Small RPS-Enabled Europa Lander Mission

Space Technologies and Applications International Forum
(STAIF 2005)

13 February 2005
Albuquerque, NM

Robert Dean Abelson, Ph.D,
James H. Shirley, Ph.D.
NASA Jet Propulsion Laboratory

This is a conceptual mission study intended to demonstrate the range of possible missions and applications that could be enabled were a new generation of Small Radioisotope Power Systems to be developed by NASA and DOE. While such systems are currently being considered by NASA and DOE, they do not currently exist.

This study is one of several small RPS-enabled mission concepts that were studied and presented in the NASA/JPL document "Enabling Exploration with Small Radioisotope Power Systems" available at:

http://solarsystem.nasa.gov/multimedia/download-detail.cfm?DL_ID=82

ELM Team Members and Acknowledgements

Science
- Ellis Miner
- Jim Shirley
- Tom Spilker

RPS Systems
- Bob Carpenter
- Bill Nesmith

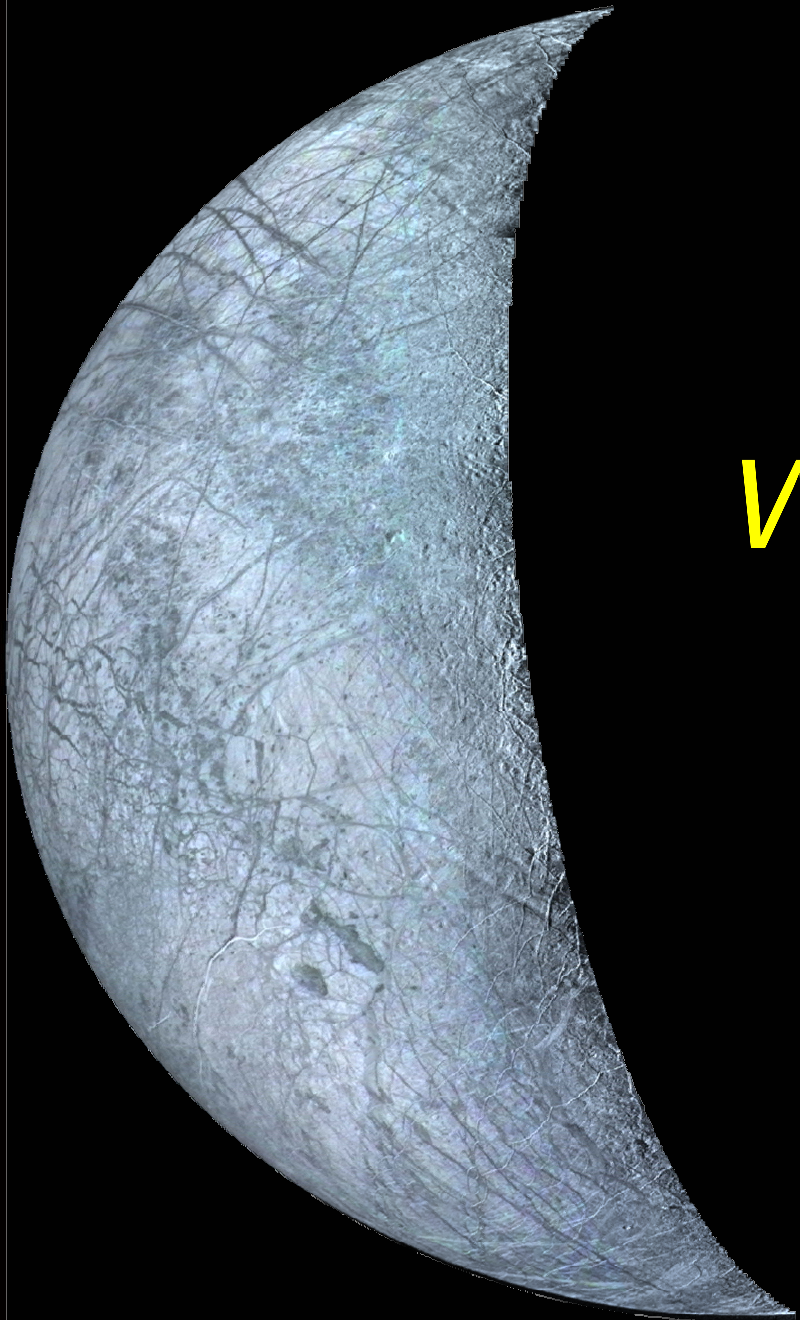
Mission Design
- Erik Nilsen

Batteries
- Rao Surampudi

Radiation Environment
- Insoo Jun

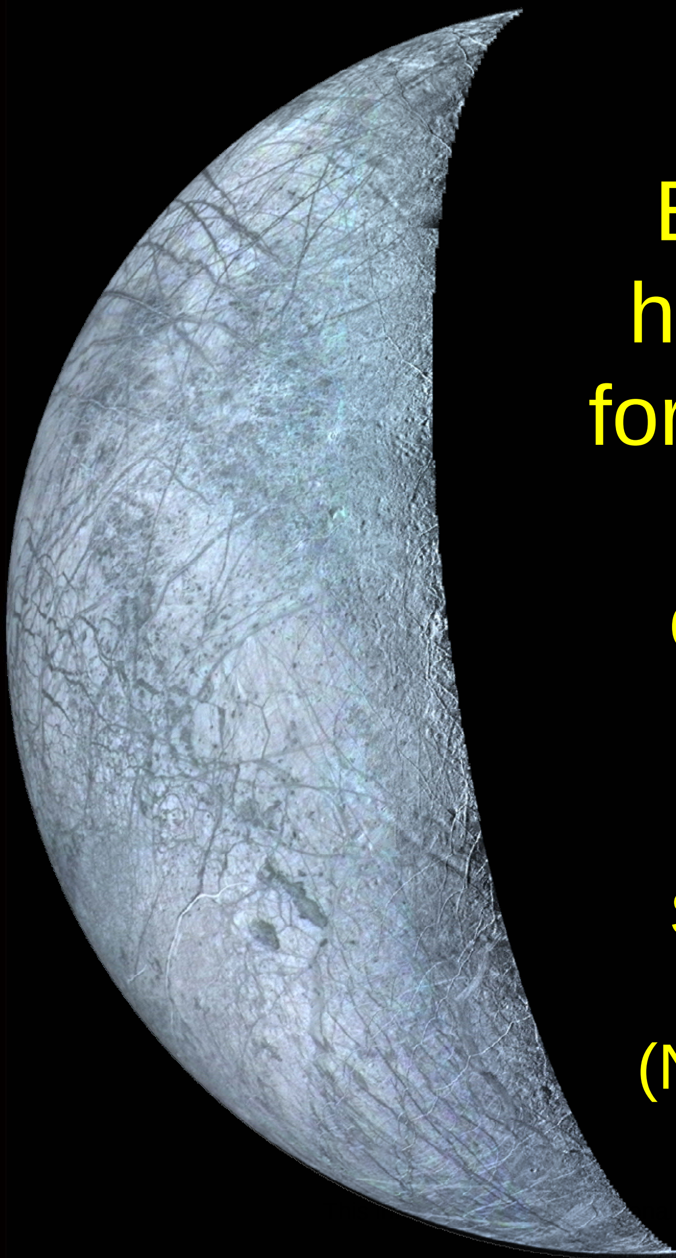
JIMO Information
- John Elliott

Europa Pathfinder (EPF) Team
- Jacklyn R. Green
- Wayne Zimmerman
- Eric Archer
- Alok Chatterjee
- Savio Chau
- Mona Delitsky
- Wai Chi Fang
- Jeff Hall
- Ron Hall
- Don Hunter
- Lonne Lane
- Bill Nesmith
- Jagdish Patel/Elizabeth Kolawa
- Adam Steltzner
- Brian Sullivan
- Leslie Tamppari
- Ben Thoma
- Marcus Traylor



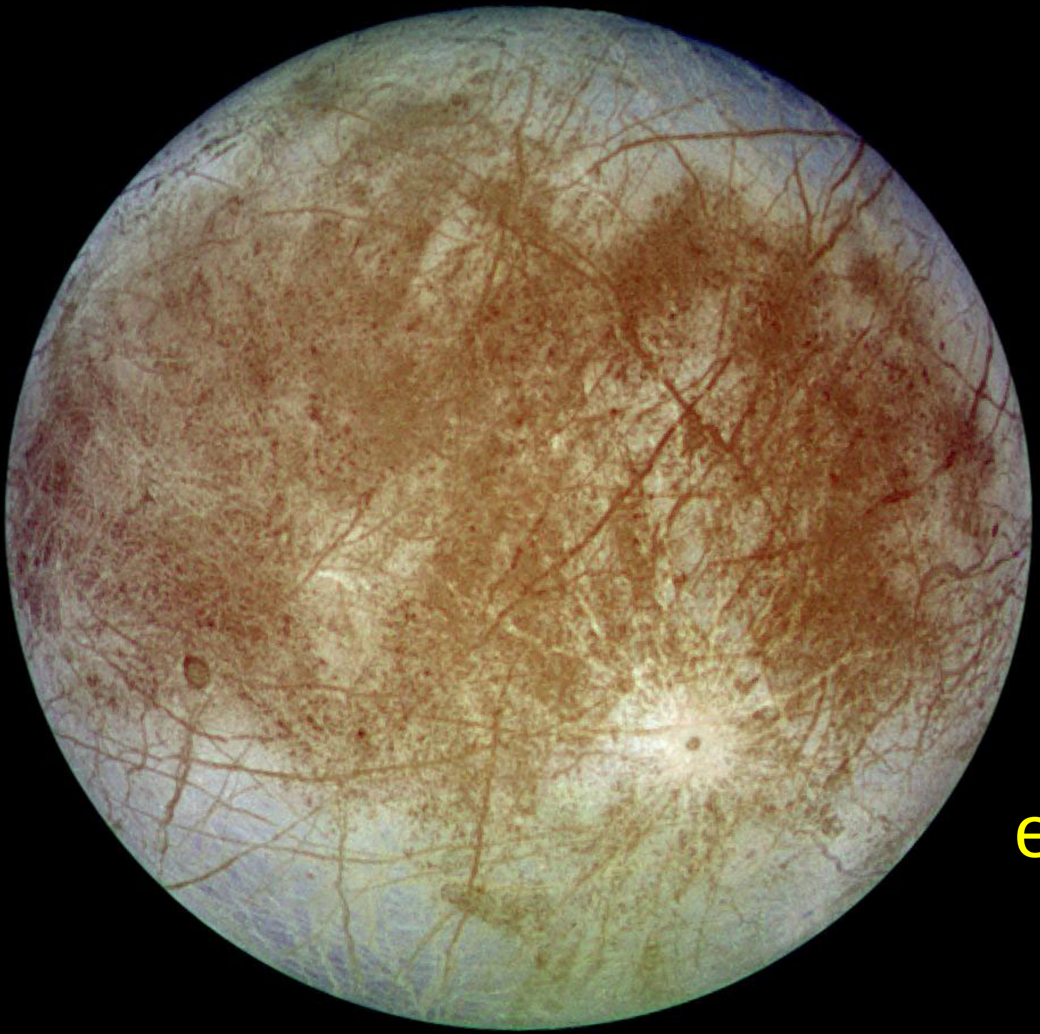
Why Europa?

