NASA's Next Outer Solar System Strategic Mission

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Jet Propulsion Laboratory, California Institute of Technology

Dec. 7, 2016

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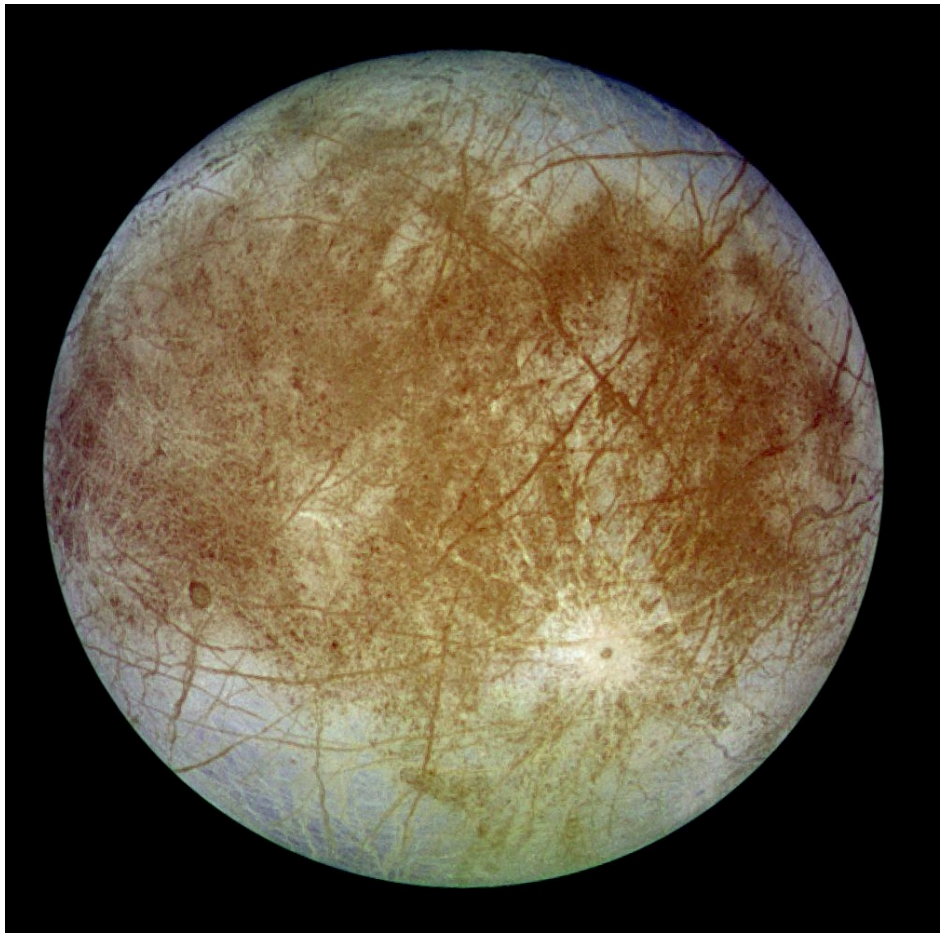
Europa: Key to Ocean World Habitability



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

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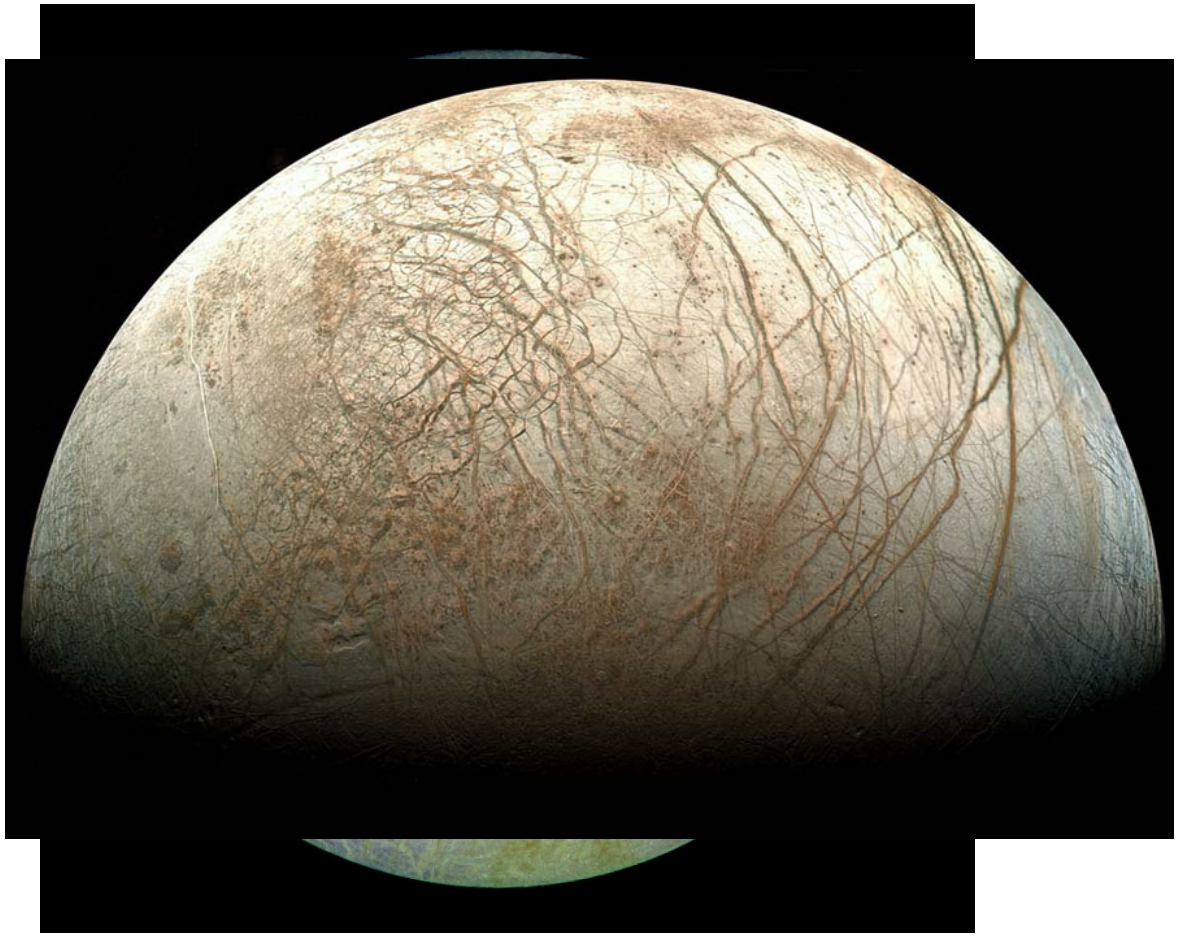

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- One of the youngest surfaces in the solar system

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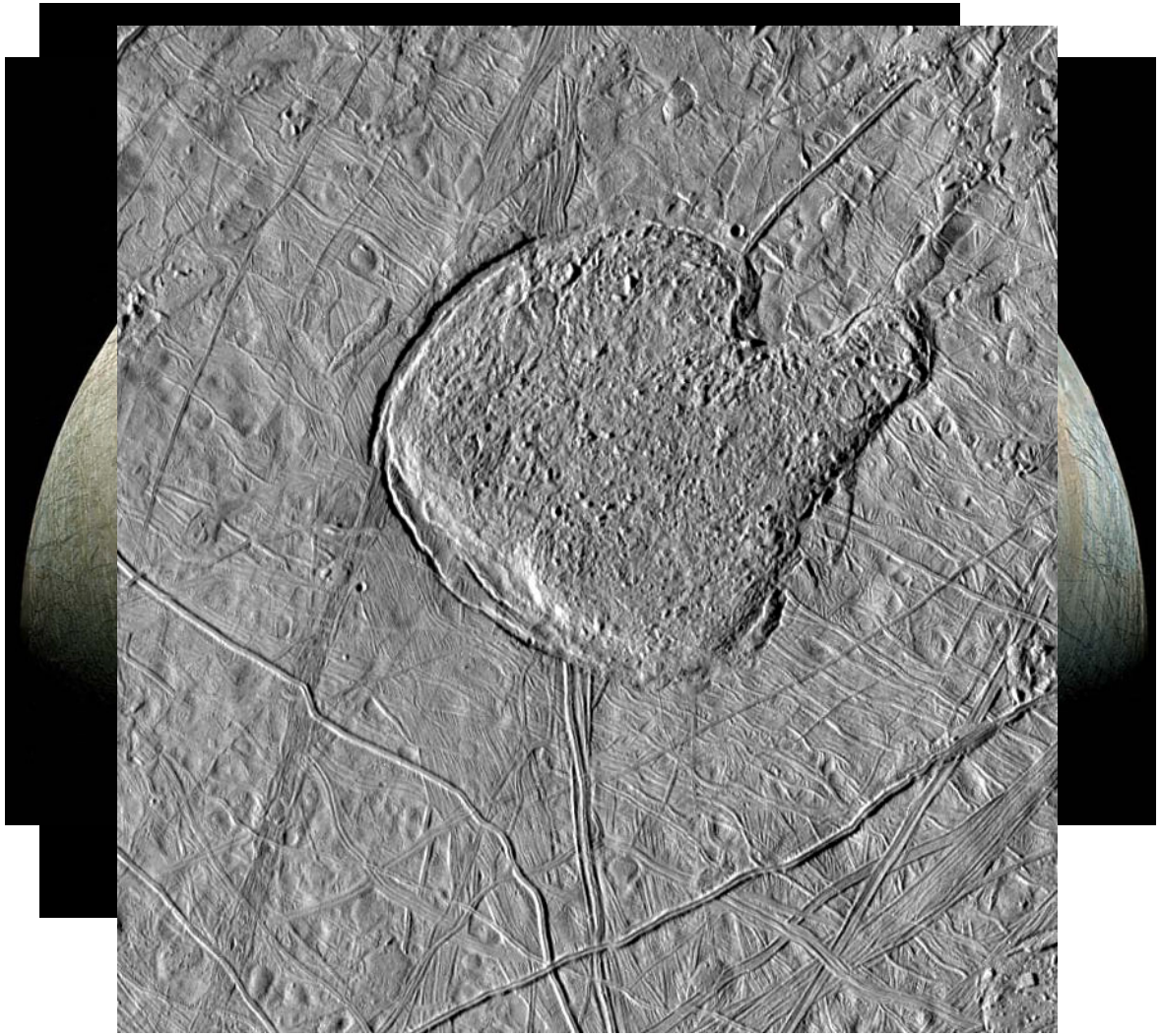

