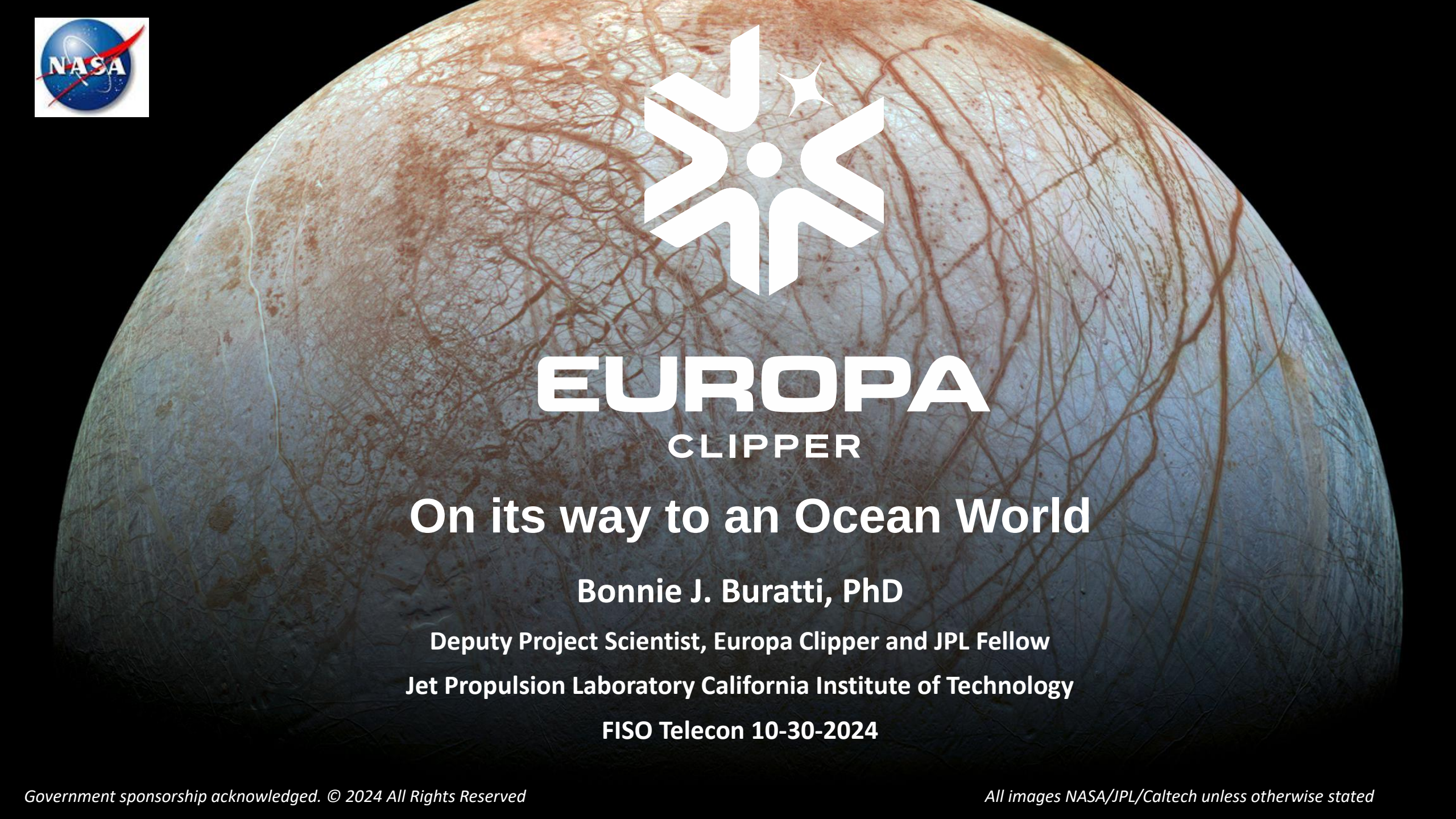


EUROPA CLIPPER

On its way to an Ocean World

Bonnie J. Buratti, PhD

Deputy Project Scientist, Europa Clipper and JPL Fellow

Jet Propulsion Laboratory California Institute of Technology

FISO Telecon 10-30-2024

Europa Clipper Project Science Group

PIs/TLs, Co-Is, Project Science

Oleg Abramov
Nicolas Altobelli
Amy Barr Mlinar
Jordana Blacksberg
Diana Blaney
Don Blankenship
Scott Bolton
Christelle Briois
Tim Brockwell
Shawn Brooks
Lorenzo Bruzzone
Dustin Buccino
Bonnie Buratti
Jim Burch
Bruce Campbell
Lynn Carter
Tony Case

Julie Castillo
Mathieu Choukroun
Phil Christensen
Roger Clark
Corey Cochrane
Geoff Collins
Kate Craft
Ingrid Daubar
Ashley Davies
Serina Diniega
Andrew Dombard
Charles Elachi
Catherine Elder
Carolyn Ernst
Paul Feldman
Leigh Fletcher
Antonio Genova

