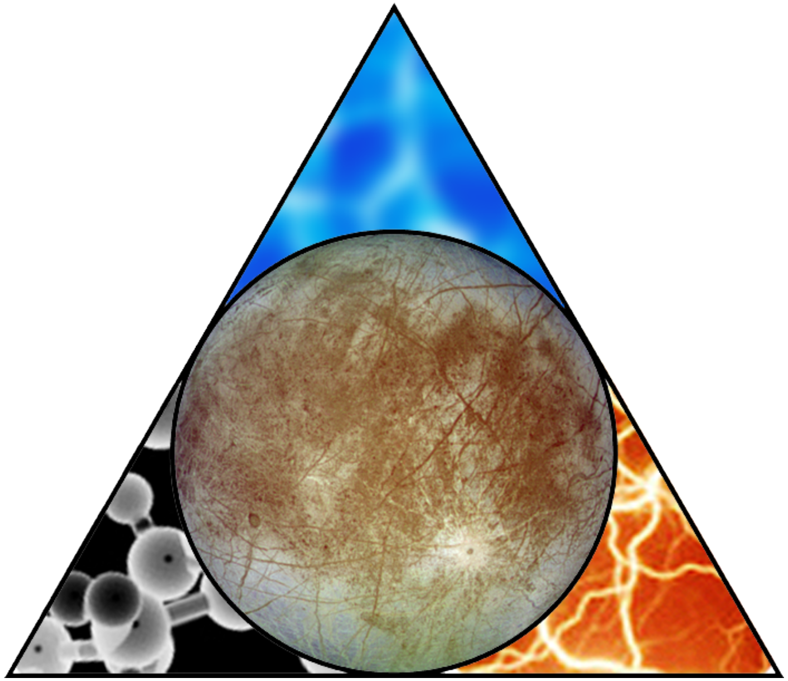


Europa Mission
Concept Study Report

Jet Propulsion Laboratory, California Institute of Technology

5/24/12

Outline

1. Introduction	Thomas Gavin
2. Why Europa?	Robert Pappalardo
3. Multiple Flyby Mission (Europa Clipper)	
Clipper Science	Robert Pappalardo
Mission & Spacecraft Design	Brian Cooke
Cost & Cost Validation	Thomas Gavin
Independent Review	Thomas Gavin
4. Orbiter & Lander Concepts	Robert Pappalardo
5. Future Work	Thomas Gavin
6. Conclusion	Thomas Gavin

Acknowledgement

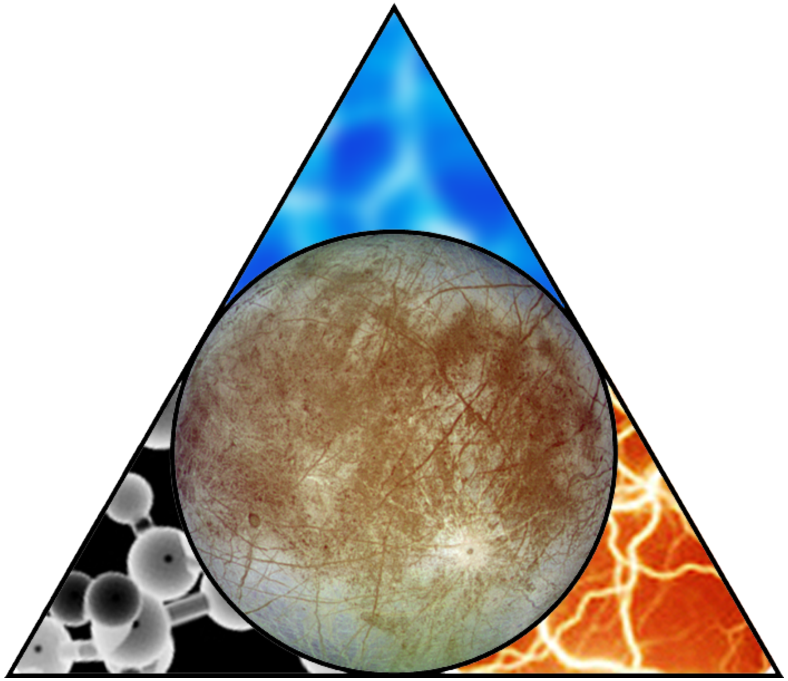
This report represents the combined effort since April 2011 of the Europa Science Definition Team and a study team from the Jet Propulsion Laboratory (JPL) and Johns Hopkins University's Applied Physics Laboratory (APL).

The team acknowledges and appreciates the support of NASA's Program Scientist and Program Executive.

National Aeronautics and Space Administration

EUROPA STUDY 2012 REPORT

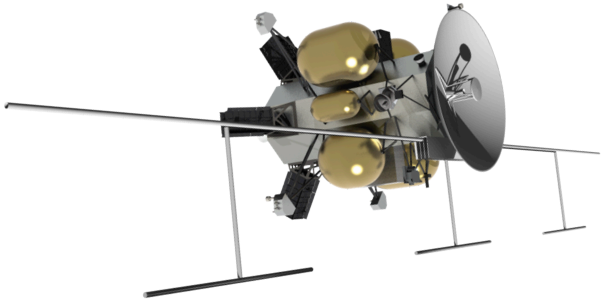
Europa Study Team, 1 May 2012, JPL D-71990
Task Order NMO711062 Outer Planets Flagship Mission
Cover art Michael Carroll



Introduction

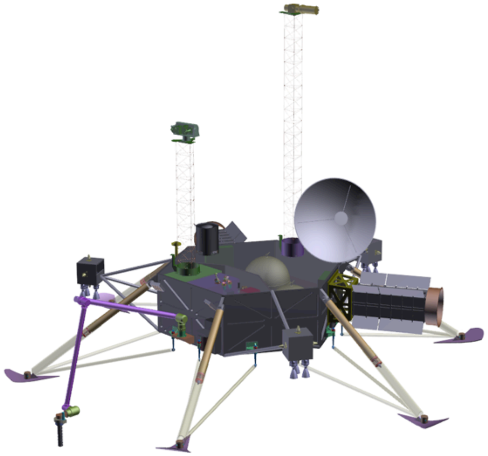
Introduction

- Proposed 2020 Jupiter Europa Orbiter (JEO) mission was deemed extremely high science value, but unaffordable by the NRC Decadal Survey, which requested a descoped option
- NASA directed a 1 year study to develop mission options that retain high science value at significantly reduced cost
- Innovative design options for mission and spacecraft have resulted in 3 mission options
- This presentation summarizes these options:



Multiple-Flyby in Jupiter Orbit (The Europa Clipper)

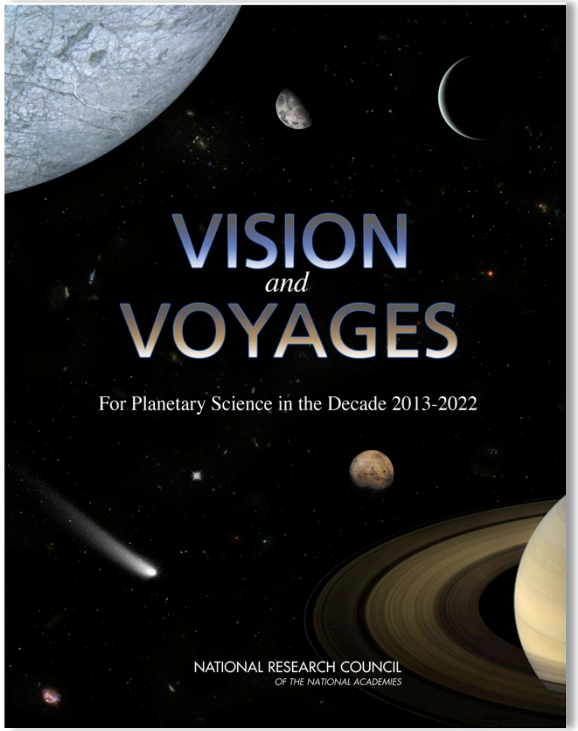
Europa Orbiter



Europa Lander

Decadal Survey Background

- JEO concept resulted from more than a decade of Europa mission science definition and technical assessment
- JEO fully addressed most key Europa science questions, and the 2011 Planetary Decadal Survey found it had *"exceptional science merit"* equivalent to Mars Sample Return
- NRC's independent cost estimate deemed it unaffordable at $4.7B
- Decadal Survey recommended: *"NASA should immediately undertake an effort to find major cost reductions for JEO…"*
- NASA enlisted the Europa Study Team and a new Europa Science Definition Team (SDT) to define a set of descoped lower-cost options for Europa exploration



VISION *and* VOYAGES

For Planetary Science in the Decade 2013-2022

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

NASA Charge to Study Team

- Develop missions options whose primary science objective is Europa
- Utilize the SDT to provide guidance on science objectives, measurements, and priorities
- Present mission options to OPAG for comments and endorsement
- Arrange for an independent cost, schedule and technical review
- Provide a final written report by May 1, 2012 detailing the mission options and review board findings
- All objectives were met and were documented in the final report, which was submitted to NASA on May 1

National Aeronautics and Space Administration

EUROPA STUDY 2012 REPORT

Europa Study Team, 1 May 2012, JPL D-71990
Task Order NMO711062 Outer Planets Flagship Mission
Cover art Michael Carroll

Europa Science Definition Team

- 6 face-to-face meetings
  - Defined reduced science scope for 3 mission options
  - Refined Goal, Objectives, Investigations, Measurements, Model Instruments
  - Iterated with technical team to derive floor and baseline science requirements

- Diverse group of 18 scientists
  - Outer planet and Europa science
  - 4 NASA centers and 8 universities and research institutes
  - Practical mission experience
    - *Galileo*, *Cassini*, *New Horizons*, *Juno*, *MESSENGER*, *Grail*, *Odyssey*, *MGS*, *MER*, *Phoenix*, *MSL*…

An 18 Member Europa Science Definition Team

Continued members from JEO SDT:

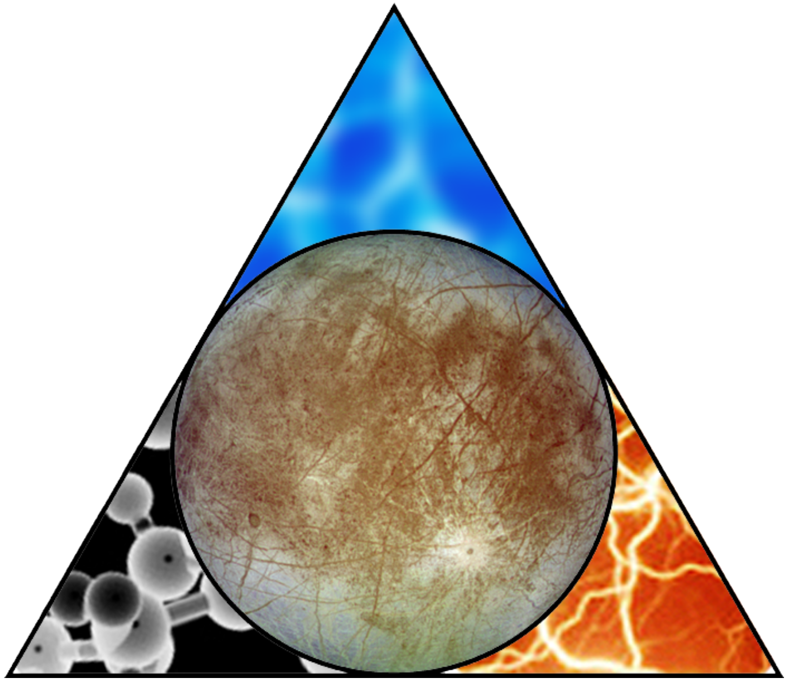
Bruce Bills	JPL	Geophysics
Diana Blaney	JPL	Composition
Don Blankenship	Univ. Texas	Ice shell
Melissa McGrath	MSFC	Atmosphere
Jeff Moore	Ames	Geology
Robert Pappalardo	JPL	Chair / Study Scientist
Louise Prockter	APL	Deputy / Geology
Dave Senske	JPL	Deputy / Geology

New members added to Europa SDT:

Fran Bagenal	Univ. Colorado	Space Physics
Amy Barr	Brown Univ.	Geophysics
Jack Connerney	GSFC	Magnetometry
Bill Kurth	Univ. Iowa	Plasma
David Smith	MIT	Geophysics

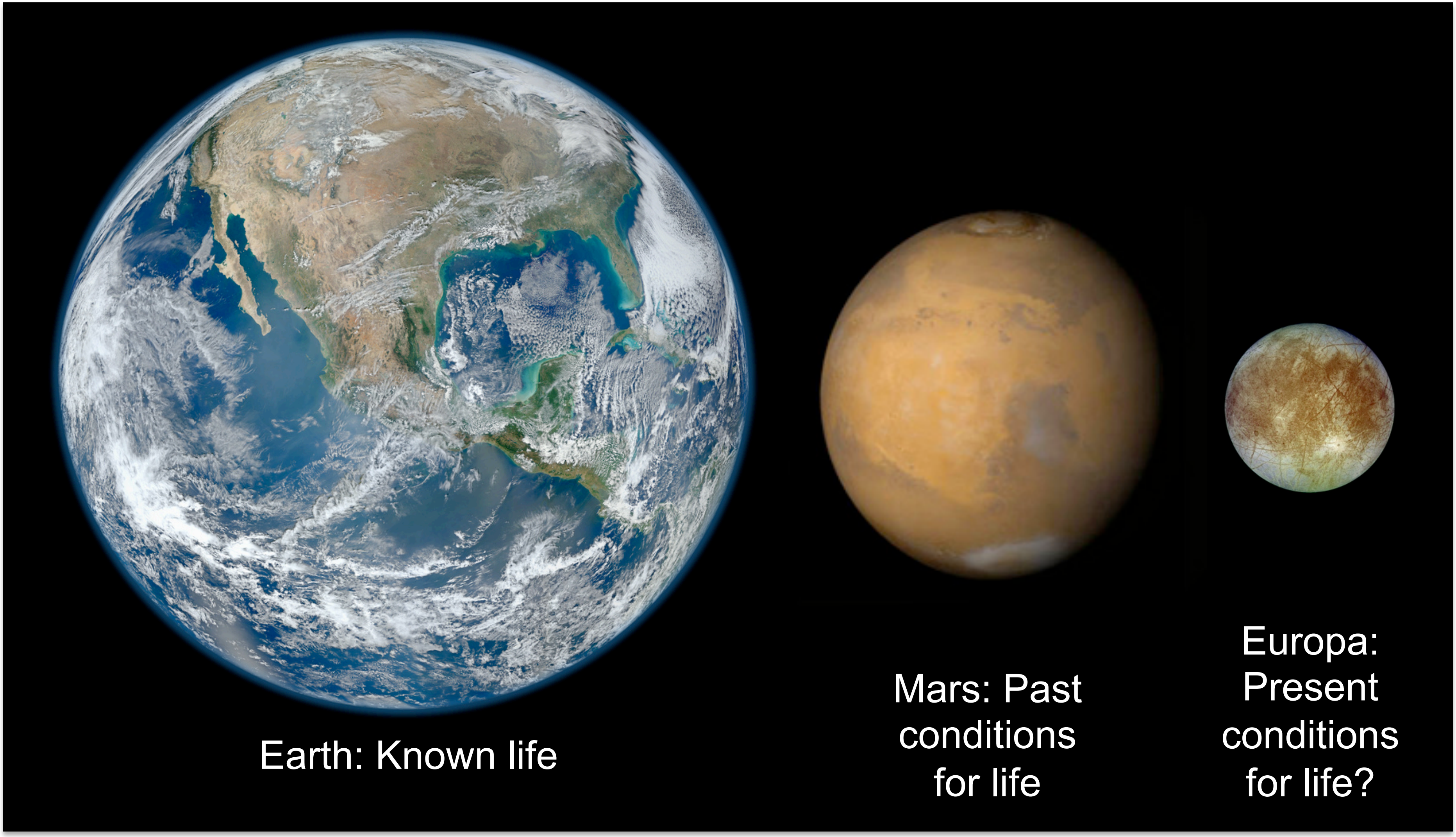
Additional members added during lander study phase:

Will Brinckerhoff	GSFC	Astrobiology
Kevin Hand	JPL	Astrobiology
Tori Hoehler	Ames	Astrobiology
Mike Mellon	SWRI	Ice Physics / Geology
Everett Shock	ASU	Geochemistry



Why Europa?

Where Can There Be Life?

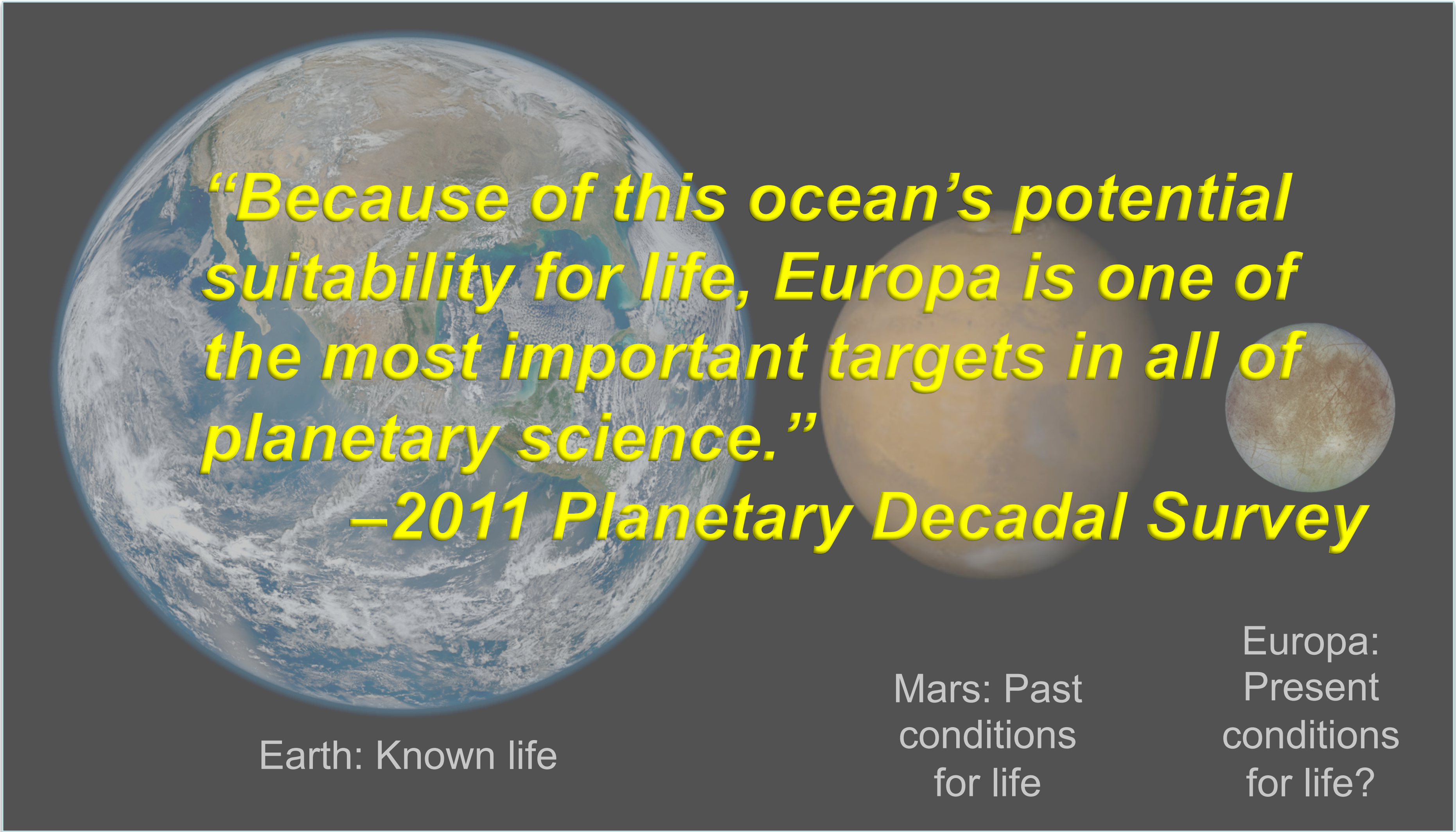


Earth: Known life

Mars: Past conditions for life

Europa: Present conditions for life?