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- Plentiful cryovolcanism

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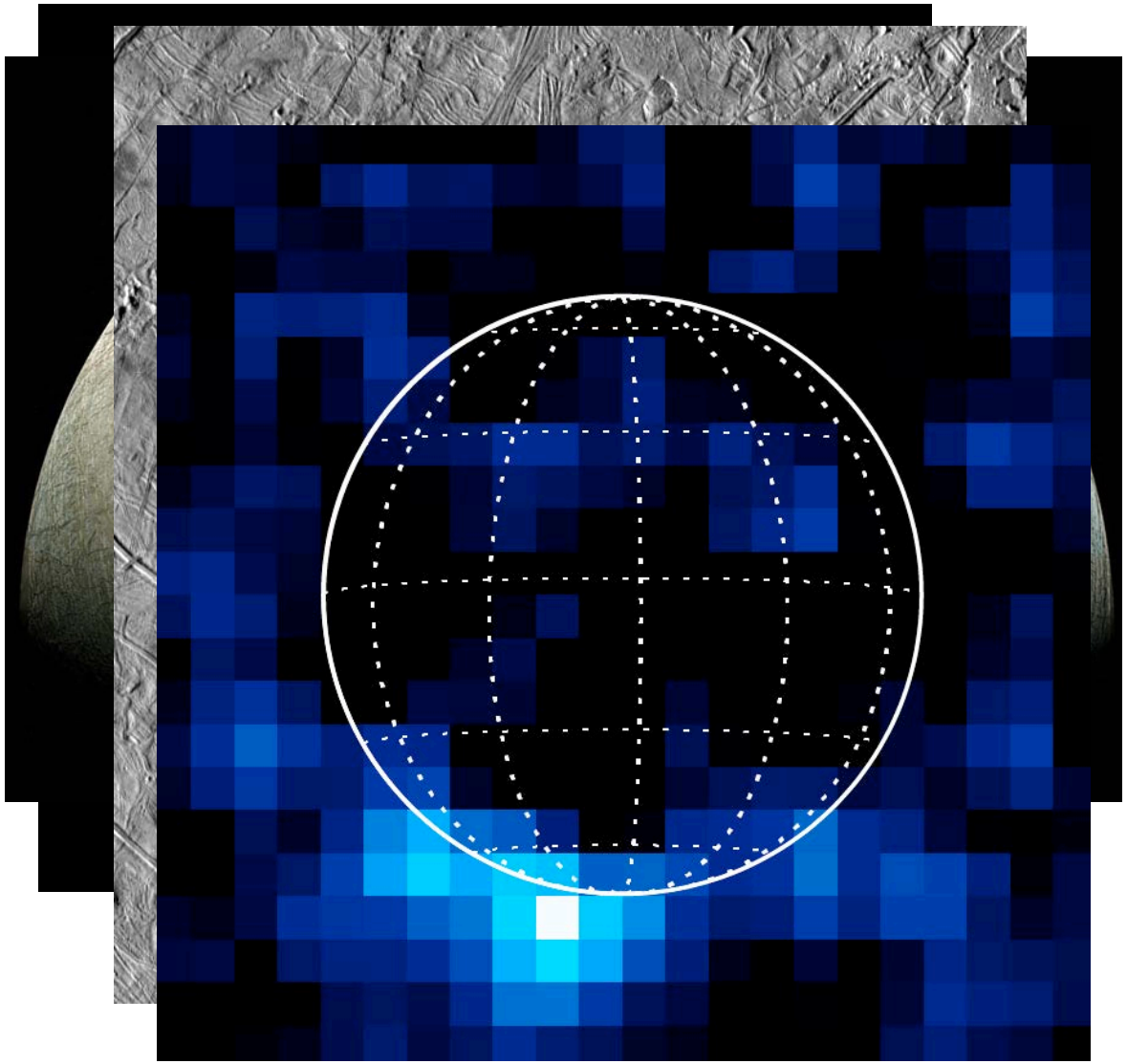

- A world of rock, ice, and water the size of Earth's moon
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- Plentiful cryovolcanism
- Possible geysers and plumes

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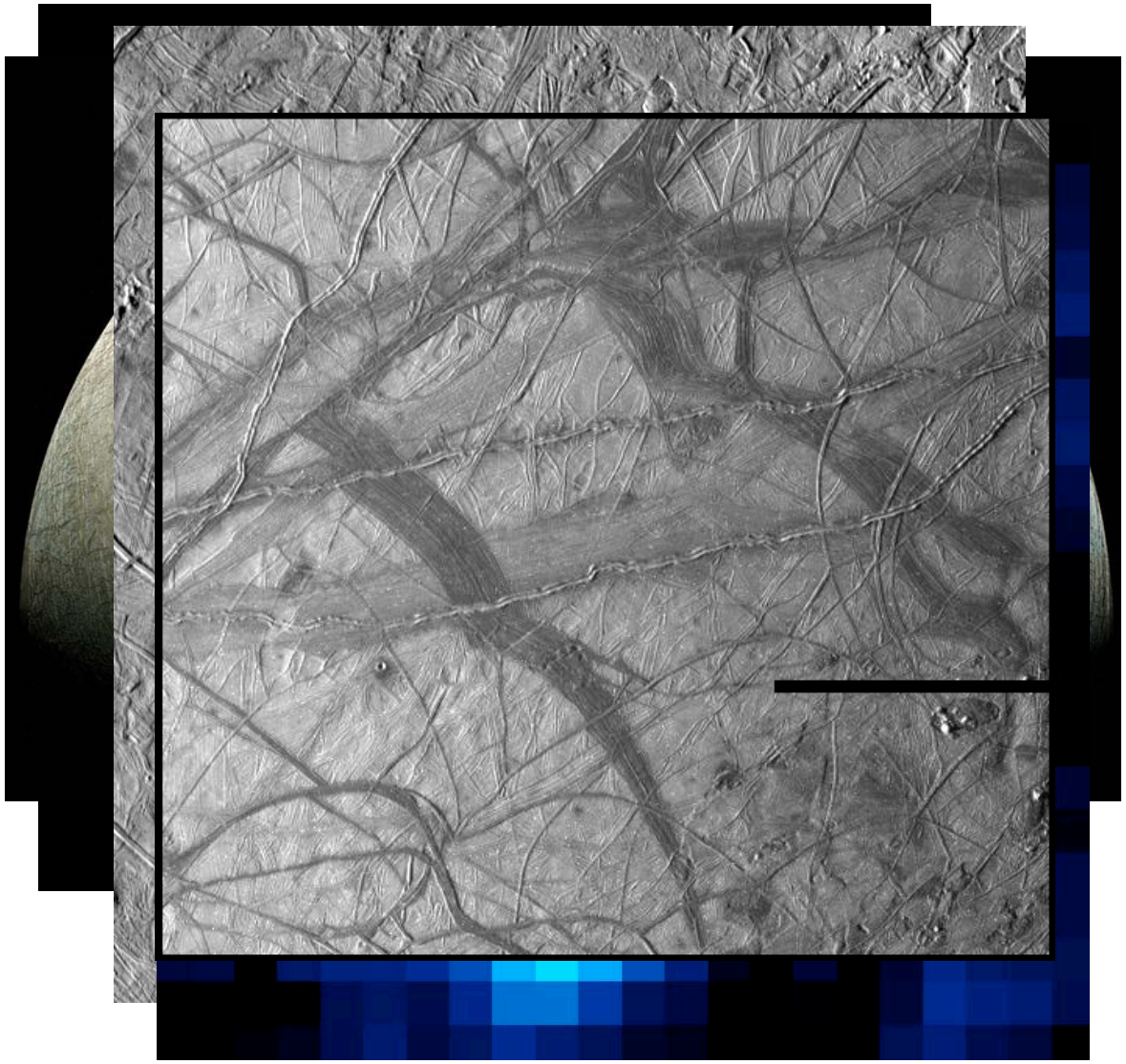

