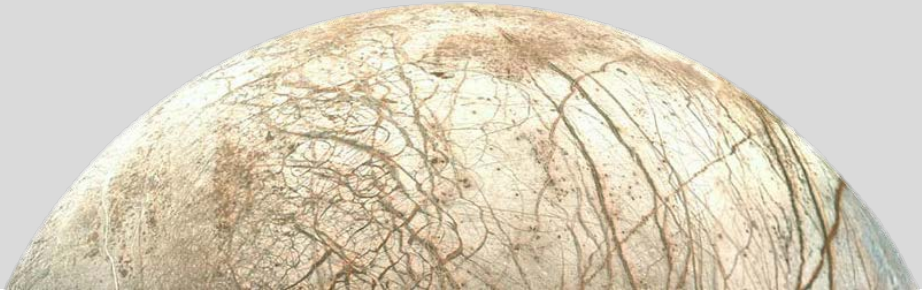

Power Subsystem Approach for The Europa Mission

Antonio Ulloa-Severino

NASA -JPL / California Institute of Technology

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Pre-Decisional Information – For Planning and Discussion Purpose Only

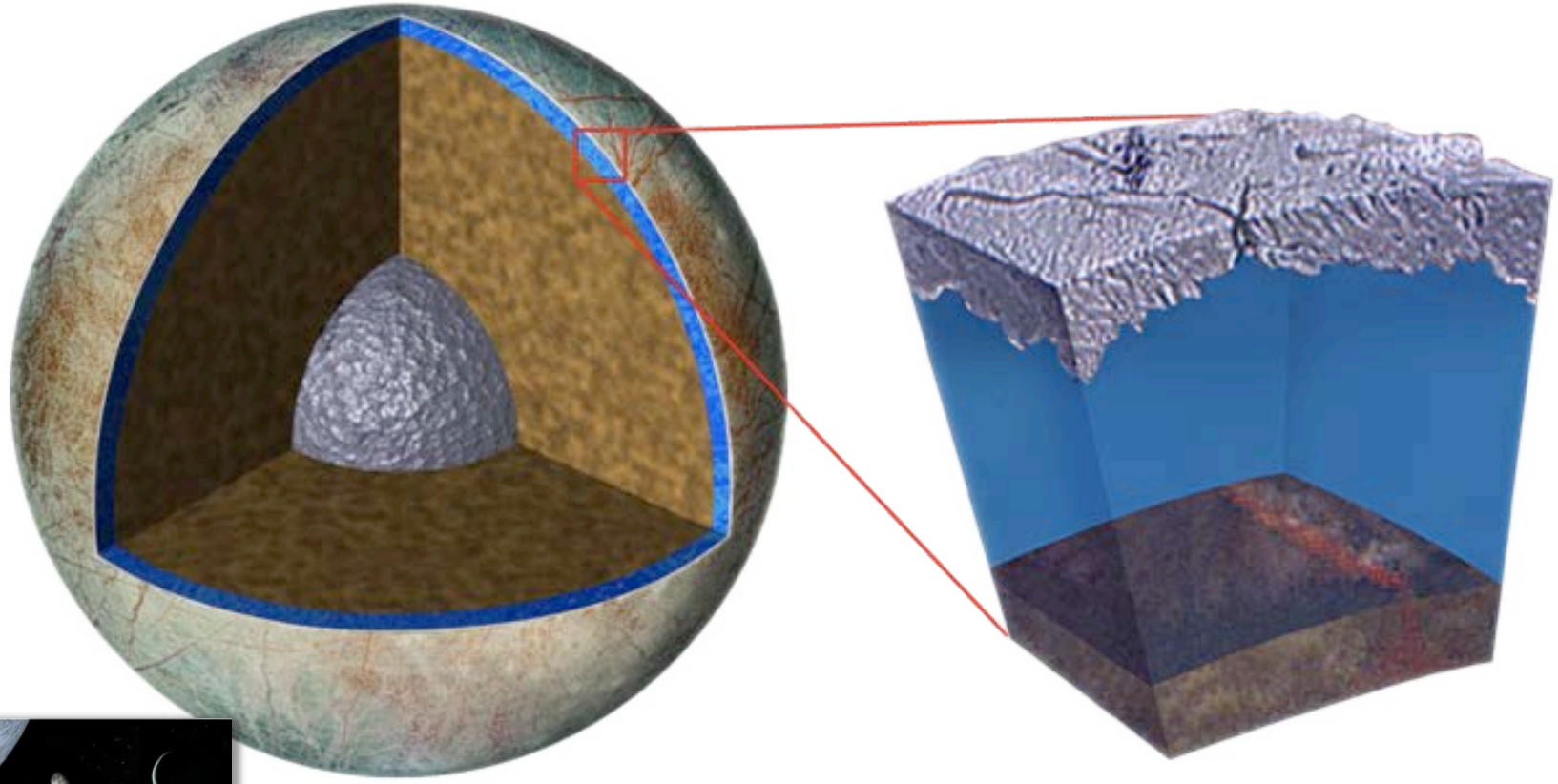
Authors

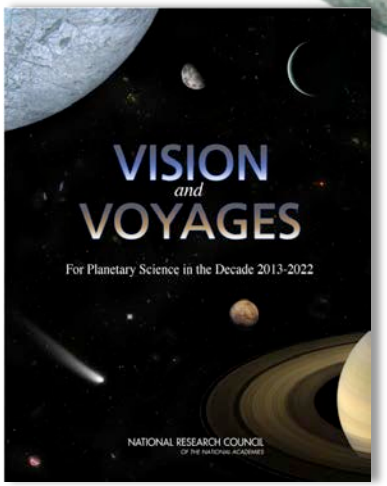
- Roxanne Arellano – System Engineer
- Andreea Boca – Solar Array Engineer/CTM
- Ratnakumar V. Bugga – Battery Technologist
- Gregory A. Carr – System Architect
- Douglas J. Clark – Lead System Engineer
- Stephen F. Dawson – Solar Array Electrical Lead
- Sonny M. Orellana – Power Electronics Lead
- Marshall C. Smart – Battery Lead
- Antonio Ulloa-Severino – Power Subsystem Product Delivery Manager

Outline

- Mission Concept Overview
- Baseline Spacecraft Configuration
- Key and Driving Requirements
- Power Subsystem Architecture
- Power Electronics
- Power Source
- Power Storage
- Conclusion

The Ocean That Beckons

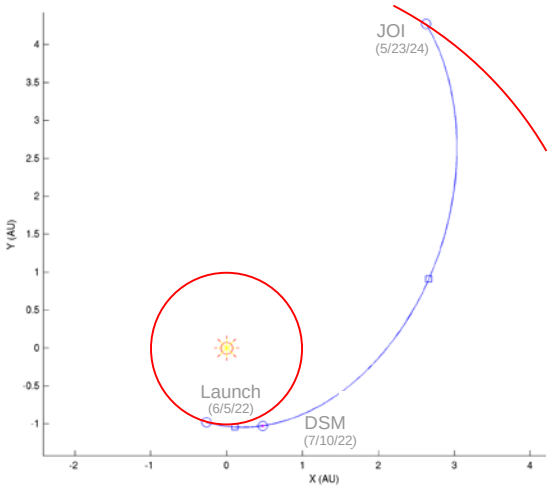




*"**Europa**, with its probable vast subsurface ocean sandwiched between a potentially active silicate interior and a highly dynamic surface ice shell, **offers one of the most promising extraterrestrial habitable environments**, and a plausible model for habitable environments beyond our solar system"*