Where Can There Be Life?

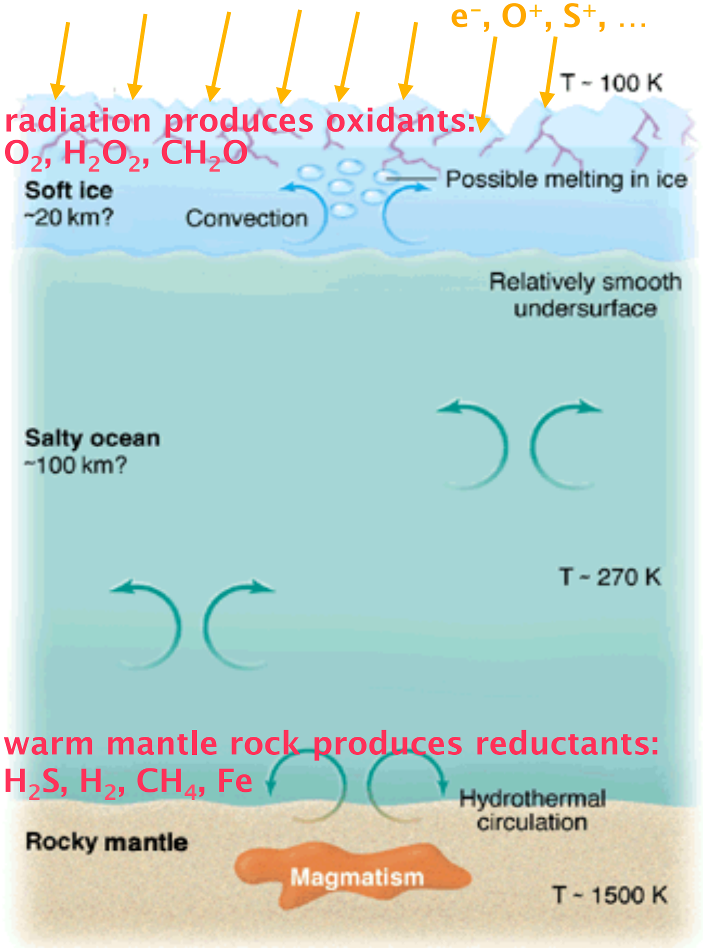


“Because of this ocean’s potential suitability for life, Europa is one of the most important targets in all of planetary science.”

–2011 Planetary Decadal Survey

Europa: Ingredients for Life?

- *Water:*
  - Probable saltwater ocean, indicated 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 tidal heating could create reductants
  - Geological activity would “stir the pot”

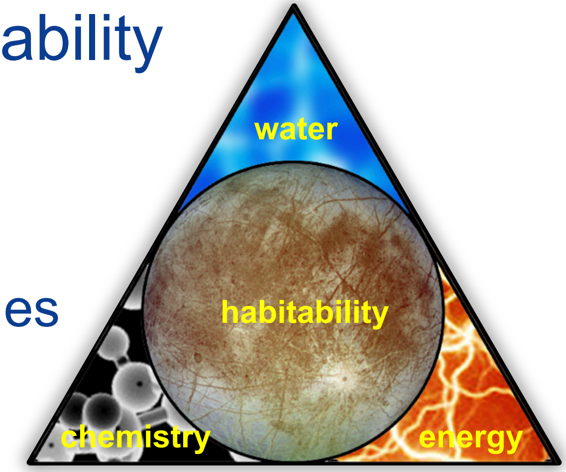


[after *Stevenson, 2000*]

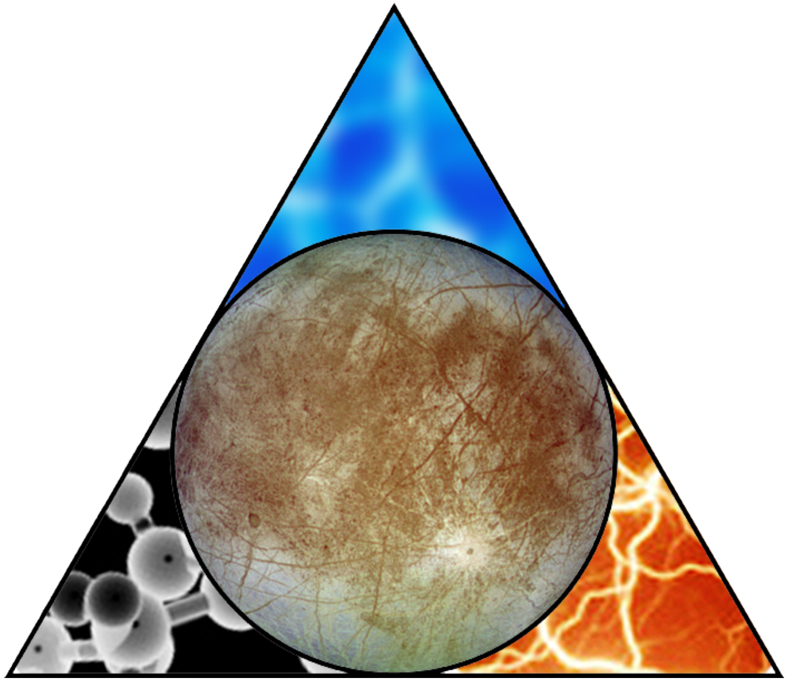
A dedicated Europa mission is required to test habitability hypotheses

Science Goal, Habitability Themes, and Objectives

- *Goal:* Explore Europa to investigate its habitability
- *Habitability Themes:*
  - **Water:** Solvent to facilitate chemical reactions
  - **Chemistry:** Constituents to build organic molecules
  - **Energy:** Chemical disequilibrium for metabolism



- *Objectives:*
  - **Ocean:** Existence, extent, and salinity
  - **Ice Shell:** Existence and nature of water within or beneath, and nature of surface-ice-ocean exchange
  - **Composition:** Distribution and chemistry of key compounds and the links to ocean composition
  - **Geology:** Characteristics and formation of surface features, including sites of recent or current activity

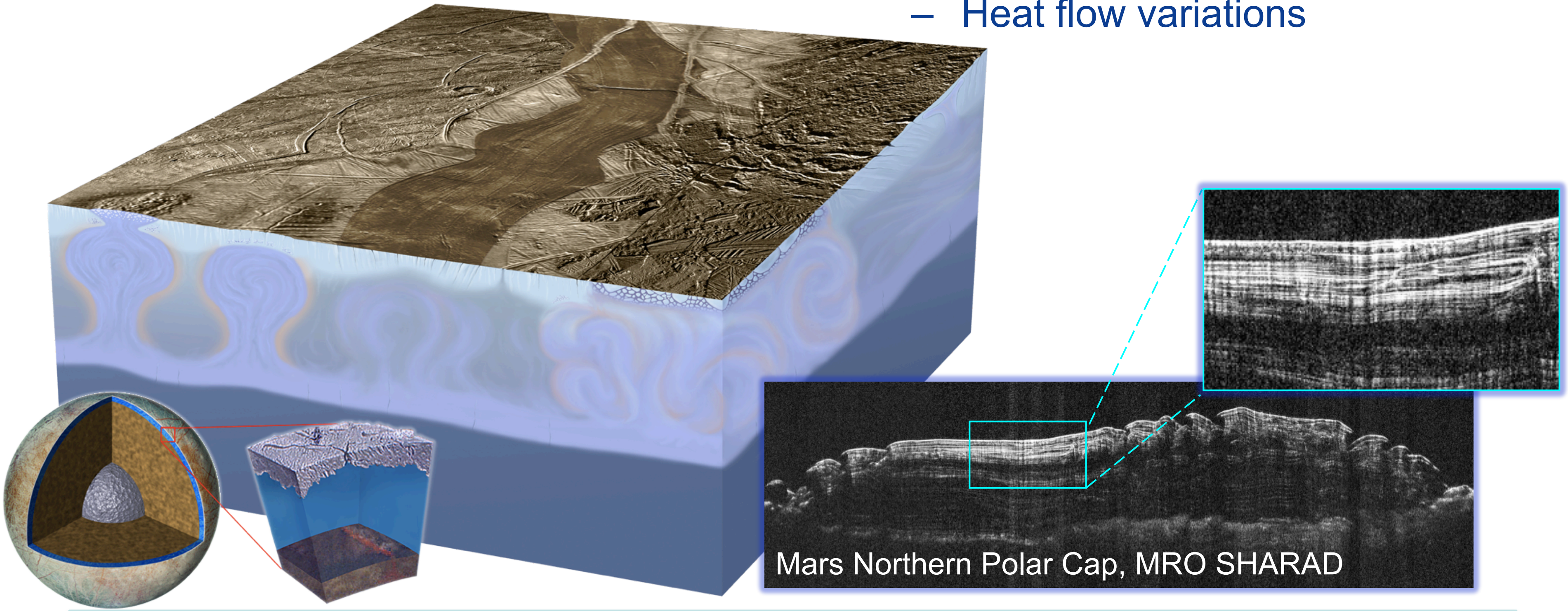


Europa Clipper

A Multiple-Flyby Europa Mission in Jupiter Orbit

Clipper Science: Ice Shell

- Characterize the ice shell and any subsurface water, including their heterogeneity, and the nature of surface-ice-ocean exchange
  - Shallow water within the ice shell
  - Depth to ice-ocean interface
  - Surface-ice-ocean exchange processes
  - Heat flow variations

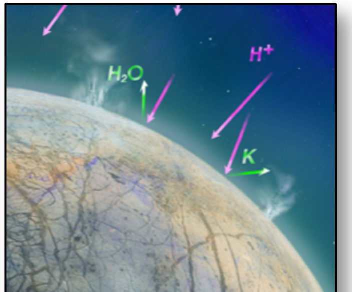


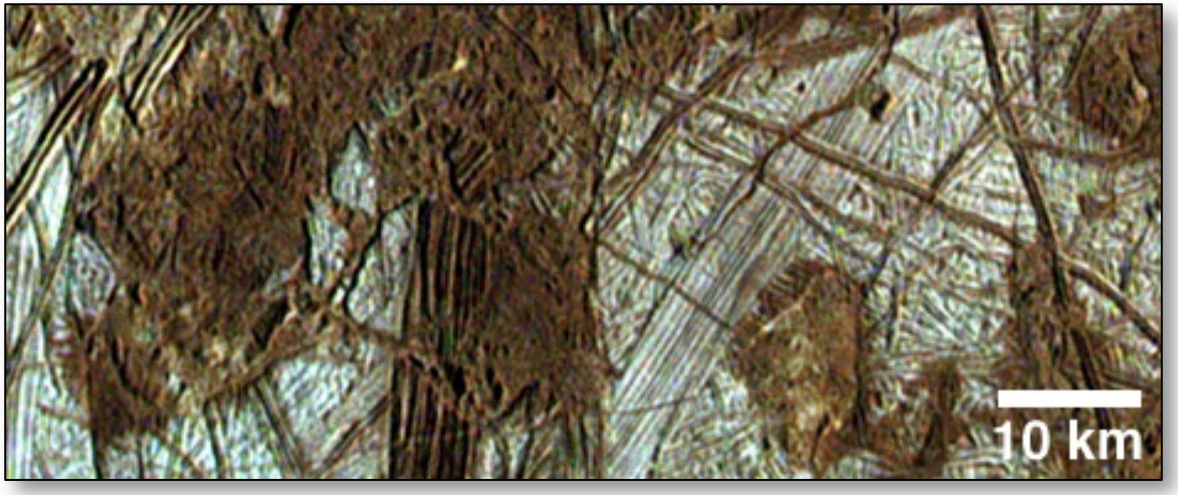
Mars Northern Polar Cap, MRO SHARAD

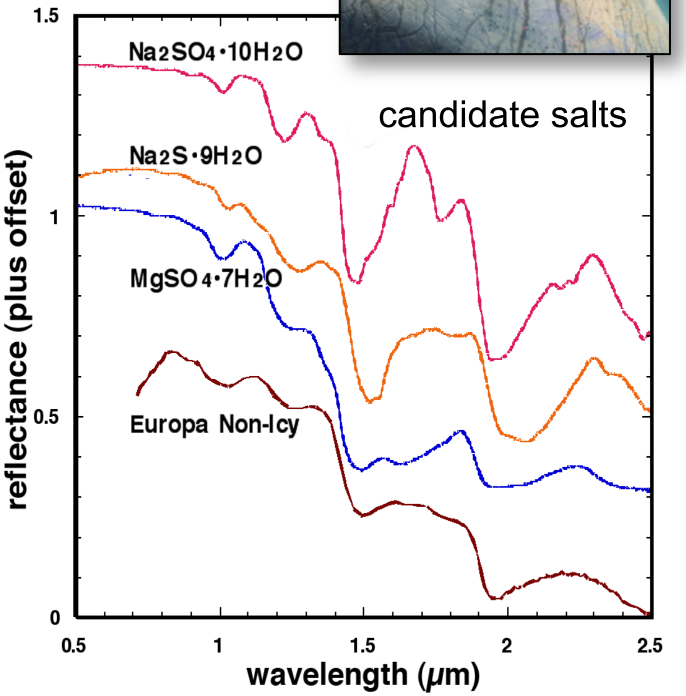
Sounding profiles could find water within and beneath the ice

Clipper Science: Composition

- Understand the habitability of Europa's ocean through composition and chemistry
  - Composition and chemistry of the ocean as expressed on surface and in atmosphere
  - Radiation processing of surface
  - Chemical and compositional pathways in Europa's ocean



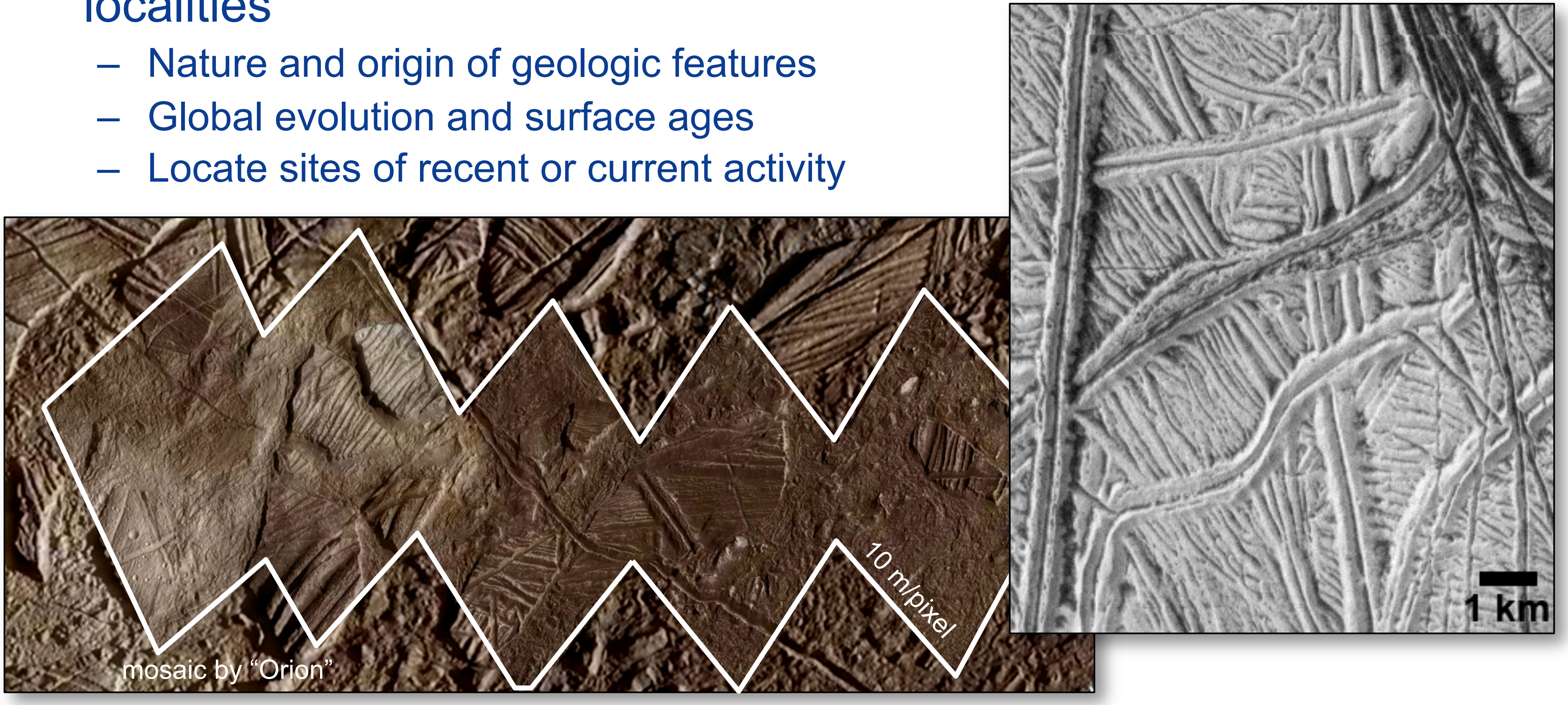




Composition is key to understanding ocean habitability

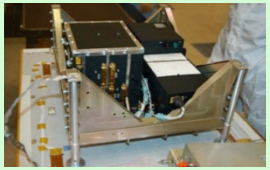
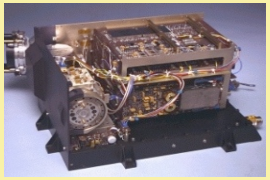
Clipper Science: Geology

- Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities
  - Nature and origin of geologic features
  - Global evolution and surface ages
  - Locate sites of recent or current activity



Stereo imaging can decipher the bizarre and complex geology

Clipper Model Planning Payload

Science Objective	Key Science Investigations	Model Instrument	Similar Instrument
Ice Shell	Sounding of dielectric horizons at two frequencies, to search for shallow water and the ocean.	**Ice-Penetrating Radar (IPR)**	 MRO SHARAD
Composition	Visible and near-infrared spectroscopy, for global mapping and high-resolution scans, to derive surface composition.	**ShortWave IR Spectrometer (SWIRS)**	 LRO M3
	Elemental, isotopic, and molecular composition of the atmosphere and ionosphere, during close flybys.	**Ion and Neutral Mass Spectrometer (INMS)**	 Cassini INMS
Geology	High resolution stereo imagery, to characterize geological landforms, and to remove clutter noise from IPR data.	**Topographical Imager (TI)**	 New Horizons Ralph/MVIC

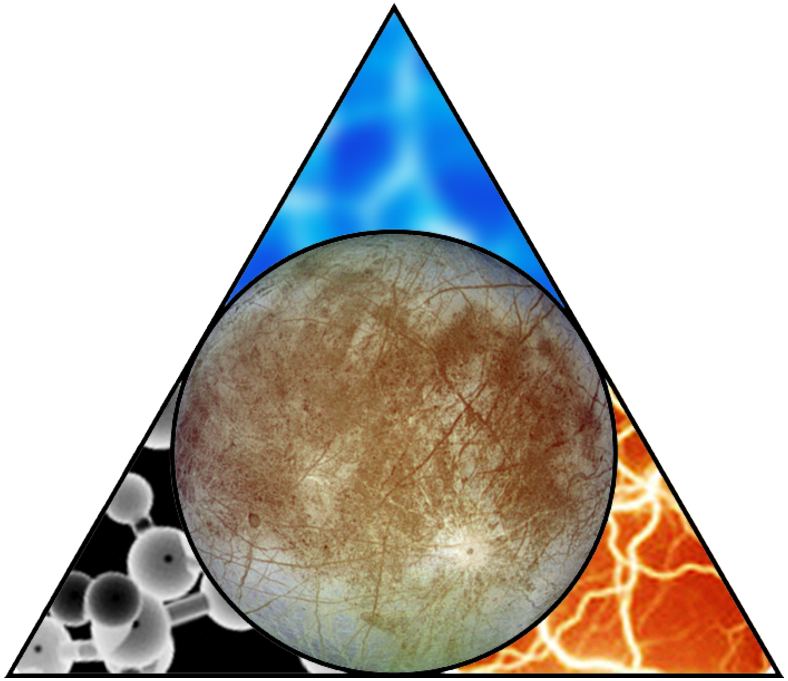
🟩 Floor model instrument 🟨 Baseline model instrument

