



# EUROPA MISSION

## NASA's Next Outer Solar System Strategic Mission

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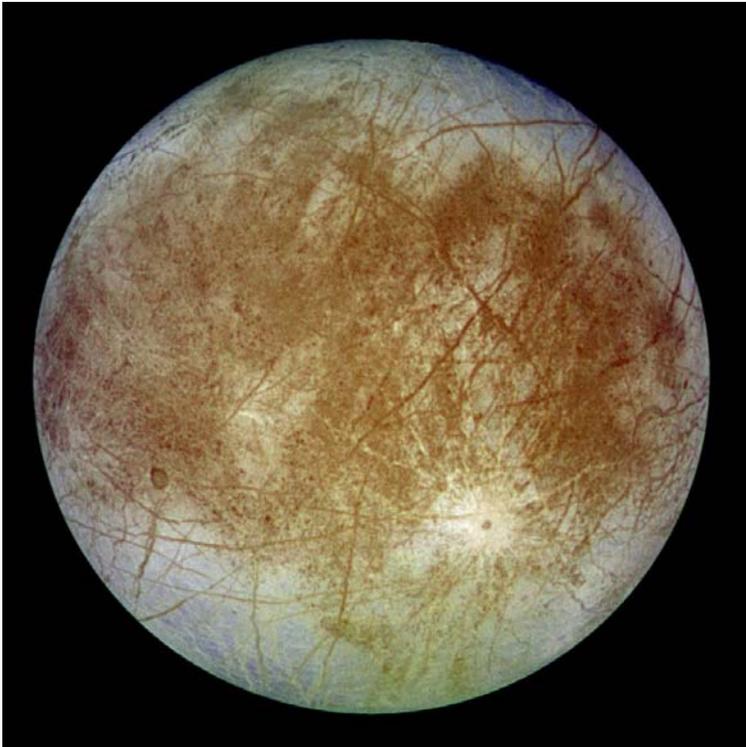
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# Europa: Key to Ocean World Habitability

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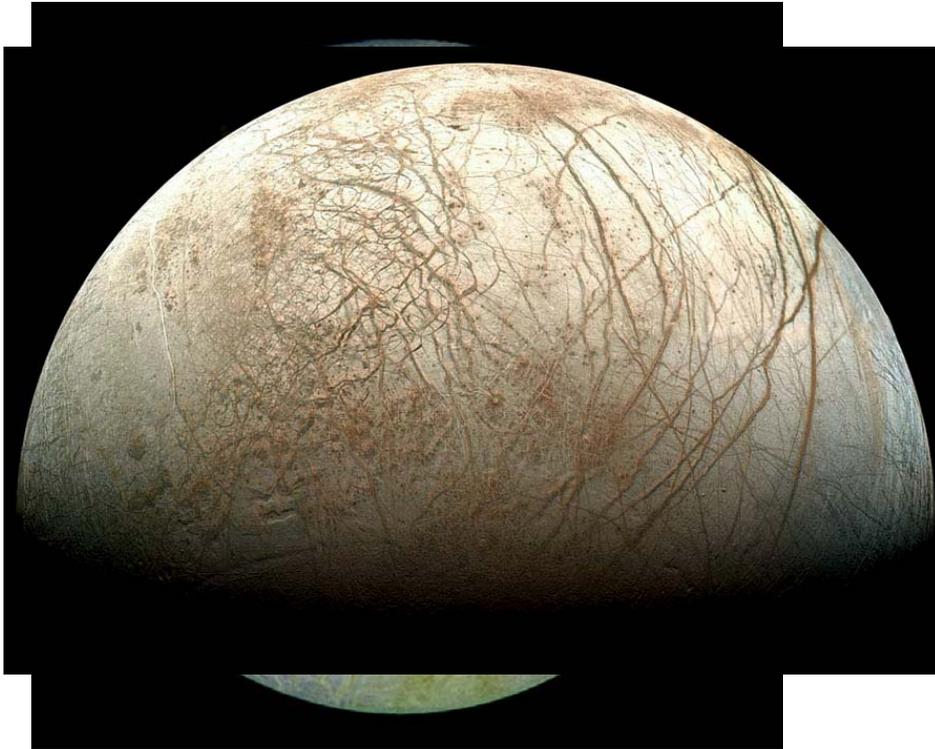


- A world of rock, ice, and water the size of Earth's moon



# Europa: Key to Ocean World Habitability

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- A world of rock, ice, and water the size of Earth's moon
- One of the youngest surfaces in the solar system



# Europa: Key to Ocean World Habitability

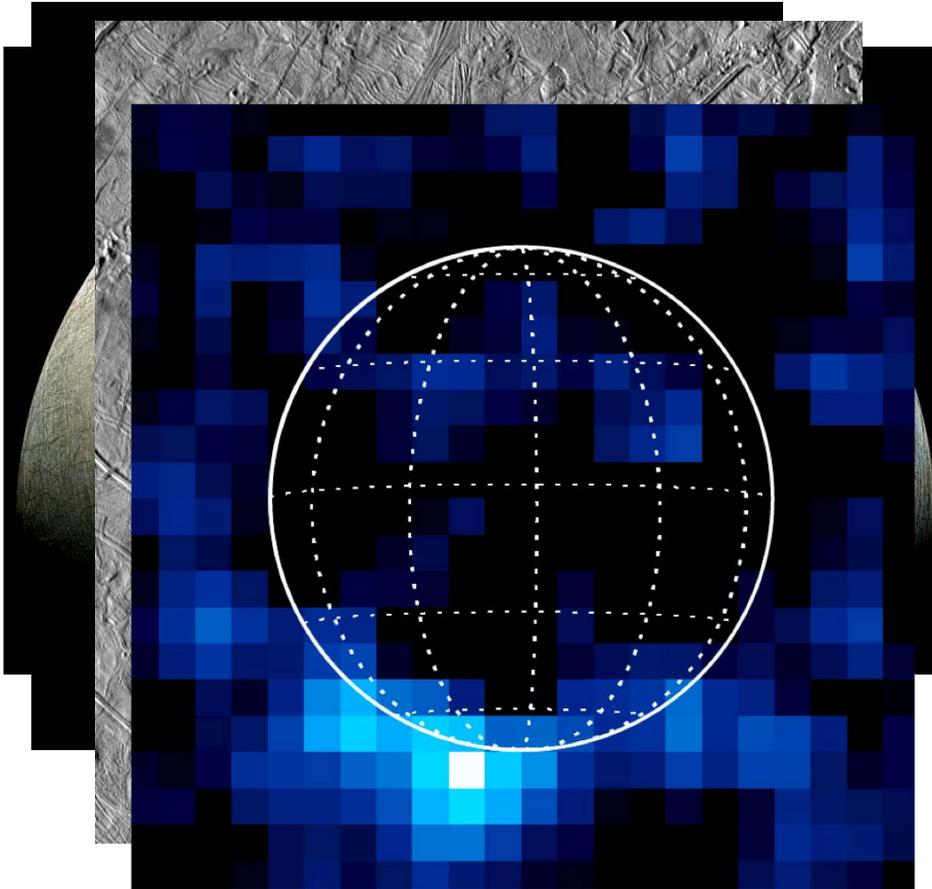
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- A world of rock, ice, and water the size of Earth's moon
- One of the youngest surfaces in the solar system
- Plentiful cryovolcanism