Europa Lander Mission



Europa is the single highest-priority target for future flagship-class missions to the outer solar system.

Solar System Exploration Decadal Survey (National Research Council)



Why Land on Europa?

Because *life* may exist within Europa's icy crust or in a subsurface ocean.

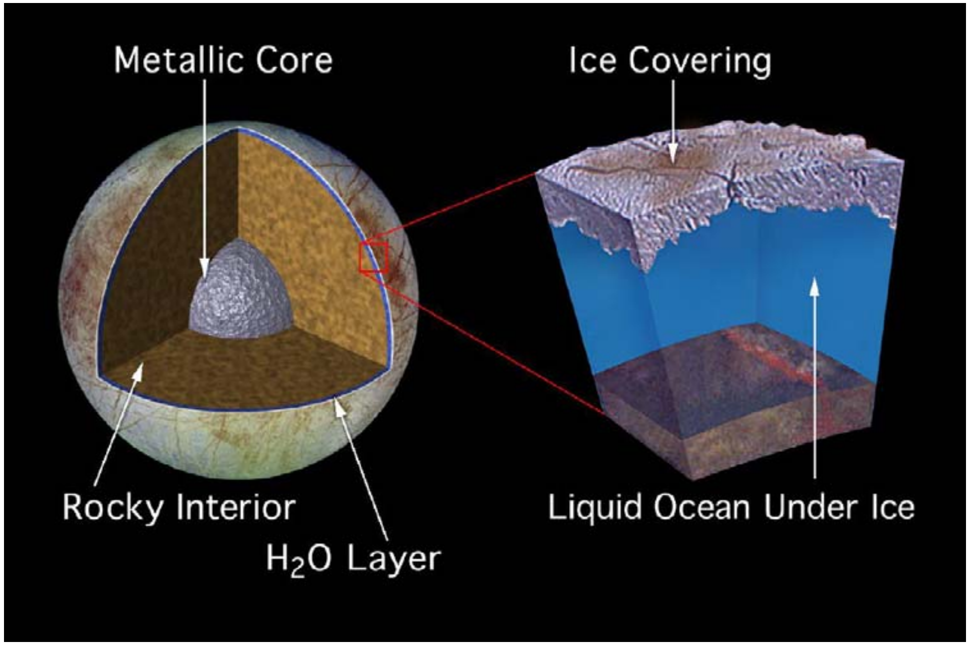
Requirements for sustaining life as we know it:

1) An energy source: Geothermal, geochemical, and gravitational heating caused by other Jovian moons

2) Biologically significant chemicals:

(E.g., C, H, O, N, P, K,..)

3) Water



Europa satisfies these requirements

Potential Scientific Objectives for ELM

- To search for signatures of biological activity.
- To assess the chemical and physical habitability.
- To measure Europa's seismicity ("icequakes") to help understand the interior structure and crustal dynamics.
- To provide "ground truth" for remote measurements of surface composition, radiation levels, and temperatures.
- To obtain close-up images of Europa surface features and geology.

Source: From discussions at the JIMO Forum, Lunar and Planetary Institute, 2003

Proposed Mission Objectives for ELM

- To land on Europa to take in-situ measurements for a minimum of 30 Earth days (8.5 Europa days) that meet the science objectives.

- Measurements include surface imagery, spectroscopy, seismometry, radiation and temperature trending.

Europa Orbital and Physical Parameters

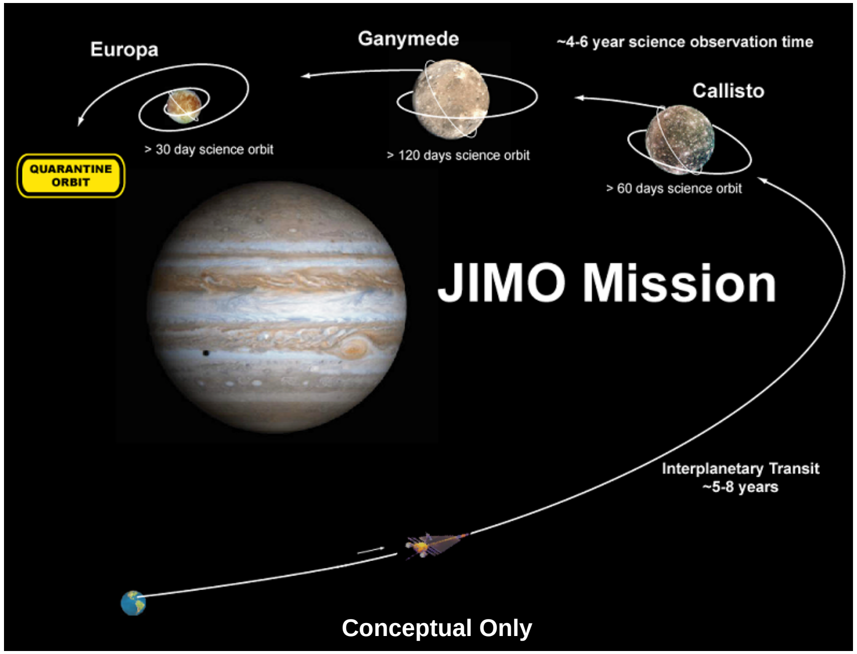
- Orbital Period about Jupiter: 3.55 Earth days (85.2 Earth hours)
- Eclipse Period: 1.78 Earth days (42.6 Earth hours)
- Semi Major Axis: 671,000 km
- Orbital Eccentricity: 0.0101
- Orbital Velocity: 13.74 km/sec
- Orbital Inclination: 0.464 deg. To Jupiter's equator

- Diameter (Mean): 3,121 km
- Mass: 4.8E22 kg (0.8035% of Earth mass)
- Gravitational Acceleration at Surface: 1.315 m/s^2 (13.4% of Earth)
- Escape Velocity: 2.026 km/s (at surface)

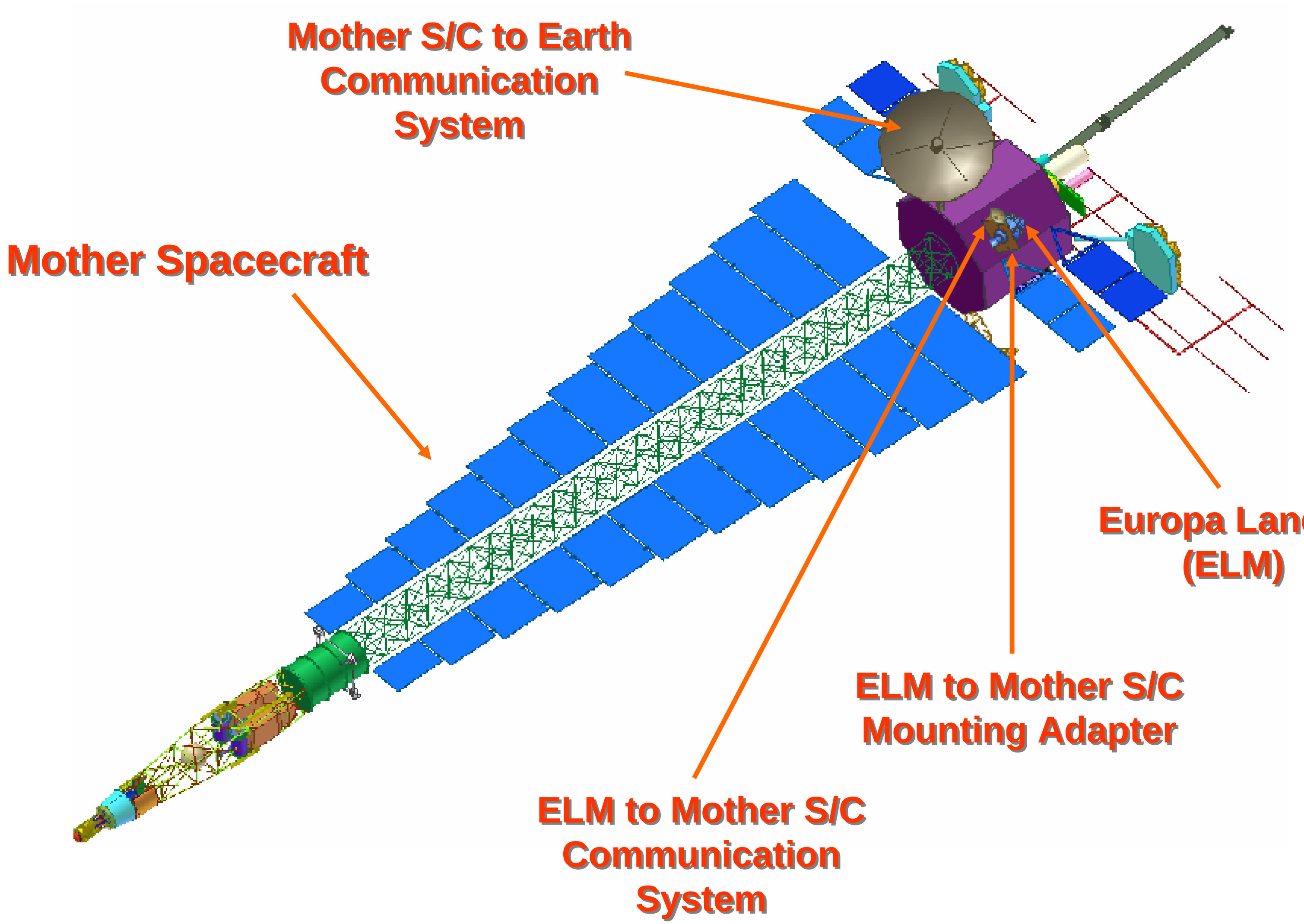
- Sun Insolation at Surface relative to Earth: 3.7%
- Daytime Temperature of Surface: 124K
- Nighttime Temperature of Surface: 85K
- Average Temperature of Surface (Avg over one day): 103K
- Radiation Environment on Surface: ~14 kRad per Earth Day
  - Assumes 100 mils of aluminum shielding

Mission Architecture Overview

- The Europa Lander Mission (ELM) is derived from the Europa Pathfinder (EPF) study and takes advantage of RPS technology to enable a 30 day surface mission (EPF baseline was battery-limited at 3.5 days).
- ELM is assumed to ride as payload on the proposed Jupiter Icy Moons Orbiter (JIMO) and arrive at Europa per the nominal JIMO timeline.
- JIMO acts as the communication relay between ELM and Earth.
- The ELM landing site would be selected to maximize science returns and minimize landing risk.
- The landing site could be updated in-flight if JIMO identified higher-priority landing areas during Europa approach.