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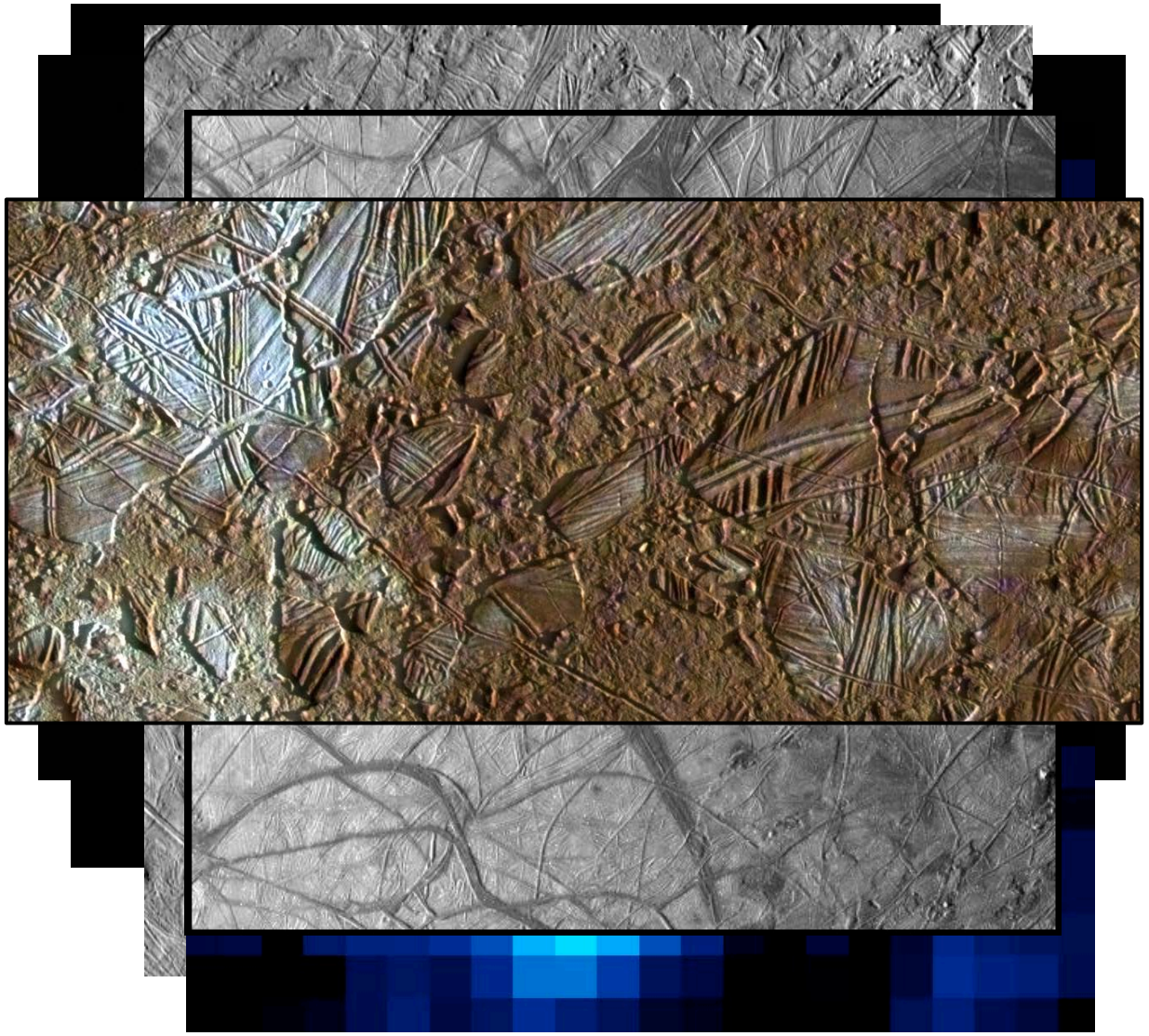

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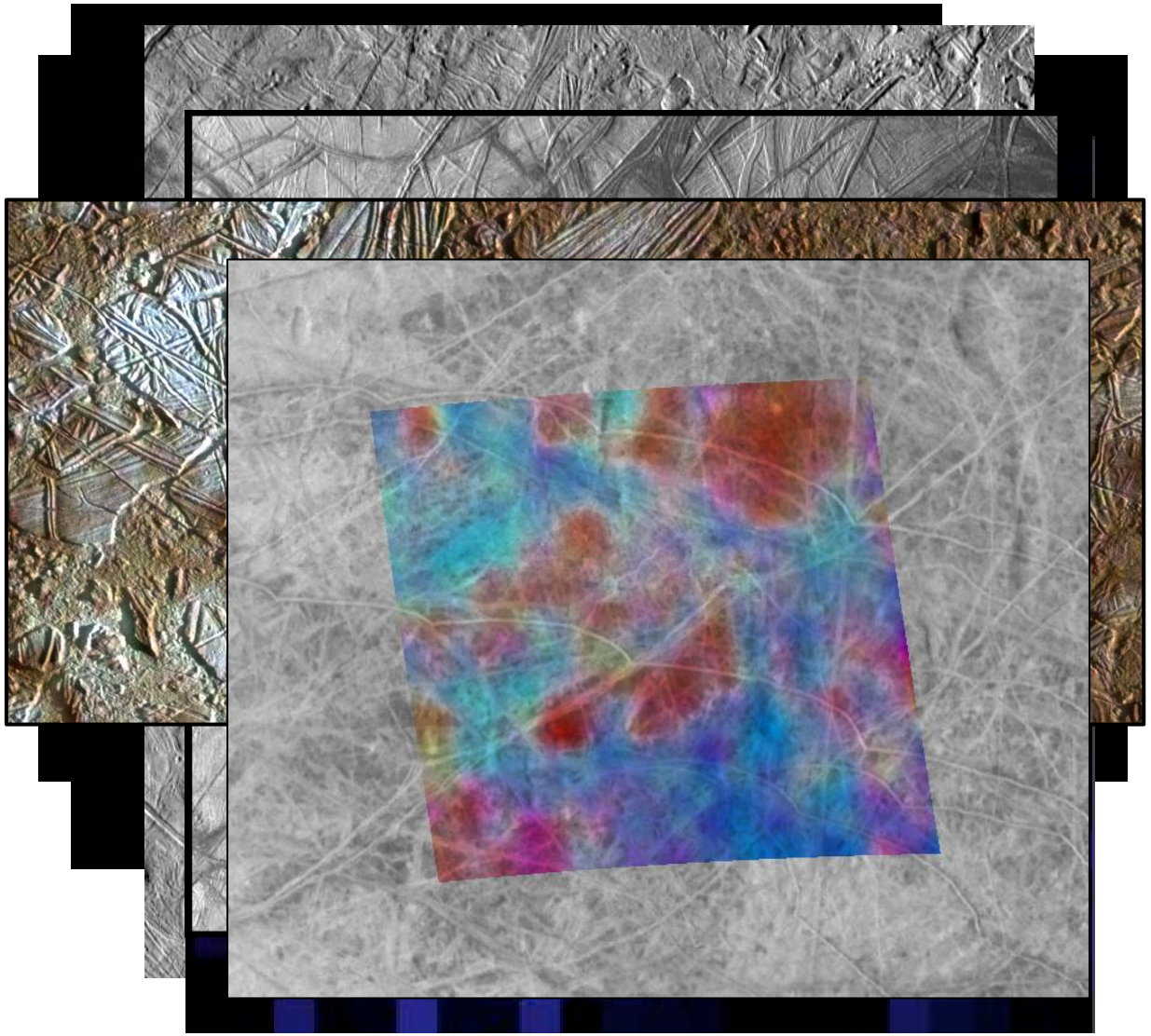

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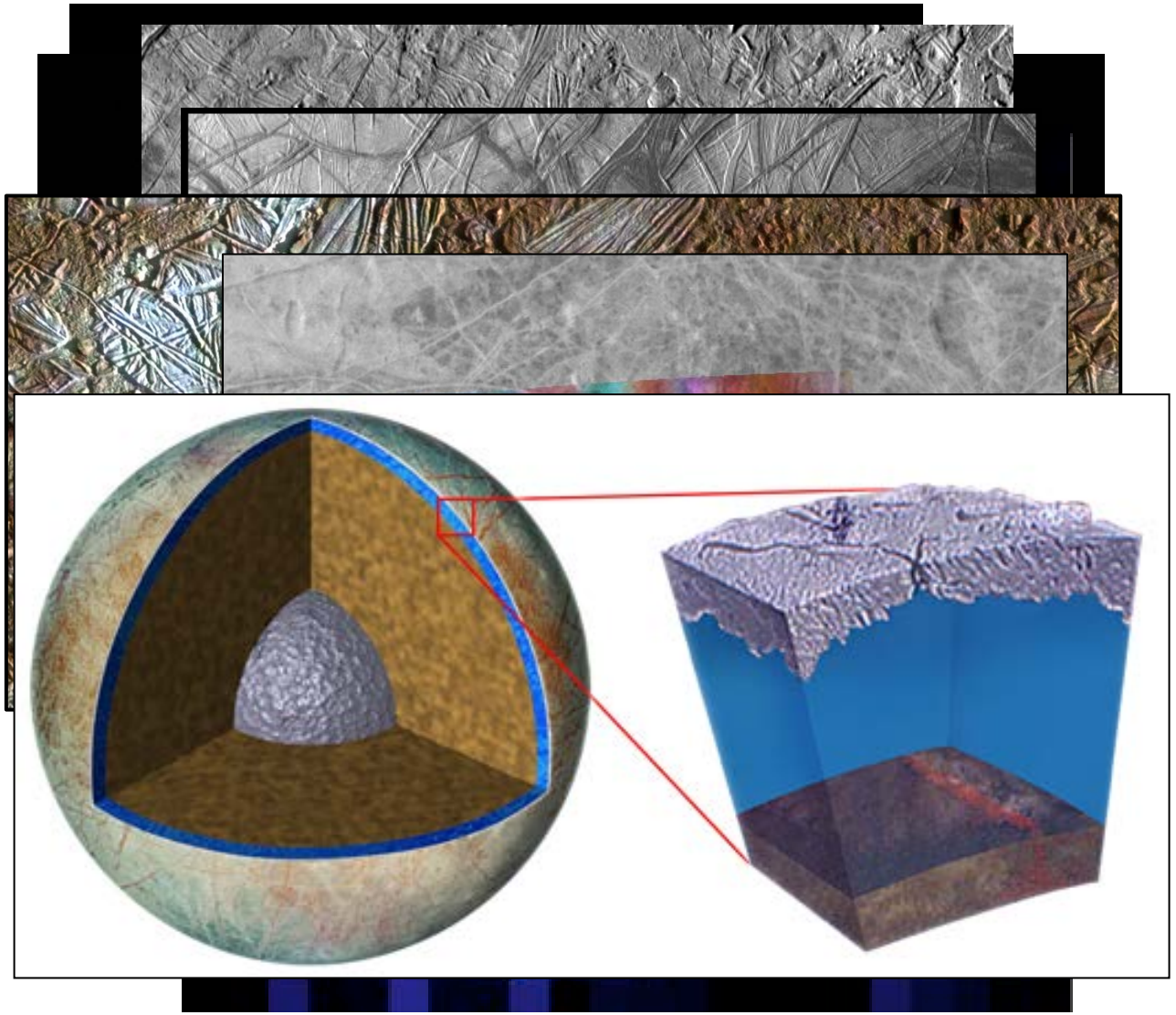