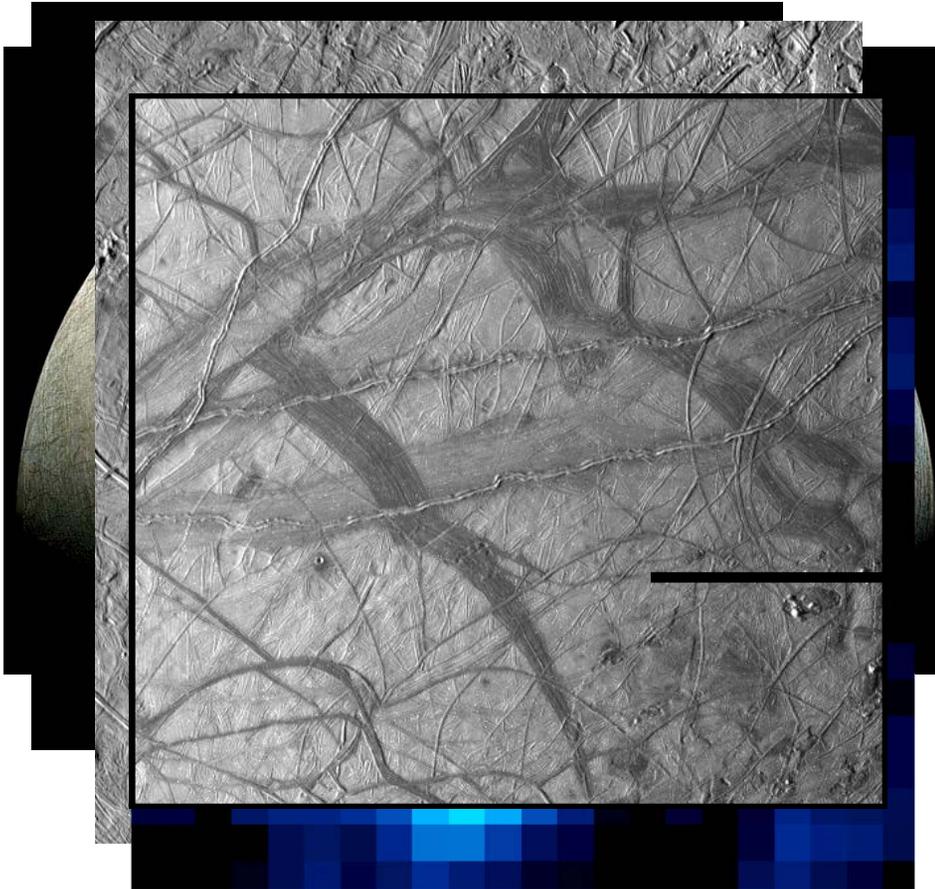
# Europa: Key to Ocean World Habitability



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- Plentiful cryovolcanism
- Possible geysers and plumes



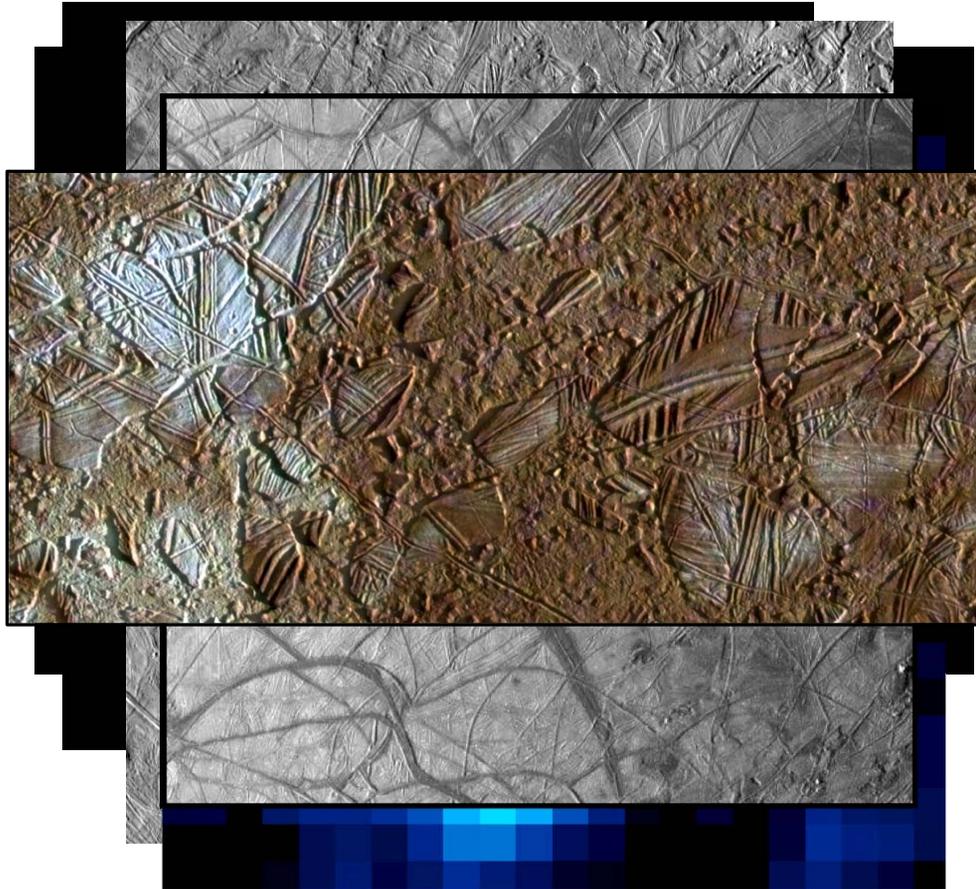
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- Possible geysers and plumes
- Earth-like global tectonic activity



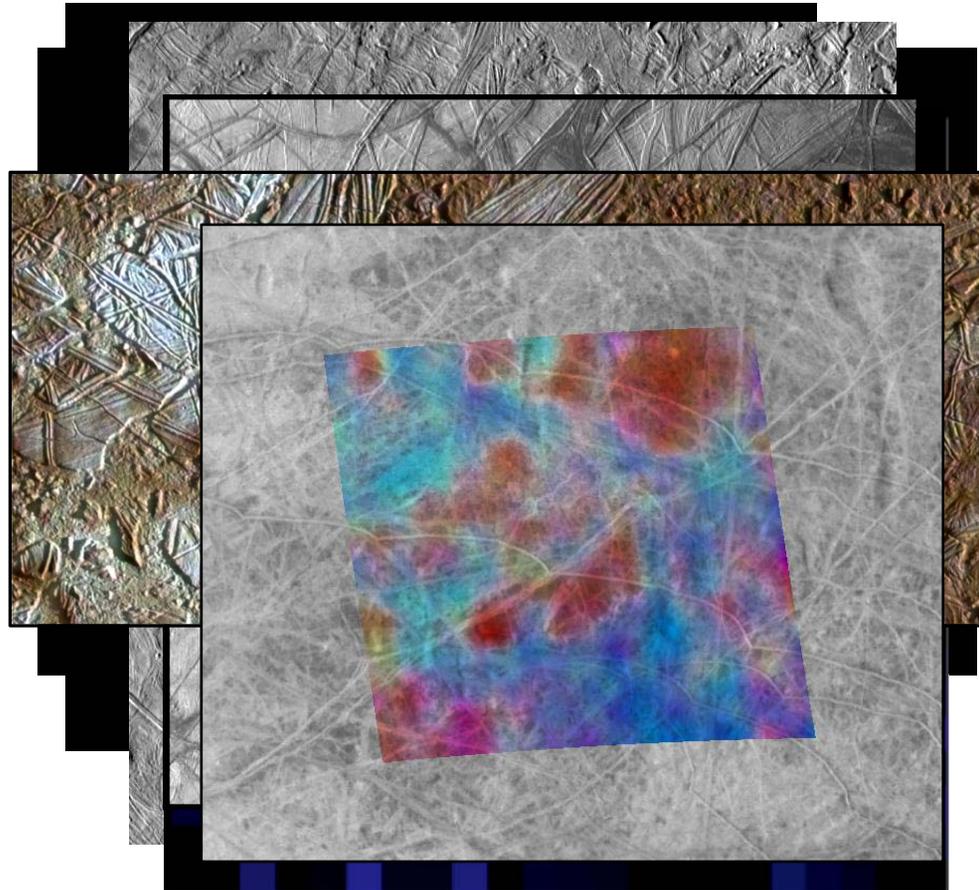
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- Earth-like global tectonic activity
- Widespread surface disruption