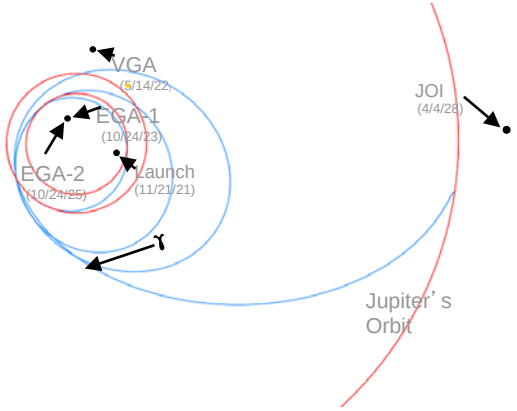
Designing for Vastly Different Roads to Jupiter

- Baseline: Space Launch System (SLS)
  - Direct trajectory via SLS cuts cruise to Jupiter to <3 years
  - Avoids Venus thermal environment



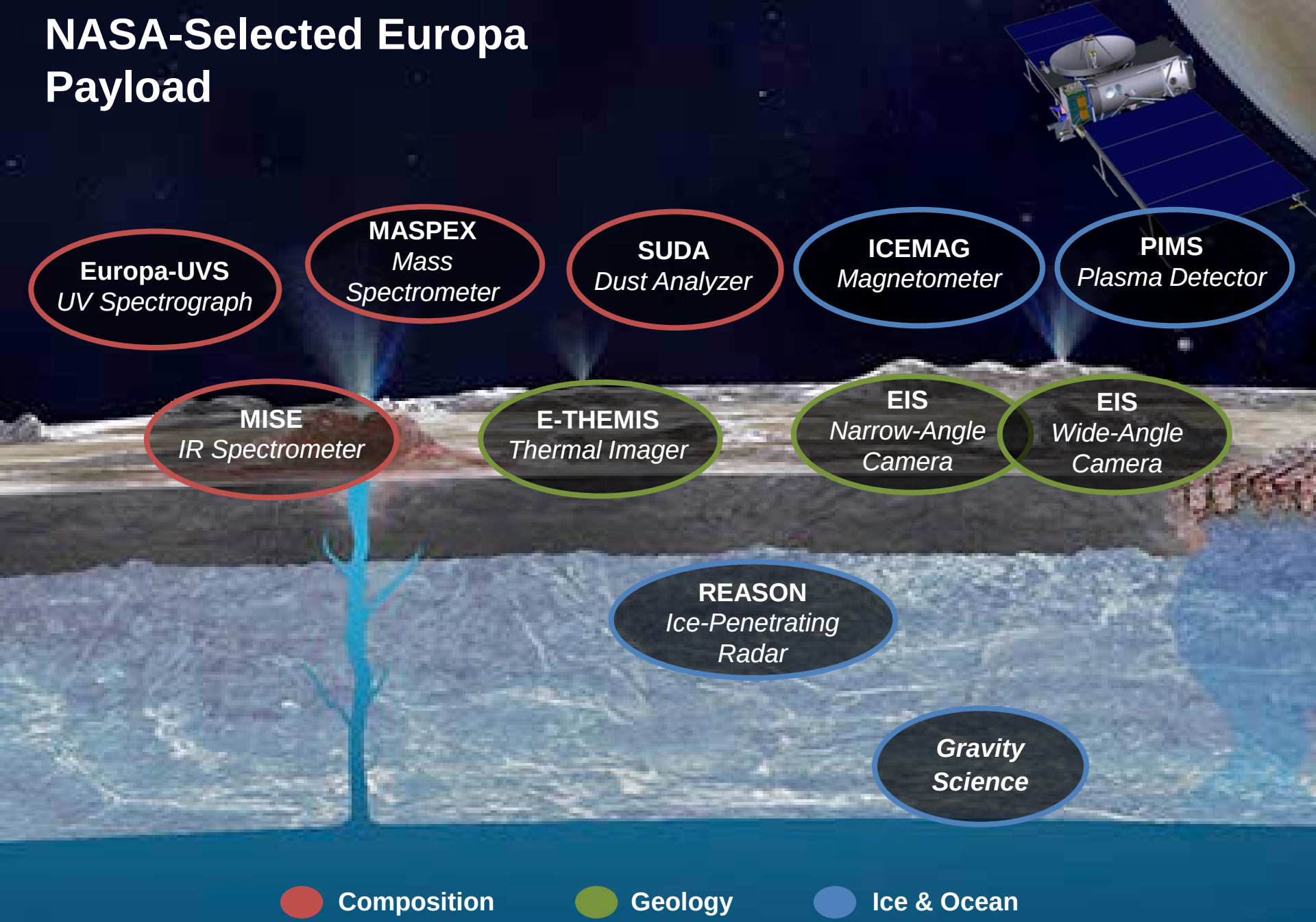
Time of flight:	1.9 years
Earth Flybys:	0
Sun Closest Approach:	1.0 AU
C3:	82 km^2/s^2
Launch Capability:	6087 kg (45% Margin)

- Maintain Ability to Fly VEEGA Interplanetary Trajectory: Atlas V 551
  - Gravity assist interplanetary trajectory with annual launch opportunities
  - Venus/Earth/Earth Gravity Assist
  - 6.4 years to Jovian System



Time of flight:	6.4 years
Earth Flybys:	2
Sun Closest Approach:	0.6 AU
C3:	15 km^2/s^2
Launch Capability:	4494 kg (41% Margin)