Clipper Science Traceability

Remote measurements accomplished via multiple flybys

Goal	Objective		Investigation	Model Planning Payload	Theme		
					W	C	E
Explore Europa to investigate its habitability	Ice Shell	Characterize the ice shell and any subsurface water, including their heterogeneity, and the nature of surface-ice-ocean exchange.	Characterize the distribution of any shallow sub-surface water and the structure of the icy shell.	Ice-Penetrating Radar, Topo. Imager	✓		✓
			Search for an ice-ocean interface.	Ice-Penetrating Radar, Topo. Imager	✓		✓
			Correlate surface features and subsurface structure to investigate processes governing material exchange among the surface, ice shell, and ocean.	Ice-Penetrating Radar, IR spectrometer, Topo. imager	✓	✓	✓
			Characterize regional and global heat flow variations.	Ice-Penetrating Radar	✓		✓
	Composition	Understand the habitability of Europa's ocean through composition and chemistry.	Characterize the composition and chemistry of the Europa ocean as expressed on the surface and in the atmosphere.	IR spectrometer, INMS	✓	✓	
			Determine the role of Jupiter's radiation environment in processing materials on Europa.	IR spectrometer, INMS		✓	✓
			Characterize the chemical and compositional pathways in Europa's ocean.	IR spectrometer, INMS	✓	✓	
	Geology	Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities.	Determine sites of most recent geological activity, and characterize high science interest localities.	Topo. Imager	✓		✓

Themes: W= Water, C = Chemistry, E = Energy

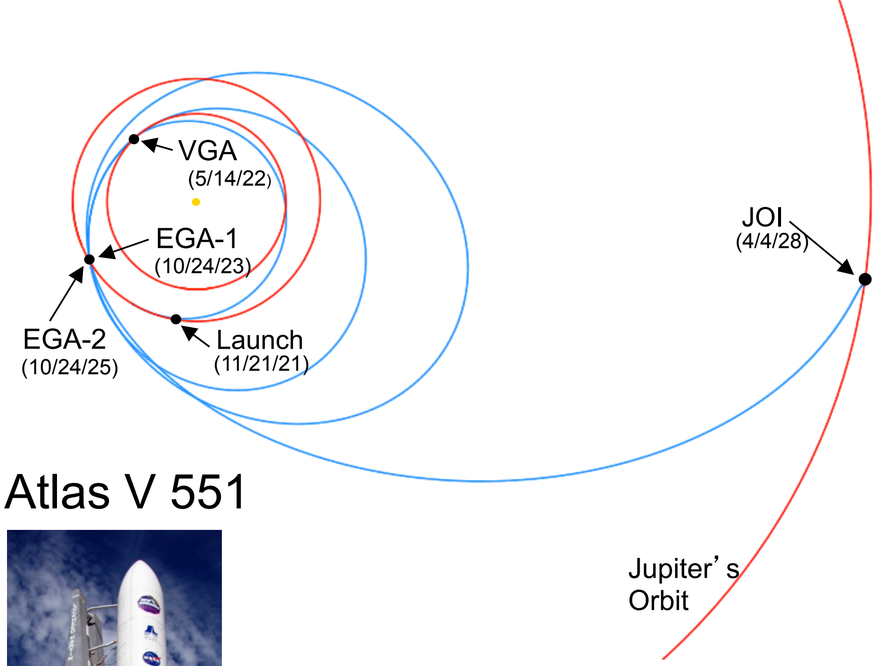


Mission Design

VEEGA Interplanetary Trajectory

Robust with Annual Launch Opportunities

Interplanetary Phase: VEEGA Trajectory (6.37 years)



Nominal IP Trajectory		
Event	**Date**	**Flyby Alt. (km)**
Launch	**21 Nov 2021**	**-**
Venus	**14 May 2022**	**3184**
Earth	**24 Oct 2023**	**11764**
Earth	**24 Oct 2025**	**3336**
G0	**03 Apr 2028**	**500**
JOI	**04 Apr 2028**	**885414**

Atlas V 551

High performance interplanetary trajectory with annual launch opportunities

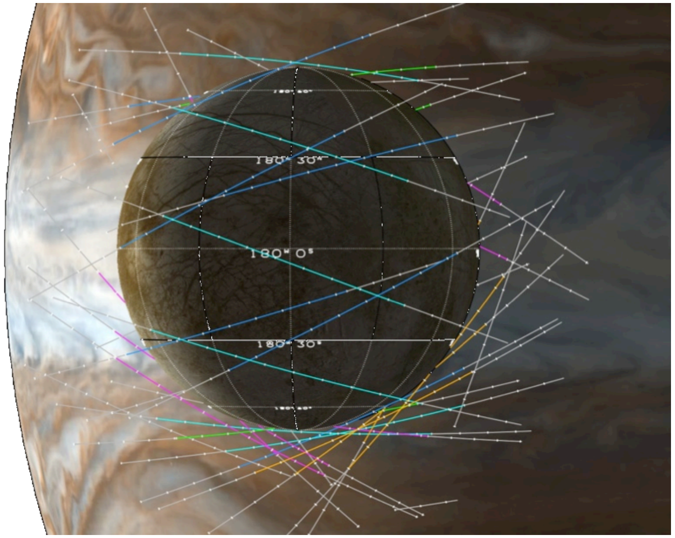
Nominal

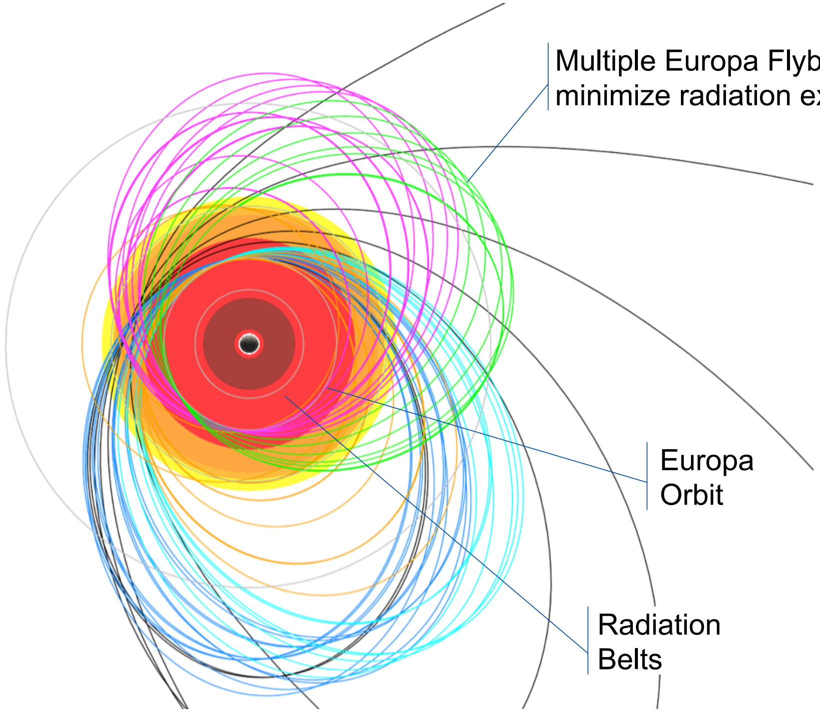
Annual Launch Opportunities				
Launch Date	**Flyby Path**	**TOF to JOI (years)**	**C_3 (km^2/s^2)**	**Atlas V 551 Capability (kg)**
17 Jul 2018	VEEE	7.29	11.4	4932
23 Mar 2019	EVEE	6.91	10.5	5011
29 Feb 2020	VEE	5.81	12.8	4794
27 May 2021	VEE	6.87	14.5	4541
21 Nov 2021	**VEE**	**6.37**	**15.0**	**4494**
15 May 2022	EVEE	7.22	10.2	4935
23 May 2023	VEE	6.18	16.4	4339
03 Sep 2024	VEE	6.71	13.8	4562

Innovative Mission Design

Enables Globally Distributed Coverage Through Multiple Flybys

- Dense, globally distributed network of intersecting ground tracks
- Fully meets science traceability matrix requirements
- Minimizes time in high radiation environment

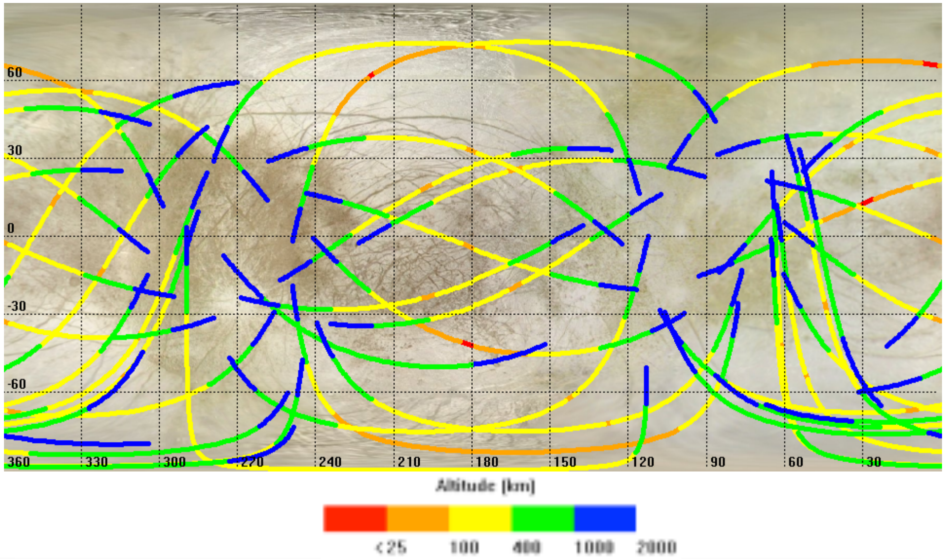




Multiple Europa Flybys minimize radiation exposure

Europa Orbit

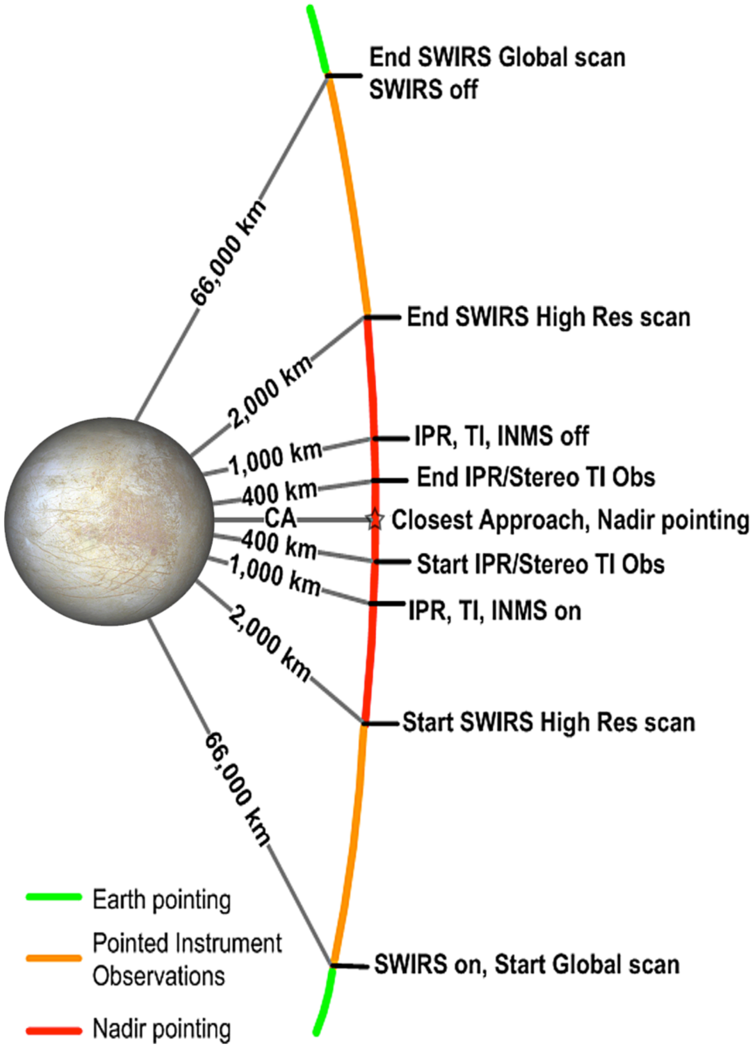
Radiation Belts



Clipper Science Ops Concept

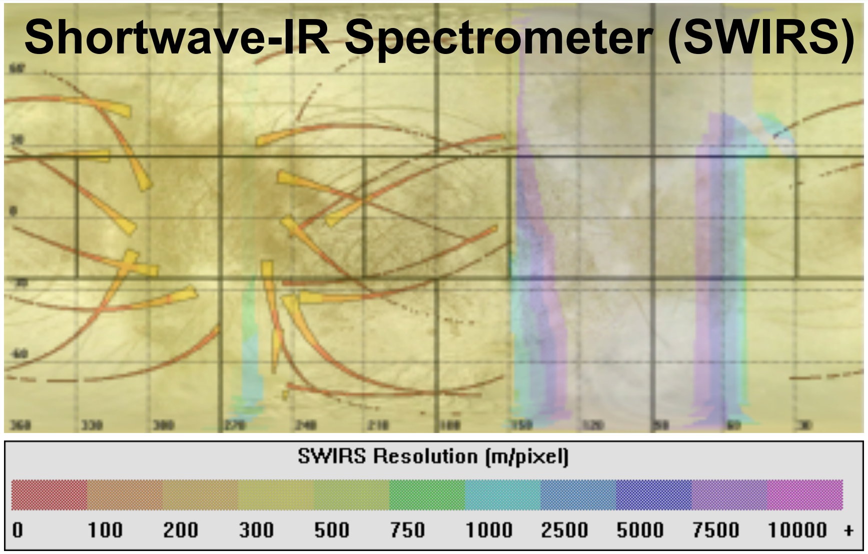
Simple and Repetitive

1. **ShortWave InfraRed Spectrometer (SWIRS)**
   - Global low resolution scan below 66,000 km altitude
   - Targeted high resolution scan below 2,000 km altitude
   - Passive below 1,000 km altitude
2. **Topographical Imager (TI)**
   - Stereo images below 1,000 km altitude
3. **Ice Penetrating Radar (IPR)**
   - Power on and calibrate at 1,000 km
   - Surface scans below 400 km altitude
4. **Ion & Neutral Mass Spectrometer (INMS)**
   - *In situ* scan below 1,000 km altitude

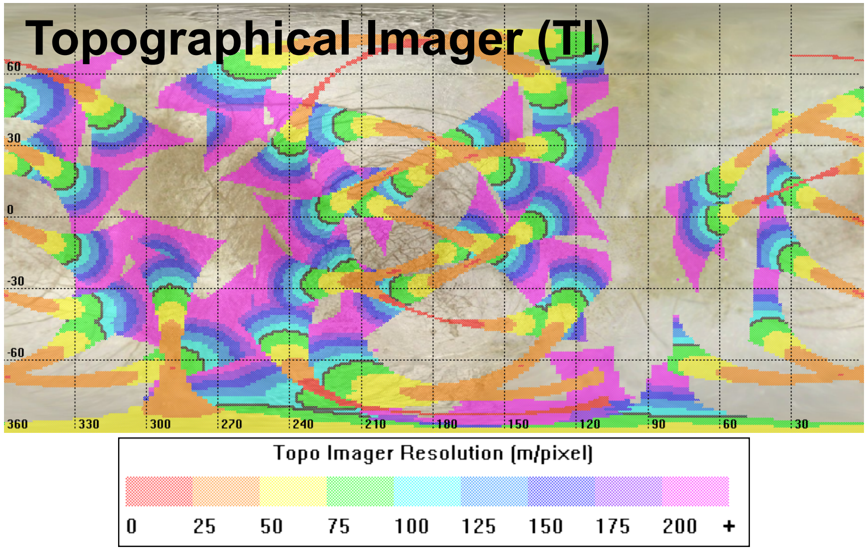


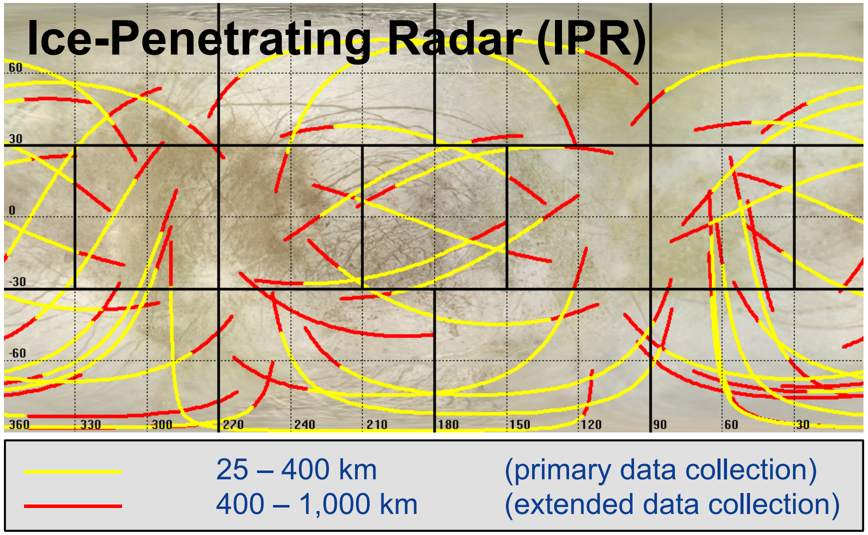
Europa Clipper

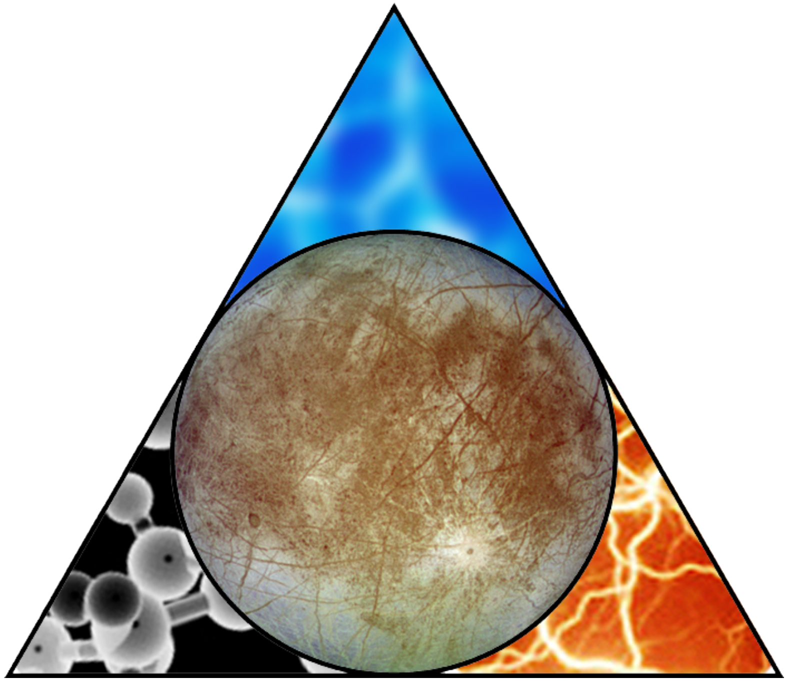
Model Instrument Coverage



- **SWIRS**: 300 m near-global; high-res swaths at better than 100 m/pixel
- **TI**: stereo high-res swaths up to ~25 m/pixel
- **IPR**: 32 crossing profiles, globally distributed
- **INMS**: 25 passes at <100 km altitude, 5 passes at <25 km altitude







