate
- Testing planned for FY2018

Electrical Wire/Cable



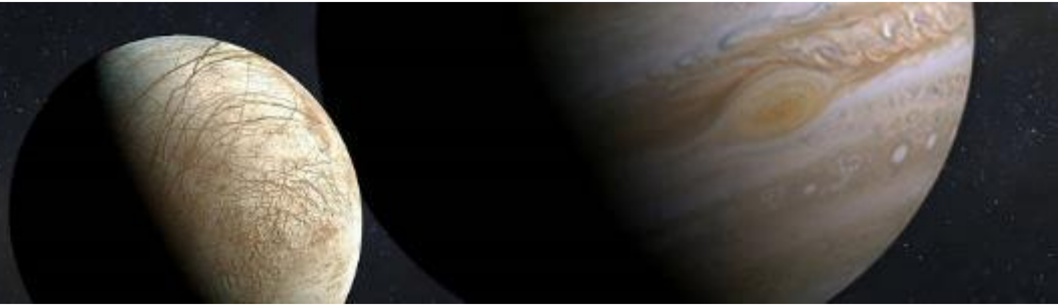
Purpose

- Determine wire/cable conductor minimum shielding for associated electronic circuits transient requirements
- Evaluate TID survivability of common spacecraft wire and cable

Approach

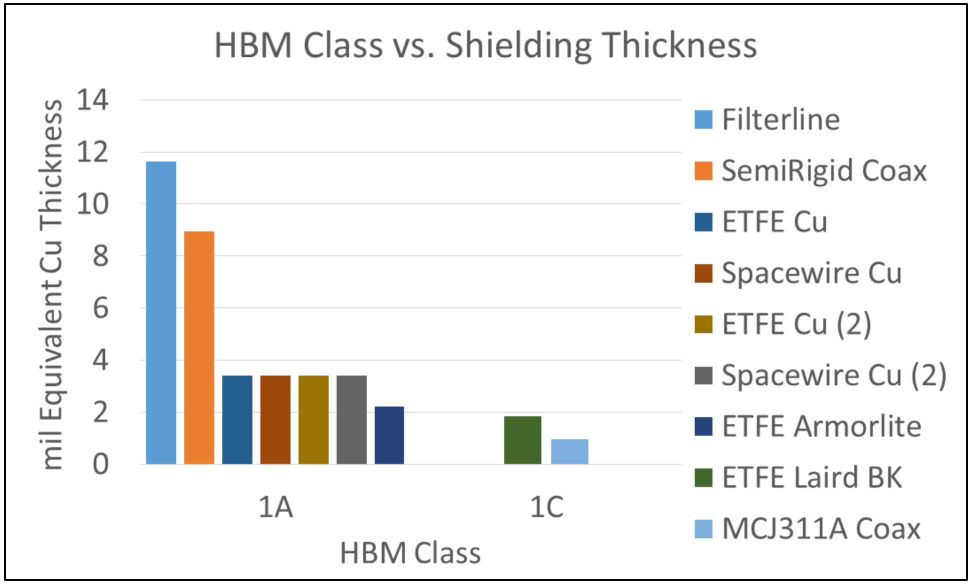
- Part I – iESD evaluation
  - Select representative wire and cable for evaluation
  - Conduct iESD tests with a variety of shielding schemes for evaluation
- Part II – TID evaluation
  - Expose wire and cable to TID levels anticipated in dielectric materials
  - Evaluated key characteristics

Electrical Wire/Cable

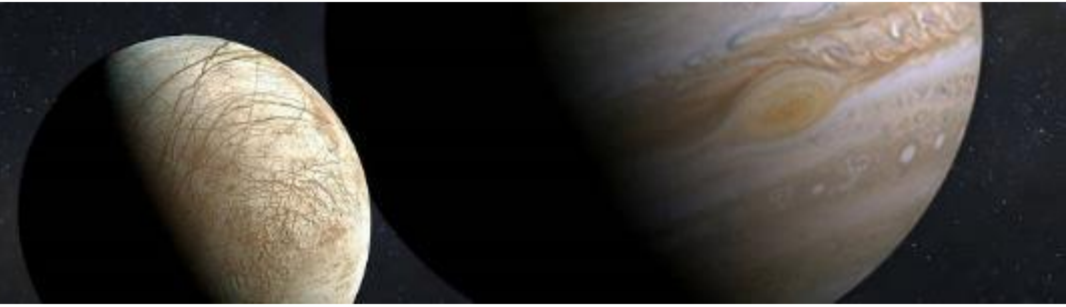


iESD evaluation

- Exposures conducted in 1x and 4x flux conditions
- Preliminary recommendations for shielding have been formulated
- Minimum copper shielding equivalent thicknesses to be implemented for wire and cable used in external (high radiation) applications