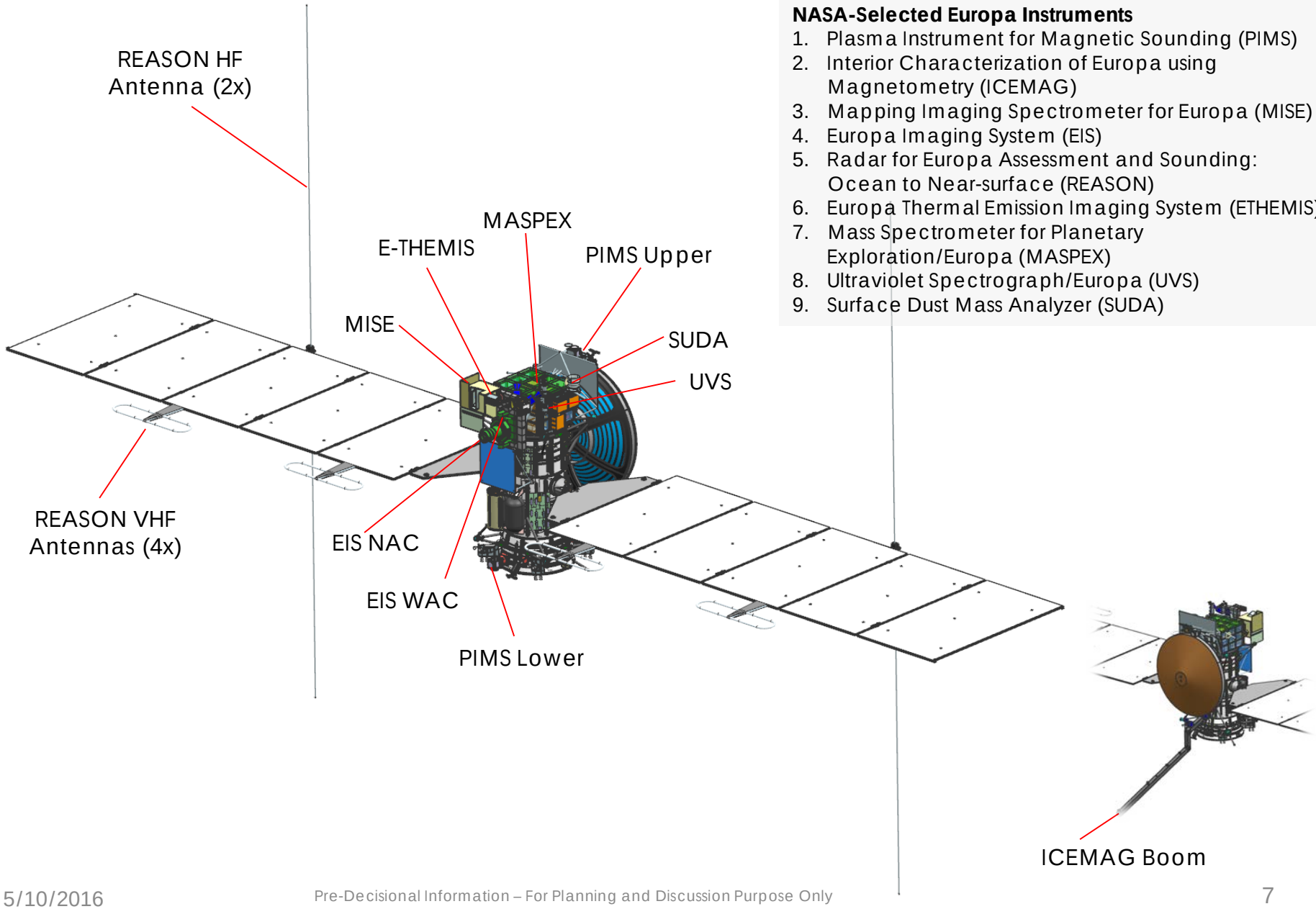
NASA-Selected Europa Payload



Baseline Spacecraft Configuration

NASA-Selected Europa Instruments

1. Plasma Instrument for Magnetic Sounding (PIMS)
2. Interior Characterization of Europa using Magnetometry (ICEMAG)
3. Mapping Imaging Spectrometer for Europa (MISE)
4. Europa Imaging System (EIS)
5. Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON)
6. Europa Thermal Emission Imaging System (ETHEMIS)
7. Mass Spectrometer for Planetary Exploration/Europa (MASPEX)
8. Ultraviolet Spectrograph/Europa (UVS)
9. Surface Dust Mass Analyzer (SUDA)

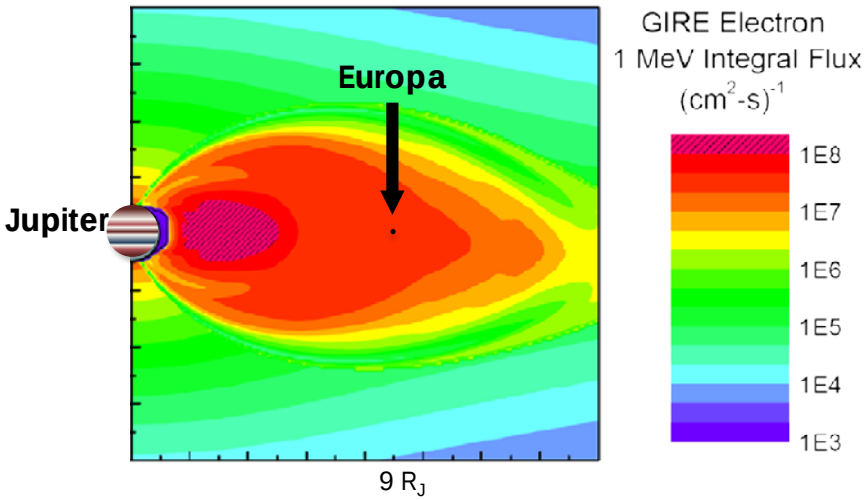


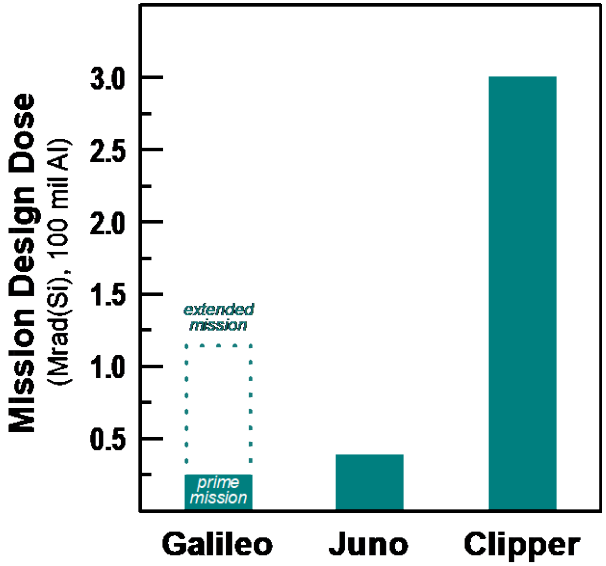
Pre-Decisional Information – For Planning and Discussion Purpose Only

Key & Driving Requirements

Lifetime and Performance in the Jovian Environment

- Europa lies within the Jovian radiation and plasma environment exposing the spacecraft to high-energy particles and extreme cold thermal cycles
- Total dose would be far higher than previous experience
- Meeting the challenge:
  - Maintain conservative design margins (RDM of 2)
  - Use commercially available parts (300 kRad)
  - House electronics in radiation vault

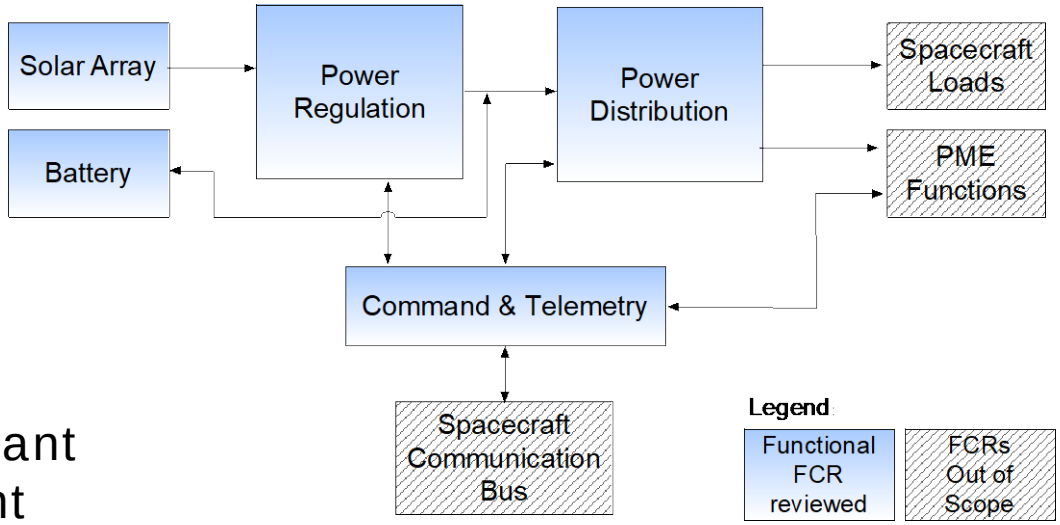




Key and Driving Requirements

Fault Tolerant Mission Critical Functions

- The power subsystem consists the following mission critical functions
  - Power source
  - Power storage
  - Power bus regulation
  - Power distribution
  - Command & telemetry
- Functions are single fault tolerant providing a robust and resilient design to support science objectives