Spacecraft

Concept Drivers

Accommodate the descoped measurements and model payload elements described in the Science Traceability Matrix

Accommodate NASA HQ directives:

- Launch in the 2018-2024 timeframe w/ annual backup opportunity
- Utilize ASRGs. No limit on number, but strong desire to minimize ^{238}Pu usage
- Use existing Evolved Expendable Launch Vehicle
- Mission Duration < 10 years, launch to EOM

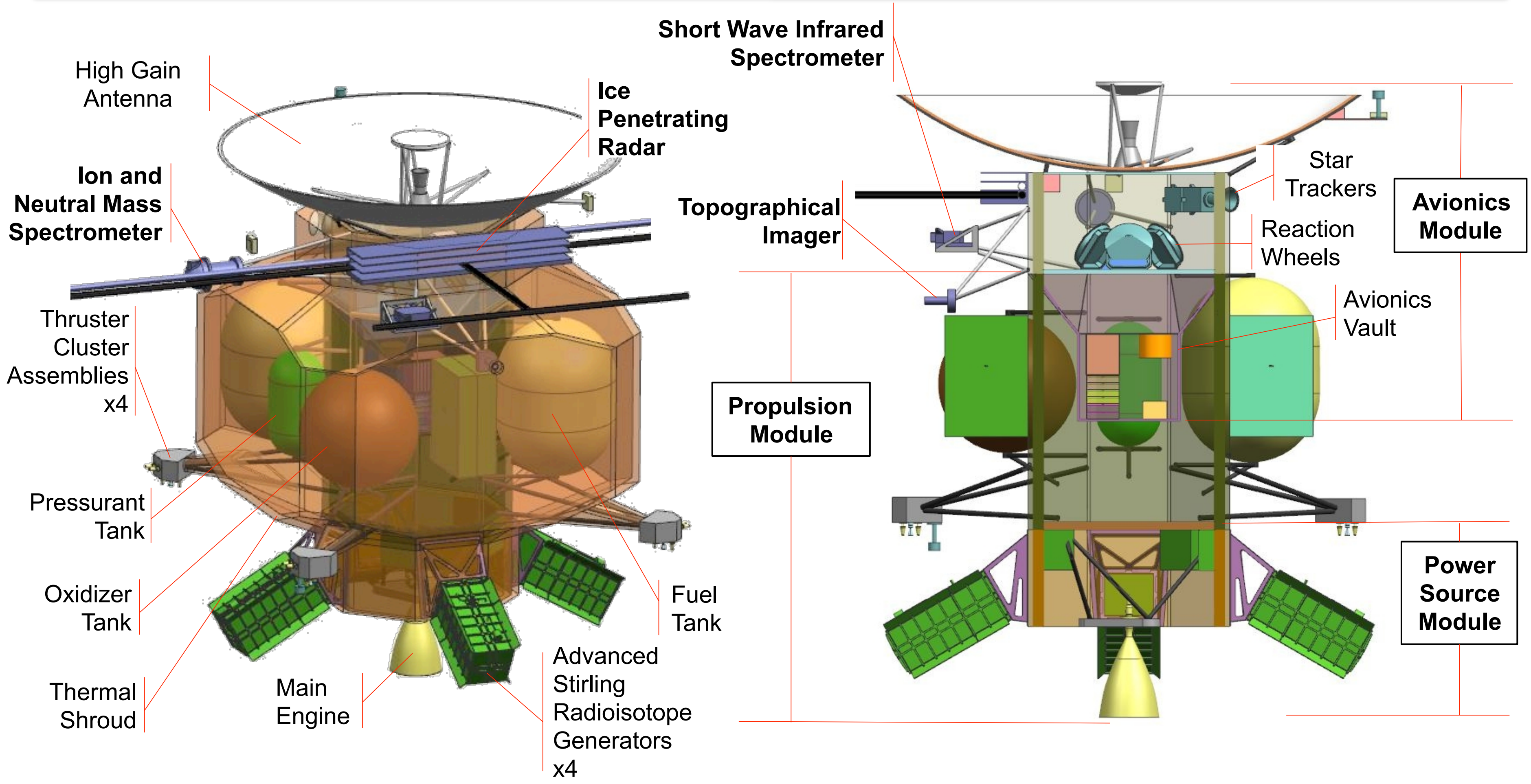
Address radiation issue:

- Reduce total radiation dose through mission design
- Reduce part level total dose through efficient shielding

Design for lower, predictable cost:

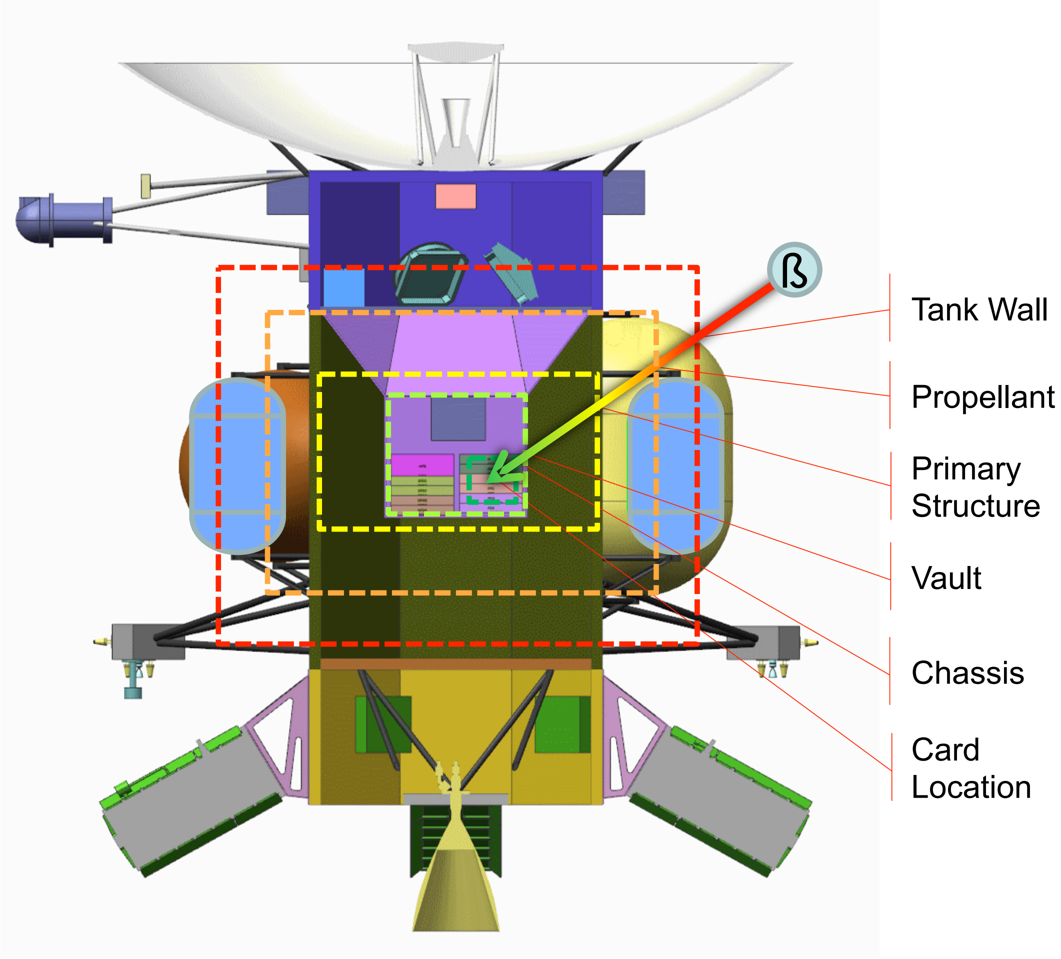
- Smaller and less massive
- Use commercially available parts
- Reduce operational complexity
- Maintain robust technical margins to support cost commitment

Europa Clipper Spacecraft Configuration



Compact, modular design mitigates radiation effects

Radiation Mitigation Approach



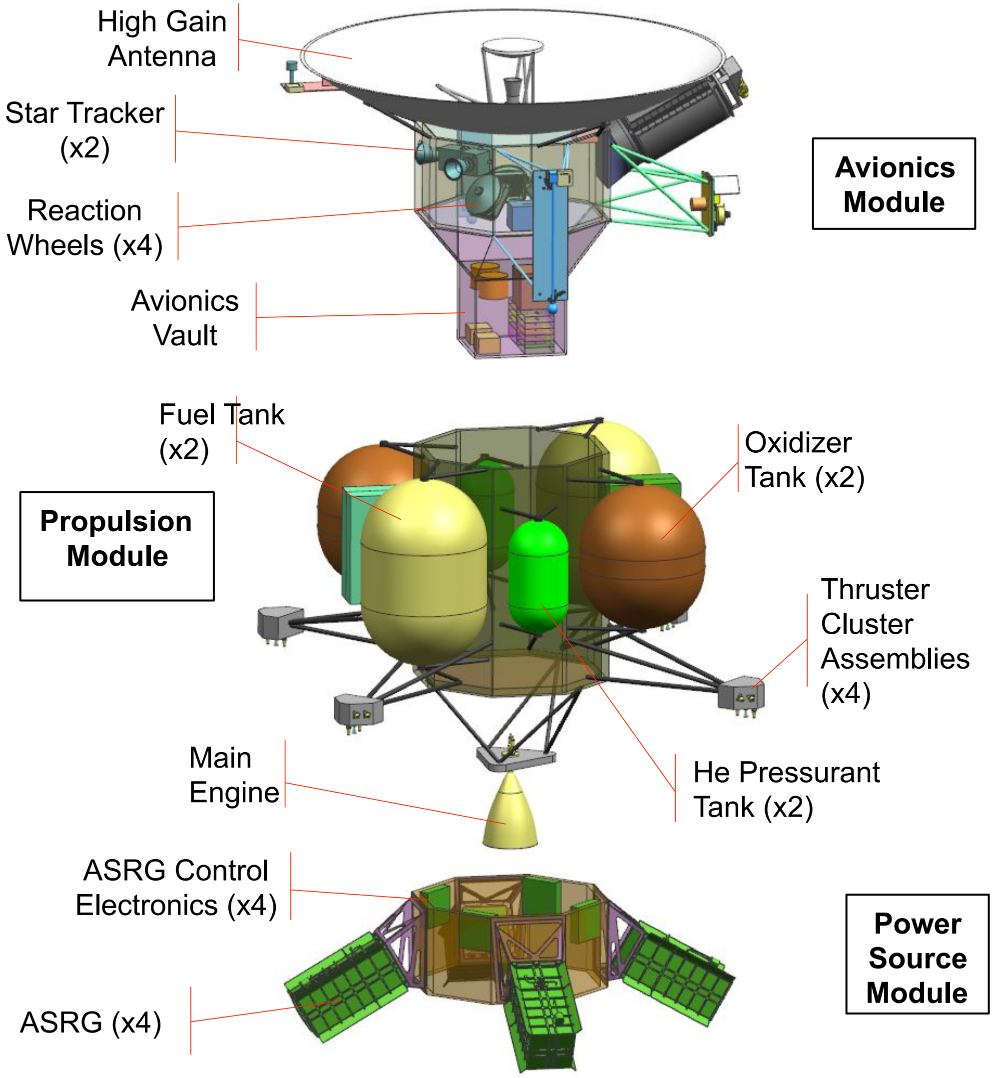
Effective Shield Thickness	Resulting End of Mission Dose
100 mil Al	2.1 Mrad (End of Mission Total Dose)
200 mil Al	900 krad
400 mil Al	350 krad
600 mil Al	150 krad
800 mil Al	110 krad
1000 mil Al	80 krad (End of Mission Total Dose)

Allows use of existing industry geosynchronous class parts

Europa Clipper Spacecraft

Benefits of Modular Configuration

- Implementation flexibility
  - Parallel integration paths
  - Module level integrated testing during Phase C
  - Isolates implementation issues at the module level
- Robust schedule management
  - Decouples qualification testing until late in integration flow
  - Allows for integration of ASRGs at KSC
- Smooth funding profile
  - Minimizes peaks in project funding profile
  - Allows flexible phasing of module implementation schedules

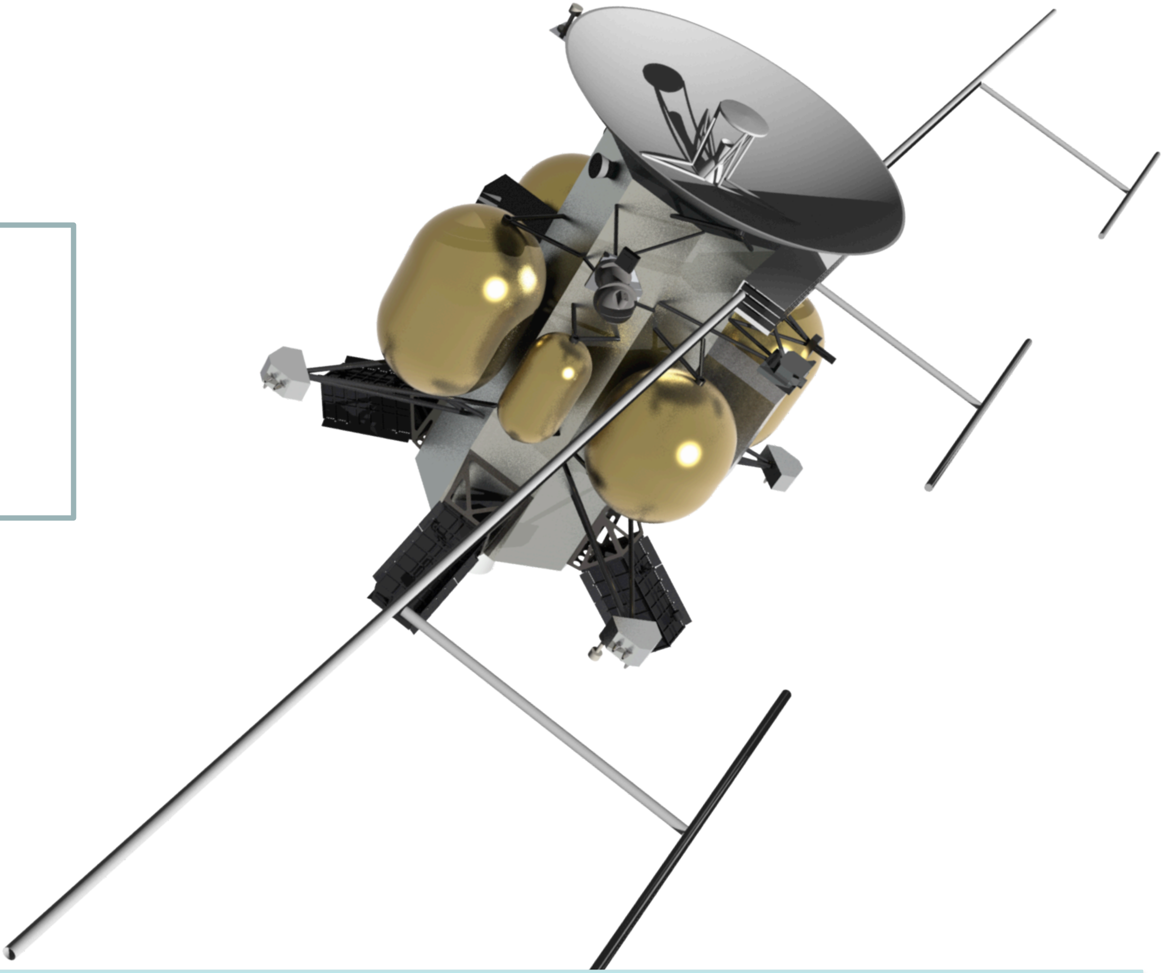


Robust Technical Margins

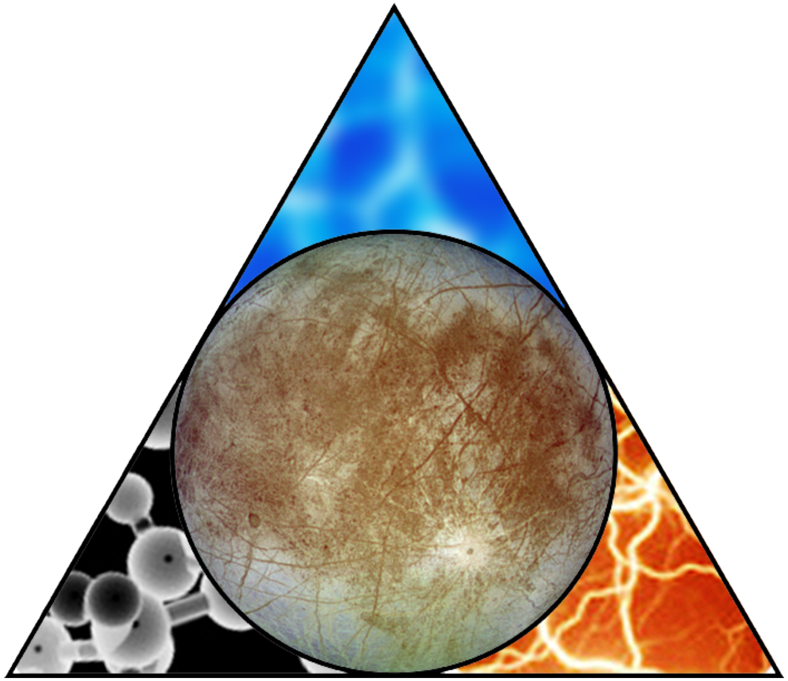
Reduces Risk of Cost Growth

Europa Clipper Technical Margins

48%	39%	80%
Mass	Power	Data



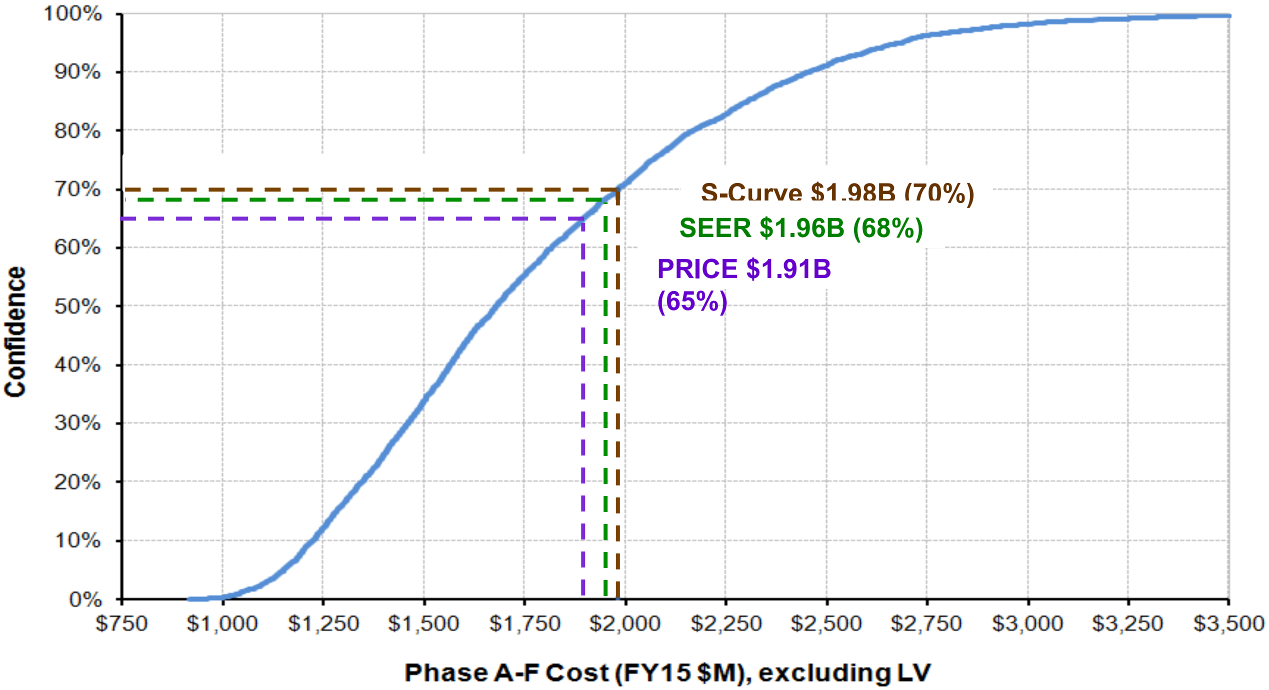
Allows solutions to future design challenges without impacting cost