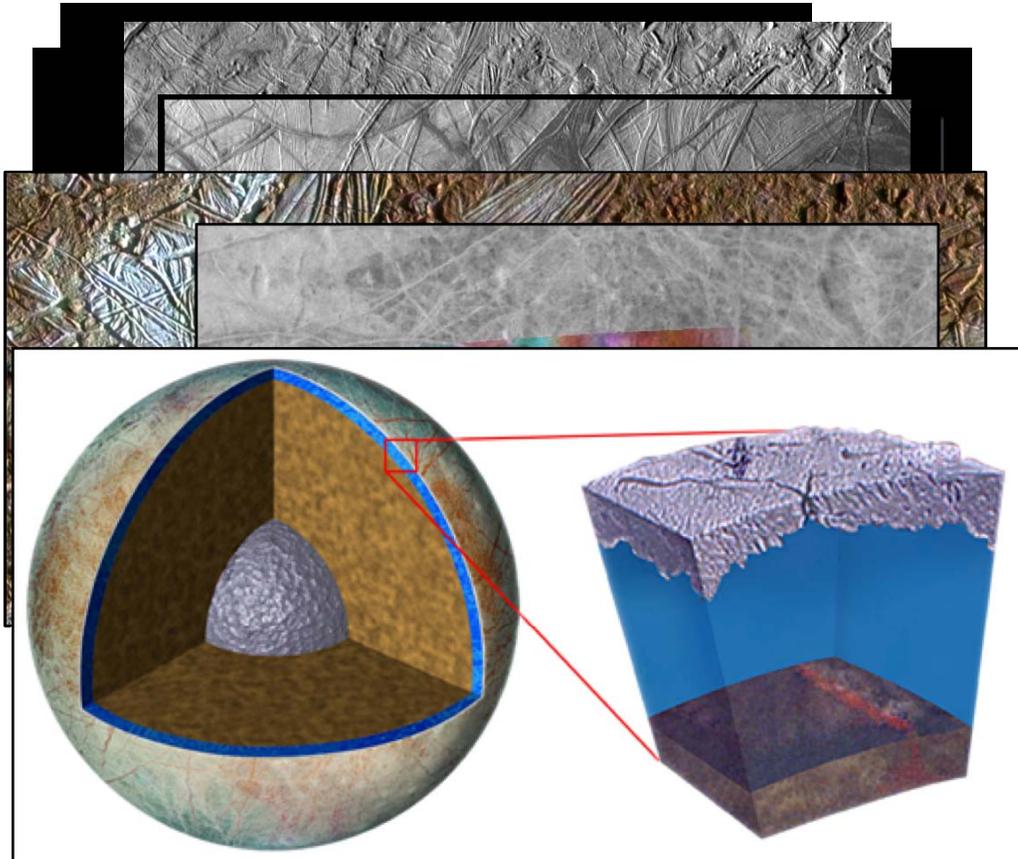
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# Europa: Key to Ocean World Habitability



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- Plentiful cryovolcanism
- Possible geysers and plumes
- Earth-like global tectonic activity
- Widespread surface disruption
- Surface chemistry of salts and acid
- Subsurface ocean: Possibly our Solar System's best chance for extant life beyond Earth



# Exploring Europa's Habitability: Ingredients for Life

## Water:

- Probable saltwater ocean, implied by surface geology and magnetic field
- Possible lakes within the ice shell, produced by local melting

## Chemistry:

- Ocean in direct contact with mantle rock, promoting chemical leaching
- Dark red surface materials contain salts, probably from the ocean

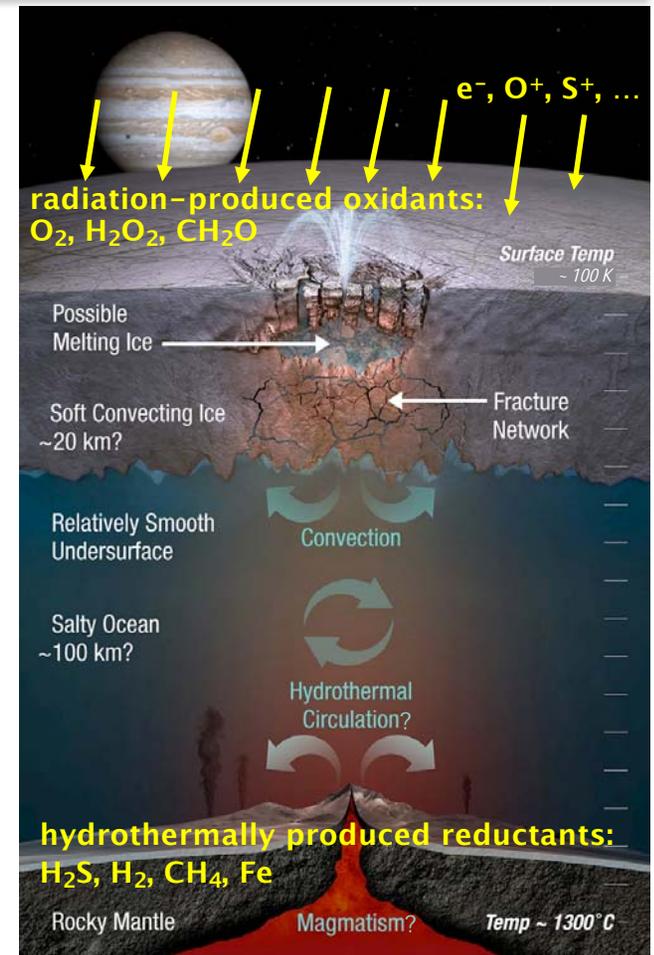
## Energy:

- Chemical energy might sustain life
- Surface irradiation creates oxidants
- Mantle rock-water reactions could create reductants (hydrothermal or serpentinization)

## Activity:

- Geological activity “stirs the pot”
- Activity could be cyclical, as tied to Io

**A Europa Mission should be capable of studying Europa as a complex interrelated system to test key habitability hypotheses**





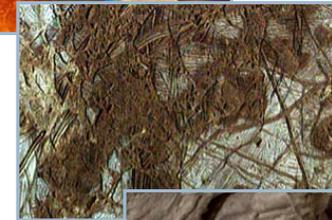
# Europa Mission Science Goal & Objectives

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- **Mission Goal: Explore Europa to investigate its habitability**

- **Objectives:**

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

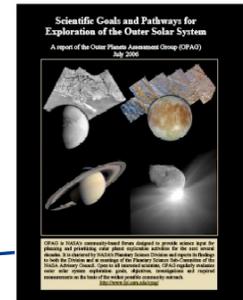
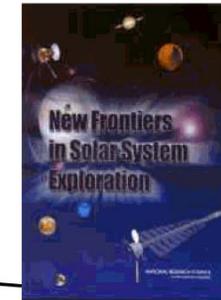
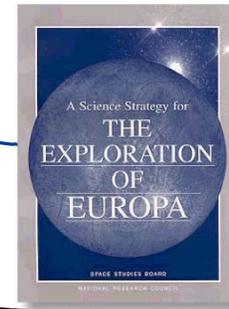


\*Science Definition Team's "Reconnaissance" goal is now folded into the Geology objective.