Key and Driving Requirements

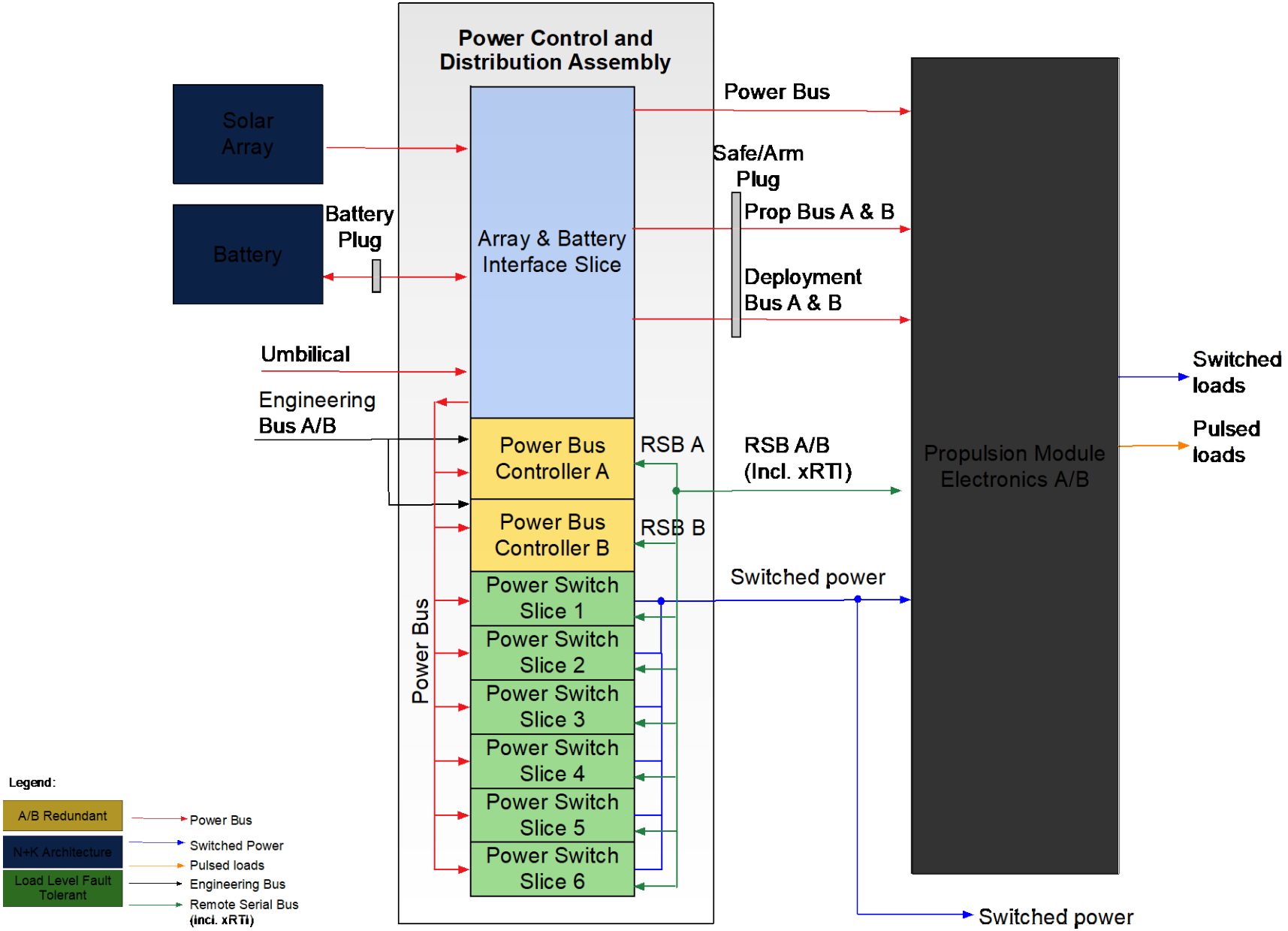
Power Subsystem Sizing

- Power and energy demands from loads drive solar array and battery sizing
  - As instrument designs mature, the power electronics need to provide the capability to process and manage the power increases
  - Designing low power consumption electronics is challenging driven by the limited sunlight available at distances of ~ 5 AU or greater

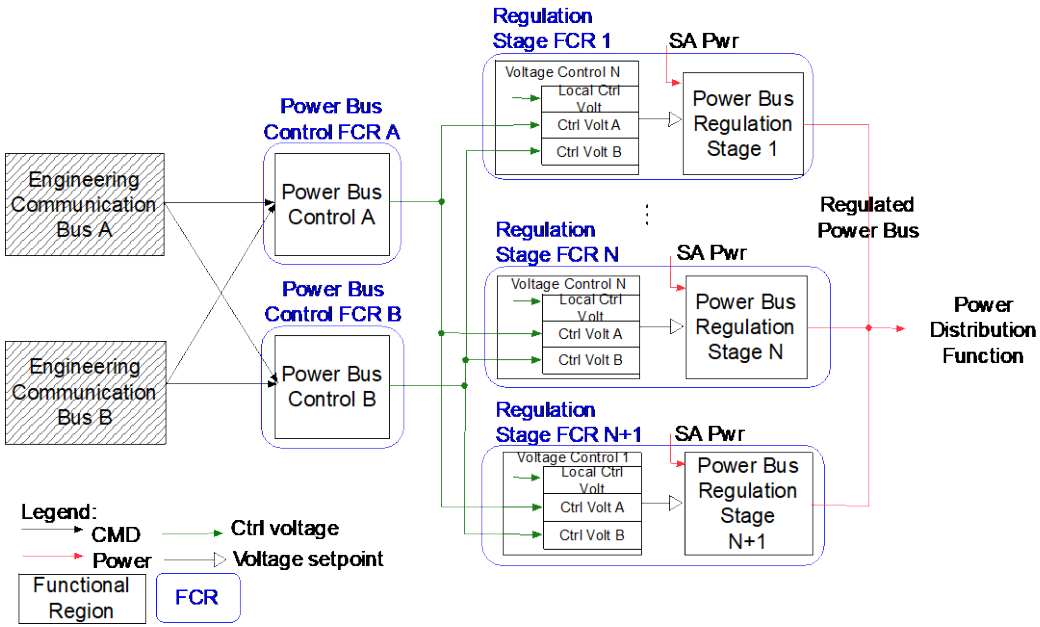
Planetary Protection (PP) Category III Rating

- Ensures rigorous PP and contamination control to lower the probability of contaminating Europa with Earth microbes
- Power hardware and materials will be subjected to stringent bioburden reduction levels
  - Approved methods are dry heat microbial reduction and vapor hydrogen peroxide treatment (surfaces)
  - Radiation dosage is under evaluation as an alternative approach

Power Subsystem Baseline Architecture



Fault Containment Regions

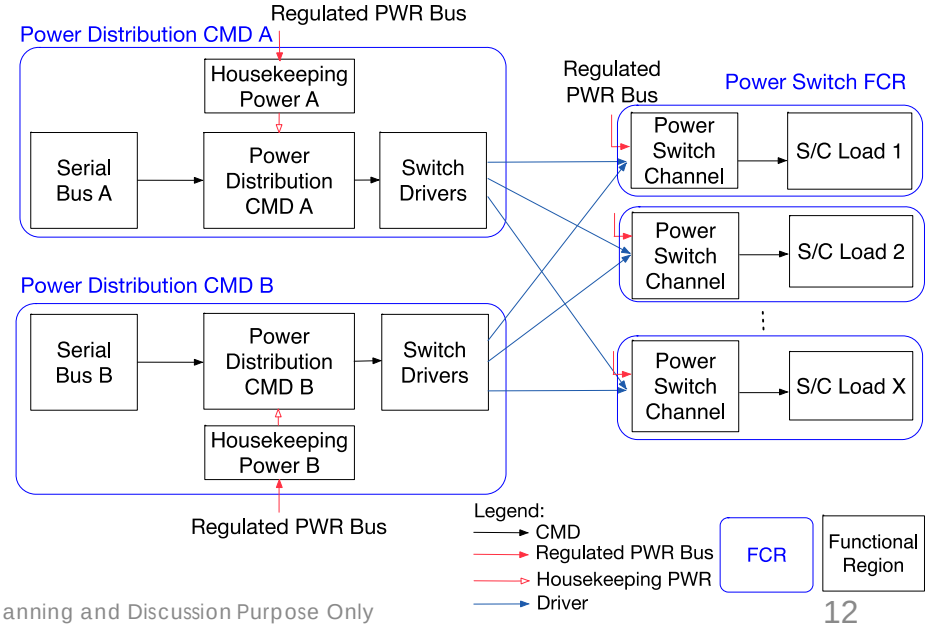


Power Regulation FCRs

- Power regulation stages are N+K, where N is number required for the mission and K is the number of additional stages provided for redundancy
- Power bus control is block redundant