ELM Mounting to Mother Spacecraft



Conceptual Only

This information is pre-decisional and for discussion purposes only.

Mission Architecture Overview (Continued)

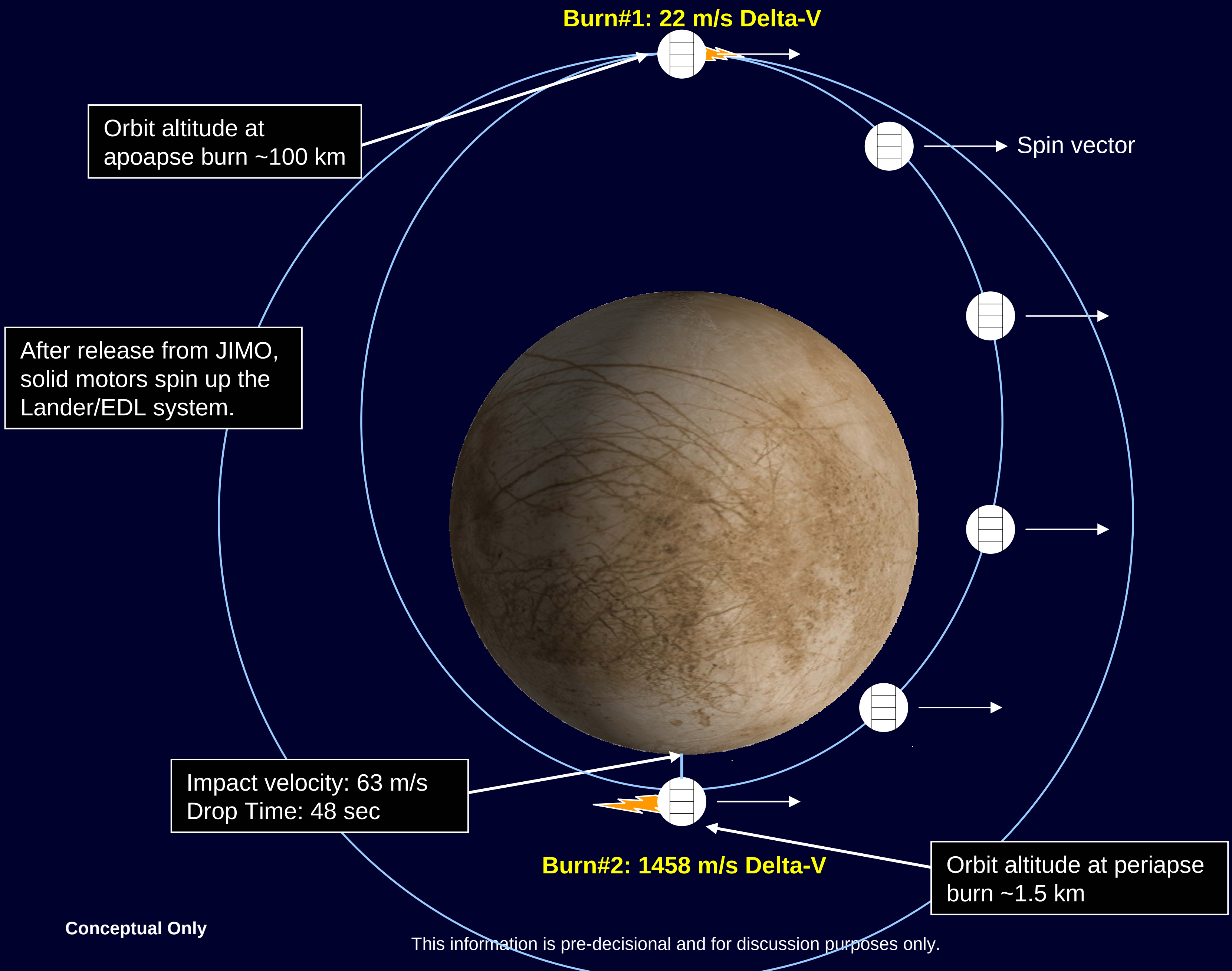
- The baseline JIMO science orbit around Europa is assumed to be 100 km (circular) at 45 degrees inclination for 30 days.

- Once in orbit, ELM would separate from the JIMO bus and spin-stabilize in preparation for two separate entry burns. The burns are used to perform a "stop and drop" maneuver.

- The first entry burn (22 m/s) changes the lander orbit from 100km elevation to 100 km x 1.5 km (elliptical) using a Star 5 engine.

- The second entry burn (1458 m/s) is performed at <u>periapse</u> (1.5km elevation) using a Star 17 engine. This stops all forward motion, causing the lander to "fall" into Europa.

Europa Lander Mission



Conceptual Only

Mission Architecture Overview (Continued)

– Aeroshells and parachutes are ineffective on Europa due to its negligible atmosphere. Must use other methods for landing.

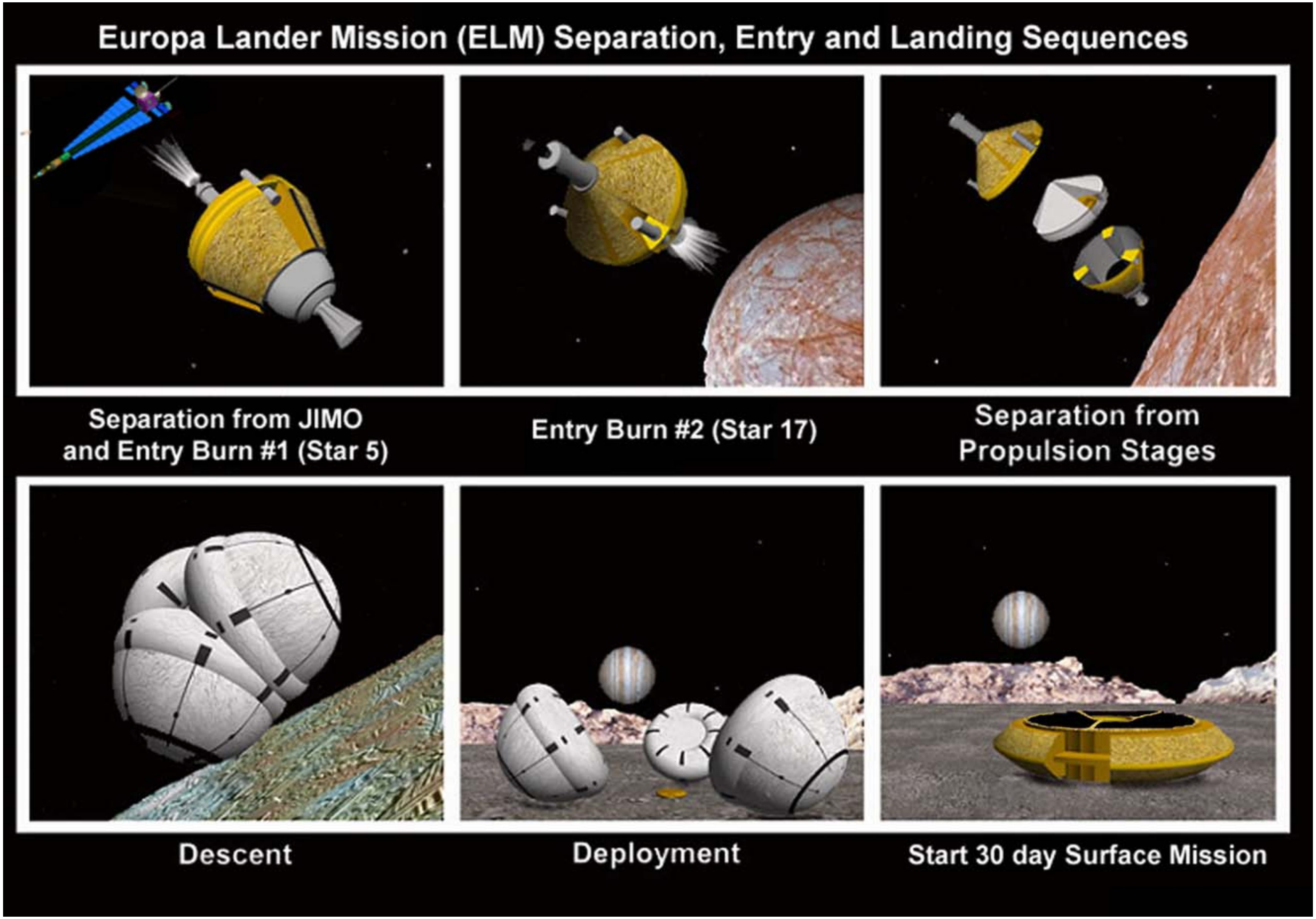
– A low periapse orbit (1.5km) is selected to reduce the impact velocity to 63 m/s while maintaining enough elevation margin to handle insertion-errors (i.e., Isp, rocket burn times, angle errors, etc.)

– Airbags are used to reduce impact accelerations to <600g.

– After landing, the pressurized air bags are separated and bounce away from the lander. This allows the lander to drop to the surface and make direct contact with Europa.

– The surface mission starts following lander contact with the surface.