Credit: W. Kim, JPL



Electrical Wire/Cable

TID evaluation

- Test planning in progress
  - Radiation exposures of wire and cable designed to expose dielectric materials to project application TID levels and environments
  - Selecting key characteristics for evaluation

Credit: P. Willis, JPL

Potential TID effects:

- External jacket insulation cracking
- Insulation degradation

Adhesives

Purpose

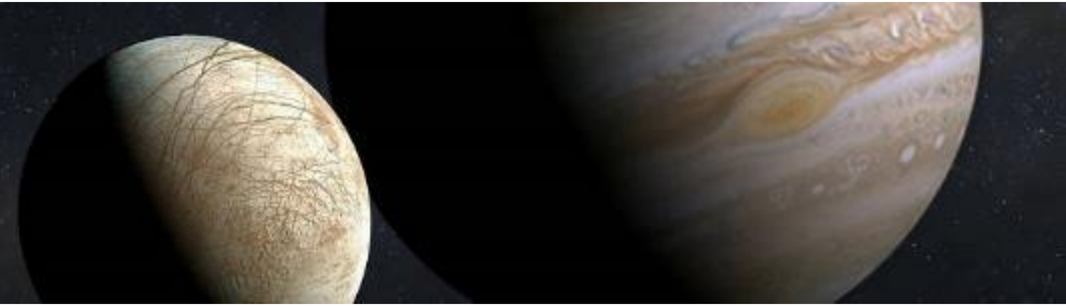
- Evaluate commonly used adhesives on spacecraft applications for radiation TID survivability

*Test Approach**

- Select adhesives from common material classes
- Radiation: Total Ionizing Dose exposures by gamma irradiation
- Thermal Exposures: from thermal analysis of applications
- Evaluation: Two types of evaluation tests conducted to date
  - Lap shear tests of adhesives applied to various adherends
  - Peel tests of adhesives applied to polyimide/aluminum adherends
- Select adhesives were subject to combination of radiation followed by thermal cycle

*Testing being conducted Johns Hopkins University Applied Physics Lab

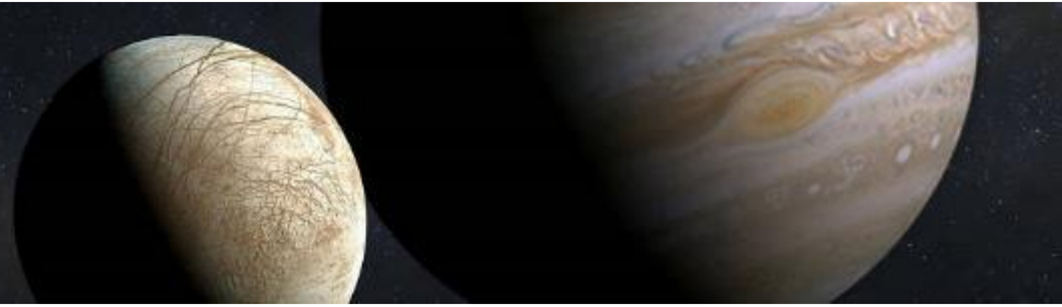
Adhesives



Test conditions

- Adhesive exposures
  - Control (no radiation or thermal cycle exposure)
  - Radiation only
  - Thermal only
  - Radiation and thermal cycle
- Radiation exposures
  - From 40 Mrad to 100 Mrad
- Thermal cycle extremes:
    - Hot Cycles: Ambient to 195 C
    - Cold Cycles: Ambient to -230 C