# Timeline of Europa Mission Science Definition

- Europa Orbiter Science Definition Team (1999)
- A Science Strategy for the Exploration of Europa, COMPLEX, National Research Council (1999)
- NASA Campaign Science Working Group on Prebiotic Chemistry in the Solar System (1999)
- New Frontiers in Solar System Exploration, Decadal Survey, (2003)
- Jupiter Icy Moons Orbiter (JIMO) Science Definition Team (2004)
- Scientific Goals and Pathways for Exploration of the Outer Solar System, OPAG (2006)
- NASA Solar System Exploration Roadmap (2006)
- Europa Explorer (EE) Report (2007)
- Jupiter Europa Orbiter Mission Final Report (2008)
- Europa Study Report (2012)



**The Europa science objectives have a long history of evolution and refinement**



# Europa Science Definition Team Members

## 1999 – 2014

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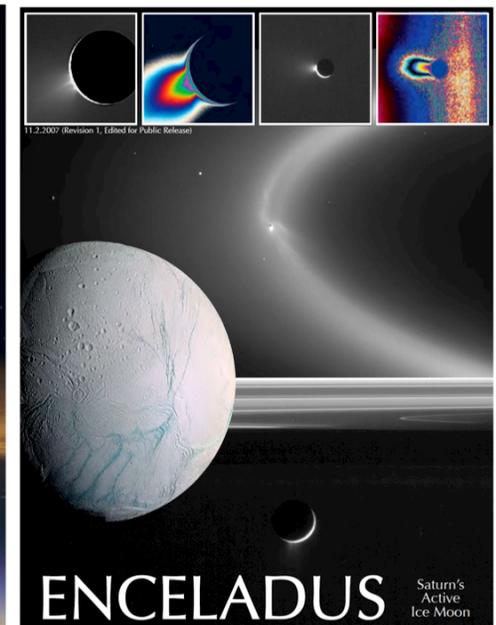
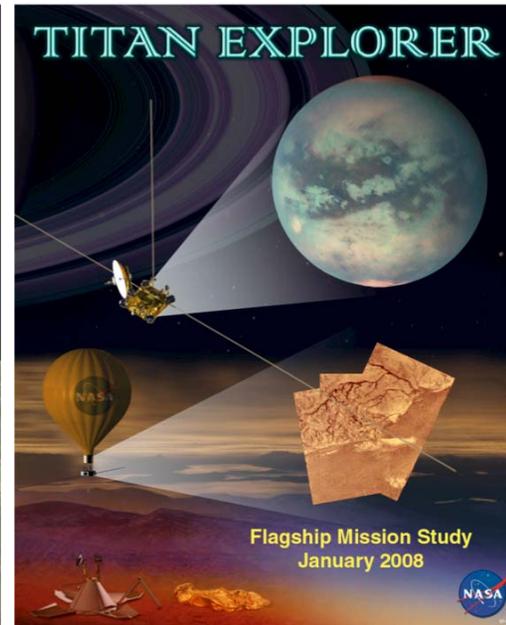
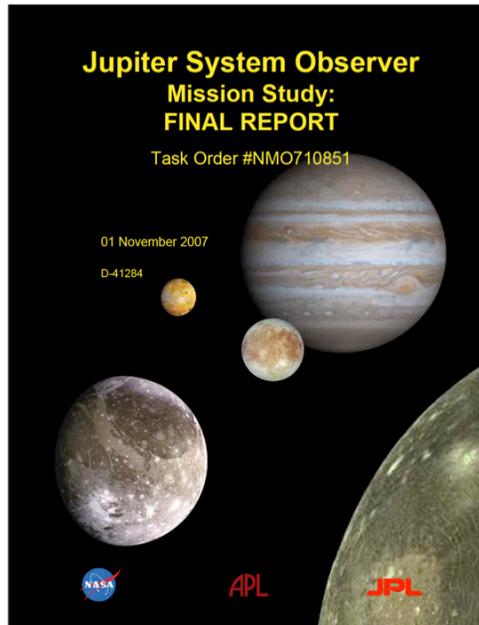
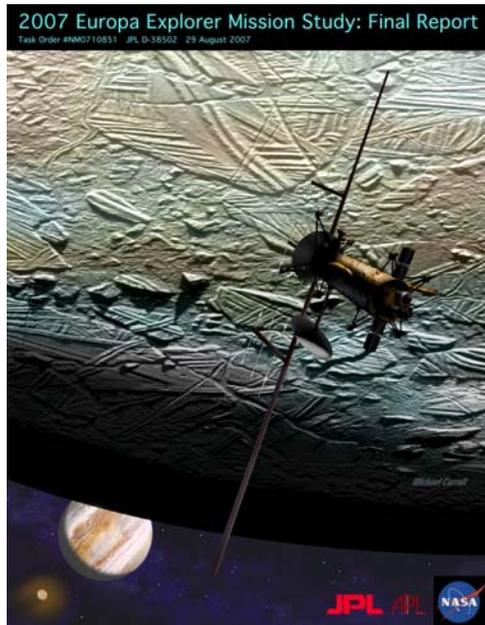
Ariel Anbar	J. Brad Dalton	Ralf Jaumann	Steve Ostro	Mitch Sogin
Fran Bagenal	John Delaney	Torrence Johnson	Bob Pappalardo	Christophe Sotin
John Baross	Jody Deming	Yasumasa Kasaba	Chris Paranicas	John Spencer
Amy Barr	Michele Dougherty	Krishan Khurana	G. Wes Patterson	Steve Squyers
Bruce Bills	Pierre Drossart	Norbert Krupp	Stan Peale	Dave Stevenson
Michel Blanc	Brad Edwards	Bill Kurth	Olga Prieto-Ballasteros	Yukihiro Takahashi
Diana Blaney	Hajo Eicken	Jean-Pierre Lebreton	Louise Prockter	Takeshi Takashima
Don Blankenship	Tony England	Ralph Lorenz	Bill Sandel	Richard Terrile
Will Brinckerhoff	Leigh Fletcher	Nick Makris	David Sandwell	Peter Thomas
Emma Bunce	Masaki Fujimoto	Essam Marouf	Sho Sasaki	Paolo Tortora
Bruce Campbell	Paul Geissler	Tom McCord	Paul Schenk	Federico Tosi
Robin Canup	Olivier Grasset	Melissa McGrath	Jerry Schubert	Elizabeth Turtle
Phil Christensen	Ron Greeley	Chris McKay	Dave Senske	Timothy Van Hoolst
Chris Chyba	Rick Greenberg	Bill McKinnon	Everett Shock	Steve Vance
Andrew Coates	Kevin Hand	Mike Mellon	Mark Showalter	J. Hunter Waite
Jack Connerney	Amanda Hendrix	Bill Moore	Adam Showman	David Warmflash
John Cooper	Tori Hoehler	Jeff Moore	Amy Simon-Miller	Dale Winebrenner
Angioletta Coradini	Hauke Hussmann	Susanne Neuer	David E. Smith	Charles Yoder
Athena Coustenis	Andy Ingersoll	Francis Nimmo	Larry Soderblom	Maria Zuber