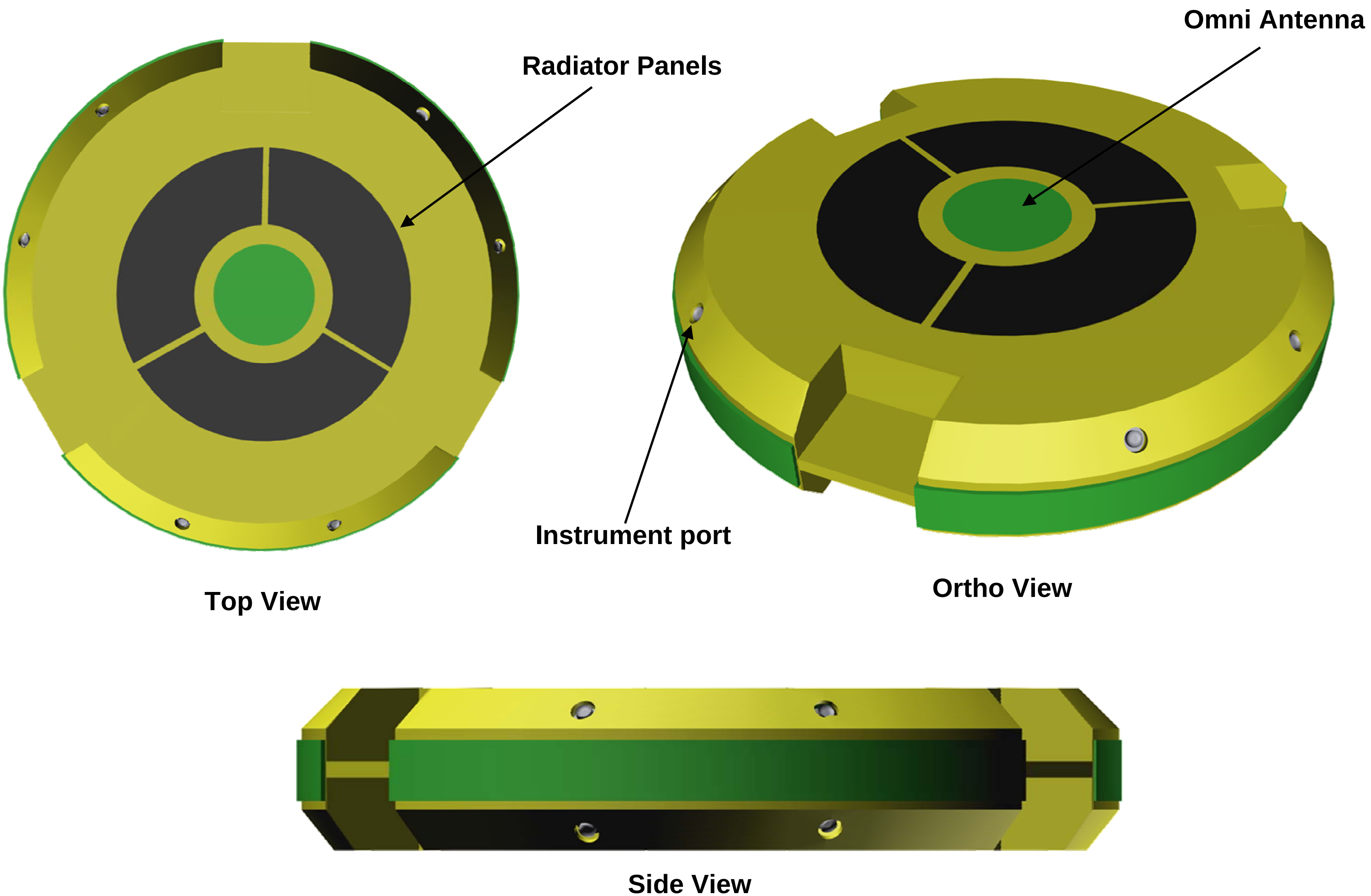
Europa Lander Mission



Conceptual Only

This information is pre-decisional and for discussion purposes only.

ELM External Configuration



Conceptual Only

Technology Applicability Trade Studies

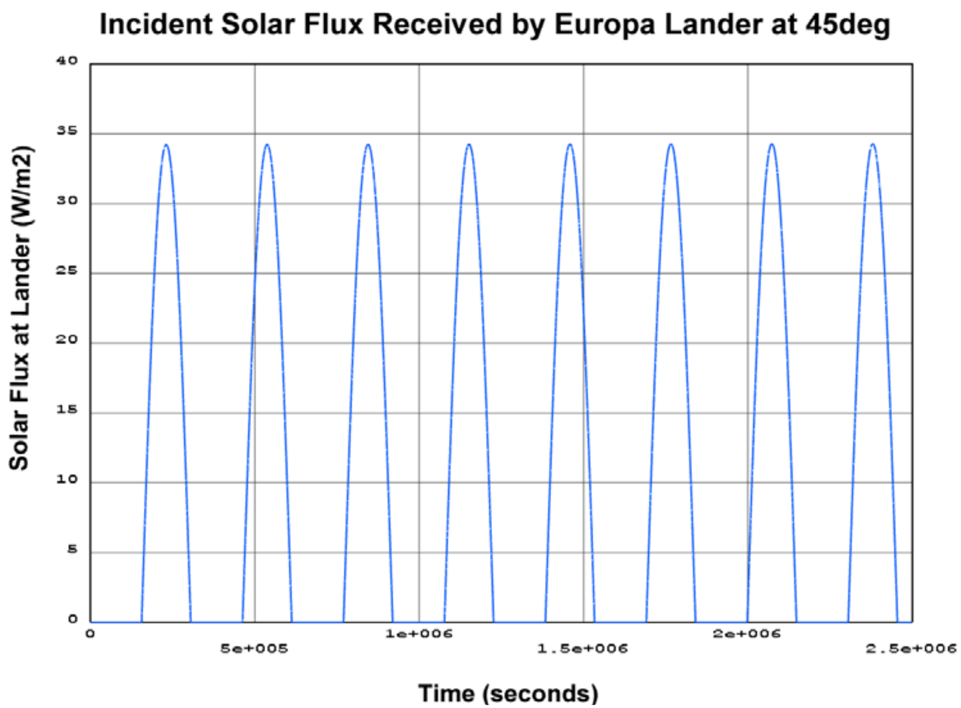
– A trade study was conducted for three different power systems for ELM (2 conventional and 1 RPS). The conclusions are summarized below.

Option 1: Solar Power	**Not Feasible**
Option 2: Primary Batteries	**Not Feasible**
Option 3: RPS	**Enabling**

Option #1 – Solar Power Trade Study

Facts:

- Europa is ~5 AU distant from the sun; receives 3.7% of the Earth insolation.
- At high latitudes (~45 degrees), the solar flux received by a lander with fixed solar arrays peaks at 34 W/m2. (Does not consider blockage of sun by Jupiter)
- Europa's rotational period has 42.6 hours (1.775 days) of shadow per Europa Day.
- Natural radiation over JIMO's 13 year mission significantly degrades solar cells.
- Lander needs to operate right-side up or upside-down.
- Europa is cold –nighttime surface temp ~ 85K.
- Significant thermal power is required to maintain operating temperatures.



Option #1 - Solar Power Trade Study (Cont'd)

Results:

- Required Solar Array (SA) size is drastically larger (order of magnitude) than the size of the entire lander.
  - Would need extensible/deployable arrays that add additional mass and complexity.
- Mass of SA and battery is significantly heavier than an equivalent RPS system (is heavier than entire lander).
- Need additional power source to operate lander and keep it warm during 13 year cruise phase.

Size and Mass Prohibitive

Option #2 - Batteries Trade Study

Results:

- Heater power required to keep the large batteries at operating temperature (>-40C) in the frigid Europan environment (as low as -188C) is prohibitive.
- Mass and volume of battery is significantly larger than an equivalent RPS system.
- Need additional power source to operate lander and keep it warm during 13 year cruise phase (i.e., for health, status and comm. checks).

Mass Prohibitive

Option #3 - RPS Analysis (Continued)

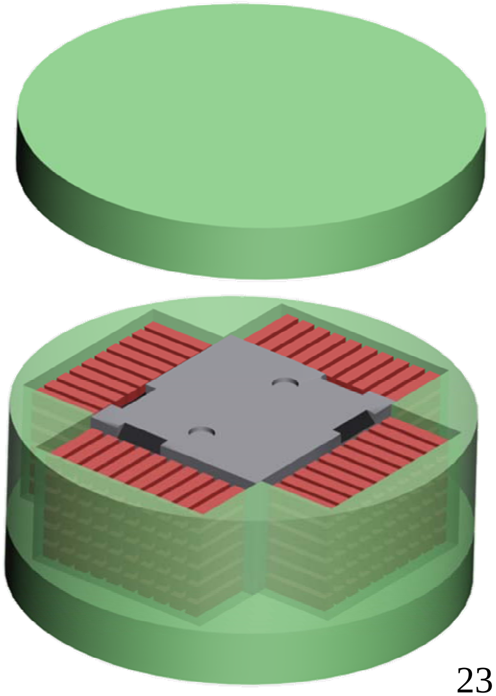
Results:

- RPS has the lightest mass of all three options.
- RPS is drastically smaller than the solar+battery option, and measurably smaller than the battery-only option.
- The RPS option produces extra heat that can be used to keep electronics, batteries and critical systems warm during the entire 13 year cruise and 30 day surface missions.
- The RPS is a self-contained system, requiring no external recharging or alternate power connectivity with the JIMO spacecraft during cruise.