Adhesives



*Preliminary Results to date**

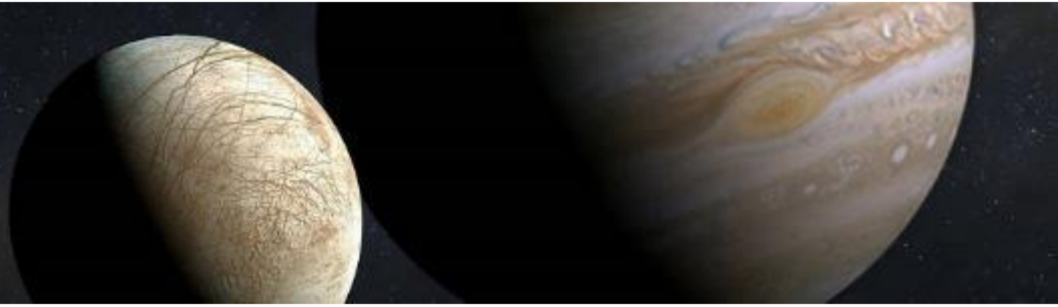
- Epoxy adhesives degrade after exposure to 100 Mrad dose but still demonstrate fair structural capability
- Acrylic and silicone adhesive peel strengths appear to degrade significantly after tens of Mrad exposure

Preliminary Recommendations for acrylic and silicone adhesives:

- Employ additional or alternate means for mechanical attachment
- Additional testing for specific applications may be necessary

*Detailed results presented by Ryan Tillman, Johns Hopkins University Applied Physics Lab

Adhesives



Forward Plans

- Conduct follow-on adhesive radiation testing
- Review developing design specific application information for adhesives from across project
- Prioritize candidates for evaluation
- Anticipated follow-on test to include the following:
  - Commonly used commercial tapes used for spacecraft applications
  - Lower radiation dose
  - Alternate thermal cycle parameters
  - Include effects of PP HMR exposure as appropriate

Thermal Control Coatings

Purpose

- Evaluate Europa radiation environment effects on candidate thermal control coatings

Approach

- Optical Property Effects
- Total Ionizing Dose Radiation and thermal cycling survivability
- Electrostatic Discharge evaluation