# Outer Planets Flagship Competition

## 2007 - 2008

- NASA pitted 4 Science Definition Teams and associated engineers in open competition to consider options for a future outer planet satellite Flagship mission

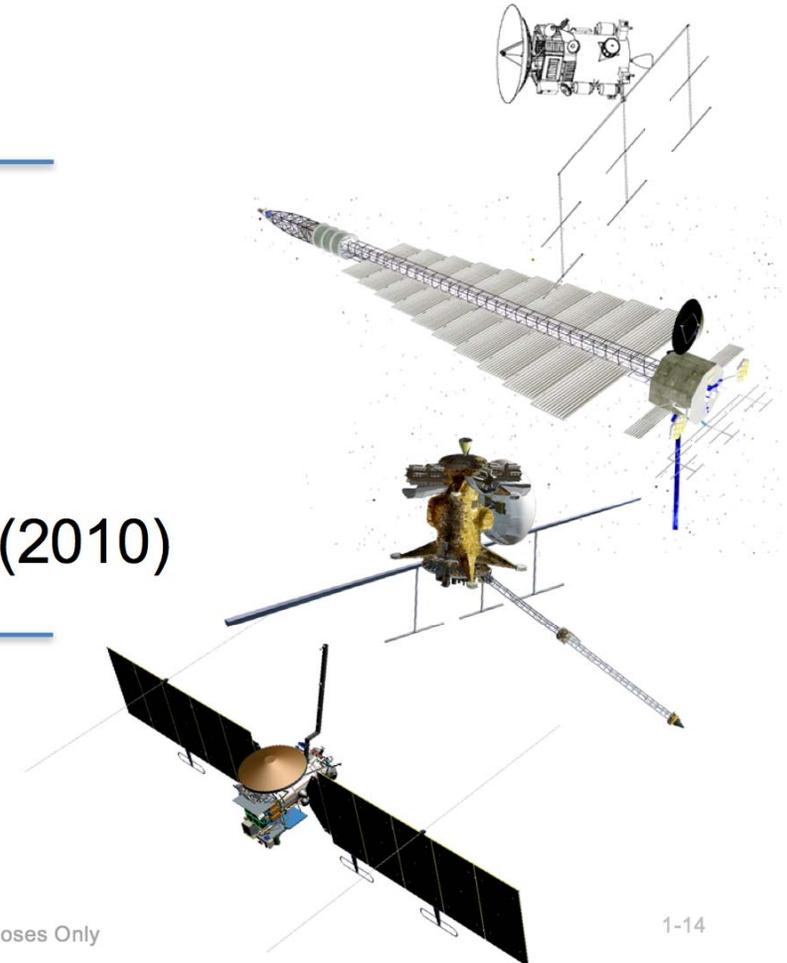


- *Pro:* Advanced mission concept options for exploring ocean world targets
- *Con:* Created animosity among science community members, persisting for years



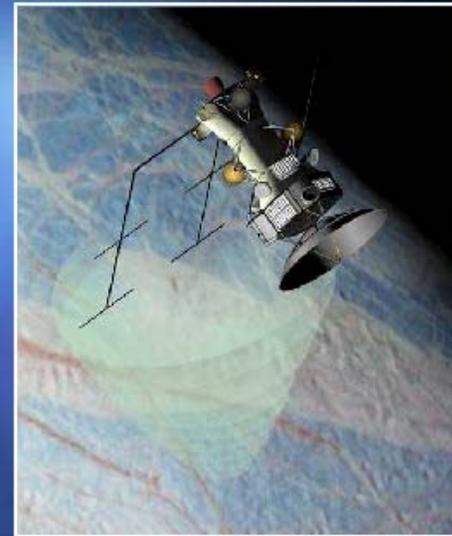
# Timeline of Europa Mission Concepts

- Europa Orbiter (2001)
- **Planetary Decadal Survey I (2003)** ————
- Jupiter Icy Moons Orbiter – JIMO (2004)
- Europa Explorer (2007 – 2008)
- Jupiter Europa Orbiter – JEO, of the  
Europa Jupiter System Mission – EJSM (2010)
- **Planetary Decadal Survey II (2011)** ————
- Europa Multiple-Flyby Mission  
– “Europa Clipper” (2015+)



# 2011 Planetary Decadal Recommendation: The Need For A Descope

- The CATE estimate for the cost of JEO is \$4.7 billion. This is too large a fraction of the planetary budget.
- *Fly JEO only if changes to both the mission and the NASA planetary budget make it affordable without eliminating other recommended missions:*
  - This will require a reduction in the mission's scope and cost
  - JEO will require a new start that increases the overall budget of NASA's Planetary Science Division



- *Immediately begin an effort to find major cost reductions in JEO, with the goal of minimizing the necessary planetary science budget increase.*
- JEO science would be enhanced by conducting the mission jointly with ESA's proposed Ganymede Orbiter mission.

*From: Squyres (2011), Visions & Voyages Rollout Presentation*

NATIONAL RESEARCH COUNCIL  
OF THE NATIONAL ACADEMIES



# Response to the 2011 Planetary Decadal Survey: Reduced-Scope Europa Mission Options

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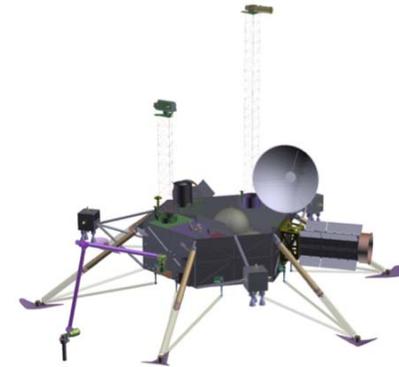
- Proposed 2020 Jupiter Europa Orbiter (JEO) mission was deemed extremely high science value, but unaffordable by the NRC Decadal Survey, which requested a descoped option
- NASA directed a 1 year study to develop mission options that retain high science value at significantly reduced cost
- Innovative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



Reduced-Scope  
Europa Orbiter



Europa Multiple-Flyby  
("Europa Clipper")



Europa Lander



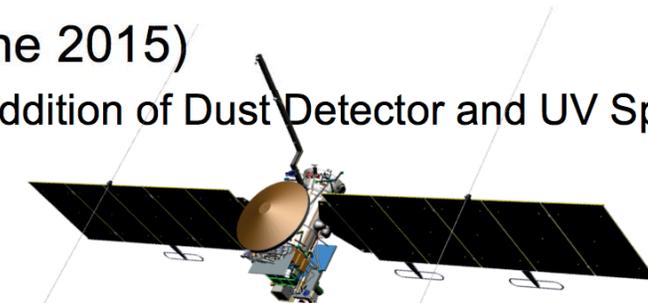
# Evolution of Europa Multiple-Flyby Mission Concept