RPS is an Enabling Power Technology for the ELM Mission

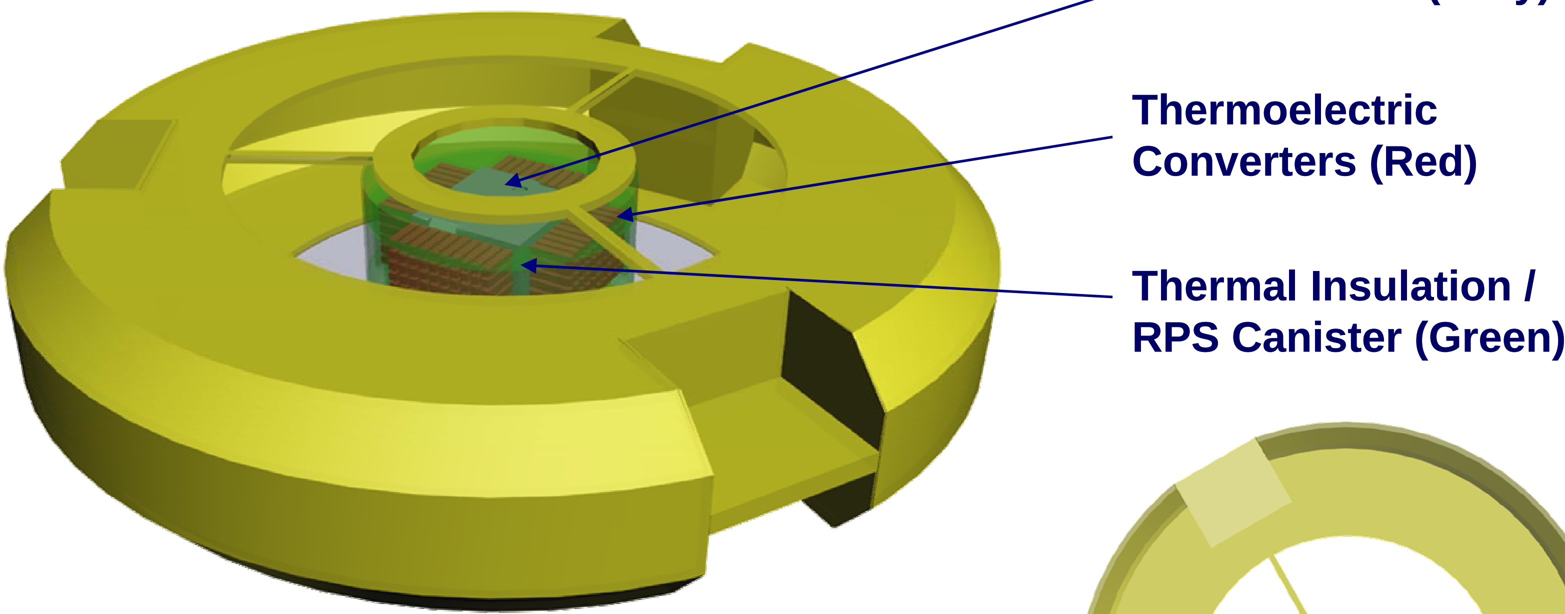
RPS Characteristics and Assumptions

- One GPHS module using a 5% efficient thermoelectric (TE) converter is assumed to provide 250 Wt (thermal) /12.5 We (electric) at BOM.
  - Conversion efficiency numbers are conservative. May be able to achieve >7.5% efficiency with segmented PbTe-TAGS/BiTe thermoelectrics (more with CPA designs) per DOE/OSC analyses.
  - Small RPS configuration based on work of DOE/OSC/Analytix
- Assume Pu283 decay decreases thermal power output by 0.8%/year.
- Assume TE decay decreases electrical power by another 0.8%/year.
- The End-of-Mission power output after 13 years is calculated at 225 Wt / 10.1 We.
- Medium temperature TEs (e.g., PbTe/TAGS) are assumed in baseline design for conservatism.
  - Cold shoe temp. ~155°C.
- The RPS is assumed capable of surviving high acceleration loads (max of 600 g) associated with the ELM landing system.
- The RPS is packaging is a short cylinder with the TEs arranged radially (i.e., TE cold shoes / heat rejection is via the sides).

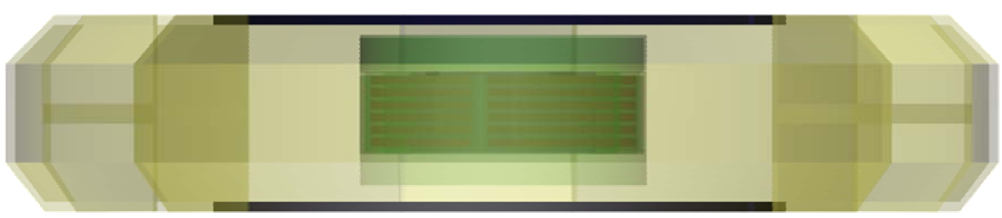


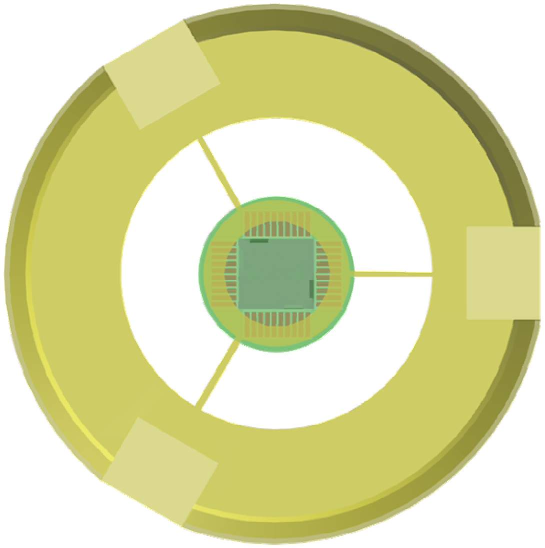
Conceptual Only

RPS Installation and Orientation within ELM



Conceptual Only





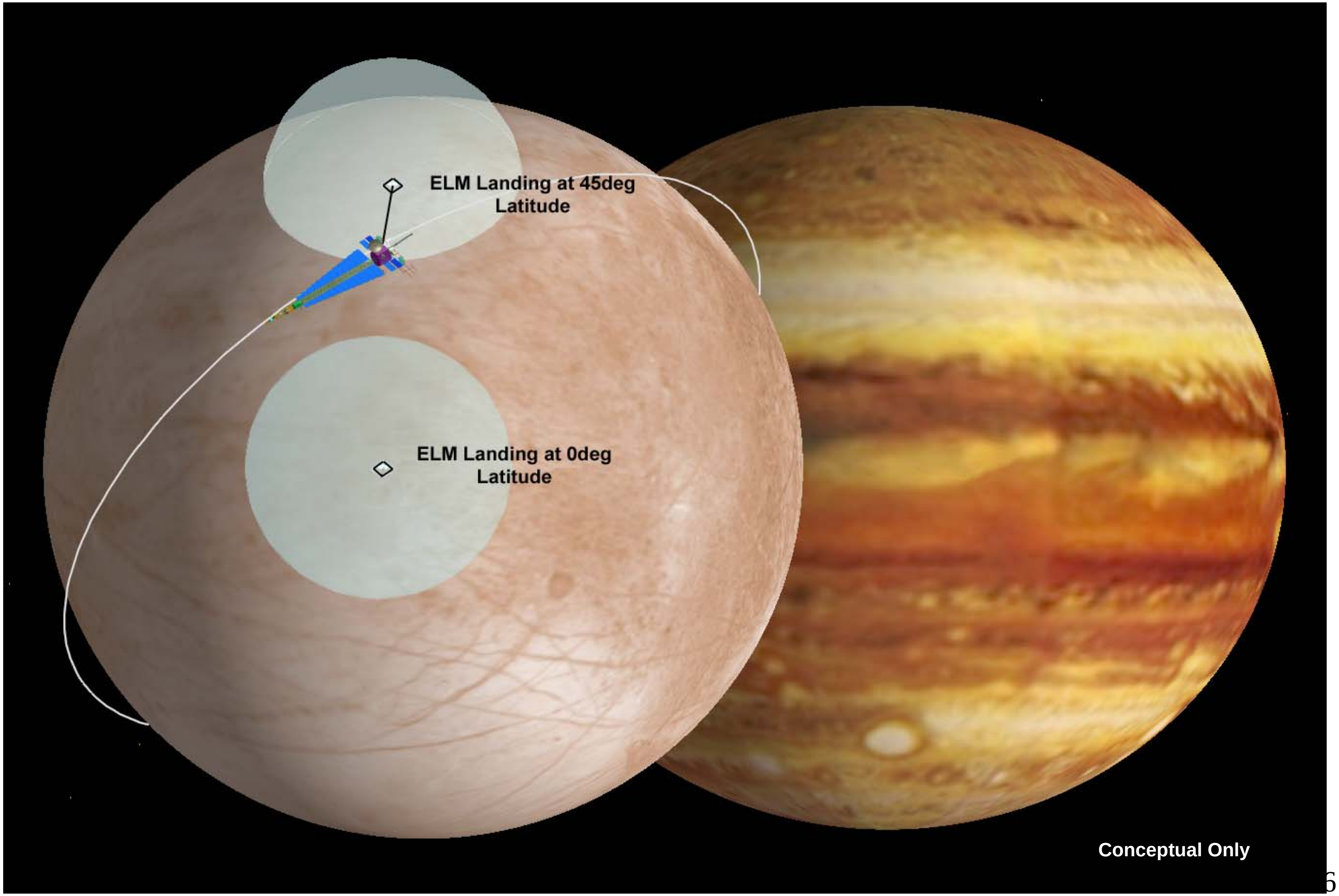
Note: Radiator panels, antennas and internal subsystems (other than RPS) not shown.

Mission Design and Constraints*

- Mission Dates
  - Earliest Availability: Assumed 2015 via JIMO; Earlier using Delta/Atlas (requires Europa Orbiter).
- Delivery Vehicle
  - Planned delivery vehicle: JIMO Spacecraft (1500 kg total science payload capability)
- Lifetime
  - Transit duration: TBD – Assumed 13 years total for power system sizing.
    - 9 years to Jupiter system, 4 more years to Europa
  - Active measurement duration: 30 days on Europa surface
  - Total: ~13 years (Assumed for power system sizing)
- Delta-V Requirements (Independent of Delivery Vehicle)
  - Delta-V: 1480 m/s for ELM Stop and Drop maneuver.
- Constraints
  - JIMO would stay in orbit around Europa for 30 days and provide the communications link between the Lander and Earth.
  - Orbital Parameters: JIMO is in a circular 100 km altitude orbit during the 30 day lander mission.
  - Operational Constraints: JIMO would need to be oriented such that the JIMO-to-Lander comm. system can point towards the lander during each comm. period to receive the omni-directional signal.

* JIMO information has not been finalized by the JIMO program office – Indicated values are study assumptions only.

ELM Communications Architecture



ELM Communication Architecture

- The frequency and duration of communication periods from ELM to JIMO drives the communications architecture.
- The frequency and duration of communication events is highly dependent upon the latitude of the ELM landing site.