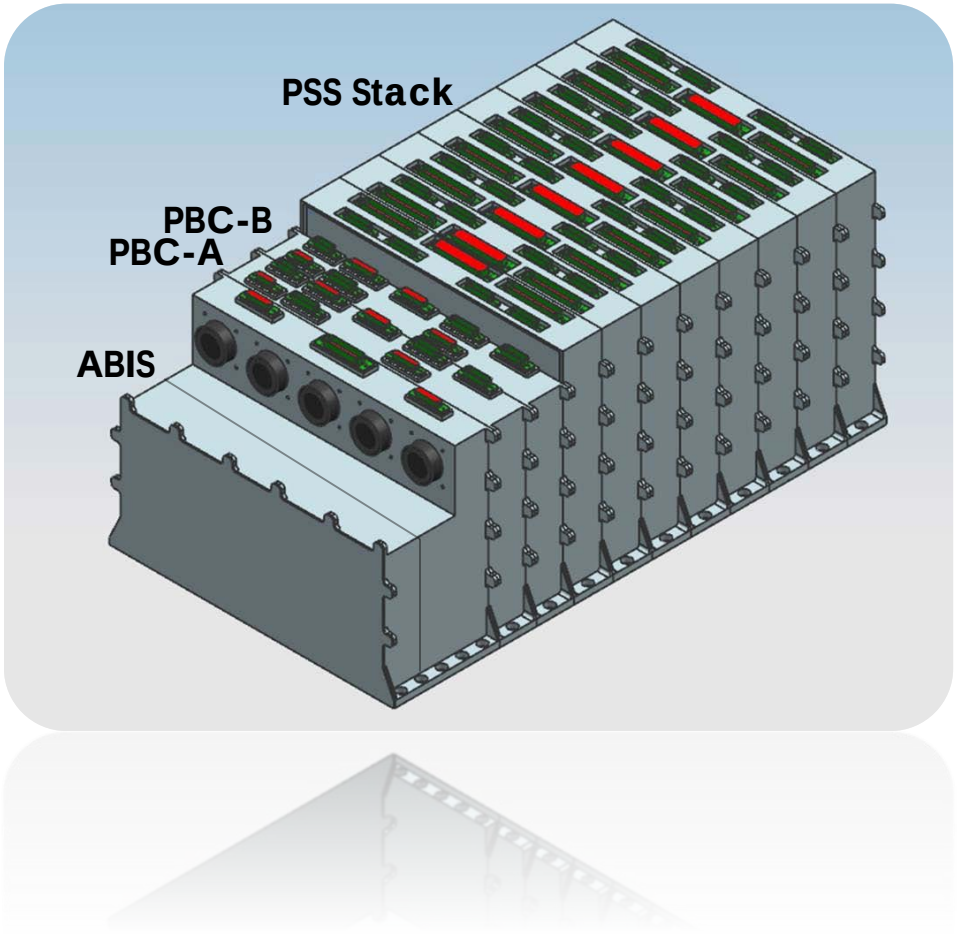
Power Distribution FCRs

- Power switching is at the load level designed with resettable circuit breaker isolation (fail safe-off)
- Power distribution commanding of block redundant



Power Electronics

- Power electronics provide a robust, reliable, and efficient power management and distribution system capable of performing in the Jovian environment
- Designed to minimize low power consumption and physical size
- Power Control and Distribution Assembly (PCDA) is comprised of the following slices:
  - Array and Battery Interface Slice (ABIS) - one slice
  - Power Bus Controller (PBC) Slice – two slices
  - Power Switch Slice (PSS) – six slices

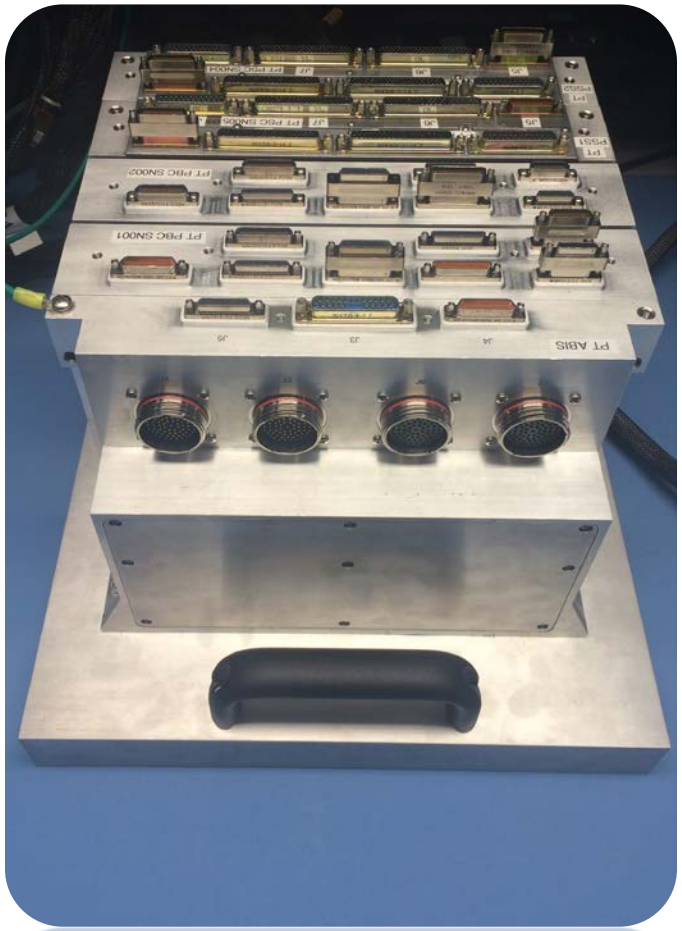


Power Electronics

PCDA Functional Description

- Regulates the spacecraft power bus
- Converts the solar array power to s/c power bus
- Provides charge control for the battery
- Contains the single point ground and balanced bus references
- Distributes power to spacecraft and instrument loads
- Detects LV break wire separation and provides safety inhibits for the deployment and propulsion buses
  - Provides communication interfaces to spacecraft engineering bus and PME