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- Plentiful cryovolcanism
- Possible geysers and plumes
- Earth-like global tectonic activity
- Widespread surface disruption
- Surface chemistry of salts and acid
- Subsurface ocean: Possibly our Solar System's best chance for extant life beyond Earth

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

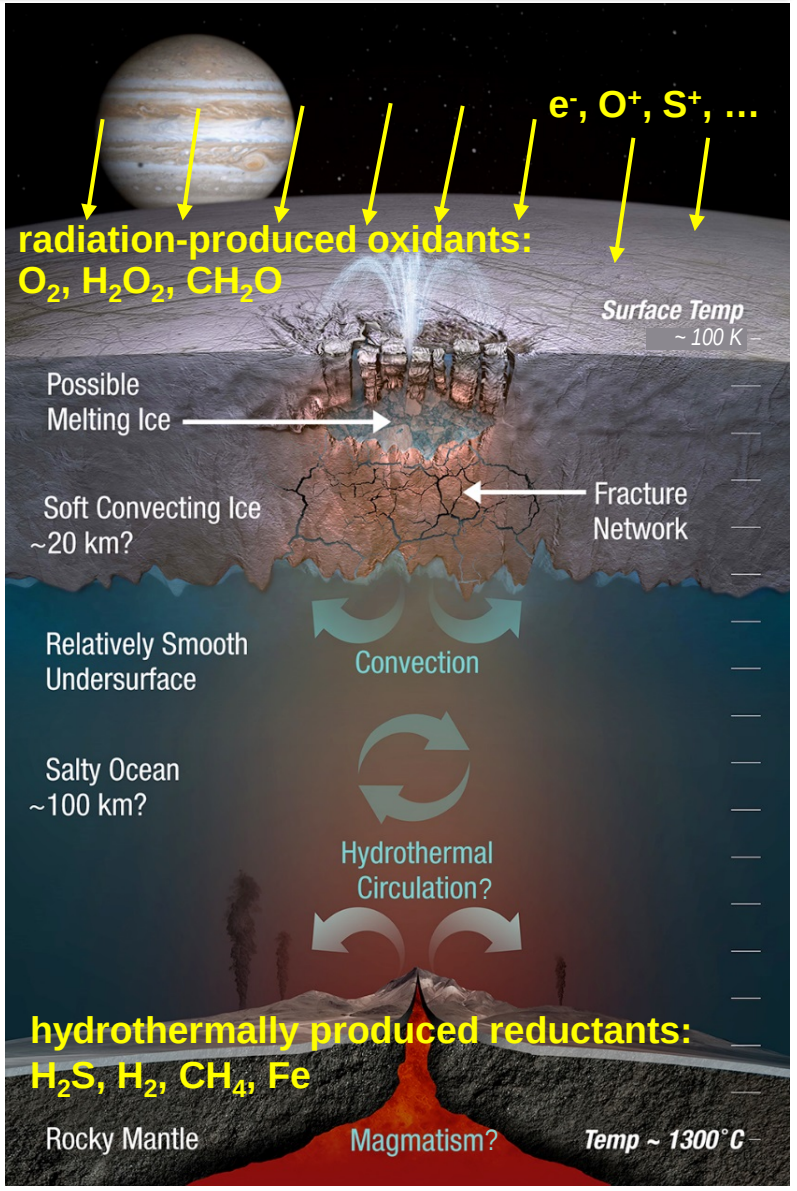
Energy:

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

Activity:

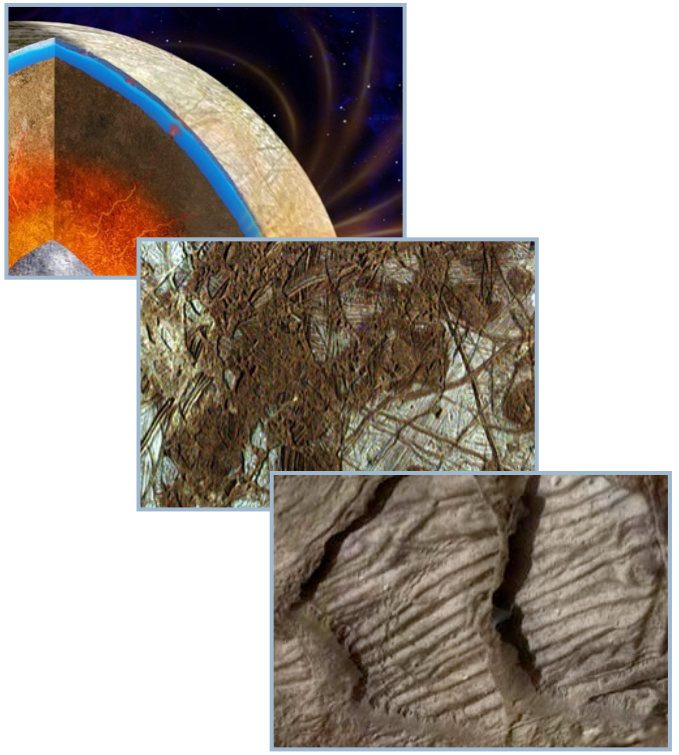
- Geological activity "stirs the pot"
- Activity could be cyclical, as tied to Io

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



Europa Mission Science Goal & Objectives

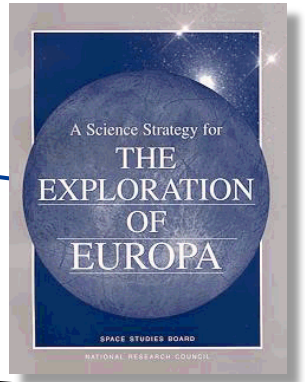
- *Mission Goal:* **Explore Europa to investigate its habitability**
- *Objectives:*
  - **Ice Shell & Ocean:** Characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of surface-ice-ocean exchange
  - **Composition:** Understand the habitability 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*

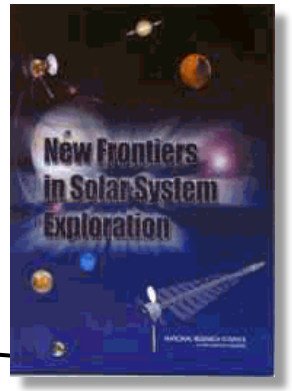


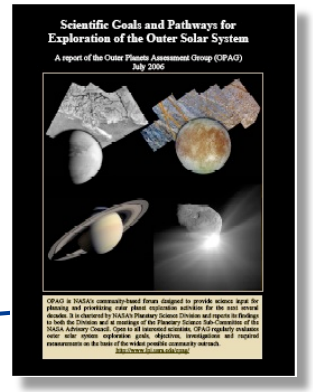
**Science Definition Team's "Reconnaissance" goal is now folded into the Geology objective.*

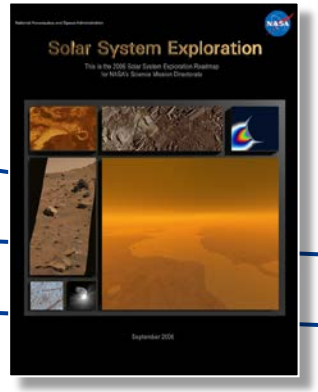
Timeline of Europa Mission Science Definition