0^{O} Lander latitude

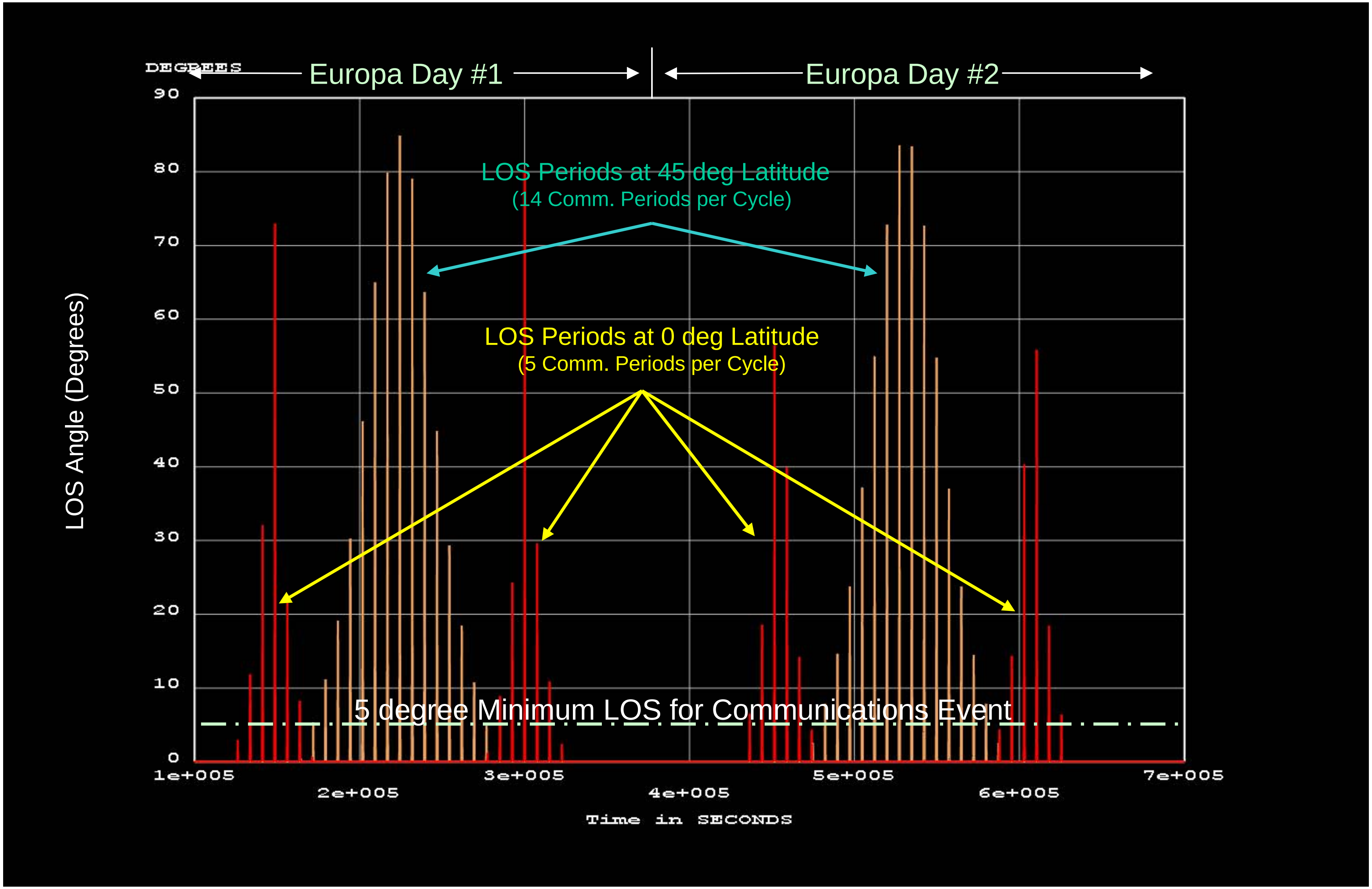
~17 Comm. Cycles (Total mission)
5 Comm. Periods / Cycle (83 total)
710 min. of Comm. (Total)
~43 min. of Comm. / Cycle (Avg)
43 hours of eclipse / Cycle

45^{O} Lander latitude

~8 Cycles (Total mission)
14 Comm. periods / Cycle (111 Total)
1050 min. of Comm. (Total)
130 min. of Comm / Cycle (Avg)
84 hours of Eclipse / Cycle

- The ELM bandwidth requirement is driven by the short communication duration (42.7 min/cycle) of the 0^{o} latitude case.
- The ELM data storage requirement is driven by the long eclipse period (84 hours/cycle) of the 45^{o} latitude case.

Elevation Line-of-Site (LOS) Angle from Lander to JIMO Over Two Europa Days (~7 Earth days)



Baseline Instrumentation Suite

Instrument	What it does	Science Objective Addressed
Imager	Obtains near-field and far-field images through viewports.	Characterize the surface characteristics and surface geology of the landing site.
Microseismometer	Detects and records ground motions (icequakes).	Determine the internal structure.
Raman Spectrometer	Measures backscattered laser light to determine composition and concentration of minerals and chemical species present, including organics.	Search for signatures of biological activity. Characterize the chemical and physical habitability. Describe the composition of non-ice materials.
Laser-Induced Breakdown Spectrometer (LIBS)	Pulsed laser focused on surface ice produces an ionized plasma whose emissions are diagnostic of the elemental composition of surface materials (Complementary to the Raman instrument).	Search for signatures of biological activity. Characterize the chemical and physical habitability. Describe the composition of non-ice materials.
Temperature Sensor	Measures ambient temperature at landing site.	Provide ground truth for remote observations. Characterize the thermal properties of the surface through measurements over the diurnal cycle
Radiation Sensor	Measures levels of ion and electron irradiation at the landing site.	Characterize surface habitability. Provide ground truth for models of surface radiation levels based on orbiter data

Data Requirements

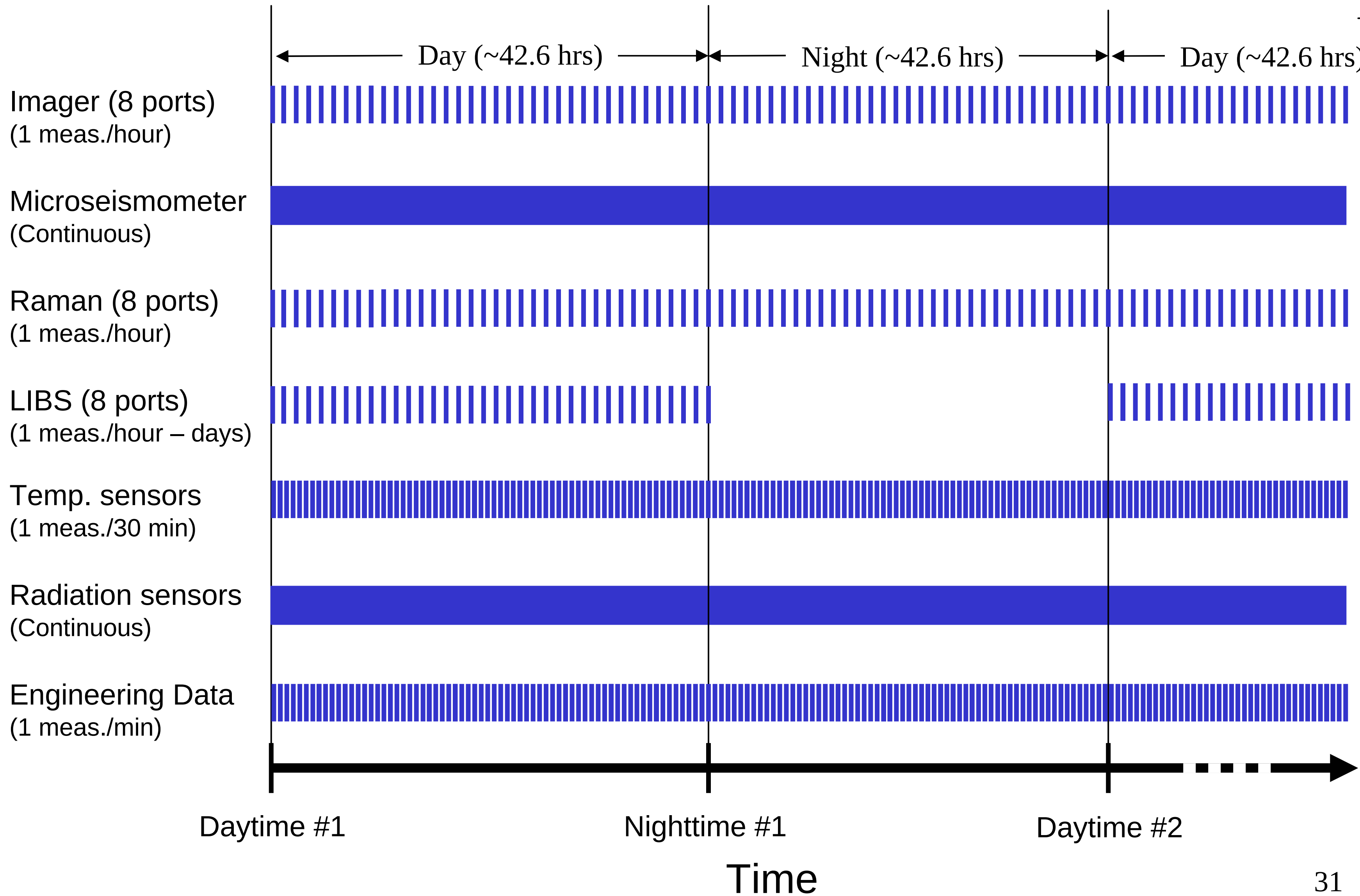
Instruments	Data Rate (kbits / msmt)	# of Instruments	#Measuremts per Europa Day	Measuremt Frequency (# / Earth Hr)	Accumulated Data Volume per Europa Day (kbits)	Accumulated Data Volume per Europa Day (Mbits)
Imager	2600	16	85	1	219762	220
Microseismometer	1	3	304286	3600	912858	913
Raman Spectrometer	10	1	85	1	845	0.85
LIBS	10	1	42	1	423	0.42
Temperature Sensors	0.016	16	169	2	43	0.04
Radiation Sensors	0.016	4	304286	3600	19474	19
Engineering Data	0.100	1	5071	60	507	0.51

Total Accumulated Data Volume / Euro Day (Mbits)	1154
Uplink Capability / Euro Day (Mbits)	3407
Req'd Uplink Rate (Mbit/s)	**0.47**
Available Uplink Rate (Mbit/s)	**1.40**
Margin in Uplink Capability (Also Have 3dB margin)	195%
Data Storage Reqt Based on Longest Eclipse (Mbits)	1154
Design Data Storage w/ 20% Margin (Mbits)	**1385**

- Data uplink requirement is 1.4 Mbit/s – Draws 6 We Peak Power.
  - Comm. design has uplink margin of ~200%
- Data storage requirement is 1.4 Gb – Draws 3 We Peak Power.