Cost, Cost Profile, and Validation

Clipper Cost Estimates and S-Curve Analysis

Europa Clipper Cost Estimates (FY15$, Phase A-F, Excludes Launch Vehicle)		
PRICE Cost Estimate	SEER Cost Estimate	S-Curve 70% Confidence Cost Estimate
$1.91B	**$1.96B**	**$1.98B**



*Includes **40% reserves for Phases A/B/C/D** and **20% for Phase E/F***

Notional Funding Profile

Clipper vs. JEO

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JEO

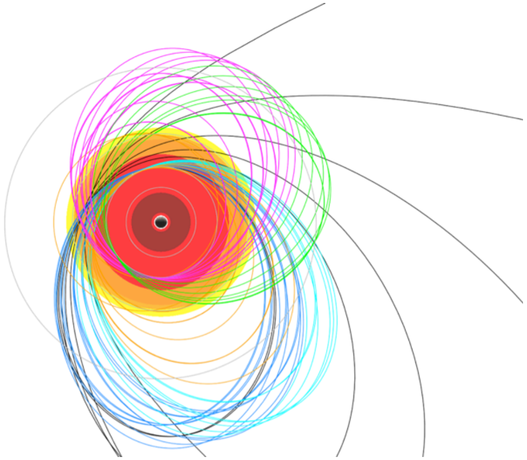
- Spacecraft PDR precedes project PDR by one year to allow reconciliation of cost prior to commitment
- Proactive programmatic approach enables significantly lower and flatter funding profile and meets 7120.5E requirements

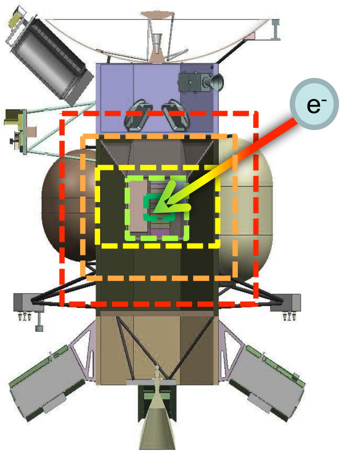
Early funding and modular design allows flat funding profile and compliance with new 7120.5E requirements

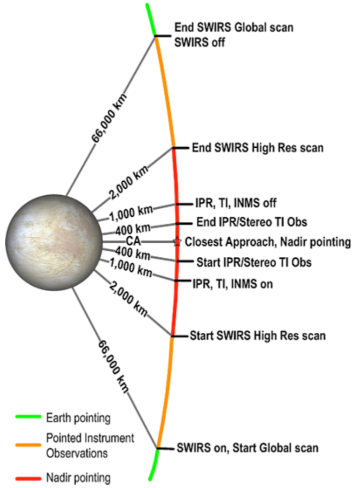
How the Cost Was Reduced

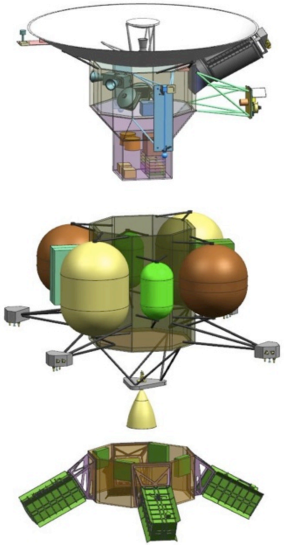
Concept modifications used to reduce cost:

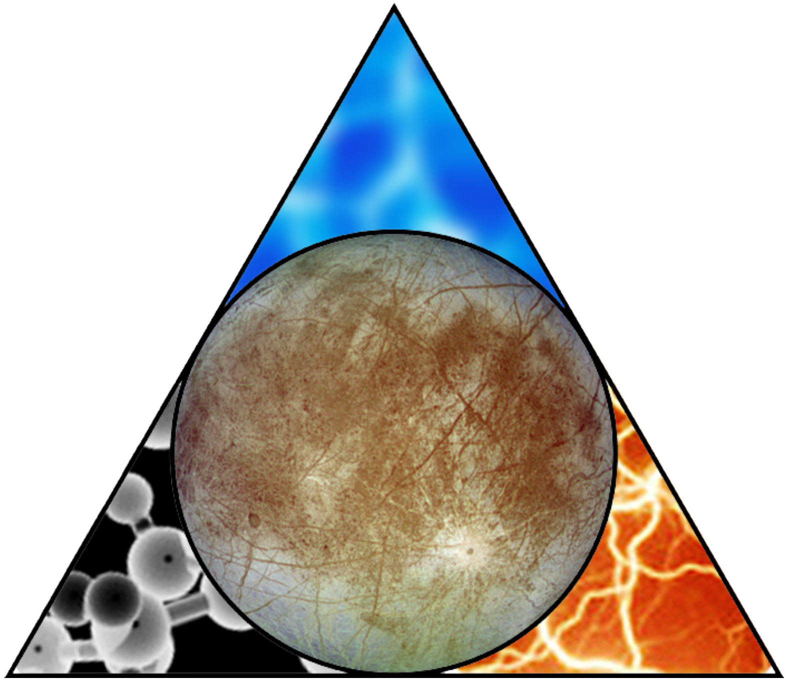
- Mission design reduces radiation levels
- Nested shielding design eliminated need for mega-rad parts
- Reduced number of instruments from 12 to 4
- Repetitive and simple science operations
- Modularity increases schedule and test flexibility and enables smoothing of funding profile







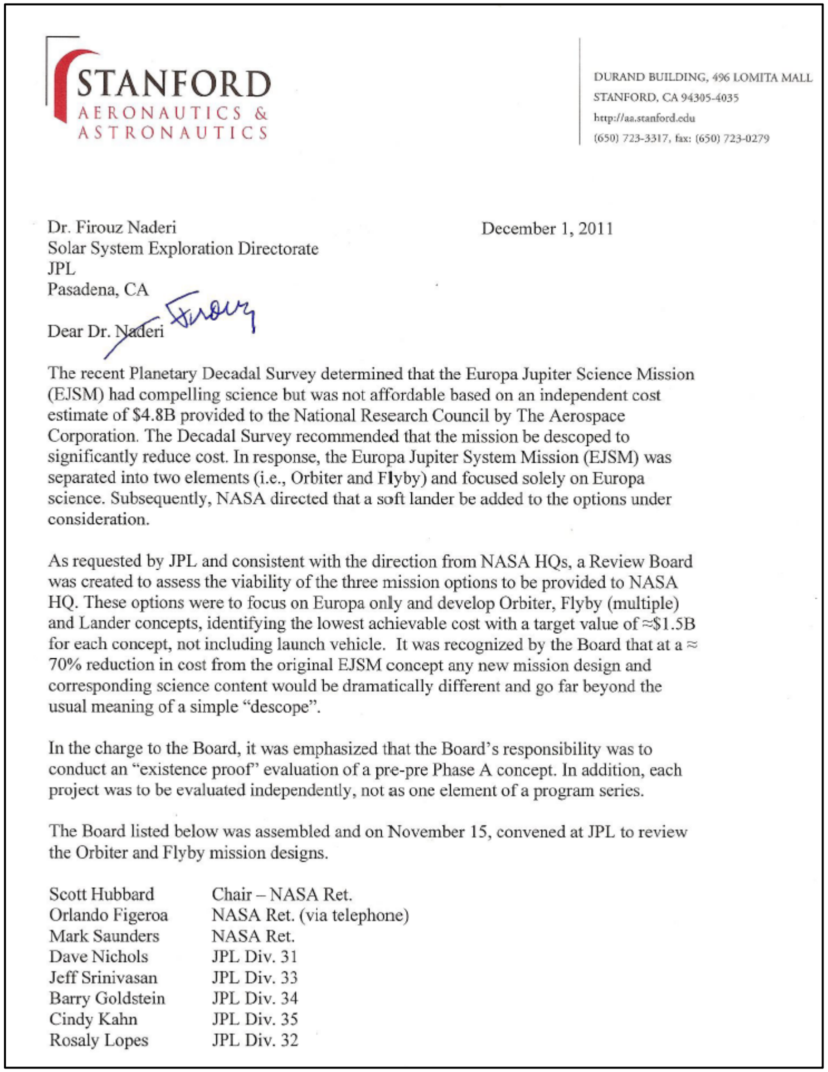




Independent Review

Independent Review

- Scott Hubbard, Chair
- Orbiter and Flyby (Clipper) Mission deemed *feasible with low risk*
- “The overall approach to spacecraft modularity and radiation shielding was unanimously lauded”
- Orbiter and Flyby (Clipper) Mission “[can] be conducted within the cost constraints provided and have substantial margins”
- Flyby (Clipper) Mission deemed higher “science per dollar than Orbiter Mission”



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Dr. Firouz Naderi
Solar System Exploration Directorate
JPL
Pasadena, CA

December 1, 2011

Dear Dr. Naderi Firouz

The recent Planetary Decadal Survey determined that the Europa Jupiter Science Mission (EJSM) had compelling science but was not affordable based on an independent cost estimate of $4.8B provided to the National Research Council by The Aerospace Corporation. The Decadal Survey recommended that the mission be descoped to significantly reduce cost. In response, the Europa Jupiter System Mission (EJSM) was separated into two elements (i.e., Orbiter and Flyby) and focused solely on Europa science. Subsequently, NASA directed that a soft lander be added to the options under consideration.

As requested by JPL and consistent with the direction from NASA HQs, a Review Board was created to assess the viability of the three mission options to be provided to NASA HQ. These options were to focus on Europa only and develop Orbiter, Flyby (multiple) and Lander concepts, identifying the lowest achievable cost with a target value of ≈$1.5B for each concept, not including launch vehicle. It was recognized by the Board that at a ≈ 70% reduction in cost from the original EJSM concept any new mission design and corresponding science content would be dramatically different and go far beyond the usual meaning of a simple “descope”.

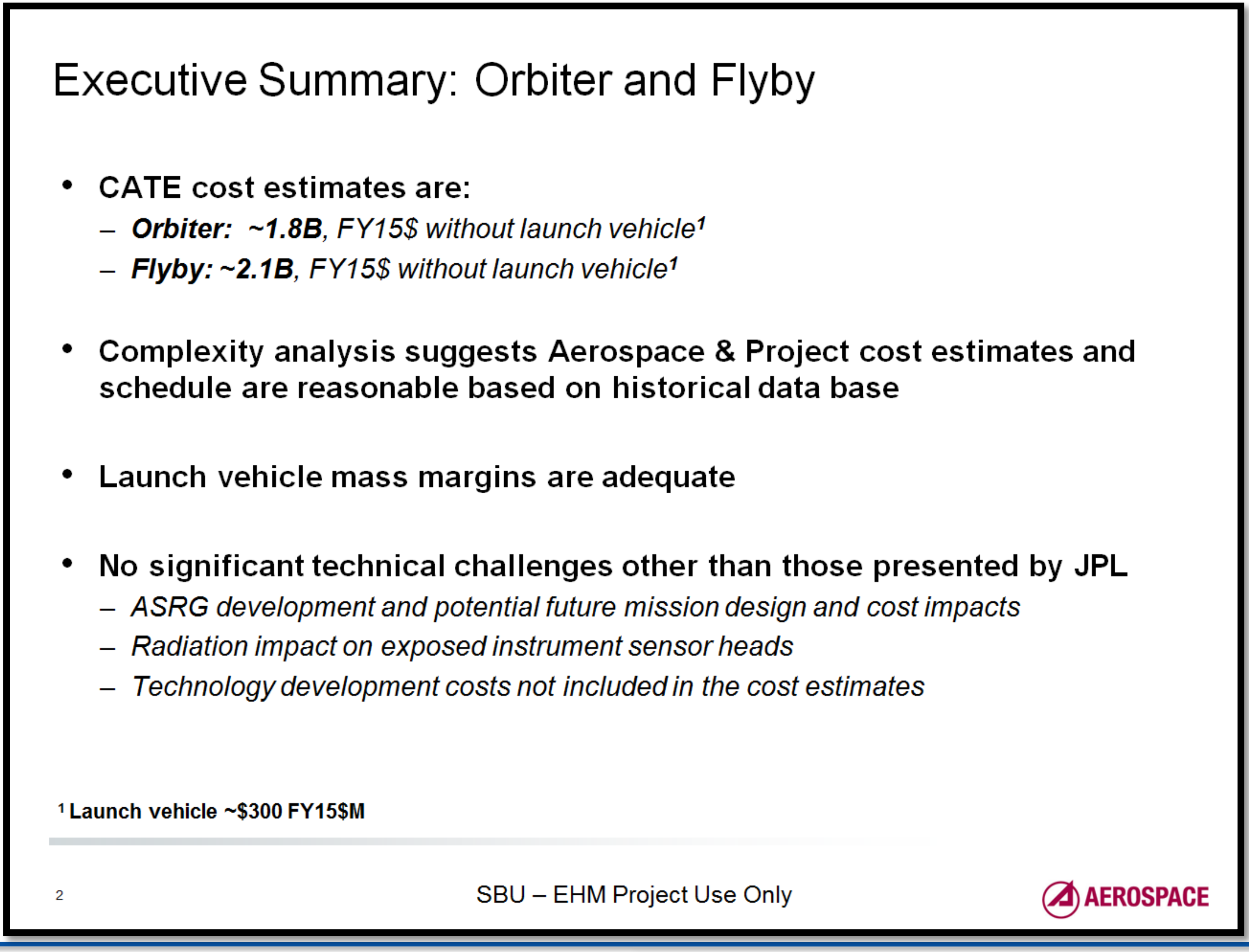
In the charge to the Board, it was emphasized that the Board’s responsibility was to conduct an “existence proof” evaluation of a pre-pre Phase A concept. In addition, each project was to be evaluated independently, not as one element of a program series.

The Board listed below was assembled and on November 15, convened at JPL to review the Orbiter and Flyby mission designs.

Scott Hubbard	Chair – NASA Ret.
Orlando Figeroa	NASA Ret. (via telephone)
Mark Saunders	NASA Ret.
Dave Nichols	JPL Div. 31
Jeff Srinivasan	JPL Div. 33
Barry Goldstein	JPL Div. 34
Cindy Kahn	JPL Div. 35
Rosaly Lopes	JPL Div. 32

Aerospace Summary

Flyby and Orbiter Mission Options



Executive Summary: Orbiter and Flyby

- CATE cost estimates are:
  - ***Orbiter:* ~1.8B***, *FY15$ without launch vehicle*[1]
  - ***Flyby: ~2.1B***, *FY15$ without launch vehicle*[1]
- Complexity analysis suggests Aerospace & Project cost estimates and schedule are reasonable based on historical data base
- Launch vehicle mass margins are adequate
- No significant technical challenges other than those presented by JPL
  - *ASRG development and potential future mission design and cost impacts*
  - *Radiation impact on exposed instrument sensor heads*
  - *Technology development costs not included in the cost estimates*

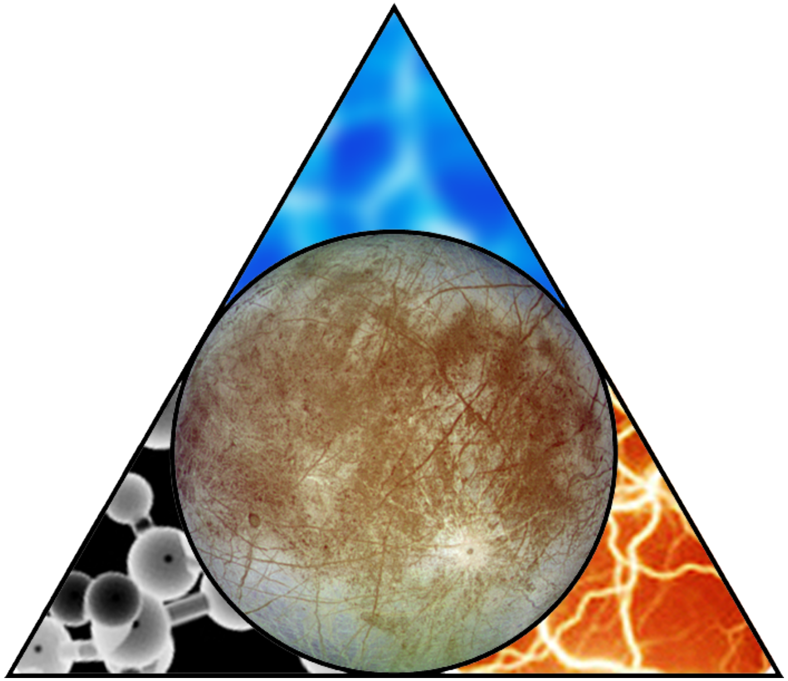
---

[1] **Launch vehicle ~$300 FY15$M**

2

SBU – EHM Project Use Only

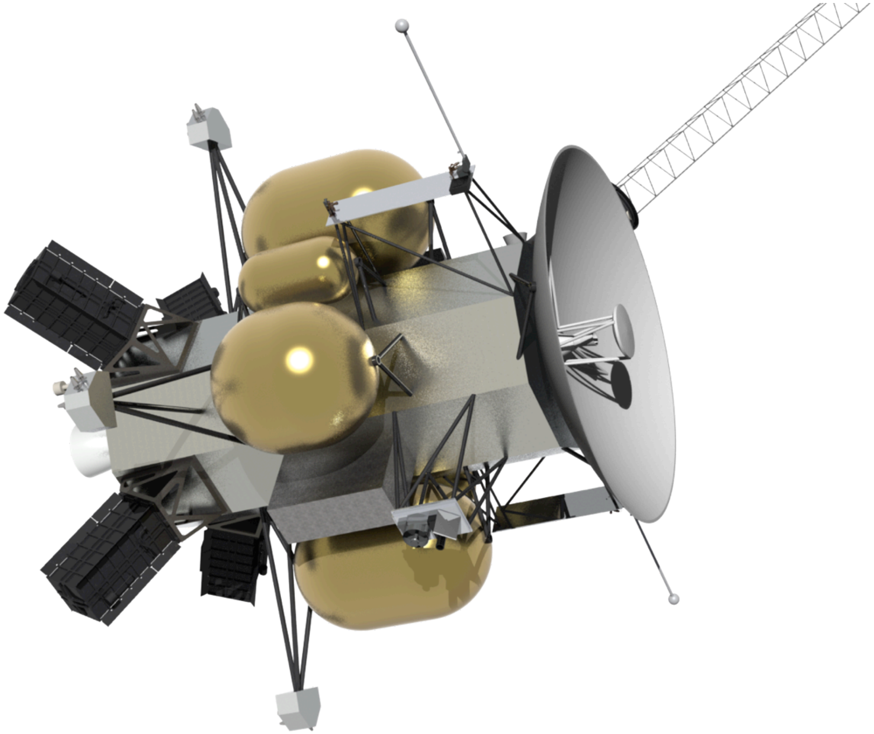
AEROSPACE



Europa Orbiter

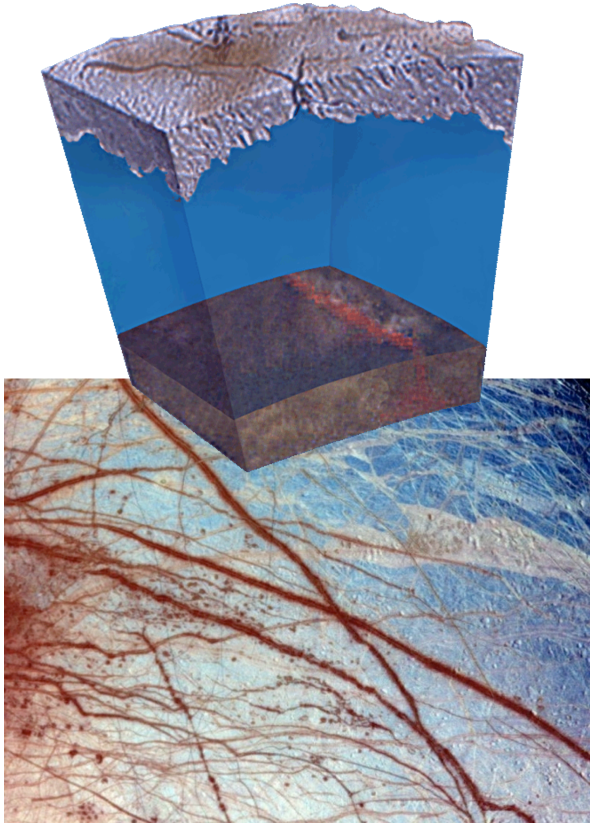
Salient Features of the Orbiter

- Comprehensive science from Europa orbit achieving important ocean and geology objectives
- Science operations for 30 days in Europa orbit
- Modular design and repetitive low cost operations concepts
- Nested shielding to mitigate radiation risk