- 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

Pre-Decisional, For Planning and Discussion Purposes Only

Europa Science Definition Team Members

1999 – 2014

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

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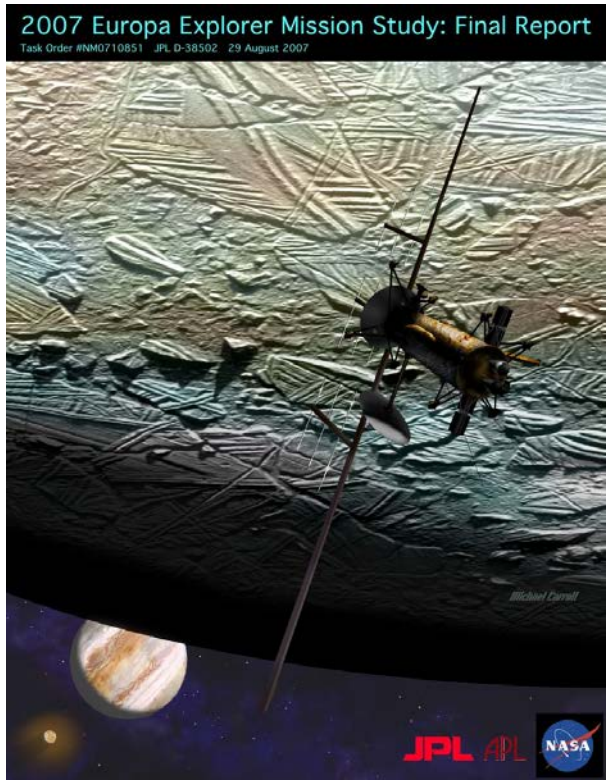
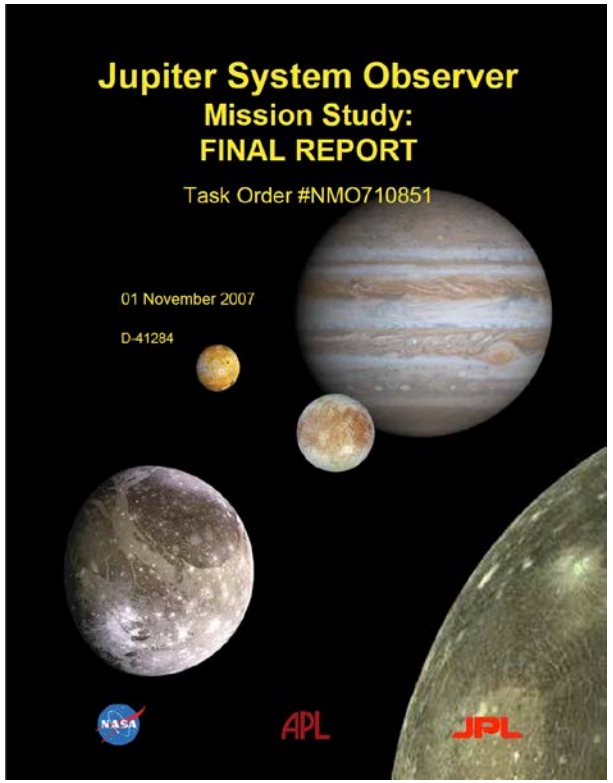
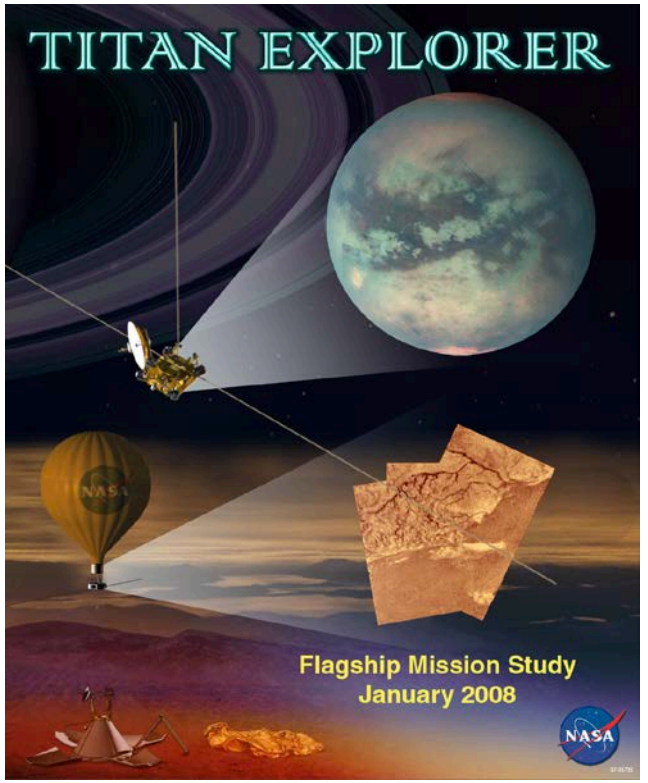
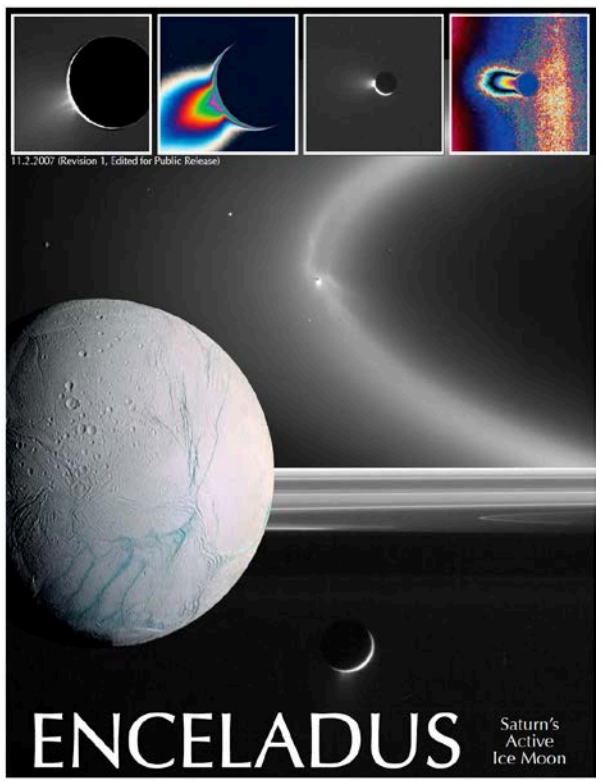
Outer Planets Flagship Competition
2007 - 2008

- NASA pitted 4 Science Definition Teams and associated engineers in an 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

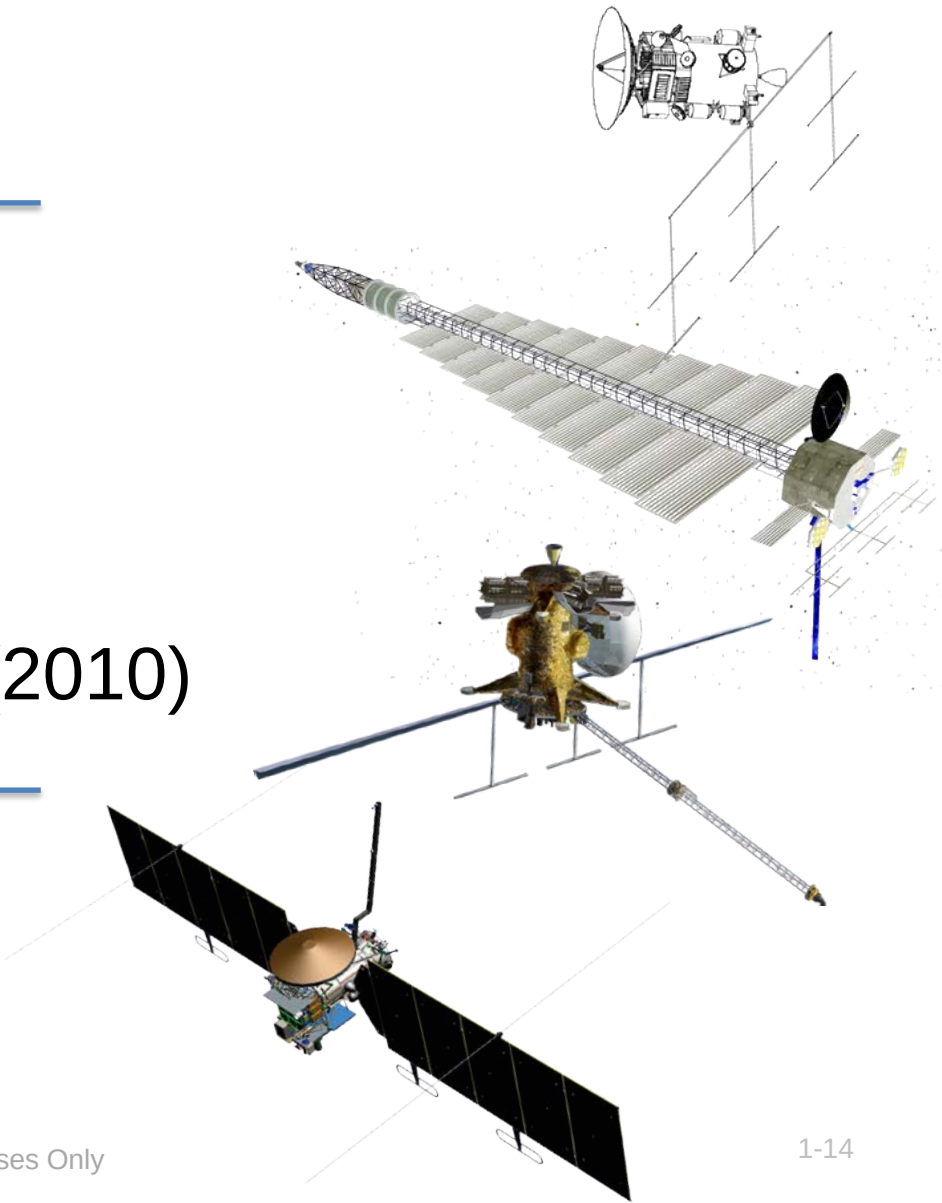
- Europa Orbiter (2001)

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)

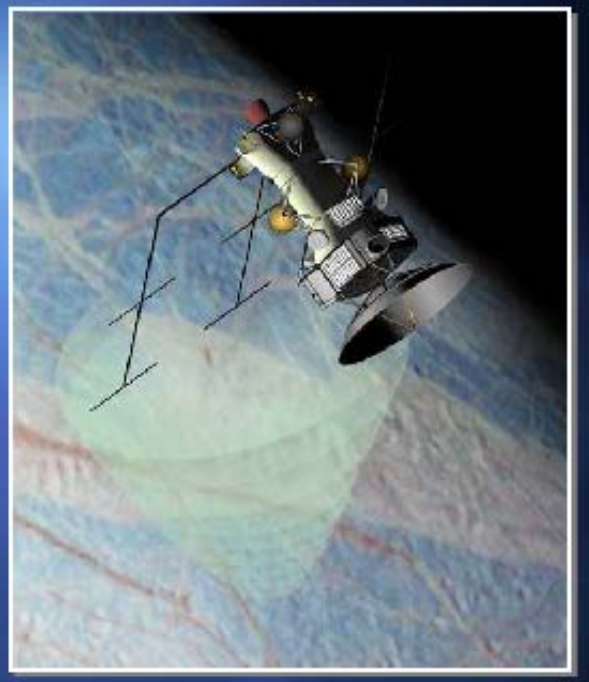
- Europa Multiple-Flyby Mission – “Europa Clipper” (2015+)



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.