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- Initial Multiple-Flyby “Clipper” concept (May 2012)
  - Model Payload: Ice-Penetrating Radar, IR Spectrometer, Topo Imager, Mass Spectrometer
- Enhanced Clipper concept (Dec. 2012)
  - NASA requested to add “ocean” science and reconnaissance: Magnetometer, Langmuir Probe, Recon Camera, Thermal Imager
- Europa Multiple-Flyby Mission Concept Review (Sept. 2014)
  - Revised to a solar mission, with short cruise on SLS
- Europa Multiple-Flyby Mission KDP-A (June 2015)
  - NASA selected high-quality instruments, with addition of Dust Detector and UV Spectrograph



Initial Europa Multiple-Flyby Concept



Current Europa Multiple-Flyby Mission Concept

# NASA-Selected Europa Investigations (May 2015)

**Europa-UVS**  
UV Spectrograph  
surface &  
plume/atmosphere  
composition

**MASPEX**  
Mass Spectrometer  
sniffing atmospheric  
composition

**EIS**  
Narrow-Angle Camera +  
Wide-Angle Camera  
mapping alien landscape  
in 3D & color

**SUDA**  
Dust Analyzer  
surface & plume  
composition

**E-THEMIS**  
Thermal Imager  
searching for hot spots

**ICEMAG**  
Magnetometer  
sensing ocean  
properties

**MISE**  
IR Spectrometer  
surface chemical  
fingerprints

**PIMS**  
Faraday Cups  
plasma environment

**REASON**  
Ice-Penetrating Radar  
plumbing the ice shell

Gravity Science  
Working Group  
confirming an ocean

Radiation Science  
Working Group  
radiation environment

● Remote Sensing

● In Situ



# Europa Mission Concept

- Ensure capability for collecting synergistic data from all instruments (nadir-pointed, ram-pointed, and commonly gravity science) simultaneously and during each flyby
  - Maximizes science return by facilitating in-depth multi-instrument interpretations
  - Minimizes data collection time in the high-radiation environment
  - Enables simple, repeatable operations

**16 m radar HF Antenna (2x)**

**Magnetometer boom  
5 m**

**Ram-pointed  
mass  
spectrometers**

**Nadir-pointed  
remote sensing  
instruments**

**Solar Panels  
2.2 m x 4.1 m each**

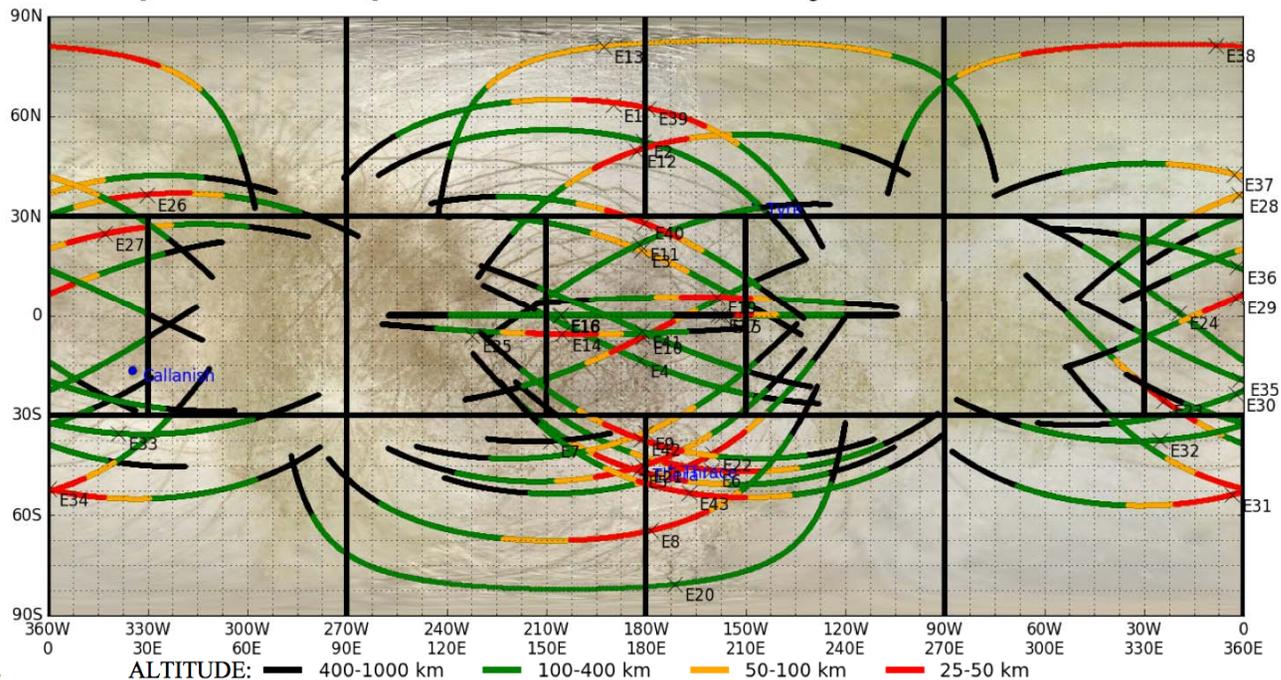
**Radar VHF  
Antennas (4x)**

Pre-decisional, for information and discussion purposes only.



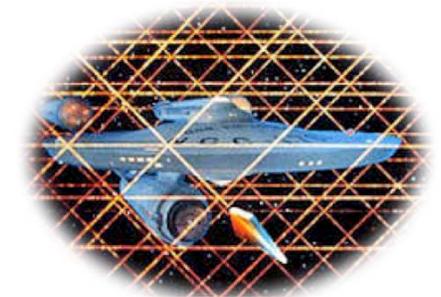
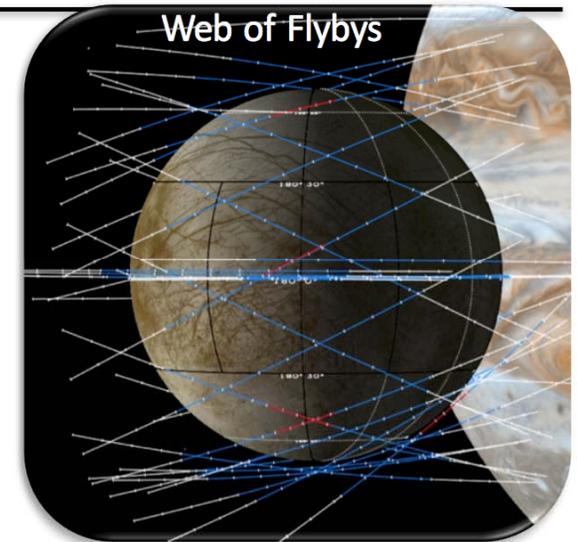
# “Global-Regional” Surface Coverage

- Utilize multiple satellite gravity assists to enable “global-regional” coverage of Europa while in orbit around Jupiter
- Current mission design consists of ~42 low-altitude flybys of Europa from Jupiter orbit over ~3.5 yr



8/X/:

Pre-Decisional, For Planning and Discussion Purposes Only

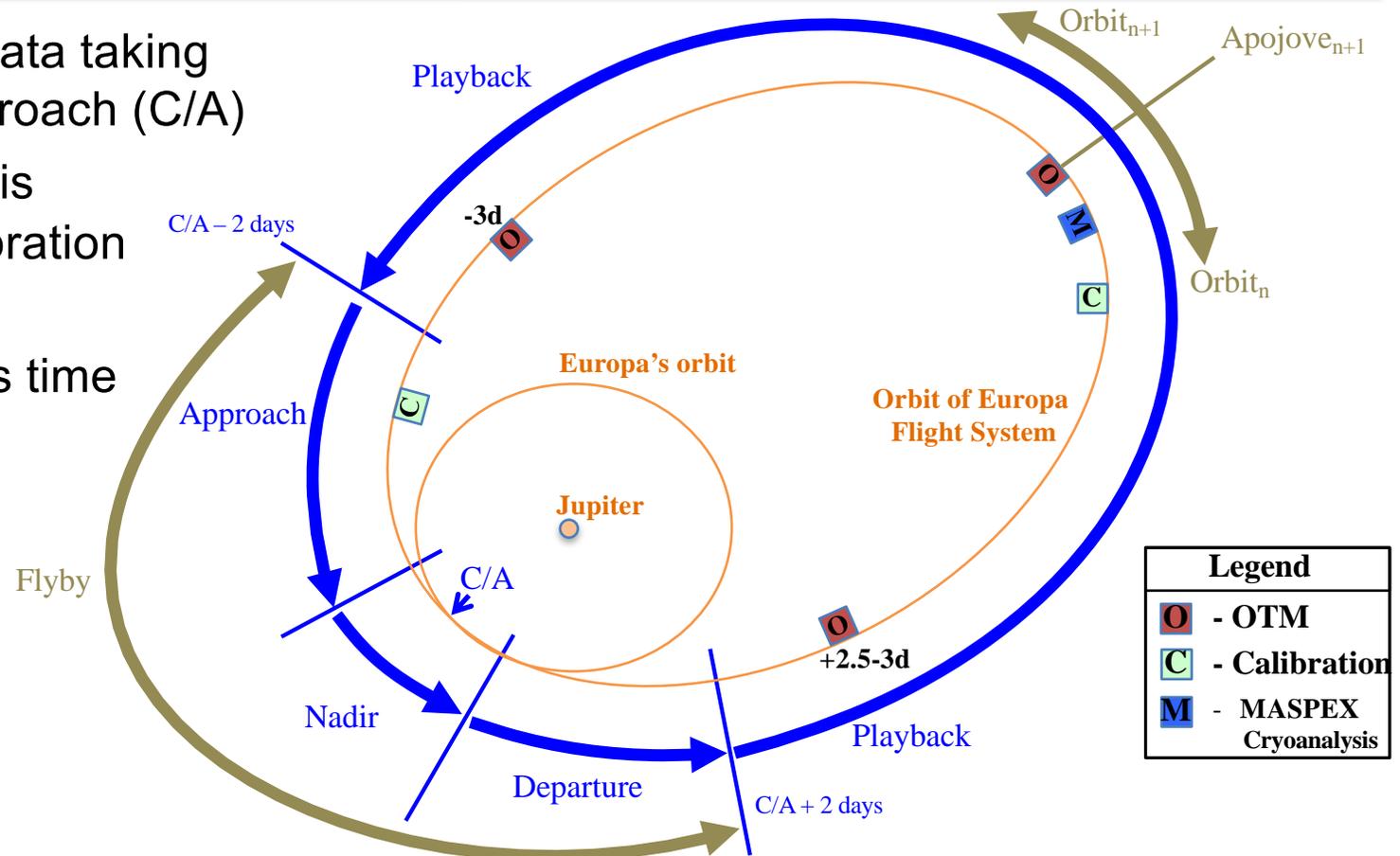


Tholian Web



# Simple and Repeatable Operations

- Intensive science data taking around closest approach (C/A)
- Remainder of orbit is predominantly calibration and data playback
- Flyby strategy limits time in high-radiation environment near Jupiter





## Europa Mission Science Objectives (1/3): *Ice Shell & Ocean*

- ***Ice Shell & Ocean Objective:***

Characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of surface-ice-ocean exchange

- ***Ice Shell & Ocean Investigations:***

- Characterize the distribution of any shallow subsurface water and the structure of the icy shell

***EIS, REASON***

- Determine ocean salinity and thickness

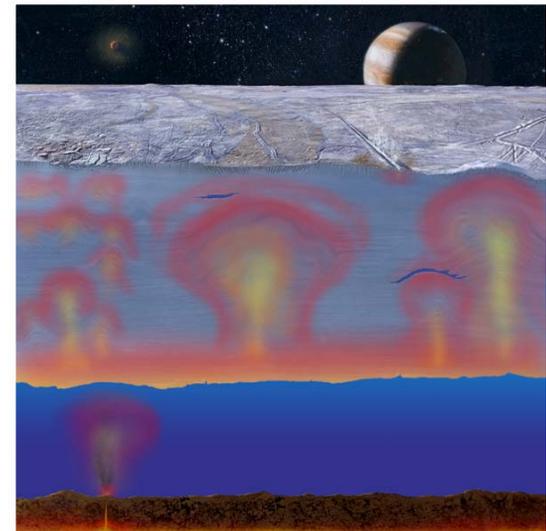
***ICEMAG, MISE, PIMS, SUDA***

- Constrain the regional and global thickness, heat-flow, and dynamics of the ice shell

***E-THEMIS, EIS, Gravity, ICEMAG, PIMS, REASON***

- Investigate processes governing material exchange among the ocean, ice shell, surface, and atmosphere

***EIS, ICEMAG, MASPEX, MISE, REASON, SUDA***





## Europa Mission Science Objectives (2/3): *Composition*

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- ***Composition Objective:***

Understand the habitability of Europa's ocean through composition and chemistry

- ***Composition Investigations:***

- Characterize the composition and chemistry of endogenic materials on the surface and in the atmosphere, including potential plumes

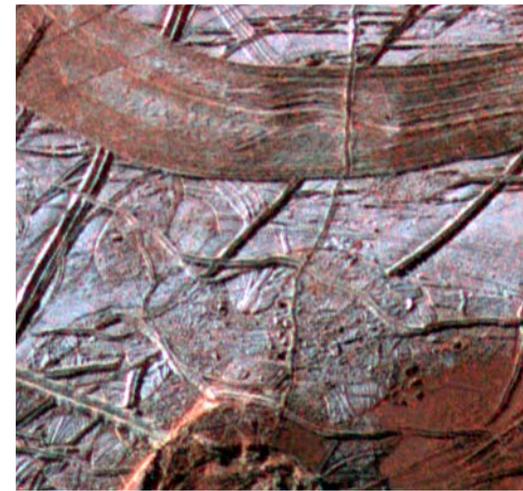
***EIS, Europa-UVS, ICEMAG, MASPEX, MISE, PIMS, REASON, SUDA***

- Determine the role of the radiation and plasma environment in creating and processing the atmosphere and surface materials

***EIS, Europa-UVS, MASPEX, MISE, PIMS, Radiation, REASON, SUDA***

- Characterize the chemical and compositional pathways in the ocean

***EIS, ICEMAG, MASPEX, MISE, SUDA***





## Europa Mission Science Objectives (3/3): *Geology*

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- ***Geology Objective:***

Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities

- ***Geology Investigations:***

- Determine sites of most recent geological activity, including potential plumes, and characterize localities of high science interest and potential future landing sites