Yonggyu Gim
Randy Gladstone
Thomas Greathouse
Robert Green
Cyril Grima
Eberhard Gruen
Murthy Gudipati
Kevin Hand
Candy Hansen
Alex Hayes
Paul Hayne
Matt Hedman
Alain Herique
Karl Hibbitts
Mihaly Horanyi
Sam Howell
Carly Howett

Terry Hurford
Hauke Hussmann
Xianzhe Jia
Steven Joy
Justin Kasper
Sascha Kempf
Walter Kiefer
Krishan Khurana
Randy Kirk
Margaret Kivelson
Rachel Klima
Wlodek Kofman
Haje Korth
William Kurth
Yves Langevin
Erin Leonard
Jonathan Lunine

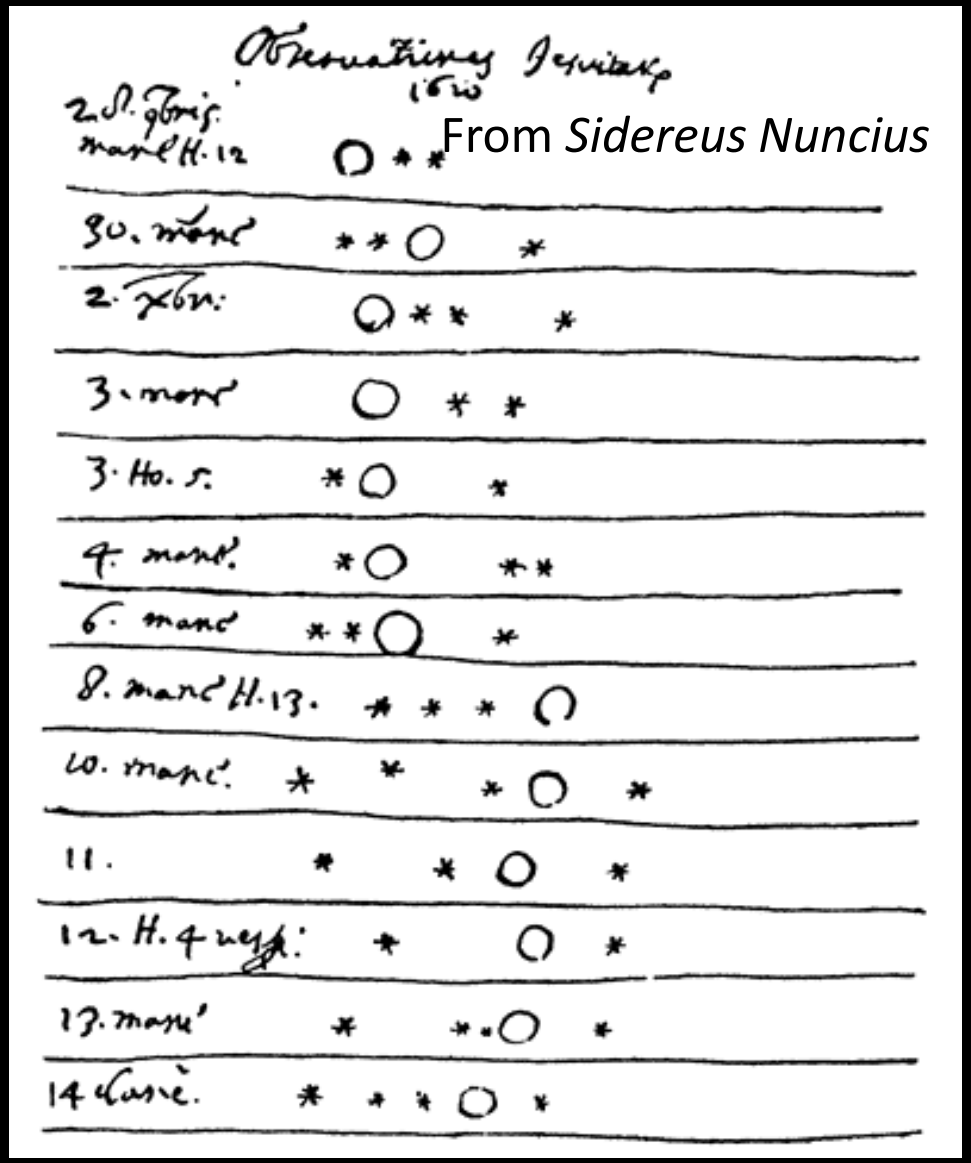
Adrienn Luspay-Kuti
Marco Mastrogiuseppe
Erwan Mazarico
Tom McCord
Alfred McEwen
Melissa McGrath
Bill McKinnon
Ralph McNutt
Mike Mellon
Jeff Moore
Olivier Mousis
Alina Moussessian
Scott Murchie
Neil Murphy
Francis Nimmo
Bob Pappalardo
Ryan Park

Chris Paranicas
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
Ingo Richter
James Roberts
Lorenz Roth

Chris Russell
Abigail Rymer
Joachim Saur
Juergen Schmidt
Britney Schmidt
Dustin Schroeder
Frank Seelos
Mark Sephton
Everett Shock
Jim Slavin
Todd Smith
Jason Soderblom
Krista Soderlund
John Spencer
Ralf Srama
Andrew Steffl
Gregor Steinbrügge