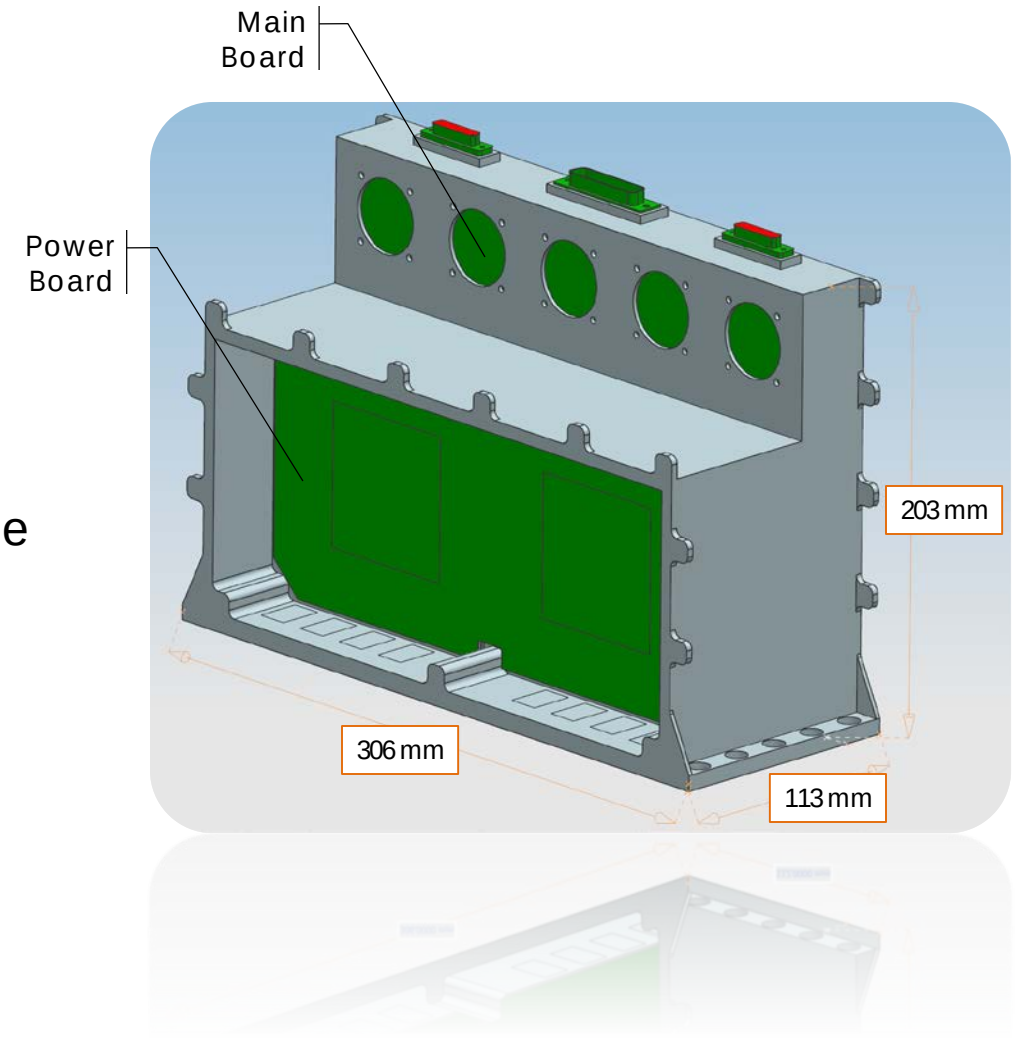
Prototype PCDA



Array and Battery Interface Slice

ABIS Functional Description

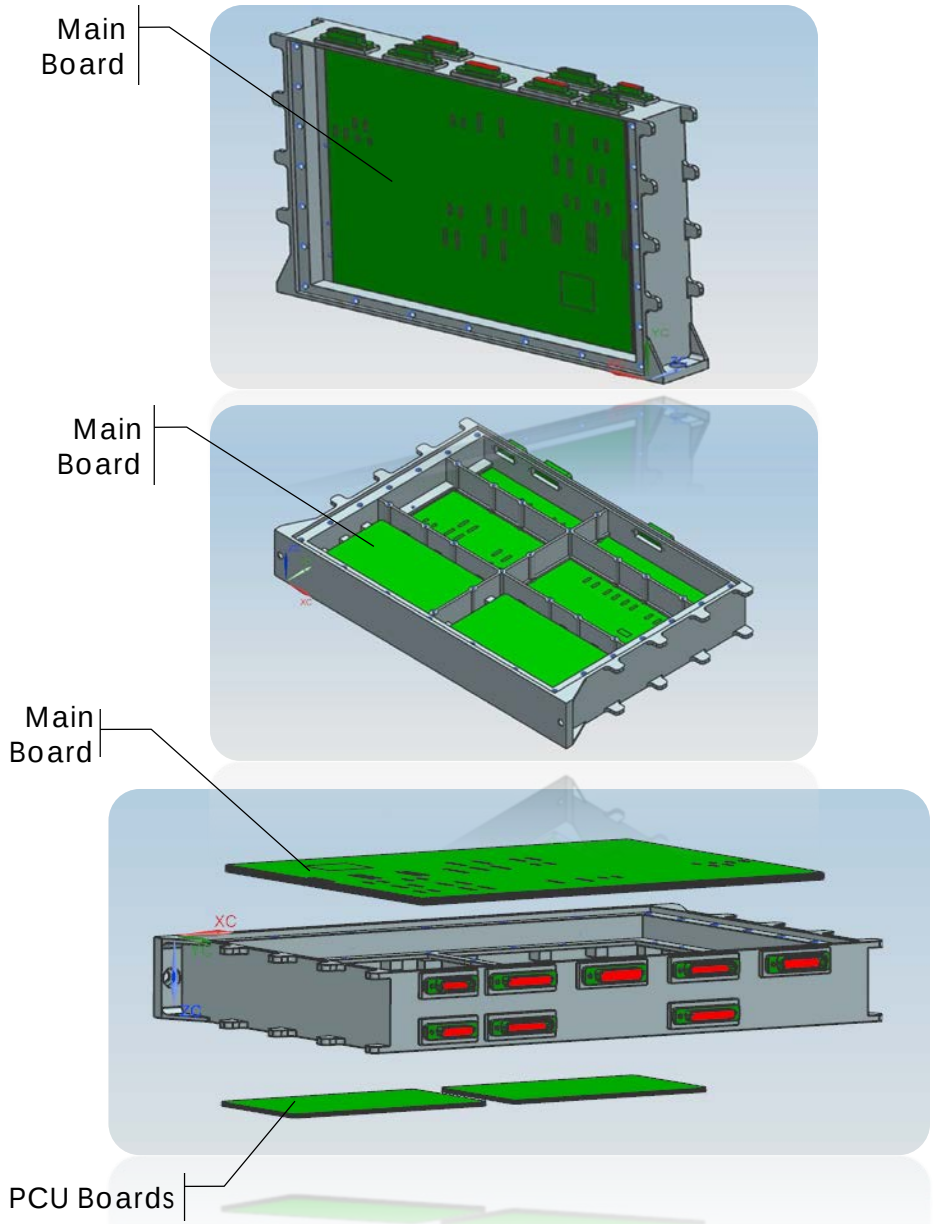
- Interfaces to the solar array, battery, and umbilical connections
- Converts solar array power to regulated spacecraft power bus
- Contains current sensors for solar array, battery, and load current measurements (measuring circuitry is within the PBCs)
- Provides safety inhibits for the deployment and propulsion buses
- Provides the power bus single point ground reference