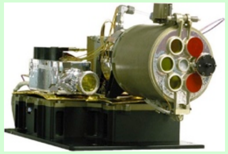
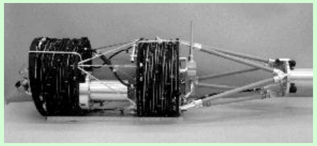
Orbiter Science

- **Ocean:** Characterize the extent of the ocean and its relation to the deeper interior
- **Geology**: Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities



Focus on providing a comprehensive understanding of the ocean and its tidal interaction with the icy crust

Orbiter Model Planning Payload

Science Objective	Key Science Investigations	Model Instrument	Similar Instrument
Ocean	Time-varying gravity field through Doppler tracking, to detect ocean and determine interior structure.	**Radio Sub-system (RS)**	
	Time-varying tidal amplitude, to detect ocean and determine interior structure.	**Laser Altimeter (LA)**	 NEAR NLR
	Magnetic induction response, to derive ocean thickness and salinity.	**Magnetometer (MAG)**	 Galileo MAG
	Local plasma and electric field, to support magnetic induction experiment.	**Langmuir Probe (LP)**	 Rosetta LAP
Geology	Uniform global mapping, for landform global distribution and stratigraphy.	**Mapping Camera (MC)**	 MPL/MSL MARDI

Note: Model instrument baseline and floor are equivalent

This document has been reviewed and determined not to contain export controlled technical data.

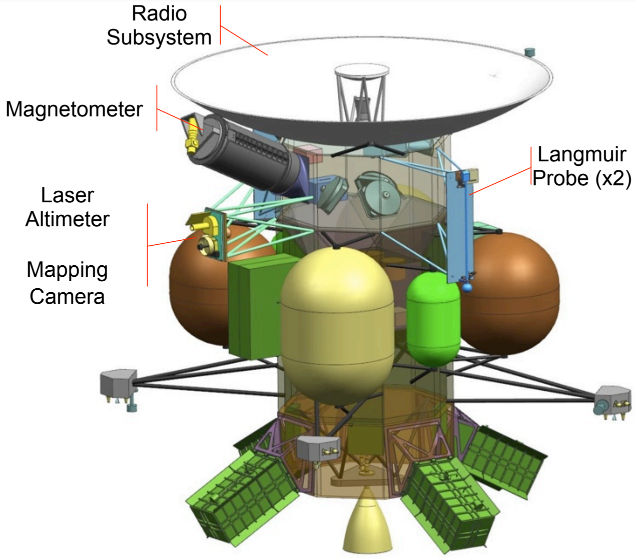
Pre-Decisional — For Planning and Discussion Purposes Only

Orbiter Science Traceability

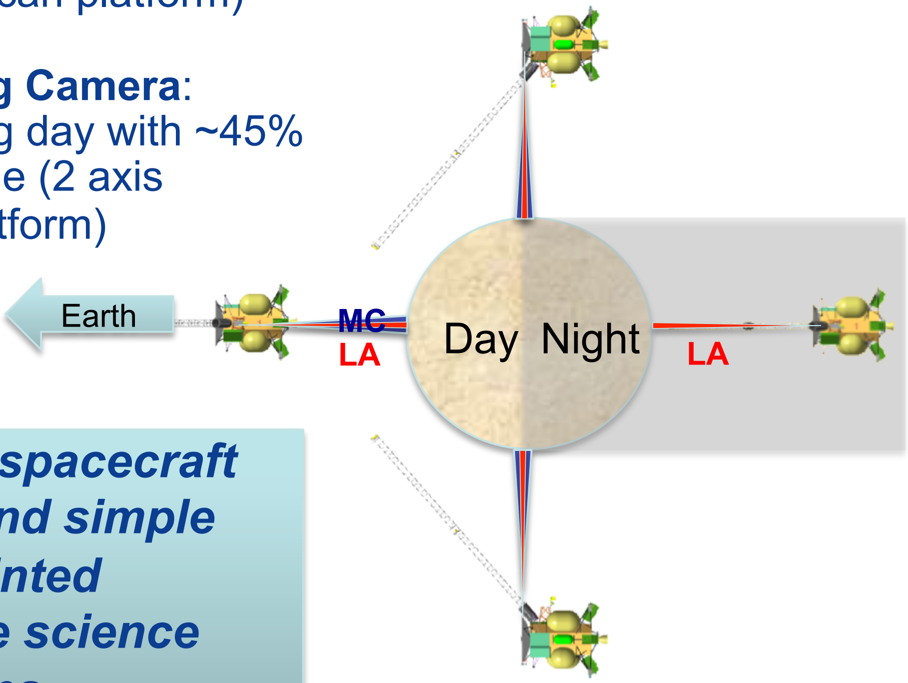
Goal	Objective		Investigation	Model Planning Payload	Theme		
					W	C	E
Explore Europa to investigate its habitability	Ocean	Characterize the extent of the ocean and its relation to the deeper interior.	Determine the amplitude and phase of gravitational tides.	Radio subsystem, Laser altimeter	✓		
			Determine Europa's magnetic induction response.	Magnetometer, Langmuir probe	✓	✓	
			Determine the amplitude and phase of topographic tides.	Laser altimeter, Radio subsystem	✓		
			Determine Europa's rotation state.	Laser altimeter, Mapping camera	✓		
			Investigate the deeper interior.	Radio subsystem, Laser altimeter, Magnetometer, Langmuir probe	✓	✓	✓
	Geology	Understand the formation of surface features, including sites of recent or current activity to understand regional and global evolution.	Determine the distribution, formation, and three-dimensional characteristics of magmatic, tectonic, and impact landforms.	Mapping camera, Laser altimeter	✓		✓

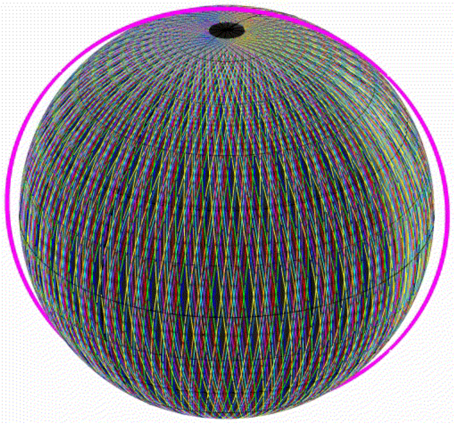
Themes: W= Water, C = Chemistry, E = Energy

Orbiter Mission Configuration and Operations



- **Gravity Science**: continuous while not occulted (Earth-pointed HGA)
- **Magnetometer** and **Langmuir Probe**: continuous data collection
- **Laser Altimeter**: continuous data collection (2 axis scan platform)
- **Mapping Camera**: on during day with ~45% duty cycle (2 axis scan platform)





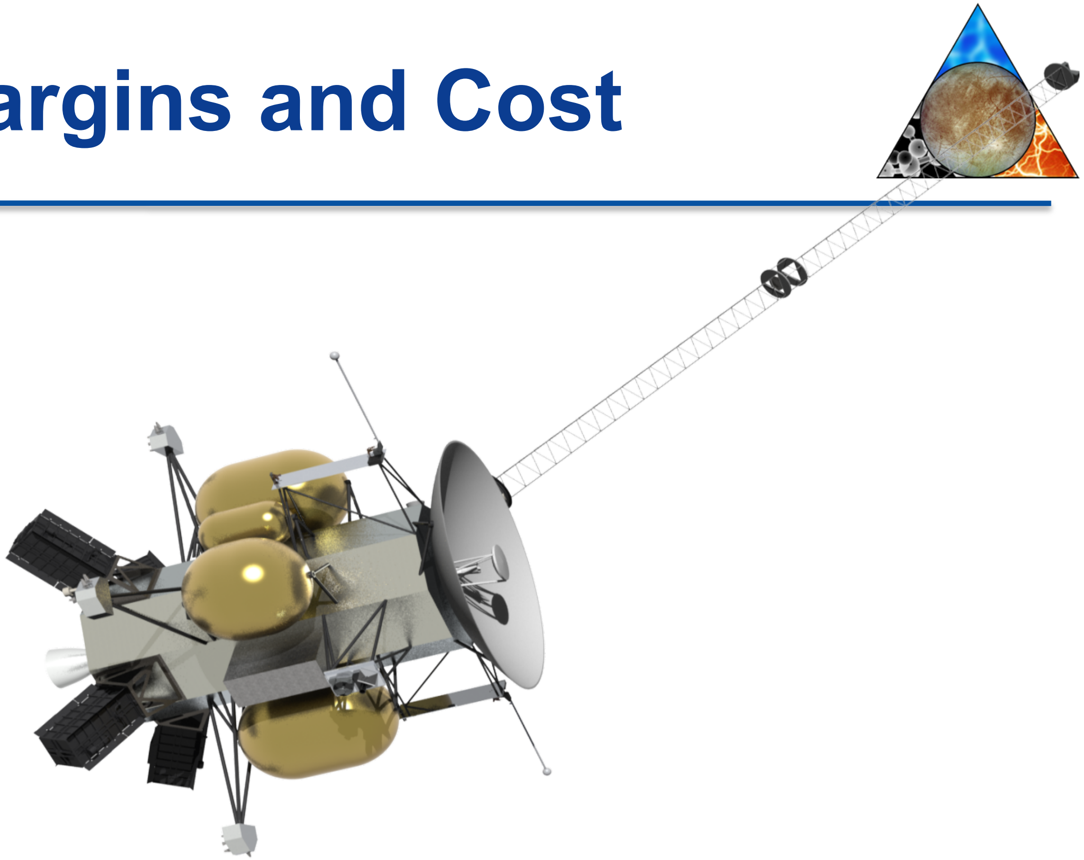
Dense global mapping in 30 day nominal lifetime

Modular spacecraft design and simple nadir pointed repetitive science operations

Orbiter Margins and Cost

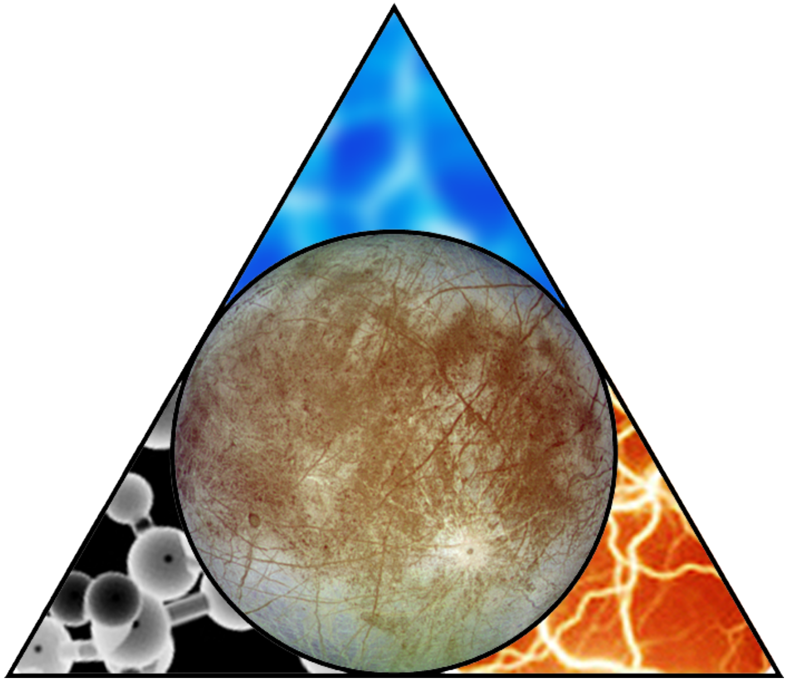
Orbiter Technical Margins

43%	39%	71%
Mass	**Power**	**Data**



Option	Cost (FY15, excl LV)	Risk	Science
Orbiter	$1.6B	Low	Very Good

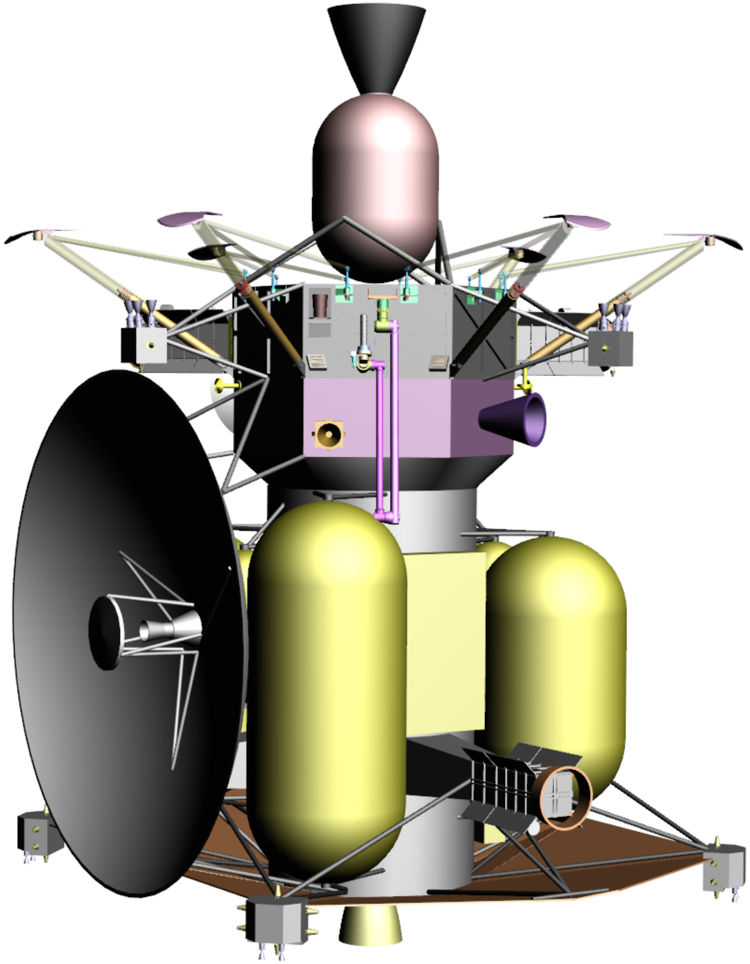
- The low risk orbiter mission would provide a comprehensive understanding of the ocean and global surface geology



Europa Lander

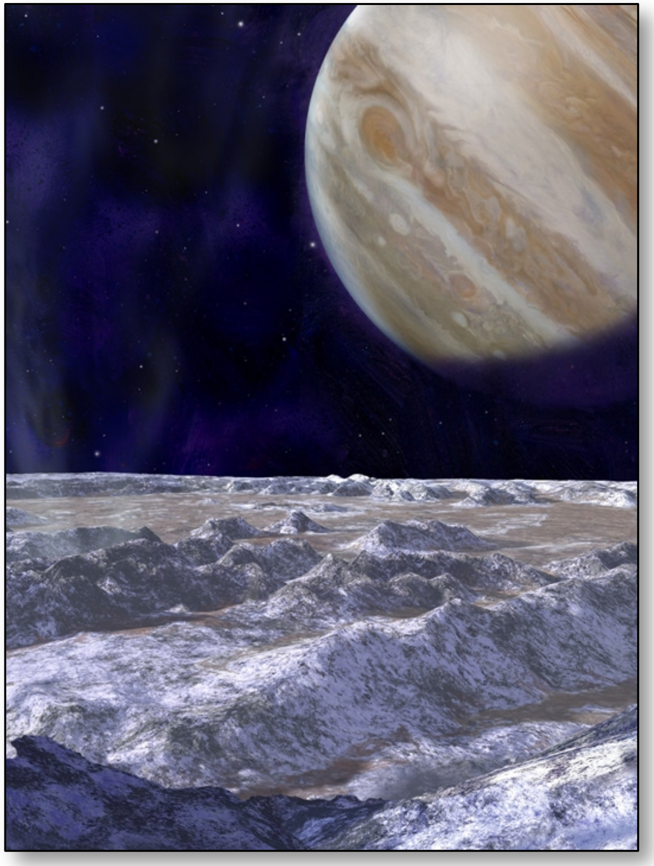
Salient Features of the Lander

- Comprehensive science from Europa's surface achieving important ocean, ice and composition objectives
- 30 days in Europa orbit to perform landing site certification
- Autonomous precision landing
- Surface operations of 9 eurosols (32 days)
- Drill and sample handling system to deliver material to science instruments
- Data returned via relay with carrier along with direct-to-earth capability



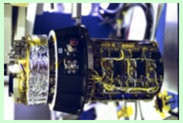
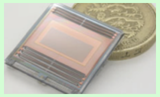
Lander Science

- **Composition:** Understand the habitability of Europa's ocean through composition and chemistry
- **Ocean & Ice Shell:** Characterize the local thickness, heterogeneity, and dynamics of any ice and water layers
- **Geology:** Characterize a locality of high scientific interest to understand the formation and evolution of the surface at local scales



Provide direct measurement of surface materials along with a geophysical and geological understanding at a local scale

Lander Model Planning Payload

Science Objective	Key Science Investigations	Model Instrument	Similar Instrument
Composition	Evolved gas analysis, pyrolysis, and gas chromatography, to determine composition of the surface and near surface, through measurement of two obtained samples.	**Mass Spectrometer (MS)**	 Huygens GCMS
	Characterization of surface and near-surface chemistry including complex organics, through measurement of shift in the wavelength of scattered laser light.	**Raman Spectrometer (RS)**	new development
Ocean & Ice Shell	Magnetic induction response, to derive ocean thickness and salinity.	**Magnetometer (MAG)**	 Galileo MAG
	Thickness of ice and water layers through seismic analysis, and characterization of seismic activity level, and its variation over the tidal cycle.	**Multi-Band Seismometer Package (MBS)**	 ExoMars SP
Geology	Stereo landform mapping of the landing site from near the lander to the horizon, including the sample acquisition location.	**Site Imaging System (SIS)**	 MER Pancam
	High-resolution imaging of collected samples to characterize ice grains and non-ice materials within.	**Microscopic Imager (MI)**	MSL MAHLI
	High-res imaging of candidate landing sites prior to Lander deployment, and imaging of lander on surface to provide context for landed measurements.	**Reconnaissance Imager (RI)**	MRO HiRISE