***E-THEMIS, EIS, Europa-UVS, MASPEX, MISE, PIMS, Radiation, REASON, SUDA***

- Determine the formation and three-dimensional characteristics of magmatic, tectonic, and impact landforms

***EIS, REASON***

- Investigate processes of erosion and deposition and their effects on the physical properties of the surface

***E-THEMIS, EIS, Europa-UVS, PIMS, Radiation, REASON, SUDA***





# Science Synergy & Redundancy

	Baseline Level-1	Threshold Level-1	REASON HF	REASON VHF	EIS NAC	EIS WAC	MISE	E-THEMIS	Europa-UVS	ICEMAG	PIMS	SUDA	MASPEX	Gravity + Altimetry
Ice/Ocean	Subsurface struct. (≥50 landforms)	Subsurface struct. (≥15 landforms)	* (Green)	* (Green)	Yellow	Orange								
	Ice thickness; ocean salinity (±50%)	Confirm ocean / thick vs. thin shell	* (Blue)	* (Blue)	Yellow	Orange				* (Green)	Orange			* (Blue)
Composition	Global comp. (≥70% coverage)	Global comp. (≥40% coverage)				Yellow	Green		Blue			Yellow	Yellow	
	Landform comp. (≥50, ≤300 m)	Landform comp. (≥15, ≤25 km)				Yellow	Green		Blue			Yellow	Yellow	
	Gas, dust, and plasma comp.	Gas or dust composition					Yellow		Blue	Yellow	* (Green)	* (Green)	* (Green)	
Geology	Global imaging (≥80% coverage)	Global imaging (≥30% coverage)			Green	Yellow	Yellow							
	High-res (≤25m) landforms (≥50)	High-res (≤50m) landforms (≥15)		Yellow	Green	Blue	Yellow	Yellow						
	Local surface (~1m, ≥40 sites)	[None]	Yellow	Yellow	Green	Yellow		Yellow						
Activity	Characterize current activity	Search for current activity	Blue	Blue	Yellow		Blue	* (Green)	* (Green)	Blue	Blue	Blue	Blue	

Primary instrument (achieves requirement)
  Supportive dependency (required support for Primary)
  Independent instrument (can achieve requirement)
  Supportive independent (enhances the science)

Baseline
  Threshold

\* In combination achieves science



# Europa Project Science Group (PSG)

PIs, Co-Is, Phase-A Working Groups, Project Science (Currently 132 total)

Oleg Abramov  
Amy Barr Mlinar  
Bruce Bills  
Jordana Blacksberg  
Diana Blaney  
Don Blankenship  
Scott Bolton  
Christelle Briois  
Tim Brockwell  
Lorenzo Bruzzone  
Bruce Campbell  
Bob Carlson  
Lynn Carter  
Tony Case  
Tim Cassidy  
Phil Christensen  
Roger Clark  
Corey Cochran  
Geoff Collins  
Kate Craft  
Brad Dalton  
Ingrid Daubar  
Ashley Davies  
Serina Diniega  
Scott Edgington  
Charles Elachi  
Carolyn Ernst

Paul Feldman  
Leigh Fletcher  
Yonggyu Gim  
Randy Gladstone  
Thomas Greathouse  
Robert Green  
Cyril Grima  
Eberhard Gruen  
Murthy Gudipati  
Dennis Haggerty  
Kevin Hand  
Candy Hansen  
Alex Hayes  
Paul Hayne  
Matt Hedman  
Alain Herique  
Karl Hibbitts  
Mihaly Horanyi  
Howett, Carly  
Terry Hurford  
Hauke Hussmann  
Xianzhe Jia  
Steven Joy  
Insoo Jun  
Justin Kasper  
Sascha Kempf  
Krishan Khurana

Randy Kirk  
Margaret Kivelson  
Rachel Klima  
Wlodek Kofman  
Peter Kollmann  
Haje Korth  
William Kurth  
Yves Langevin  
Jonathan Lunine  
Jean-Luc Margot  
Marco Mastrogiuseppe  
Erwan Mazarico  
Tom McCord  
Alfred McEwen  
Melissa McGrath  
Bill McKinnon  
Ralph McNutt  
Mike Mellon  
Jeff Moore  
Olivier Mousis  
Alina Mousessian  
Scott Murchie  
Neil Murphy  
Francis Nimmo  
Bob Pappalardo  
Chris Paranicas

Ryan Park  
Wes Patterson  
Carol Paty  
Cynthia Phillips  
Sylvain Piqueux  
Jeff Plaut  
Dirk Plettemeier  
Frank Postberg  
Louise Prockter  
Lynnae Quick  
Julie Rathbun  
Trina Ray  
Carol Raymond  
Kurt Retherford  
James Roberts  
Lorenz Roth  
Chris Russell  
Abigail Rymer  
Joachim Saur  
Juergen Schmidt  
Britney Schmidt  
Dustin Schroeder  
Frank Seelos  
Dave Senske  
Mark Sephton  
Everett Shock

James Slavin  
David Smith  
Todd Smith  
Jason Soderblom  
Krista Soderlund  
Sean Solomon  
John Spencer  
Ralf Srama  
Andrew Steffl  
Alan Stern  
Michael Stevens  
Robert Strangeway  
Ben Teolis  
Nick Thomas  
Gabriel Tobie  
Zibi Turtle  
Steve Vance  
Hunter Waite  
Mike Watkins  
Ben Weiss  
Joe Westlake  
Danielle Wyrick  
Duncan Young  
Cary Zeitlin  
Mikhail Zolotov  
Maria Zuber

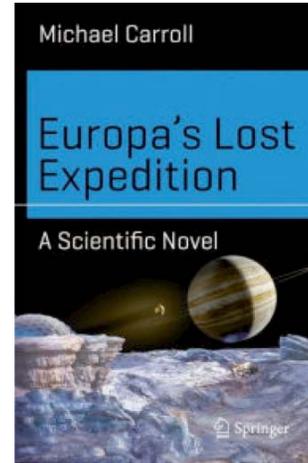
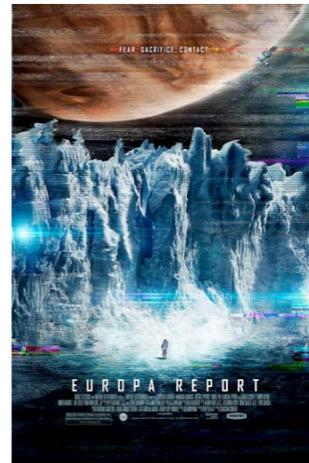


Europa Project Science Group (PSG)

Europa  
Project Science Group Meeting #1  
August 4, 2015



# Europa Is Gaining Foothold in Popular Culture





# Personal Observations and Conclusions

- When the science goal is high priority and the target difficult to explore, strategic missions should be capable and well-instrumented
- It was valuable for the Decadal Survey and NASA to push on the Europa study team to find a descoped mission option that lowered cost and maximized science per dollar
- Pitting the science community in a strategic mission open competition was not worth the damage it caused to the community
- It was scientifically valuable for NASA to augment the Europa mission to find the “sweet spot” in cost and capability
- In studying a complex interrelated system, synergies and complementarity among instruments is key to maximizing science, such as through co-publications among science team members
- Large strategic missions provide vital support of a cross-section of the science community, notably young researchers





<http://www.nasa.gov/europa>