Power Bus Controller

PBC Functional Description

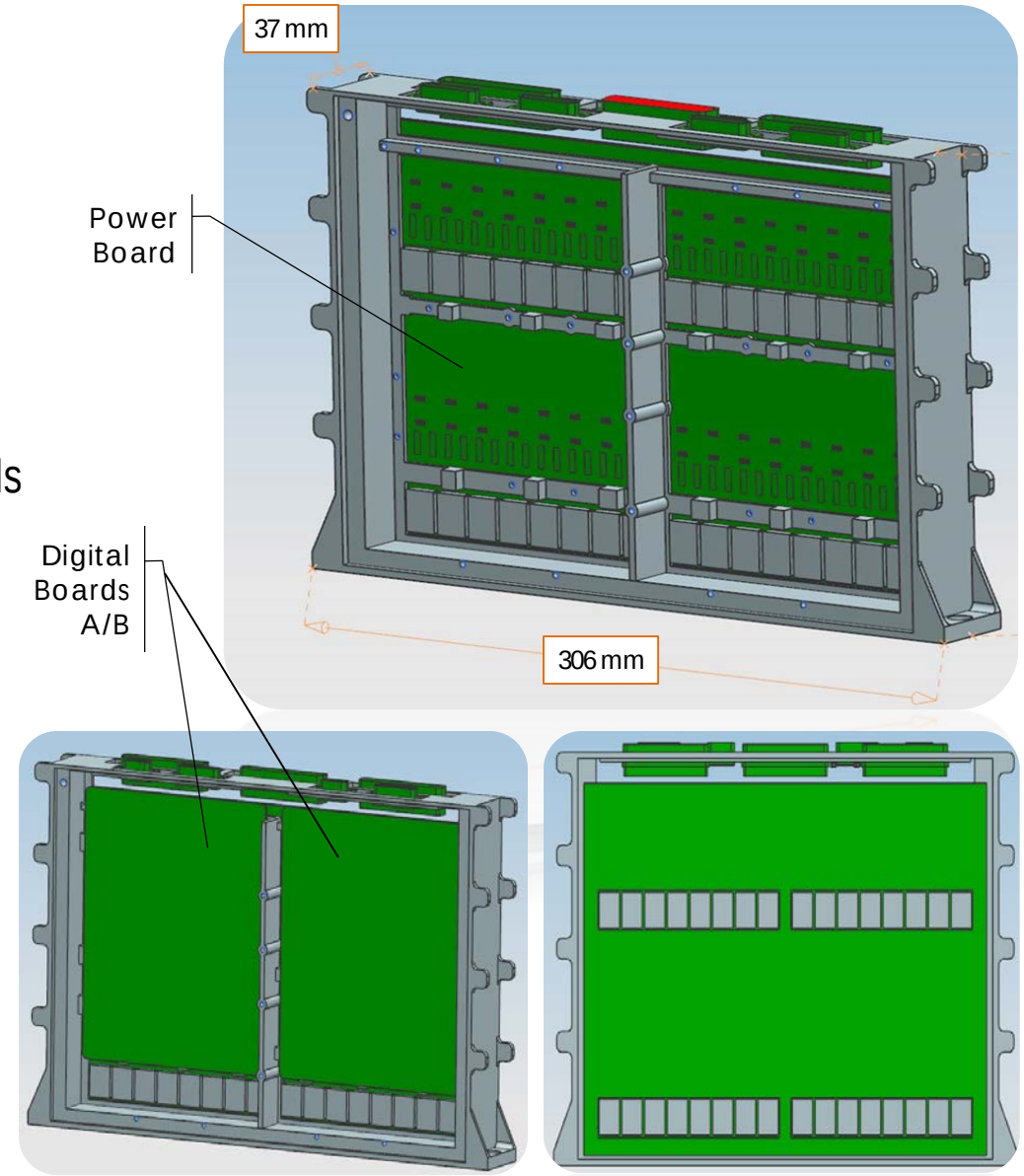
- Communicates with CDH through the 1553 bus interface
- Communicates to the PSSs and PMEs through the internal RSB interface
- Performs battery charge control
- Provides status of breakwires and arm plug signals
- Provides control and status of the inhibited buses
- Generates the power bus control voltage based on the selected set-point and the measured bus voltage and battery current
- Detects and signals under-voltage lockout fault condition
- Provides solar array, battery, and load telemetry
- Provides solar array IV curve measurements



Power Switch Slice

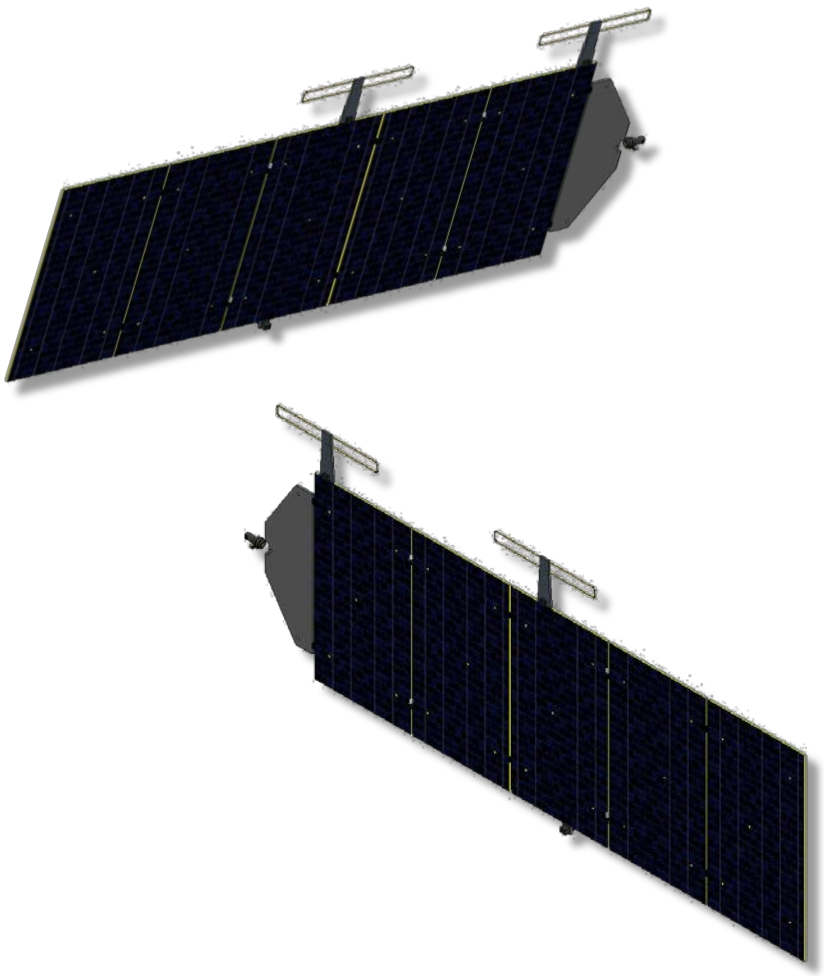
PSS Functional Description

- Provides high and low side power switch channels
  - Four 5 A channels and twenty-eight 2 A channels per slice
  - Configurable switch behavior for the 5A channels based on POR and/or UV conditions
- Provides current telemetry for each high and low side switch
- Provides overcurrent switch protection for each high and low side switch



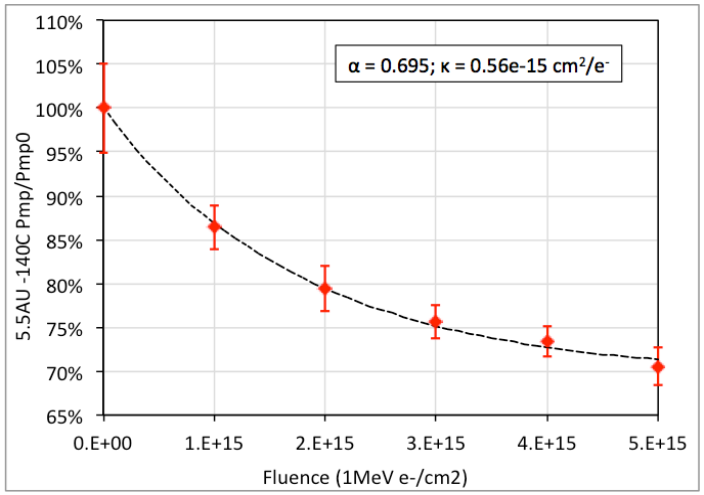
Power Source

- Solar array is comprised of two deployable solar wings, each with single axis gimbal drive
- Each wing is comprised of five solar panels
  - Panel area is ~ 9 m^2
- Uses SolAero ZTJ solar cells
- FCR is at the string level, N+1
- Environmental conditions driving the solar array size are distance of 5.5 AU, temperature of -140 ^oC at end of mission (EOM), and radiation and combined degradation effects