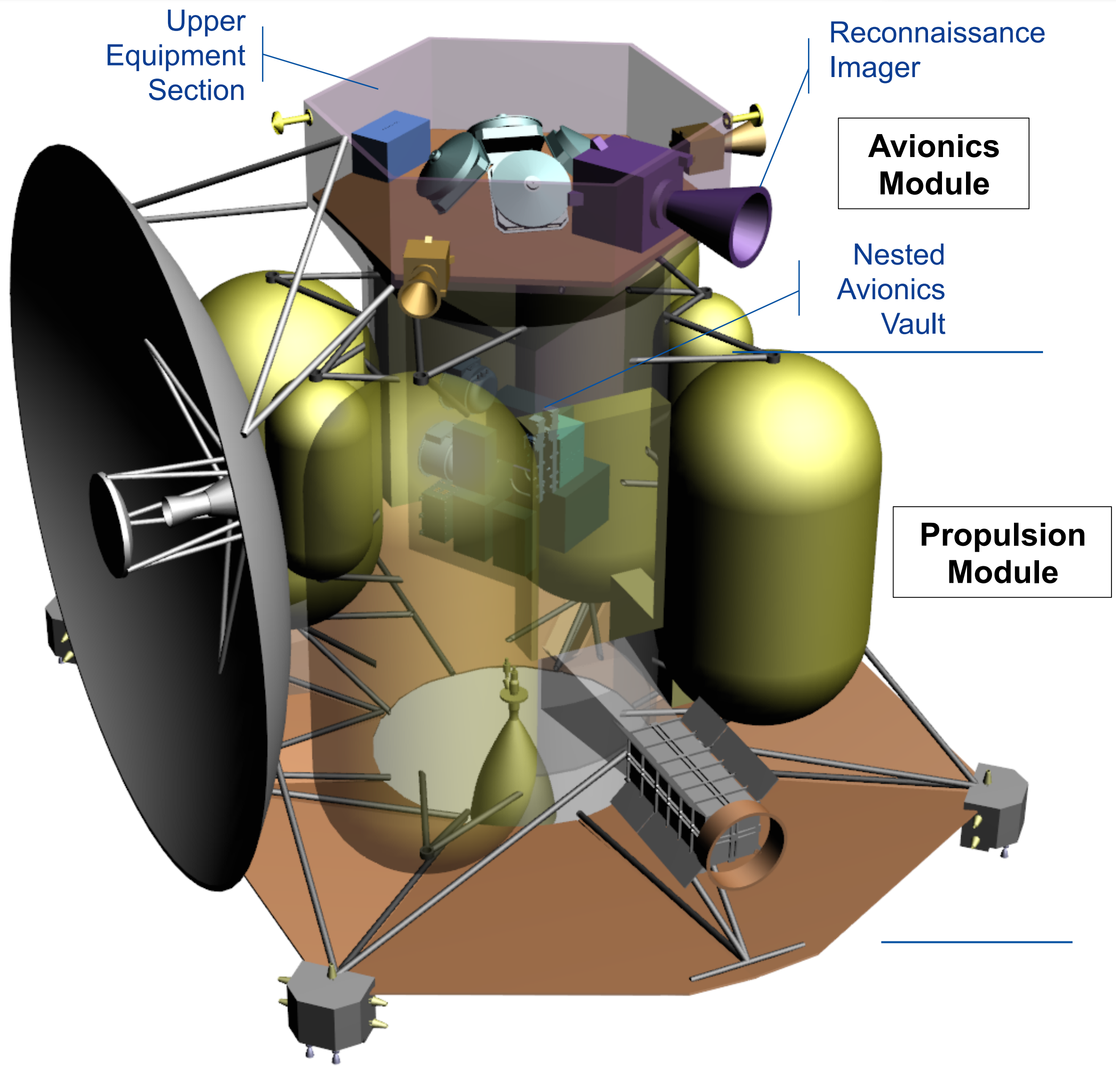
🟩 Floor model instrument 🟨 Baseline model instrument

Lander Science Traceability

Goal	Objective		Investigation	Model Planning Payload	Theme		
					W	C	E
Explore Europa to investigate its habitability	Composition	Understand the habitability of Europa's ocean through composition and chemistry	Characterize surface and near-surface chemistry, including complex organic chemistry to constrain ocean composition and understand the endogenic processes from which it evolves	Mass Spectrometer, Raman Spectrometer		✔	✔
			Characterize surface and near-surface chemistry, including complex organic chemistry to constrain the exogenic processes and material fluxes that affect ocean composition	Mass spectrometer, Raman Spectrometer		✔	✔
			Constrain the context of compositional measurements	Site Imager, Reconnaissance Imager, Microscopic Imager	✔	✔	✔
	Ocean & Ice Shell	Characterize the local thickness, heterogeneity, and dynamics of any ice and water layers	Constrain the thickness and salinity of Europa's ocean	Magnetometer, Multi-Band Seismometer Package	✔	✔	
			Constrain the thickness of ice and the thickness of any water layers in the region	Magnetometer, Multi-Band Seismometer Package	✔		
			Search for local heterogeneity of the ice and any subsurface water	Multi-Band Seismometer Package	✔	✔	
			Characterize Europa's seismic activity and its variation over the tidal cycle	Multi-Band Seismometer Package	✔		✔
	Geology	Characterize a locality of high scientific interest to understand the formation and evolution of the surface at local scales	Constrain the processes that exchange material between the surface, near-surface, and subsurface	Site Imager, Reconnaissance Camera, Microscopic Imager	✔	✔	✔
			Constrain the processes and rates by which the surface materials (regolith and bedrock) form and evolve over time	Site Imager, Reconnaissance Imager, Microscopic Imager	✔	✔	✔
			Understand the regional and local context of the landing site	Site Imager, Reconnaissance Camera	✔	✔	✔
			Constrain the physical properties of the surface and near-surface at the landing site to provide context for the sample	Reconnaissance Imager, Microscopic Imager, Engineering data		✔	

Themes: W= Water, C = Chemistry, E = Energy

Carrier Element



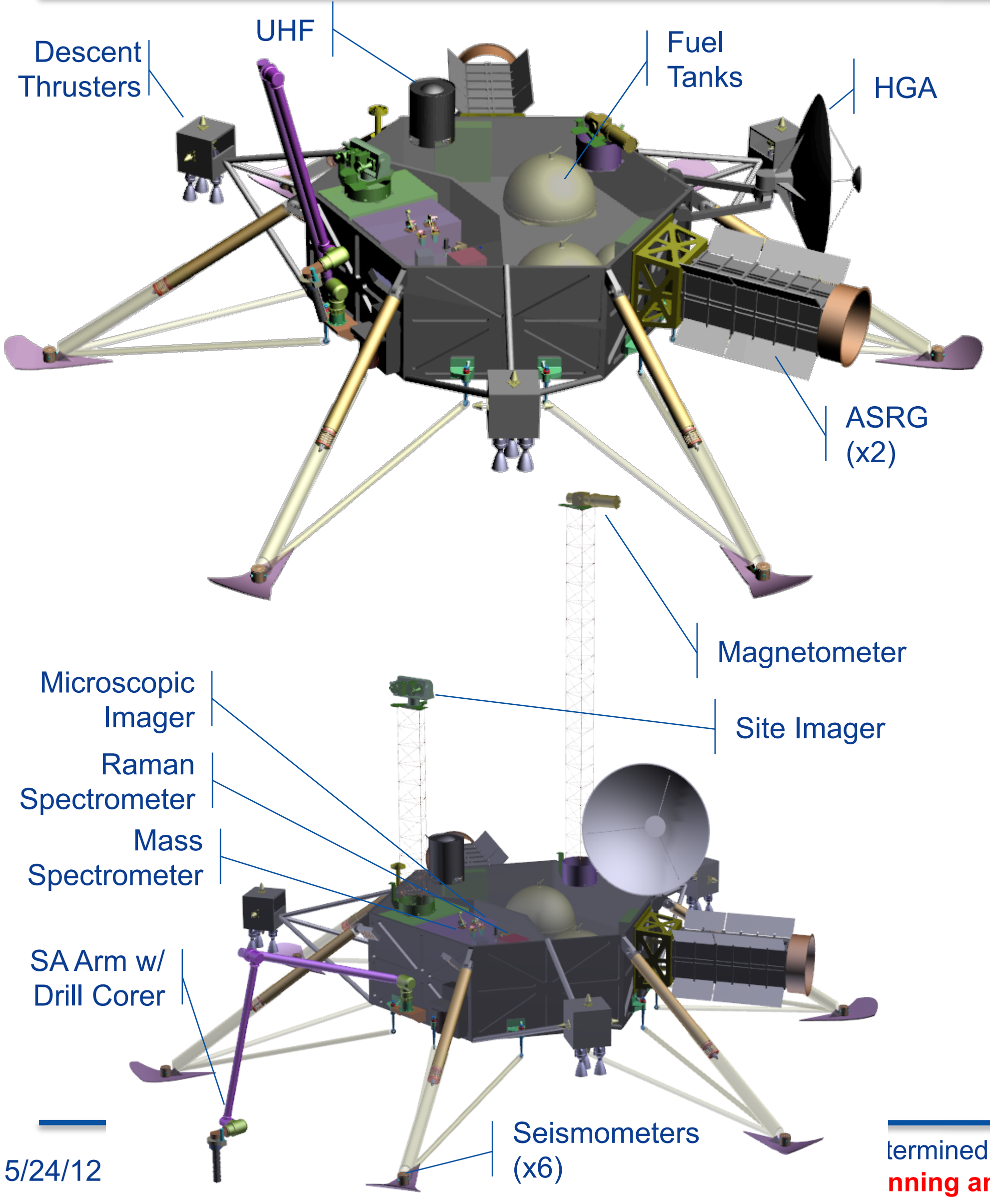
Before Lander Separation:

- Provides all spacecraft functions
- Performs landing site reconnaissance imagery from Europa orbit
- Executes Lander separation

After Lander Separation:

- Imagery for landing site context
- Serves as a high bandwidth telecommunications relay link between the lander and Earth

Lander Element



<u>Before Lander Separation</u>:

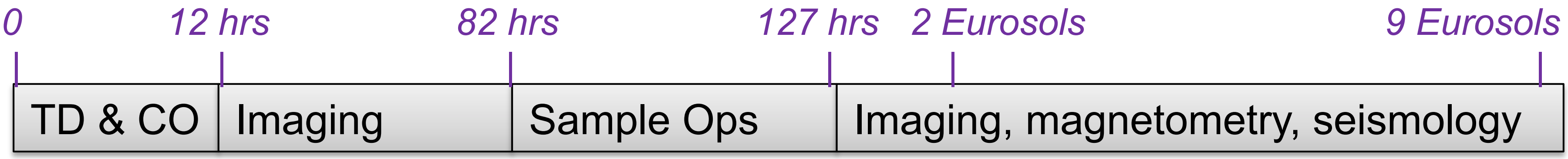
- Powered off for majority of cruise to Europa
- Passive thermal subsystem maintains thermal control of Lander and Deorbit SRM
- Excess power from Lander's (2) ASRGs available to Carrier

<u>After Lander Separation</u>:

- Performs SRM deorbit burn, descent, terrain relative navigation, hazard avoidance and landing
- Executes science measurements, performs sample collection and transmits results to Carrier spacecraft

Lander Science Operations

- Surface Operations divided into four phases:
  - Phase 1: Touchdown & Checkout
  - Phase 2: Worksite Imaging
  - Phase 3: Sample Operations
  - Phase 4: Panoramic Imagery, Magnetometry, Seismometry



0 *12 hrs* *82 hrs* *127 hrs* *2 Eurosols* *9 Eurosols*

TD & CO | Imaging | Sample Ops | Imaging, magnetometry, seismology

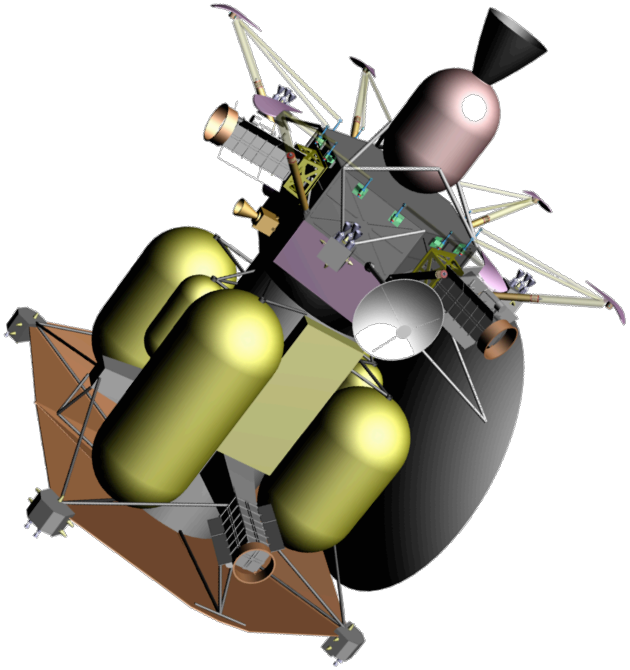
Surface Operations timeline

Floor science objectives achieved in 2 eurosols (7 days); with 7 eurosols (25 days) of contingency

Lander Margins and Cost

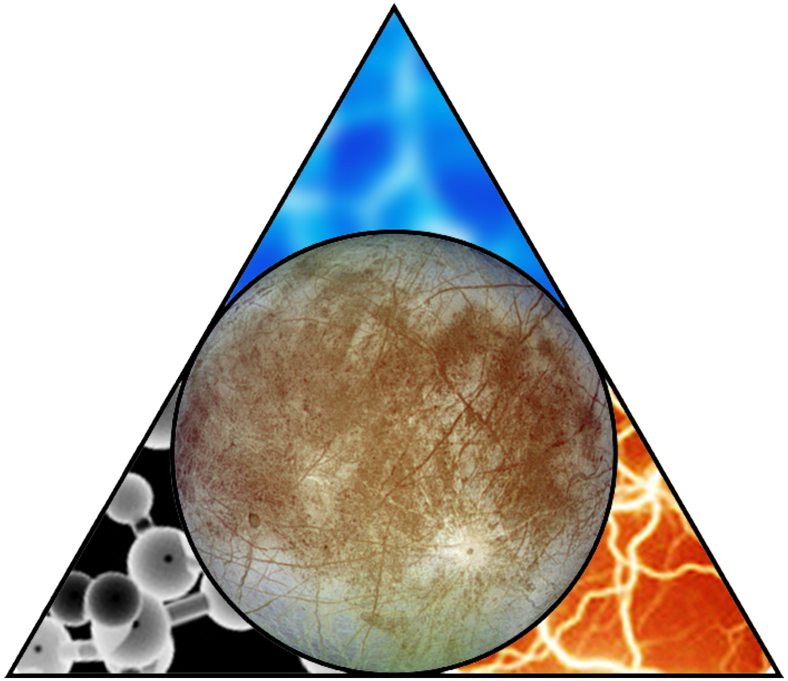
Lander Technical Margins

29%	38%	41%
Mass	**Power**	**Data**



Option	Cost (FY15, excl LV)	Risk	Science
Lander	$2.8B	High	Excellent

Comprehensive investigation of Europa at a local scale but significant cost and technical challenges



Comparison

Key Science Questions for Europa

Science Question	JEO	Clipper	Orbiter	Lander
1. What are the characteristics of Europa's ocean?	✓	*	✓	✓
2. How thick is the icy shell?	✓	✓	✓	✓
3. Is there near-surface water within the ice shell?	✓	✓		✓
4. What is the global distribution of geological features?	✓	✓	✓	
5. Is liquid water involved in surface feature formation?	✓	✓		
6. Is the icy shell warm and convecting?	✓	✓		✓
7. What does the red stuff tell us about ocean composition?	✓	✓		✓
8. How active is Europa today?	✓	✓		✓
9. What is the plasma and radiation environment at Europa?	✓			
10. What is the specific nature of organics and salts at Europa?				✓

* **Will be addressed in Summer 2012 study.**

Mission Option Comparison

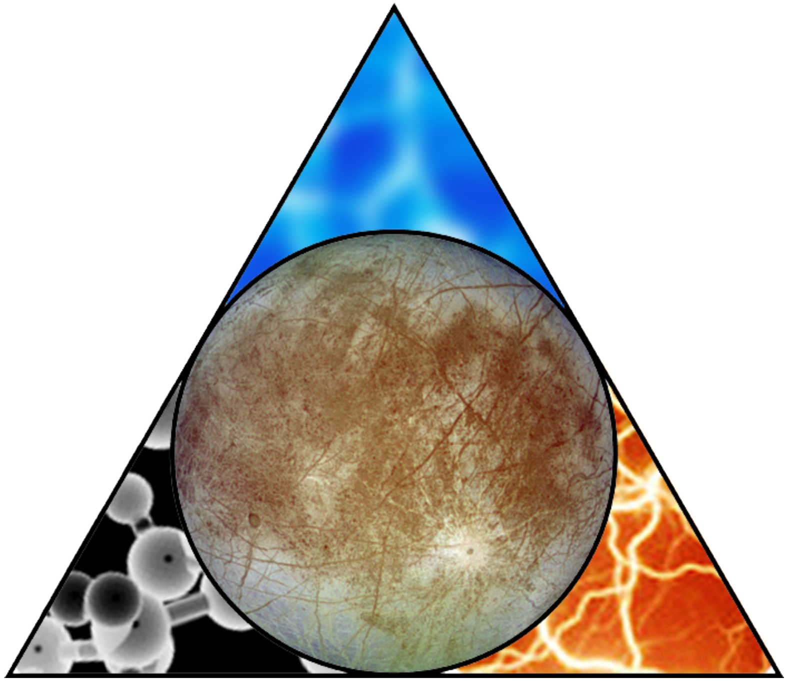
Option	Cost (FY15, excl LV)	Risk	Science
Europa Orbiter	$1.6B	Low	Very Good
Europa Clipper	$1.9B	Low	Excellent
Europa Lander	$2.8B	High	Excellent

OPAG Finding

"A single, ***descoped*** *Europa 'flagship-science-class' mission should move forward with a detailed design study for optimization and a possible new start....*

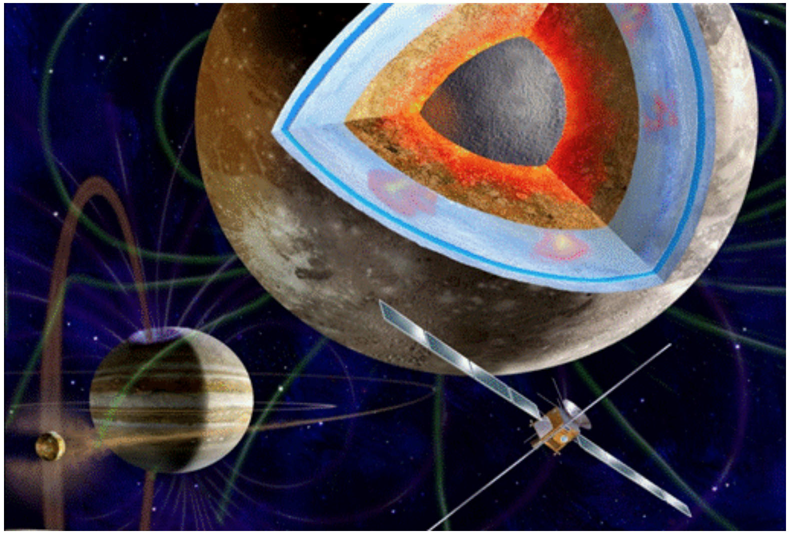
"All 3 Europa mission options are highly scientifically meritorious and responsive to the Planetary Science Decadal Survey....

"The strong majority view of the OPAG community is that the Multiple-Flyby [Clipper] option … offers the greatest science return per dollar, greatest public engagement, and greatest flow through to future Europa exploration."