Data Taking Schedule

Measurements Stop During All Comm. Events



ELM Duty Cycles and Subsystem Power Levels

System		Qty	Power Draw (W / unit)	Power Draw All Units (W)	Duty Cycle	Avg Power Draw per Europa Day (W)	Operating Time per Europa Day (Hrs)
Command Data and Handeling							
	System Flight Computer	1	2.60	2.60	0.30	0.78	85.20
	Peripheral Subsystem Intf (PSI)	1	1.00	1.00	0.30	0.30	85.20
Power Distribution							
	DC/DC Converter Card	1	3.00	3.00	0.30	0.90	85.20
	Power Distribution Slice	1	2.20	2.20	0.30	0.66	85.20
Science Instruments							
	Imager	1	0.20	0.20	1.00	0.20	0.23
	Microseismometer	3	0.14	0.42	1.00	0.42	84.52
	Raman Spectrometer	1	5.00	5.00	1.00	5.00	2.82
	LIBS	1	5.00	5.00	1.00	5.00	2.82
	Temperature Sensors	16	0.10	1.60	1.00	1.60	0.47
	Radiation Sensors	4	0.10	0.40	1.00	0.40	84.52
Comm. Subsystem (JIMO Link)							
	Transceiver (2W RF Output, 33% Efficient)	1	6.00	6.00	1.00	6.00	0.68
Data Storage							
	Data Storage (SSR)	1	3.00	3.00	0.30	0.90	85.20

ELM Operating Modes and Durations are selected to Maximize Science Return while Meeting the Power Budget.

ELM Operating Modes and Power Requirements

Mode	Peak Power Draw (W)	Avg Power Draw (W)	RPS Output Power at EOM (W)	Duration of Mode / Europa Day (hr)	Total Energy Used During Mode (W-hr)
1: Standby Mode	11.80	1.50	10.14	N/A	N/A
2: Basic Measurement Taking Mode	12.34	4.12	10.14	78.89	325.02
3: Raman Measurement Taking Mode	17.34	9.12	10.14	2.82	25.70
4. LIBS Measurement Taking Mode	17.34	9.12	10.14	2.82	25.70
5: Communications Mode	17.80	7.50	10.14	0.68	5.07
Max (Max Power Draw) (W)	17.80	Energy Required / Europa Day (W-hr)=			381
Avg Power Draw (W) =	4.5	RPS Energy Generated / Europa Day (W-hr)=			864
GPHS Power Output (W) =	10.14	Total Energy Req'd for Surface Mission (W-Hr)=			126%

Maximum Power Draw: 17.8 W

Avg Power Draw: 4.5 W

RPS Power Output (EOM): 10.1 W

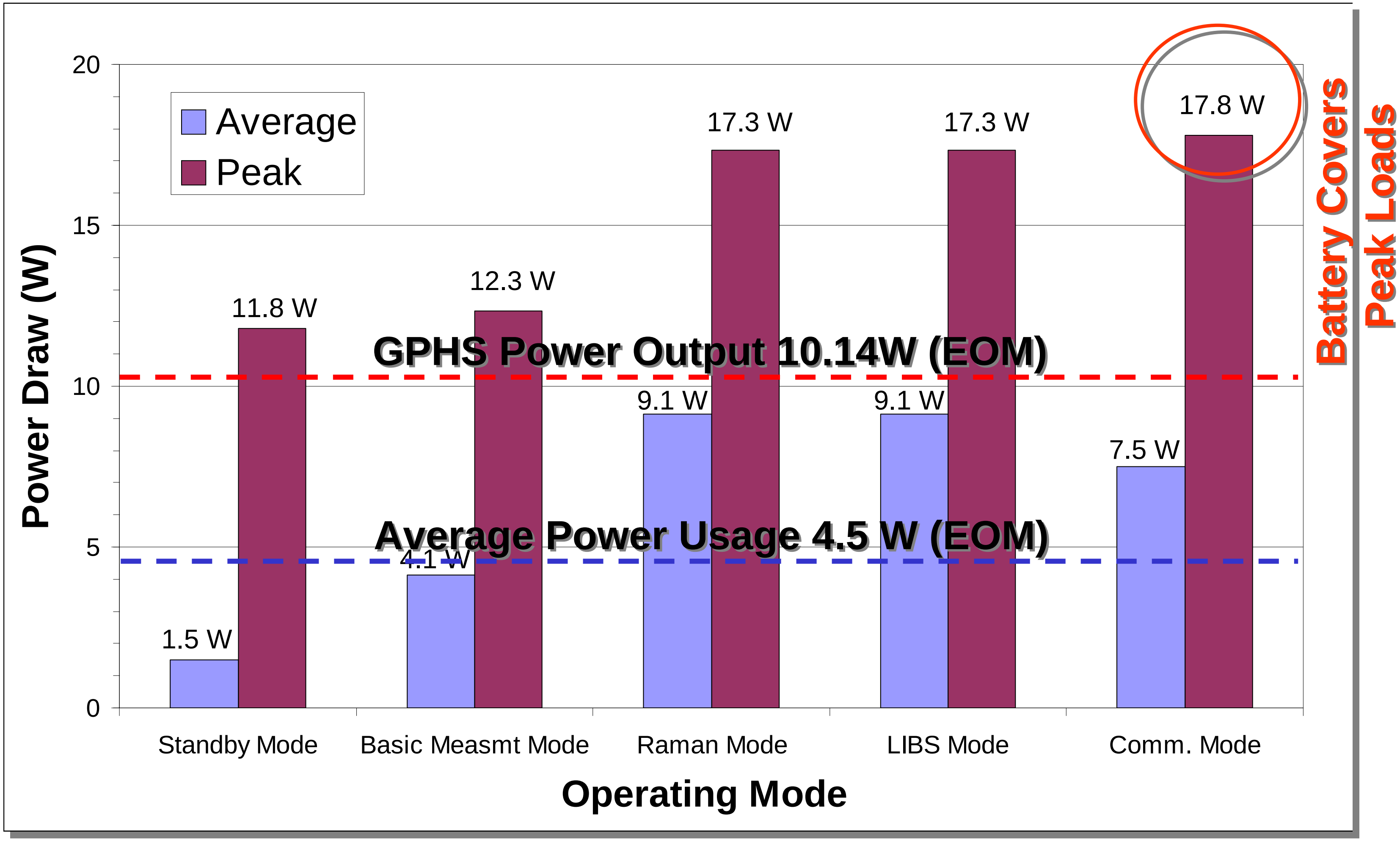
Req'd Battery Size: 63.1 W-Hr

Req'd Battery Mass: 0.53 kg

Battery Requirements

Additional Peak NRG Req'd (W-Hr)	**12.49**
Battery Depth of Discharge (%)	33%
Battery Charging Efficiency (%)	90%
Battery Energy Density (W-Hr/kg)	120
Battery Energy Volume (W-Hr/liter)	200
Min. Reqd Batt. (W-Hr)	42.05
Batt w/ 50% Margin (W-Hr)	**63.08**
Batt Mass (kg)	**0.526**
Batt Volume (Liters)	**0.315**

Power Levels for Each Operating Mode



ELM Mass Requirements

Item	Qty	CBE (kg)	Uncertainty (kg)	Total CBE (kg)
Lander Payload				**38.7**
Command Data and handling				**1.84**
System Flight Computer	1	0.50	0.08	0.58
Peripheral Subsystem Intf (PSI)	1	0.10	0.02	0.12
Bus	1	1.00	0.15	1.15
Power Distribution				**1.64**
Power Distribution Slice	1	0.49	0.05	0.54
DC/DC Converter Card	1	1.00	0.10	1.10
Power				**11.16**
GPHS RPS	1	5.00	5.00	10.00
Batteries	1	0.33	0.17	0.50
Packaging	1	0.63	0.03	0.66
Pyro and Valve Control				**0.87**
Battery Charge Control	1	0.30	0.03	0.33
Prop Drive	1	0.49	0.05	0.54
Science Instruments				**9.30**
Seismometer	3	0.05	0.01	0.18
Imagers	16	0.20	0.04	3.84
Raman Spectrometer	1	2.00	0.40	2.40
LIBS	1	2.00	0.40	2.40
Radiation Sensor	4	0.10	0.02	0.48
Temp sensors	16	0.01	0.00	0.17
***Telecom* - S-Band Subsystem**				**3.30**
Transceiver	1	0.30	0.03	0.33
S-Band Antenna	6	0.25	0.03	1.65
Packaging	1	0.30	0.03	0.33
Coax Cables to antennas	6	0.15	0.02	0.99
G & C Sensors				**0.21**
Accelerometers	3	0.05	0.00	0.16
3 axis gyro	1	0.05	0.00	0.05
Thermal				**1.26**
Heater Elements	10	0.02	0.00	0.21
Insulation	1	1.00	0.05	1.05
Mechanical Systems				**10.00**
Structure	1	3.60	0.36	3.96
Covers	6	0.10	0.01	0.66
Misc (fasteners)	1	0.72	0.03	0.75
Cabling	1	0.60	0.03	0.63
Radiation Shielding	1	2.00	2.00	4.00
Net Lander				**38.7**

Item	Qty	CBE (kg)	Uncertainty (kg)	Total CBE (kg)
Propulsion				**111.4**
Upper Desent Stage				**13.7**
Support and Separation Mechanism	3	1.00	0.05	3.15
Support structure	1	2.54	0.25	2.79
ARC Solid KS40B Thrusters (spin-up)	2	0.38	0.02	0.80
ARC Solid PAC-3 Thrusters (spin-down)	2	0.16	0.01	0.34
Hydrazine trim system	1	1.80	0.09	1.89
Star 5 rocket motor	1	4.50	0.23	4.73
Lower Desent Stage				**97.7**
Support and Separation Mechanism	3	1.00	0.05	3.15
Support Structure	1	5.70	0.57	6.27
Star 17 Motor	1	84.10	4.21	88.31
Thermal				**2.2**
Thermal Blankets	1	1.00	0.05	1.05
Temp sensors	10	0.01	0.00	0.11
Misc	1	1.00	0.05	1.05
Mechanical Systems				**13.9**
JIMO Attachment System	1	5.00	3.00	8.00
Ballest	1	5.00	0.50	5.50
Fasteners	1	0.40	0.01	0.41
Landing System				**61.0**
NSI - Gas Generator	3	1.00	0.05	3.15
Airbags	3	16.06	3.21	57.82
JIMO-Based Comm.system				**5.5**
Antenna	1	3.00	1.00	4.00
Gimbal	1	1.00	0.50	1.50
Net Spacecraft (EPF)				**232.7**
Lander Mass (Total)				**38.7**
Propulsion Mass (Total)				**111.4**
Thermal Mass (Total)				**2.2**
Mechanical Systems Mass (Total)				**13.9**
Landing System Mass (Total)				**61.0**
JIMO-Based Comm. System				**5.5**
S/C subtotal				**232.7**

Lander Mass: 38.7kg

Total S/C Mass: 232.7kg

ELM Thermal Requirements

- Assumptions
  - GPHS Thermal Power: 250 We (BOM) / 225 We (EOM @ 13yrs)
  - Thermoelectric Cold-Leg Temp. 155^{o}C
- Thermal Control is Accomplished via Multiple Approaches:
  - Conduction straps and thermal switches keep critical electronics, batteries and subsystems warm.
  - Thermal radiation to space is performed through variable-emissivity radiators mounted on both surfaces of the lander.
    - The emissivity can be actively varied between ~0.3 and 0.7 to maintain the desired lander temperature profile (Beasley, Kislov, Biter STAIF 2004).
  - Heat rejection to the Europan surface is made via contact conduction between the surface and lander structure. Thermal switches control heat flow.