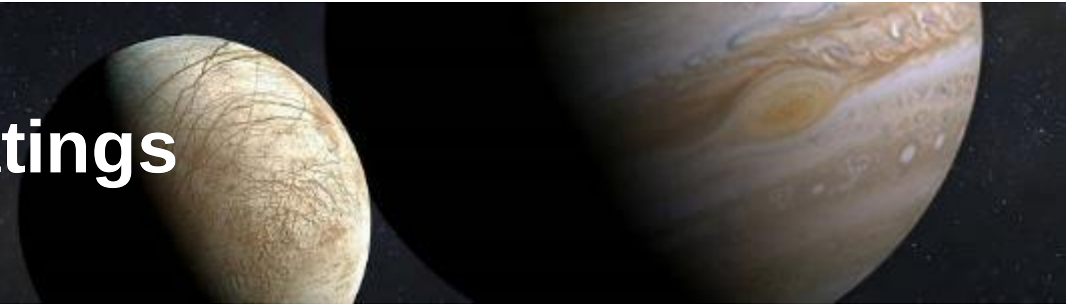
Candidates

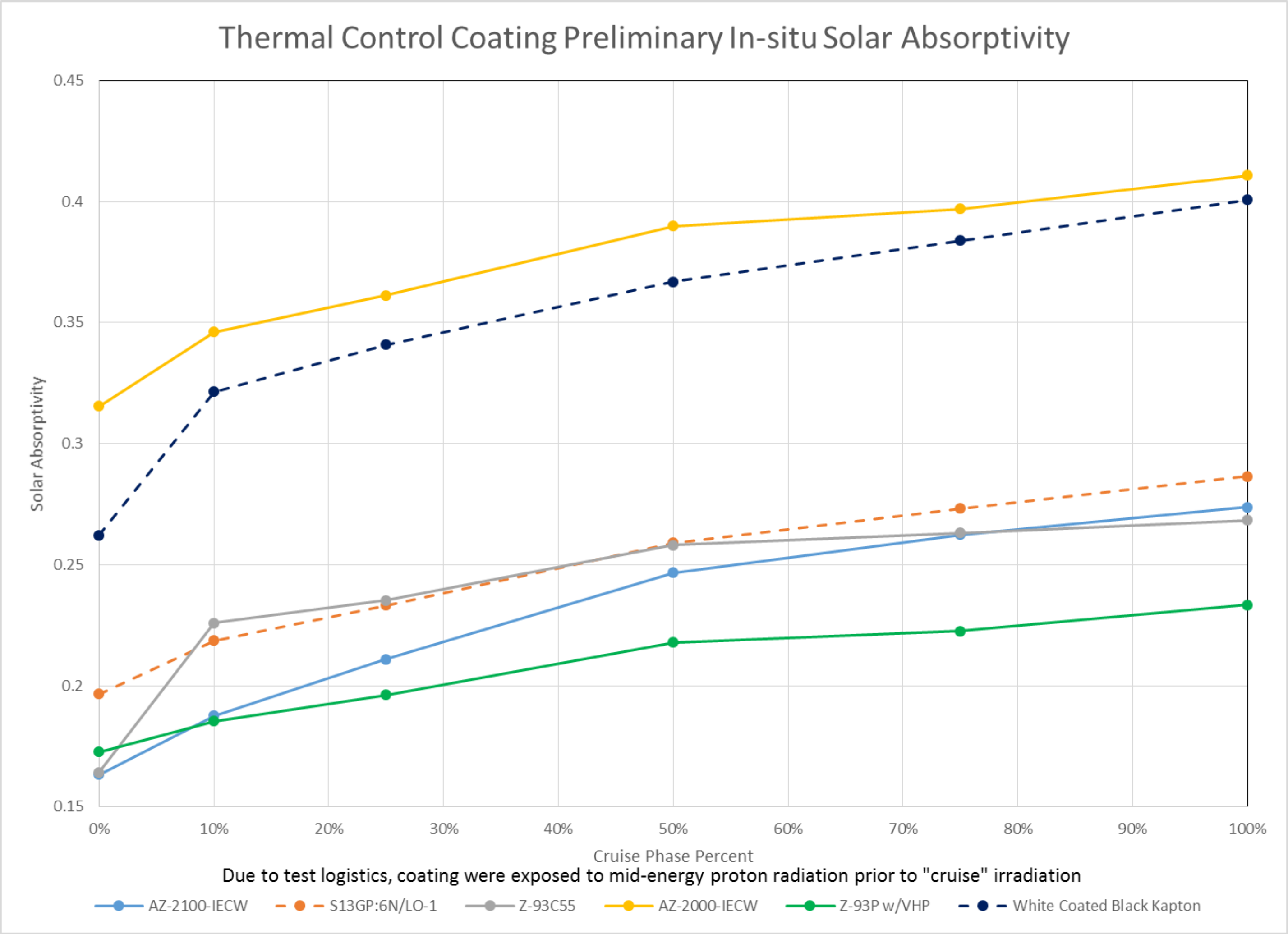
- White organic and inorganic, electrically dissipative, low absorptivity coatings
- Black organic and inorganic, electrically dissipative, high emissivity coatings