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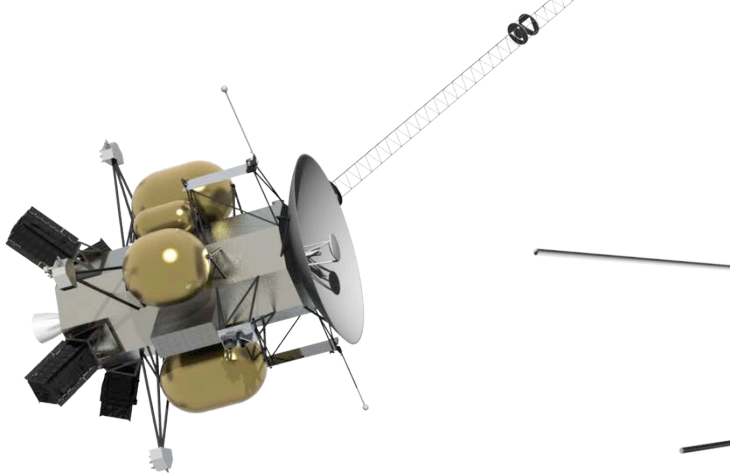
OF THE NATIONAL ACADEMIES

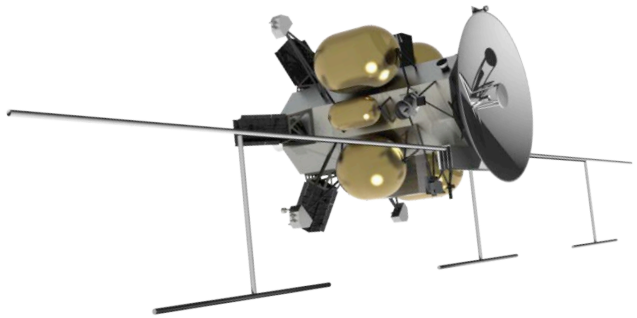
From: Squyres (2011), Visions & Voyages Rollout Presentation

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

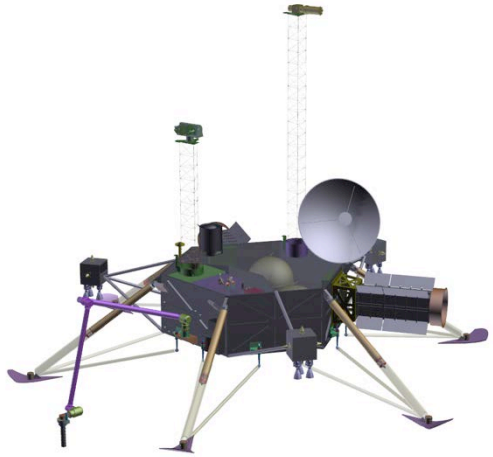
- Proposed 2020 Jupiter Europa Orbiter (JEO) mission was deemed extremely high science value, but unaffordable by the NRC Decadal Survey, which requested a descoped option
- NASA directed a 1 year study to develop mission options that retain high science value at significantly reduced cost
- Innovative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



Reduced-Scope Europa Orbiter



Europa Multiple-Flyby ("Europa Clipper")

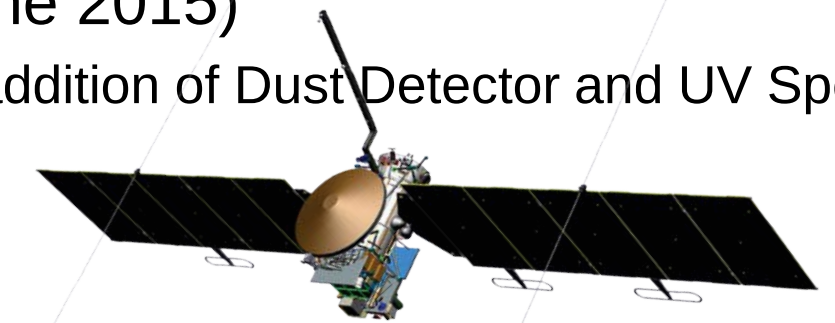


Europa Lander

Evolution of Europa Multiple-Flyby Mission Concept

- 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

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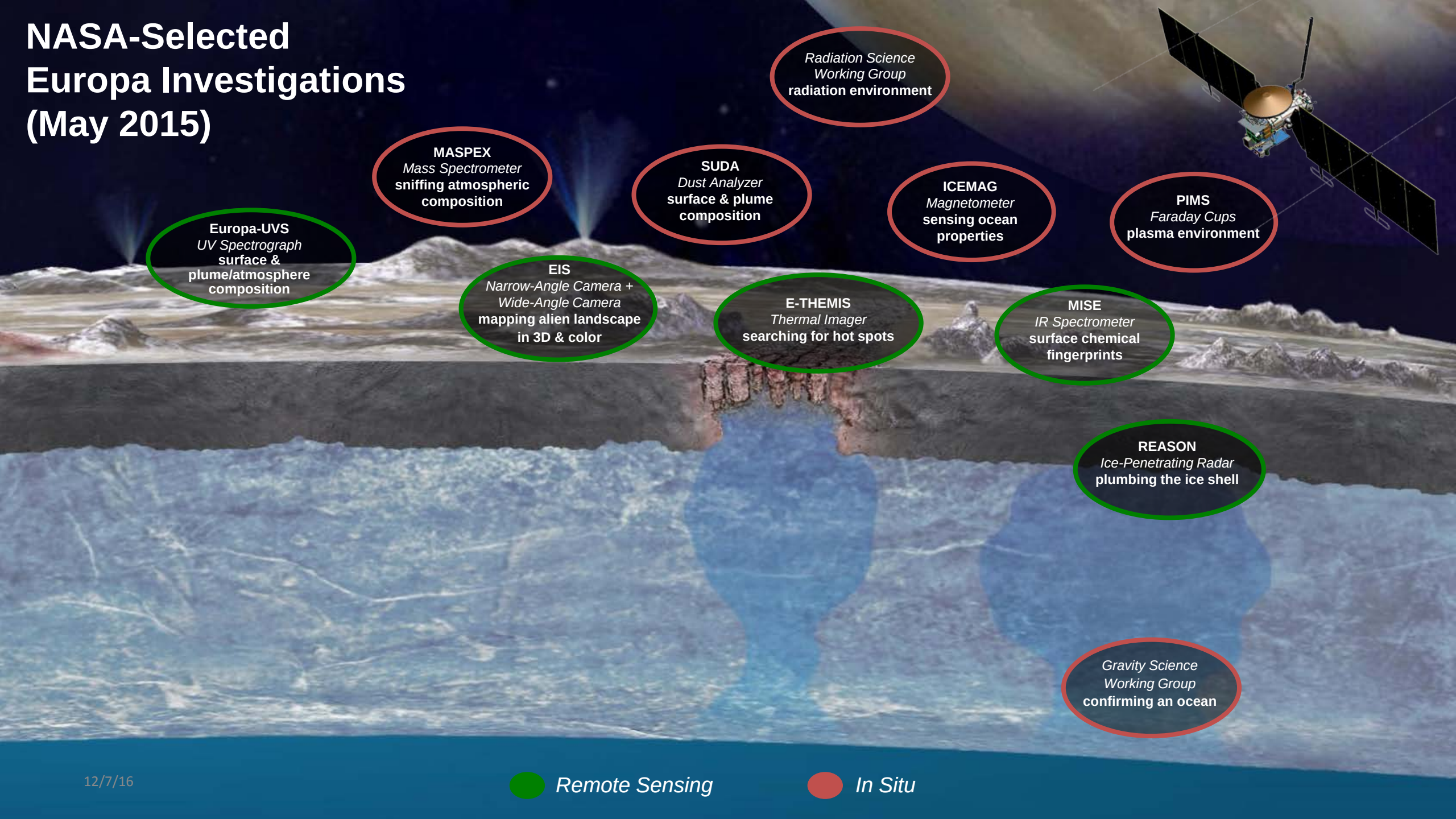
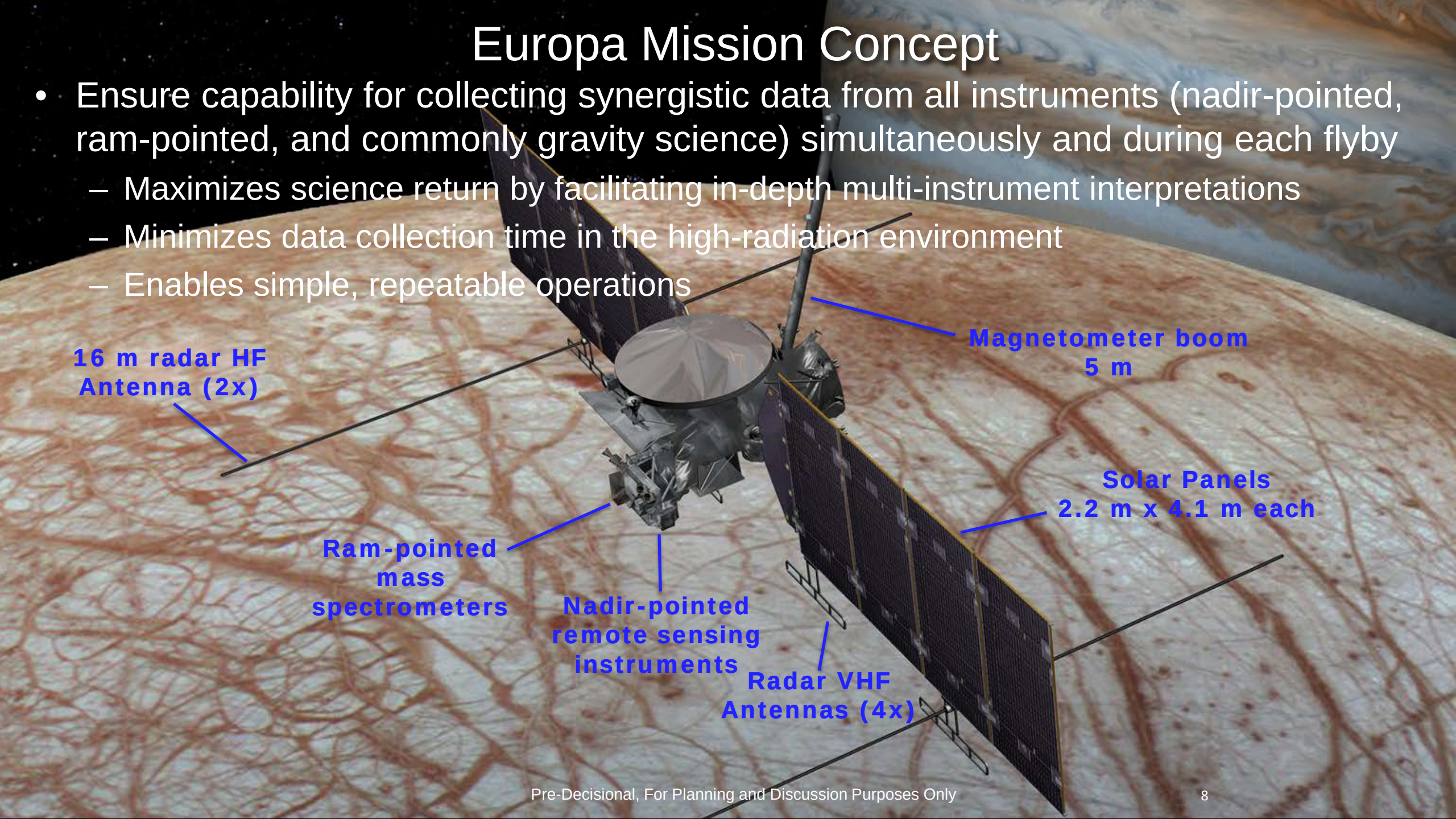
NASA-Selected Europa Investigations (May 2015)