- The RPS Waste Heat is Used to Keep Critical Electronics and Subsystems Warm.
- Variable emissivity radiators permit active thermal control using minimal power and no moving parts.

Radiation Environment

– **Externally Generated Radiation**

- ELM receives an external dose of ~420 kRad during the 30 day surface mission*.
- The total received lifetime (13 year) dose is ~6 MRad*.
- Potential mitigation strategies include housing ELM in a JIMO-mounted radiation shelter, using spot shielding around critical components, and employing rad-hard electronics with >1 MRad tolerance.
  - Shelter and shielding could potentially reduce lifetime ELM external dose to <1 MRad.
- ELM will capitalize off the JIMO radiation studies and technology currently being studied, and will utilize similar or identical mitigation schemes.

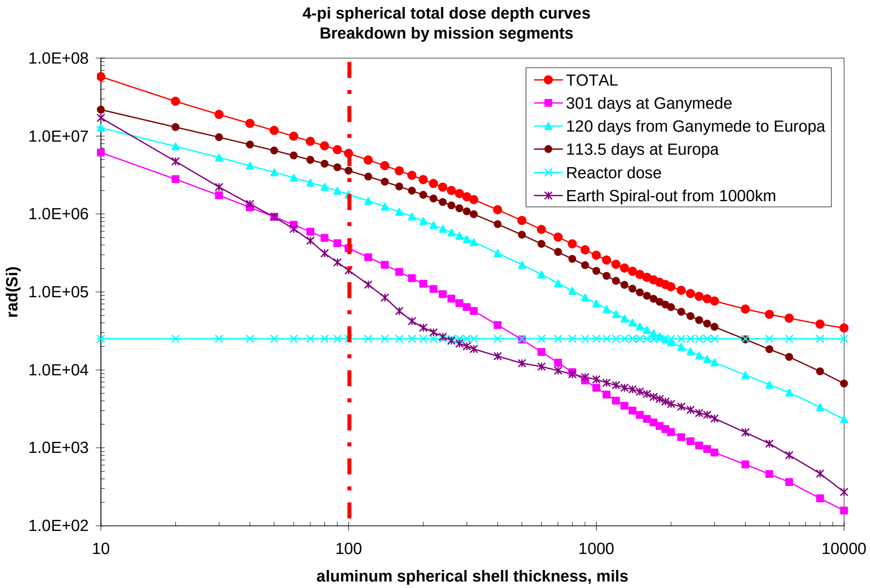
– **Internally Generated Radiation**

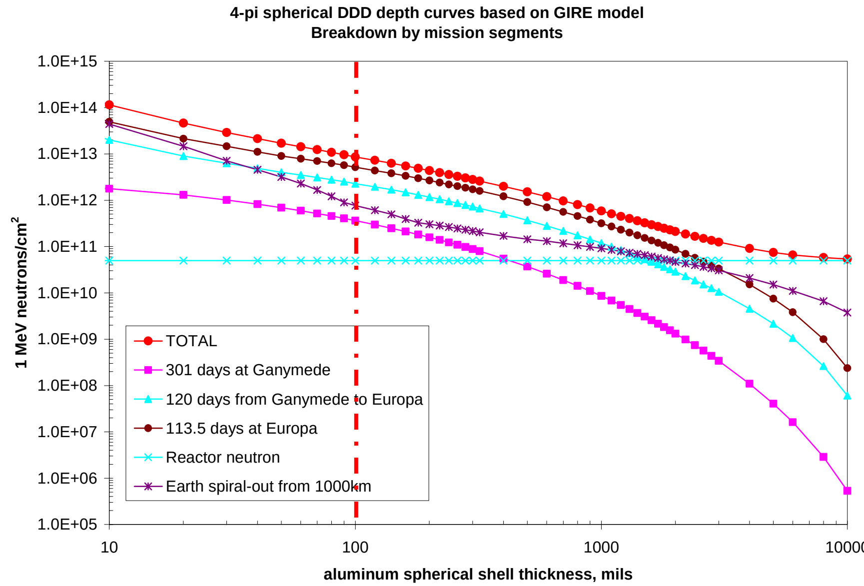
- Internally-generated radiation is produced by the GPHS module.
- Intensity of radiation falls of quickly with distance from the GPHS due to spatial and structural attenuation through the RPS and ELM structure.
- GPHS-generated radiation is significantly lower than the natural radiation dose (Can be made <100 kRad with proper design).
- Judicious placement of electronic and lander structure can keep the total GPHS-emitted dose to levels tolerable with existing technology.

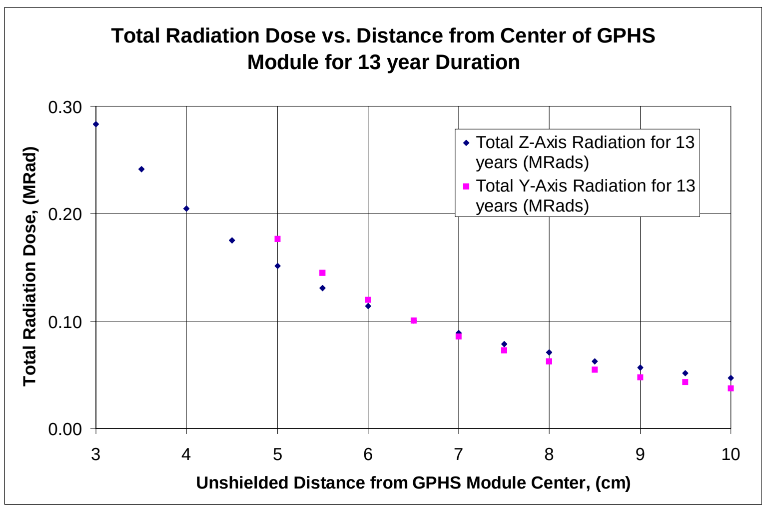
Radiation can be mitigated using a JIMO-mounted radiation shelter, spot shielding, and rad-hard parts.

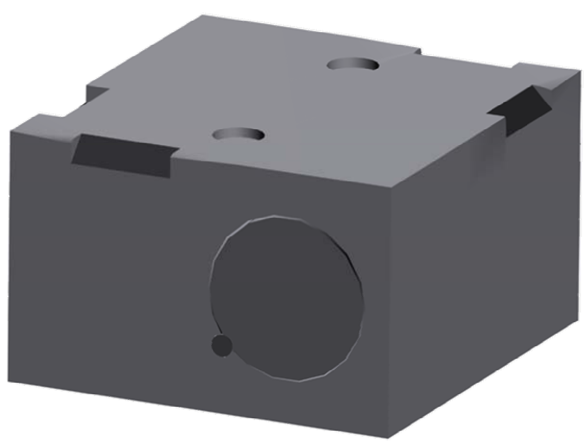
* Calculations extrapolated from those provided by Insoo Jun (JPL) and assume 100 mil aluminum shielding.

Radiation Environment (Continued)*









GPHS Module

*Radiation Data provided by Insoo Jun (JPL).

Alternate Power System Concepts

- Current ELM design uses one GPHS/TE RPS and a small battery to meet all power requirements.
  - Battery needed to supply peak power demands during LIBS, Raman and Communication events (max. of 17.8 Watts).
- Could eliminate the need for a battery using alternate power system architecture, including:

- Use Two GPHS RPSs with baseline 5% TE Conversion Efficiency
  - Capable of generating 20.2W (EOL) – meets all power modes.
  - Requires larger, more massive spacecraft – redesign necessary.
  - Heat rejection becomes a significant issue.

Not recommended

- Use Higher-Efficiency Power Converters
  - A 9% efficient TE converter could generate >17.8 W (EOM) using one GPHS module.
  - A small 20% efficient Stirling engine could generate >17.8 W (EOM) using just two GPHS Fuel Pellets.
    - » Stirling needs to be sufficiently vibration-free to prevent interference with microseismometer measurements.

Summary and Conclusions

- The Europa Lander Mission (ELM) is designed to search for signatures of biological activity and measure the chemical and physical properties of Europa.
- ELM would ride "piggyback" on the proposed JIMO S/C during the ~13 year cruise phase, and would land on Europa to perform its 30 day science mission.
- The ELM Mission is enabled by the RPS power system.
  - A single GPHS/TE RPS powers ELM and provides 126% energy margin.
  - A small 63 W-Hr Li-Ion battery is used to carry the peak loads.
  - The excess heat is used to warm critical electronics, batteries and subsystems in the frigid Europan environment.
- Higher-efficiency power converters could further optimize the system:
  - Could eliminate the need for the Li-Ion battery.
  - Could reduce the req'd amount of Pu238 fuel. (Use 2 pellets vs. current 4).

Additional RPS-Enabled Missions

– The ELM configuration can be used for missions on Callisto and Ganymede with minimal modification.
  - The ELM RPS configuration would be adequate for a 60 day Callisto surface mission, and a 120 day Ganymede mission
    – Durations are based on a preliminary JIMO mission timeline.

– Additional small RPS-enabled Lander mission could include:
  - Small landers for outer solar system solid bodies.
    – Includes moons, Pluto, asteroids and comets.
  - Lunar human-precursor missions
    – RPS enables operation through the 14 day eclipse, at poles and in the shadows of canyons and mountains.
  - Mars Network, Scout Class and Human Precursor Landers
    – RPS permits continuous, long term missions in polar regions and other low-insolation areas.