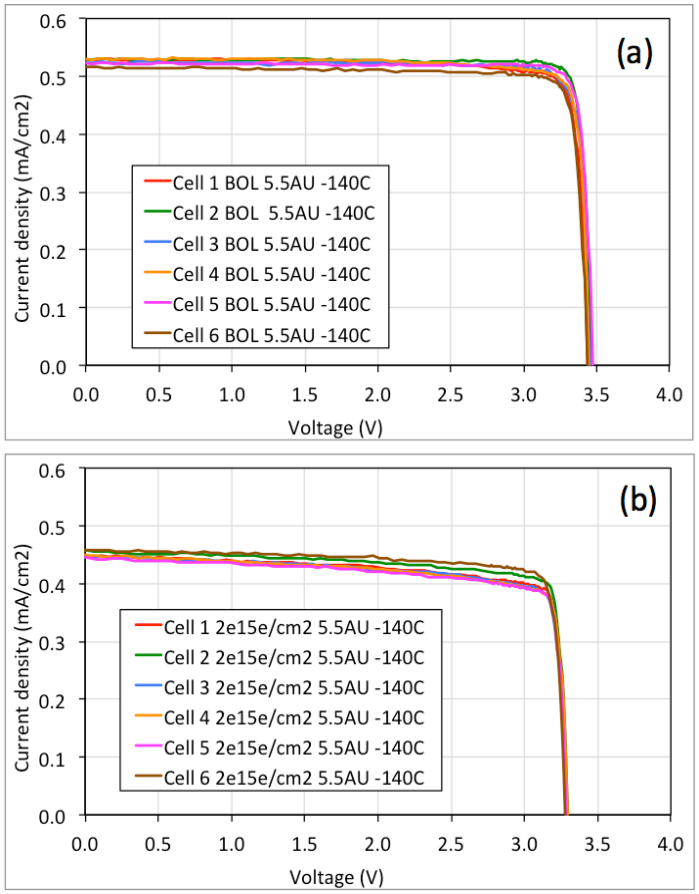


LILT and Radiation Testing

- Currently performing testing on ZTJ bare cells and CICs under the environmental conditions of irradiance, temperature, and radiation dose
- Measurements will be performed over multiple irradiances, temperatures, and radiation doses; results will be used for flight performance predictions



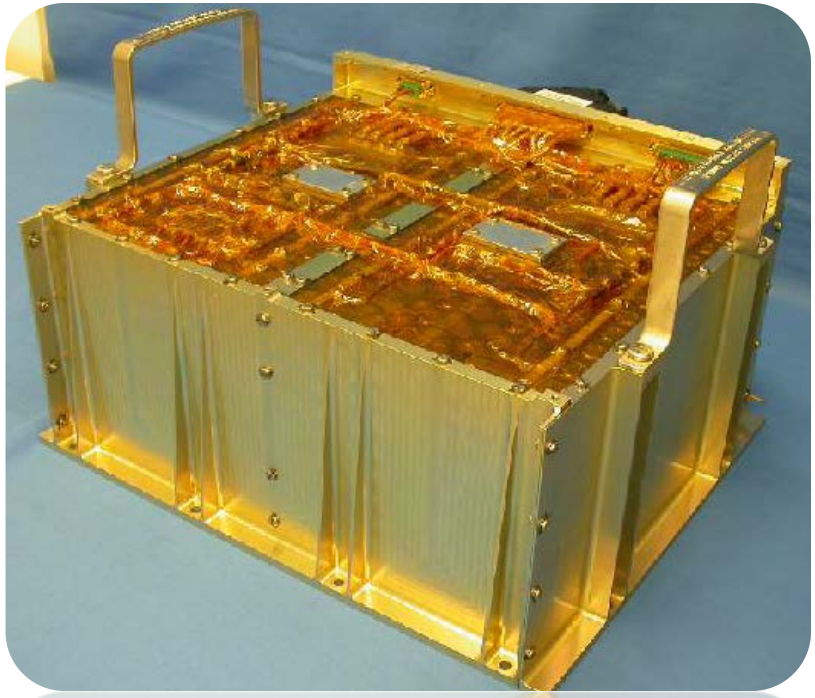
ZTJ CIC remaining power fraction at LILT(5.5AU, -140 °C) as a function of applied radiation dose



ZTJ bare cell LILT LIV sweep data at 5.5 AU, -140 °C:(a) pre-radiation; (b) after 2e15 1 MeV e- /cm2

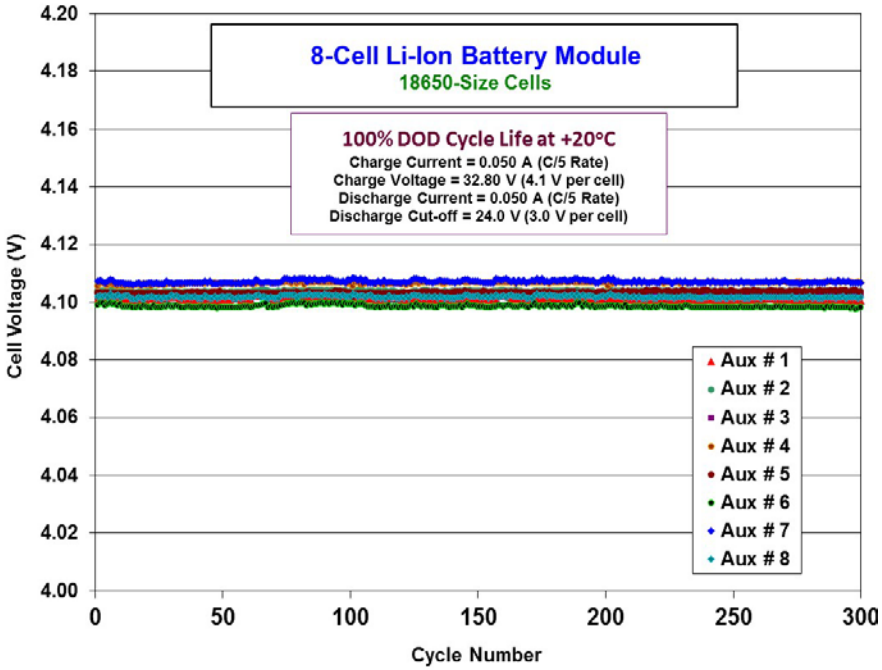
Power Storage

- Power storage is comprised of three secondary lithium-ion batteries
  - Two 8s52p's and one 8s32p
- EOM capacity of ~220 Ah
- Battery design uses high specific energy, small 18650-size lithium-ion cells
  - High energy capacity
  - Internal safety functions
  - Provide excellent cell to cell reproducibility and do not require cell monitoring or balancing electronics
- FCR is at the string level, N+1
- Environmental conditions driving the battery size are radiation, operation in a wide temperature range, storage life in long cruise period (~6.4 yrs) and mission life (> 11 yrs)



Environmental and Lifetime Testing

- Evaluating potential cell chemistries for performance in the Jovian environment
- Radiation testing of commercial lithium-ion cells
  - Large format cells showed 10% capacity loss at 25 Mrad
  - Sony 18650-size lithium-ion cells showed 4% to 6% capacity at 18 Mrad
  - Panasonic NCR-A and NCR-B cells 18650-size showed minimal capacity fade and impedance growth at 18 Mrad
- Storage and lifetime characterization testing of candidate high specific energy 18650-size lithium-ion cells continues
  - Storage testing over moderate temperature ranges as well as characterizing high temperature for short durations at high SOC (launch condition)
  - After 6 months in storage, observed minimal cell voltage dispersion storage after being subjected to 100% depth-of discharge(DOD) cycle life testing at 20 °C



Conclusion

- The power subsystem architecture has been designed to meet the challenging mission requirements that include high levels of ionizing radiation, extreme temperatures, and low solar irradiance at distances greater than 5 AU.
- The architecture is robust, single fault tolerant design with high reliability providing efficient delivery of power to the loads.