Thermal Control Coatings

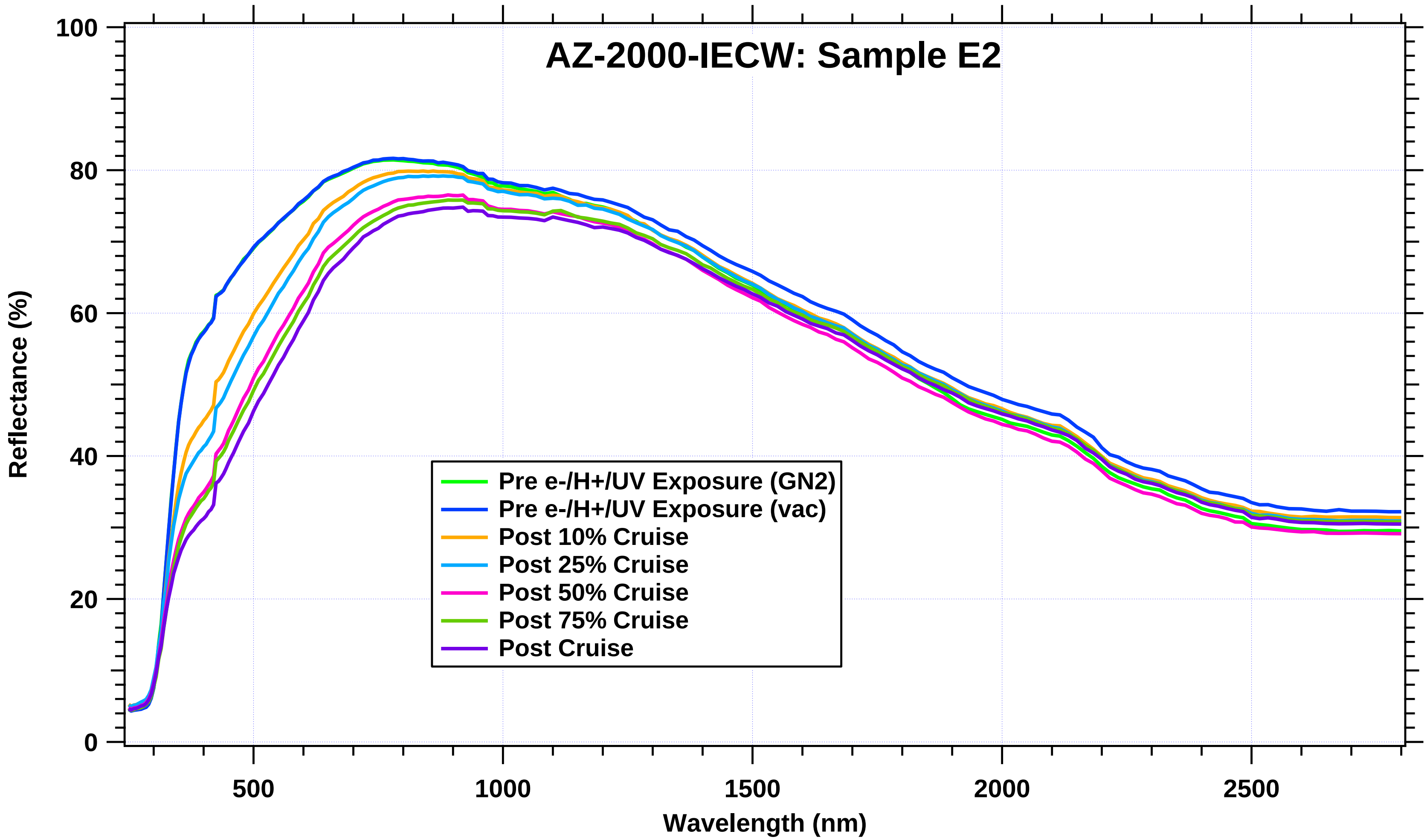
- Optical Property Effects – in progress
  - Subject coatings to simulated 2x mission charged particle dose (electrons, protons) and UV exposure
  - Evaluate optical property effects (including in-chamber vacuum solar reflectance)
- TID Radiation and thermal cycling survivability – planned
  - Subject select coatings to 2x TID radiation and encompass expected thermal cycling
  - Evaluate survivability using standard adhesion tests
- ESD evaluation – in progress
  - Investigate resistivity in operational environment
    - Measurements to cold temperatures and in vacuum
  - Conduct discharge testing