Remote Sensing In Situ

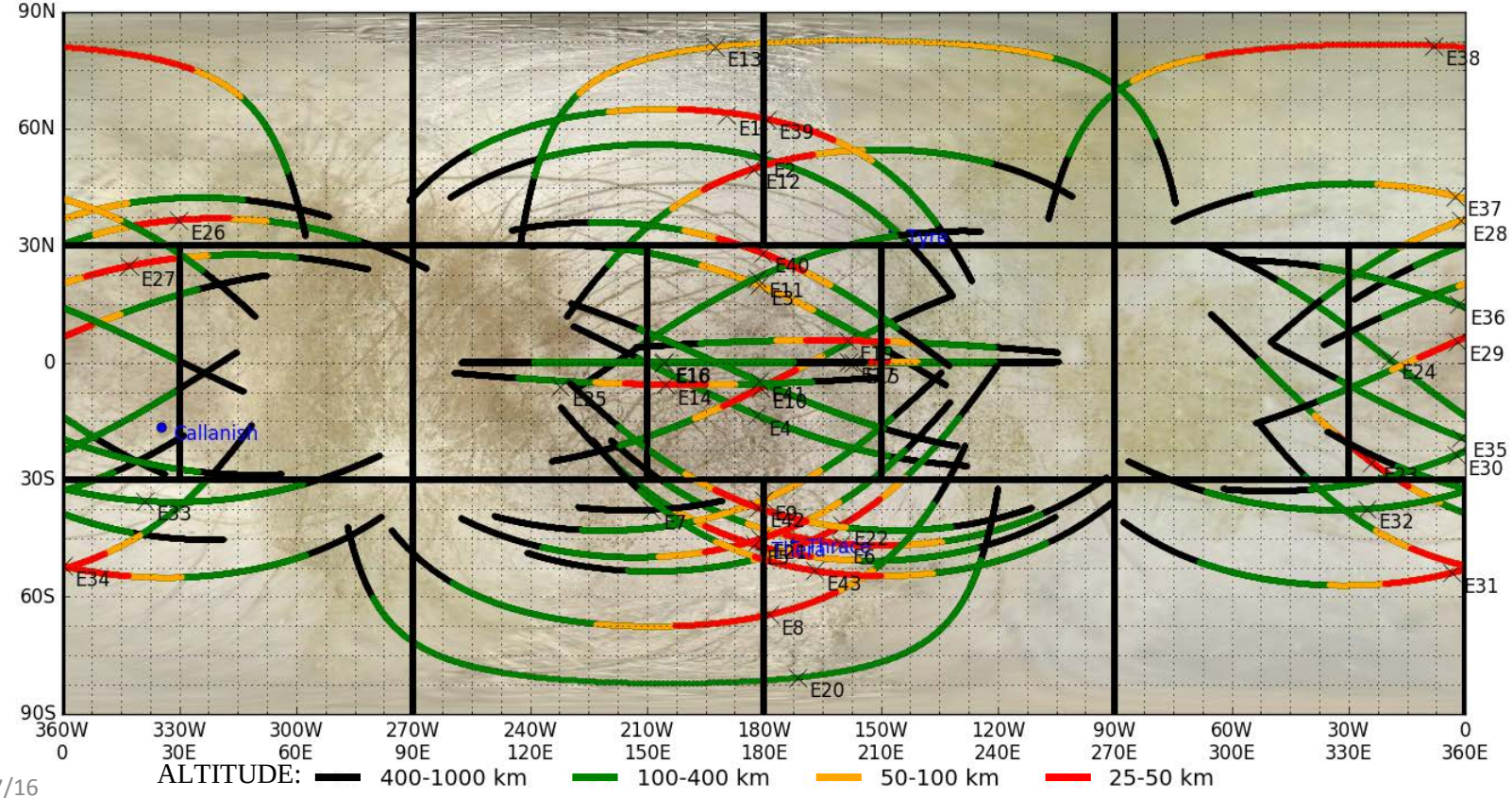
Europa Mission Concept

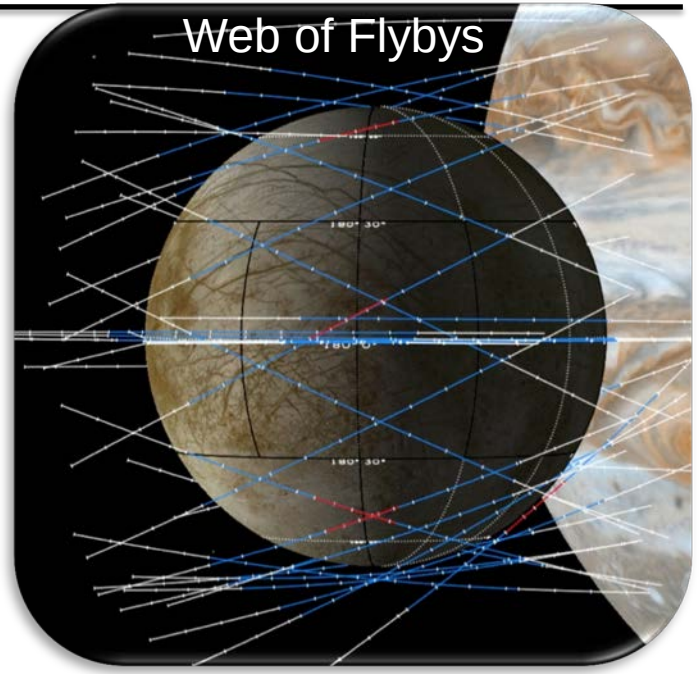
- Ensure capability for collecting synergistic data from all instruments (nadir-pointed, ram-pointed, and commonly gravity science) simultaneously and during each flyby
  - Maximizes science return by facilitating in-depth multi-instrument interpretations
  - Minimizes data collection time in the high-radiation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