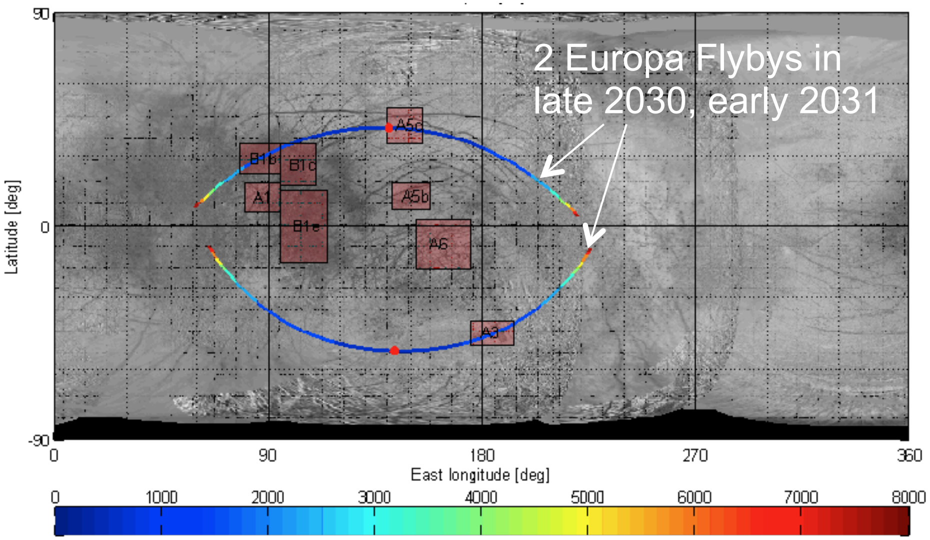
The ESA JUICE Mission

The ESA JUICE Mission



- Science focus on Ganymede and the Jupiter system, ending in orbit around Ganymede
- Science Goals:
  - Emergence of habitable worlds around gas giants
  - Jupiter system as an archetype for gas giants

- Science payload of 11 instruments
  - Composition of non-ice material
  - Look for liquid water in ice shell
  - Study recent active processes
- Limited to 2 Europa flybys because of radiation



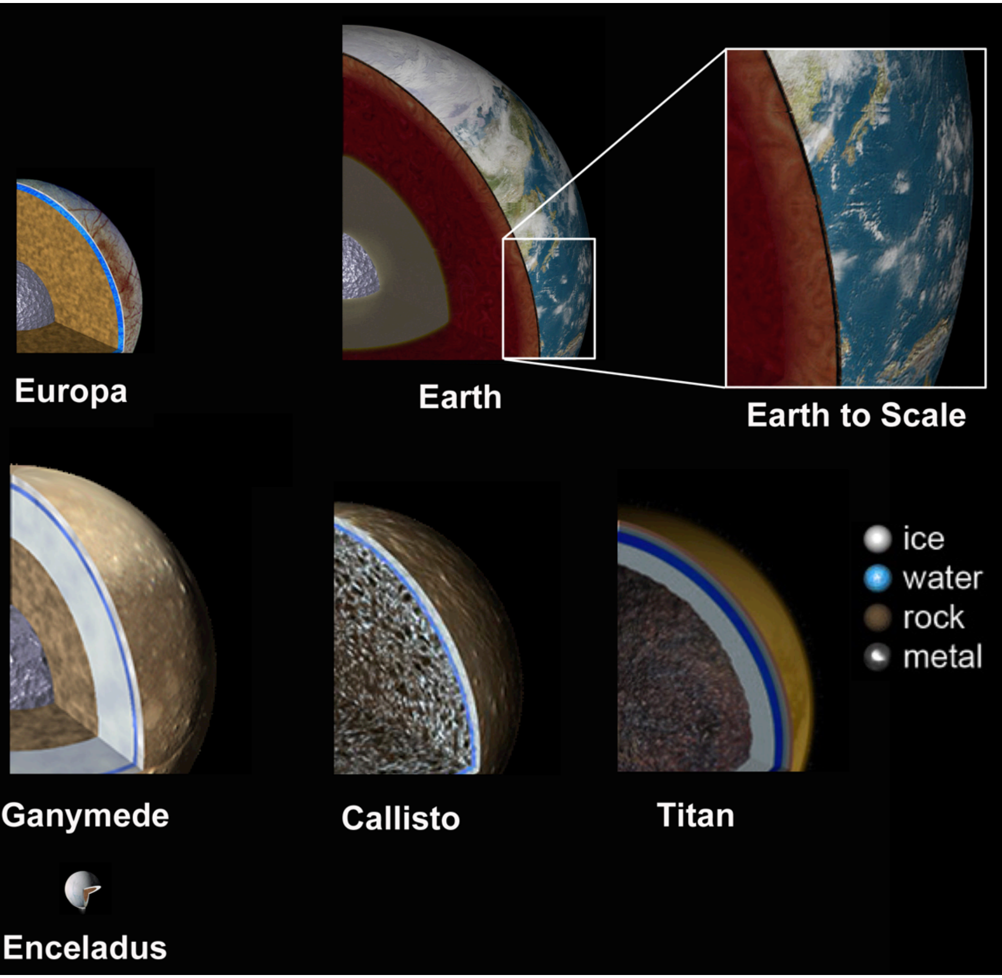
2 Europa Flybys in late 2030, early 2031

Europa’s Unique Water World

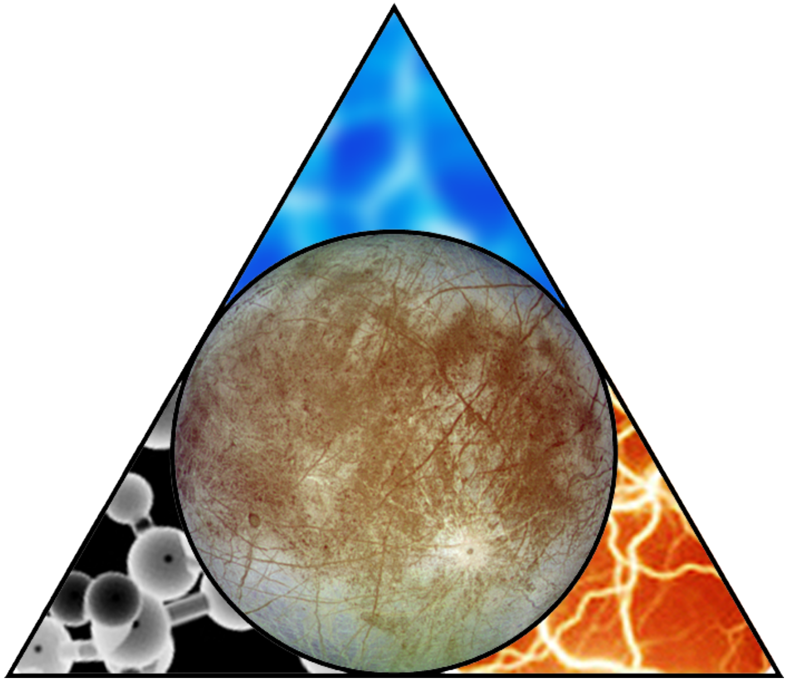
Oceans in direct contact with rock:

Oceans sandwiched by ice layers:

Transient sea:



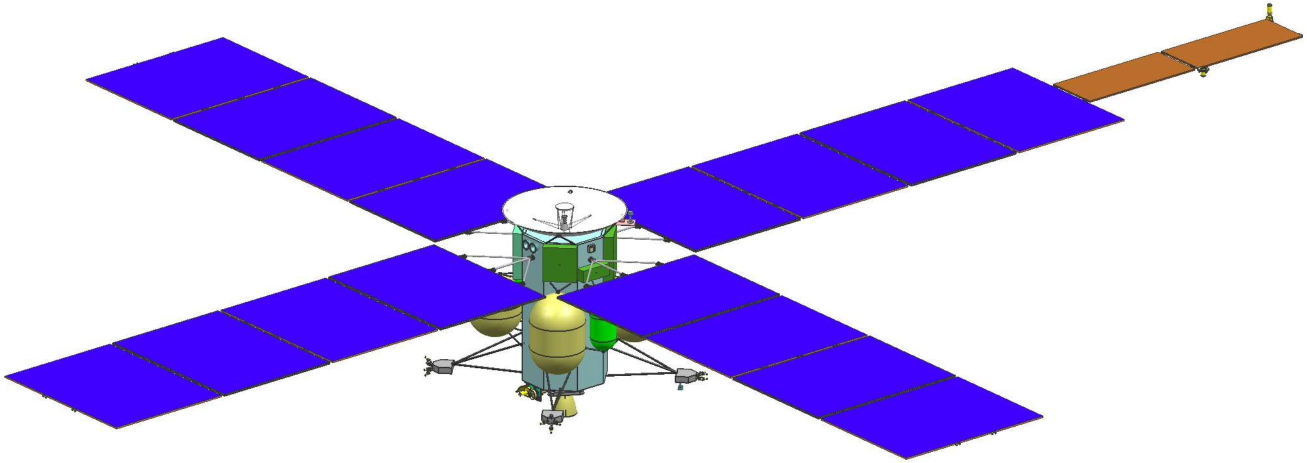
Europa’s uniquely Earth-like ocean: in contact with rock and long-lived



FY12 Continued Study

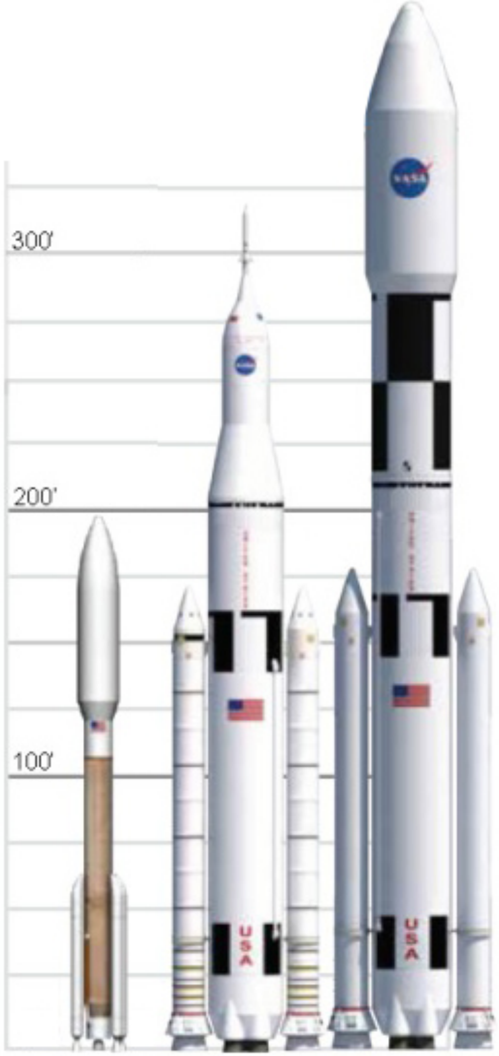
Power Systems

- Examine the viability of solar power technology
  - Advanced solar cell technology
  - Concentrator arrays
- Mitigate technology development risk due to ASRG



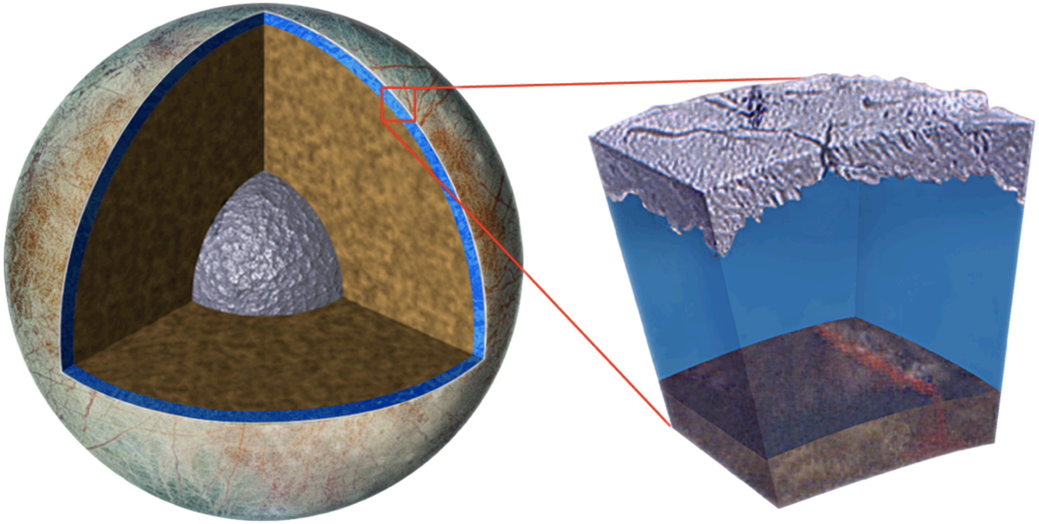
Space Launch System

- Examine the benefits of using SLS
  - Increase mass margins
  - Reduce trip time via more efficient Interplanetary trajectory
  - Work with MSFC on cost model for SLS use by Strategic Missions



Clipper Science

- Examine the accommodation of expanded Ocean Science objectives into the Clipper concept
  - Include gravity science
  - Include magnetometry
  - Revise mission design to encounter Europa at additional tidal positions



This document has been reviewed and determined not to contain export controlled technical data.

Pre-Decisional — For Planning and Discussion Purposes Only

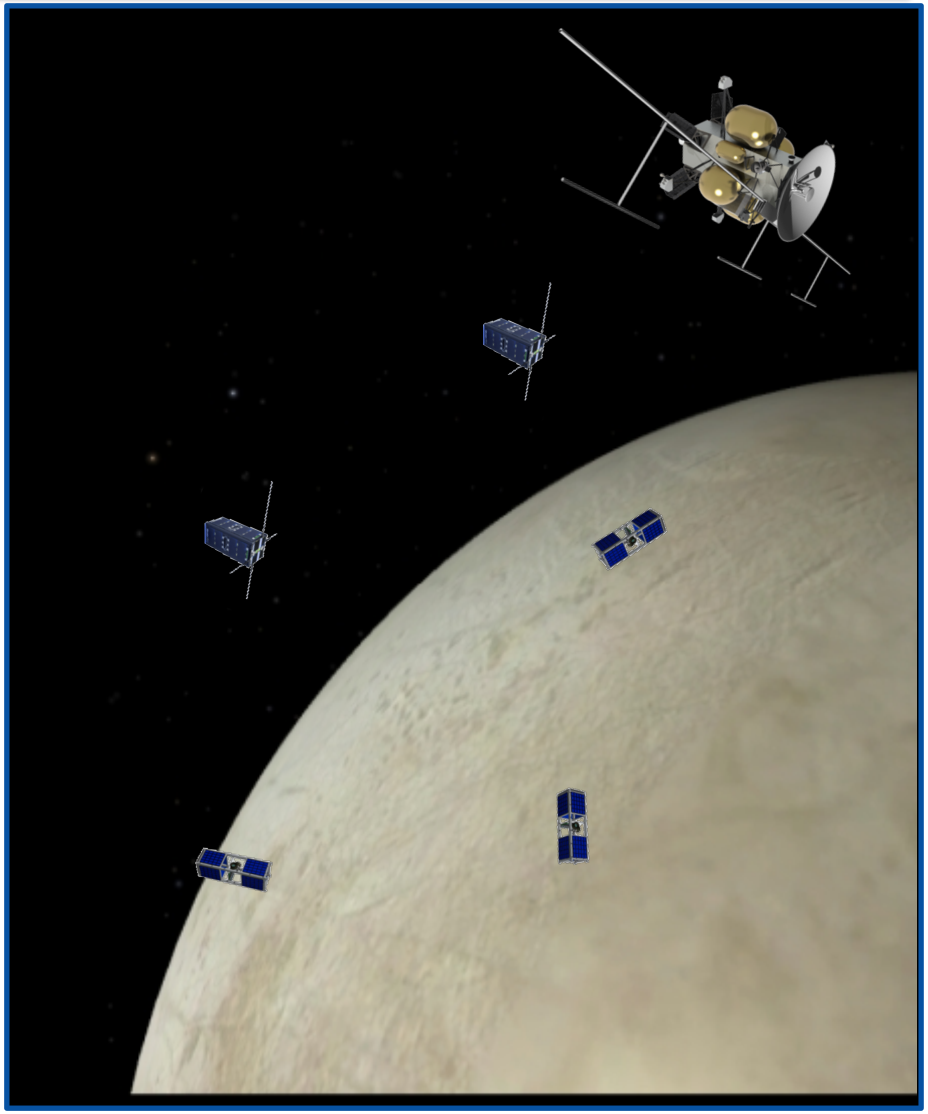
Cubesats

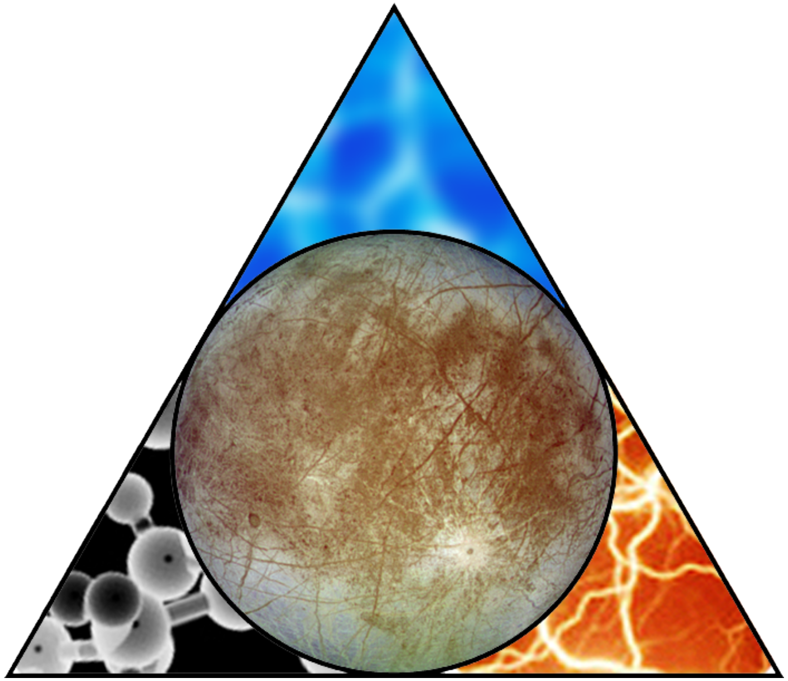
Potential Cubesat Science

- Ocean conductance measurement
- Radio Science
- High resolution descent imagery
- Magnetometry
- Radiation measurements

Cubesat Development

- University competition, selected on the basis of science, risk, and cost
- 6-12 Cubesats at max. 15kg
- Deployed during flyby
- Project could provide rad-hard parts as required





Conclusion

In the Words of the Reviewers

- Independent technical reviews chaired by Scott Hubbard

  Clipper Mission "could be conducted within the cost constraints provided and have substantial margins"

- Independent cost reviews by the Aerospace Corporation

  "Complexity analysis suggests Aerospace & Project cost estimates and schedule are reasonable based on historical data base."

- OPAG finding

  "All 3 Europa mission options are highly scientifically meritorious and responsive to the Planetary Science Decadal Survey. ... The strong majority view of the OPAG community is that the Multiple-Flyby [Clipper] option … offers the greatest science return per dollar, greatest public engagement, and greatest flow through to future Europa exploration."

Summary

National Aeronautics and Space Administration

EUROPA STUDY 2012 REPORT

Europa Study Team, 1 May 2012, JPL D-71990
Task Order NMO711062 Outer Planets Flagship Mission
Cover art Michael Carroll

- SDT and the Study Team have delivered concepts that are:
  - Scientifically compelling and would change the way we understand icy satellites and their potential habitability
  - Architecturally innovative
  - Significantly reduced in cost
  - Independently reviewed and validated