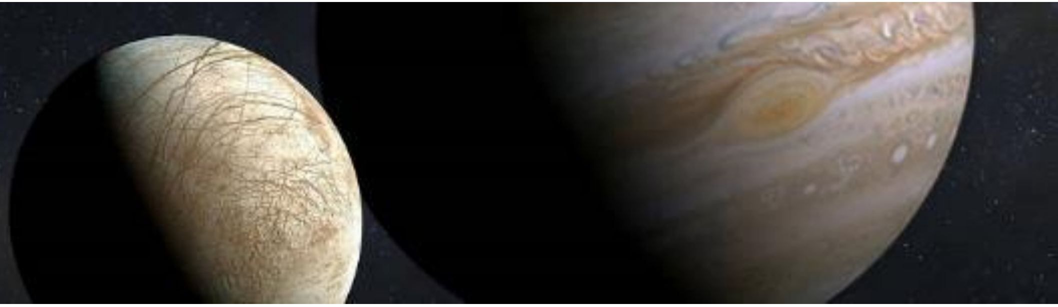
Thermal Control Coatings





Thermal Control Coatings





Composite Overwrap

Application

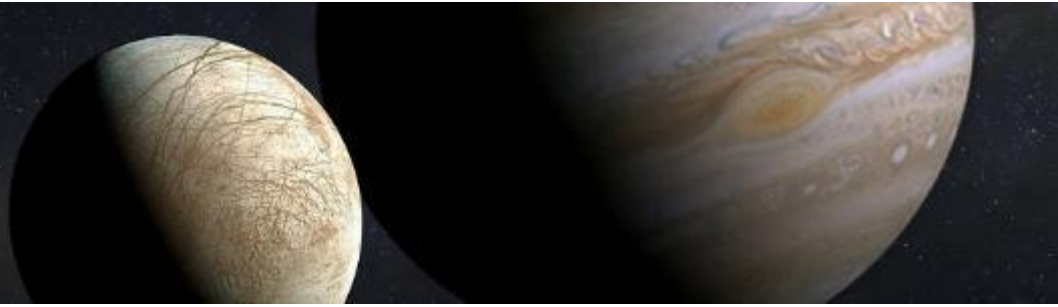
- Baseline Europa Clipper propulsion system is considering the use of Composite Overwrapped Pressure Vessels (COPVs)

Approach

- Subject COPV strands to radiation dose while under sustained load
- Design experiment to allow for statistical evaluation of tensile strength and modulus changes
- Fabrication of COPV strands and mechanical testing consistent with NESC* stress rupture fabrication and test regime

*NASA Engineering and Safety Cetner

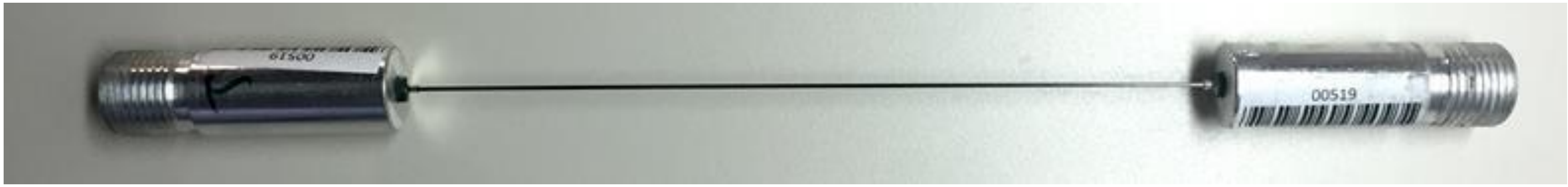
Image:: https://www.nasa.gov/offices/nesc/home/Feature_COPVs_Jan-2012.html



Composite Overwrap

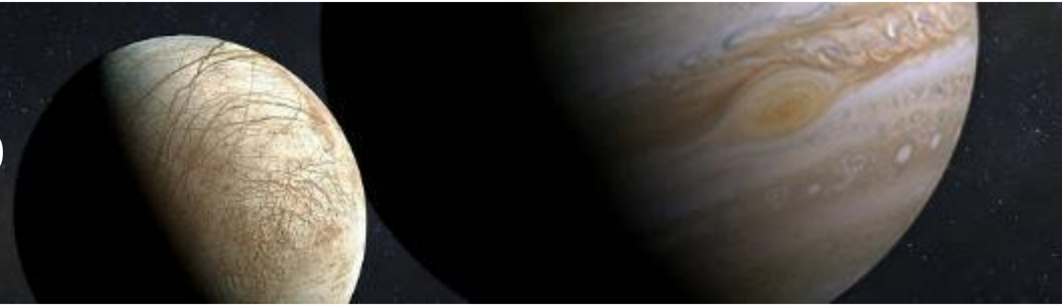
Strand Details:

- Composite material: COPV industry standard T-1000 fiber with epoxy Epon-862 with Hardener W
- Target pre-load of Stands: just under 50% of breaking strength during radiation exposure
- Each strand is individually torqued in test rigs developed to apply load during radiation
- Total of 60 strands for radiation and statistical results



Credit: L. Grimes-Ledesma, P. Willis, S. Matthews JPL

Composite Overwrap



Preliminary Test:

- Assumes statistical variance due to strand manufacturing process and test variability characterized by NESC COPV test campaign
  - Employed statistical test matrix randomization for manufacturing lot, radiation exposure, and testing rigs
- Composite strands pre-loaded during radiation
- Test sample environment controlled using nitrogen purge box
- Radiation exposure with Co-60 source
  - 6 Mrad over 3 days
- Strands tensile tested

Credit: L. Grimes-Ledesma, P. Willis, S. Matthews JPL

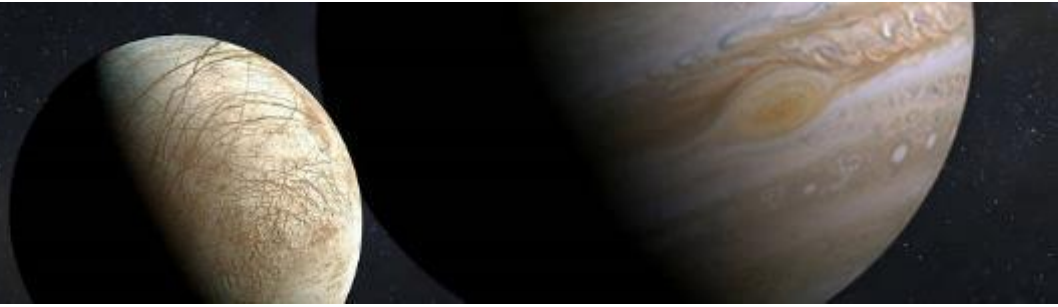
Composite Overwrap

Preliminary Results:

- Three separate groups of data were compared:
  - NESC Stress Rupture Assessment strength data (61 data points)
  - Non-irradiated data (20)
  - Irradiated data (20)
- Strength data was compared in several ways using Anderson-Darling test:
  1. Non-irradiated to NESC Stress Rupture Assessment strength data
  2. Non-irradiated to Irradiated
  3. Comparison of all 3 groups
- No difference was found between any of the groups indicating:
  - No significant effect of radiation on strength (comparison 2, 3)
  - Additional handling of the strands due to loading/unloading from irradiation fixture did not result in damage significant enough to reduce strength (comparison 1)
  - Strands tested in this study were not significantly different than the strands tested in the NESC stress rupture study (comparison 1, 3)
- Post-test calibration of load test fixtures were lower than target

Credit: L. Grimes-Ledesma, P. Willis, S. Matthews JPL

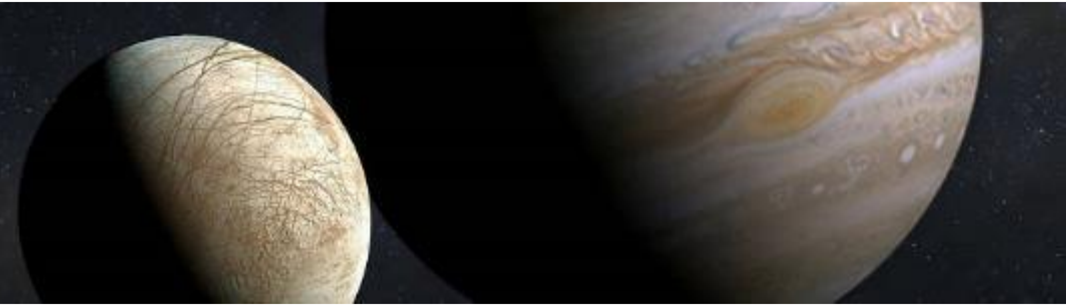
Composite Overwrap



Forward Work

- Redesign load test fixtures
- Conduct higher level radiation exposures commensurate with higher dose Europa application

Additional Plans



- Heaters and Thermostats TID radiation evaluation
- Common aluminum finish compatibility with long term Planetary Protection Heat Microbial Reduction
- Application specific evaluations
  - Solar Array coverglass radiation effects on transmissivity
  - Honeycomb composite structure radiation and thermal effects on mechanical properties
  - Component radiation exposure tests
  - Dielectric material ESD and key characteristics tests at liquid He temperatures
  - Radiation testing of low friction, anti-galling coating

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jpl.nasa.gov