“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





Tholian Web

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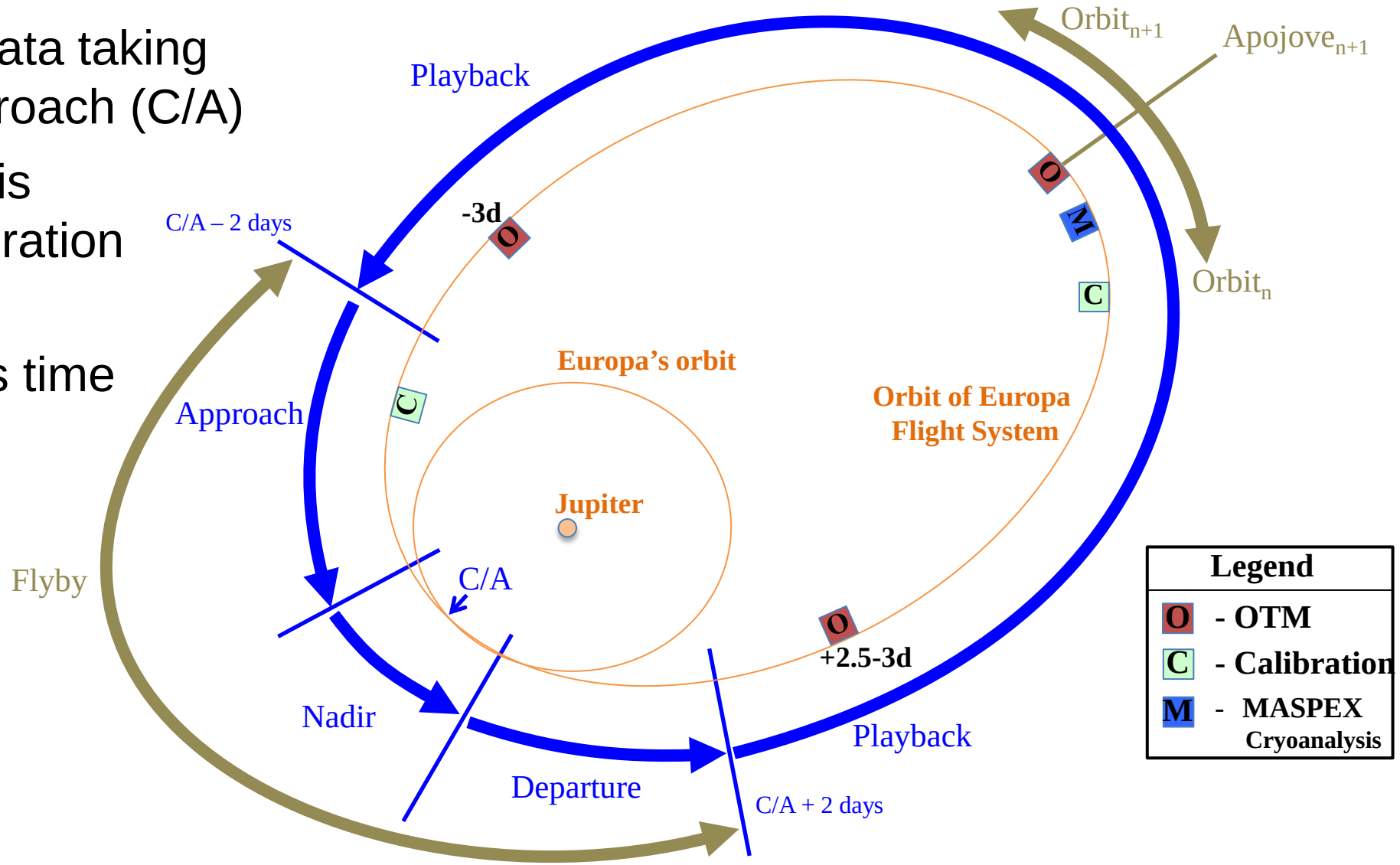
Simple and Repeatable Operations

- 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



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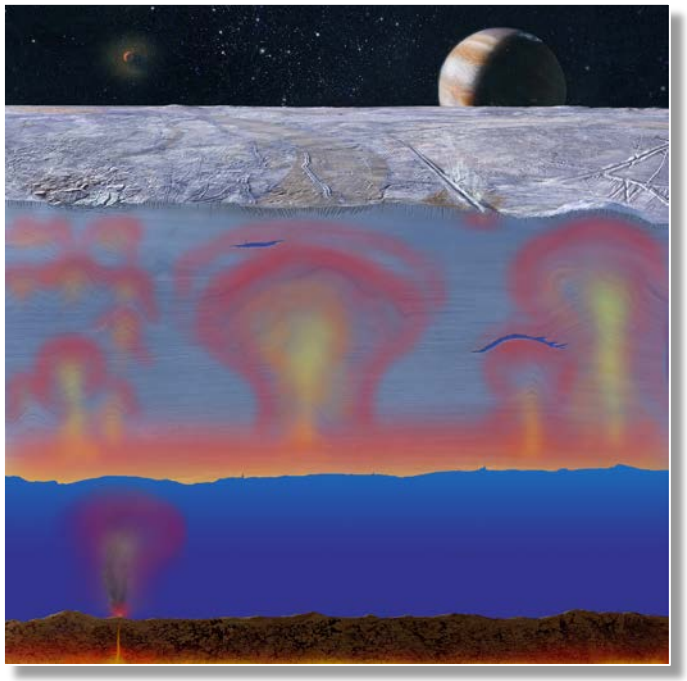
Europa Mission Science Objectives (1/3): *Ice Shell & Ocean*

- ***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



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

- ***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

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

- ***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)	*	*										
	Ice thickness; ocean salinity (±50%)	Confirm ocean / thick vs. thin shell	* *							*				*
Composition	Global comp. (≥70% coverage)	Global comp. (≥40% coverage)												
	Landform comp. (≥50, ≤300 m)	Landform comp. (≥15, ≤25 km)												
	Gas, dust, and plasma comp.	Gas or dust composition									*	*	*	
Geology	Global imaging (≥80% coverage)	Global imaging (≥30% coverage)												
	High-res (≤25m) landforms (≥50)	High-res (≤50m) landforms (≥15)												
	Local surface (~1m, ≥40 sites)	*[None]*												
Activity	Characterize current activity	Search for current activity						*	*					

Primary instrument (achieves requirement)

Supportive dependency (required support for Primary)

Baseline

Independent instrument (can achieve requirement)

Supportive independent (enhances the science)

Threshold

* In combination achieves science

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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 Cochrane
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
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Tom McCord
Alfred McEwen
Melissa McGrath
Bill McKinnon
Ralph McNutt
Mike Mellon
Jeff Moore
Olivier Mousis
Alina Moussessian
Scott Murchie
Neil Murphy
Francis Nimmo
Bob Pappalardo
Chris Paranicas

Ryan Park
Wes Patterson
Carol Paty
Cynthia Phillips
Sylvain Piqueux
Jeff Plaut
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Cary Zeitlin
Mikhail Zolotov
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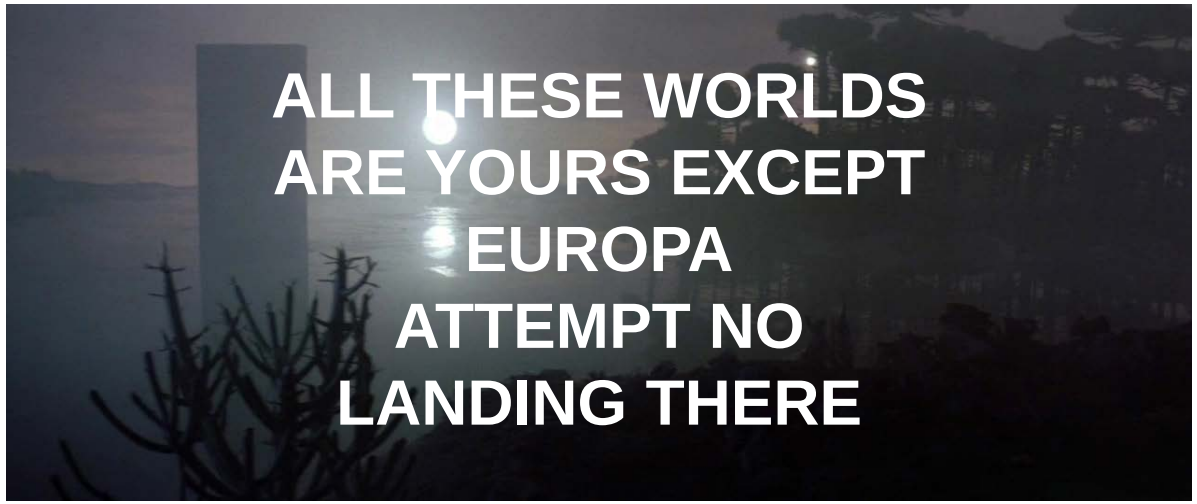
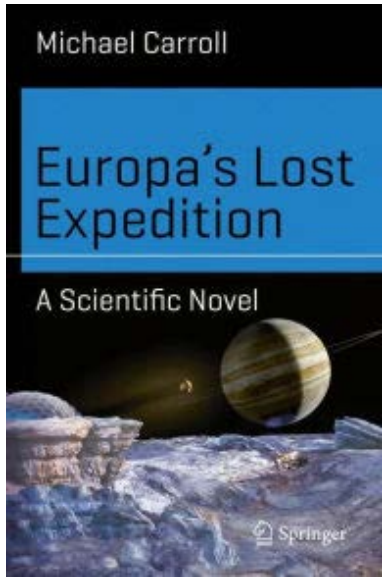
Europa Project Science Group (PSG)

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

Pre-Decisional, For Planning and Discussion Purposes Only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