Alan Stern
Michael Stevens
Robert Strangeway
Ben Teolis
Nick Thomas
Gabriel Tobie
Paolo Tortora
Zibi Turtle
Hunter Waite
Ben Weiss
Joe Westlake
Paul Withers
Danielle Wyrick
Duncan Young
Mikhail Zolotov

Discovery of Europa: Galileo* (the man), 1610



From *Sidereus Nuncius*

Justus Sustermans 1636

*Counterclaim of discovery by Simon Mayr (Marius); also Gan De may have observed Ganymede and Callisto in the fourth century BCE

(Pictures both public domain)

Basic facts about Europa

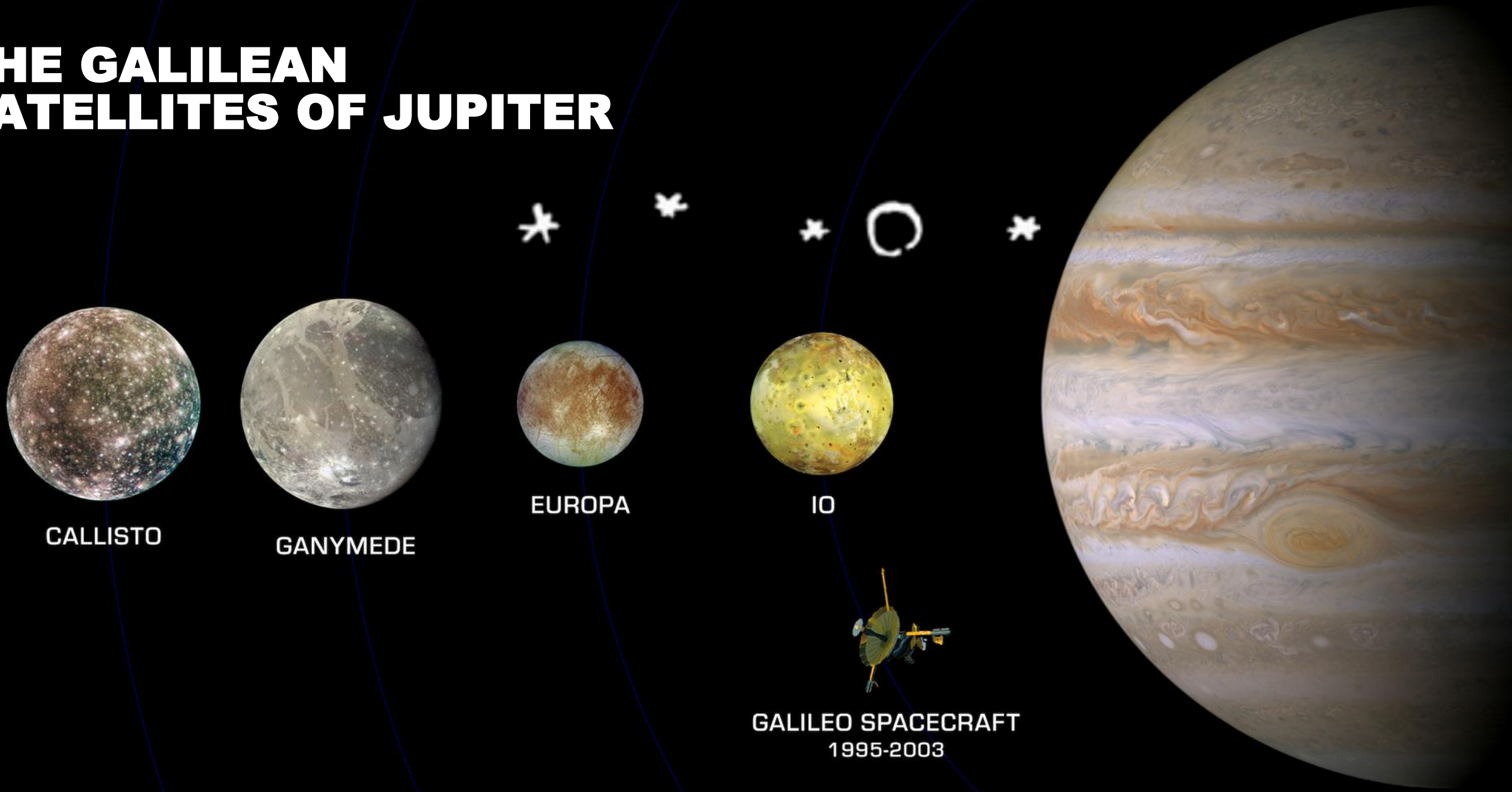
Moon

Europa

Earth

- Distance from Sun 5 AU
- Solar orbital period 11.9 years
- Rotation period around Jupiter 3.55 days
- Radius: 1561 km
- Density 3.01 gm/cc
- Albedo (Reflectivity) 0.67
- Atmosphere 10^{-12} bar
- Discovery Galileo (1610)
- Composition H_2O; rock; CO_2; salts; S

THE GALILEAN SATELLITES OF JUPITER



Early Spacecraft Observations

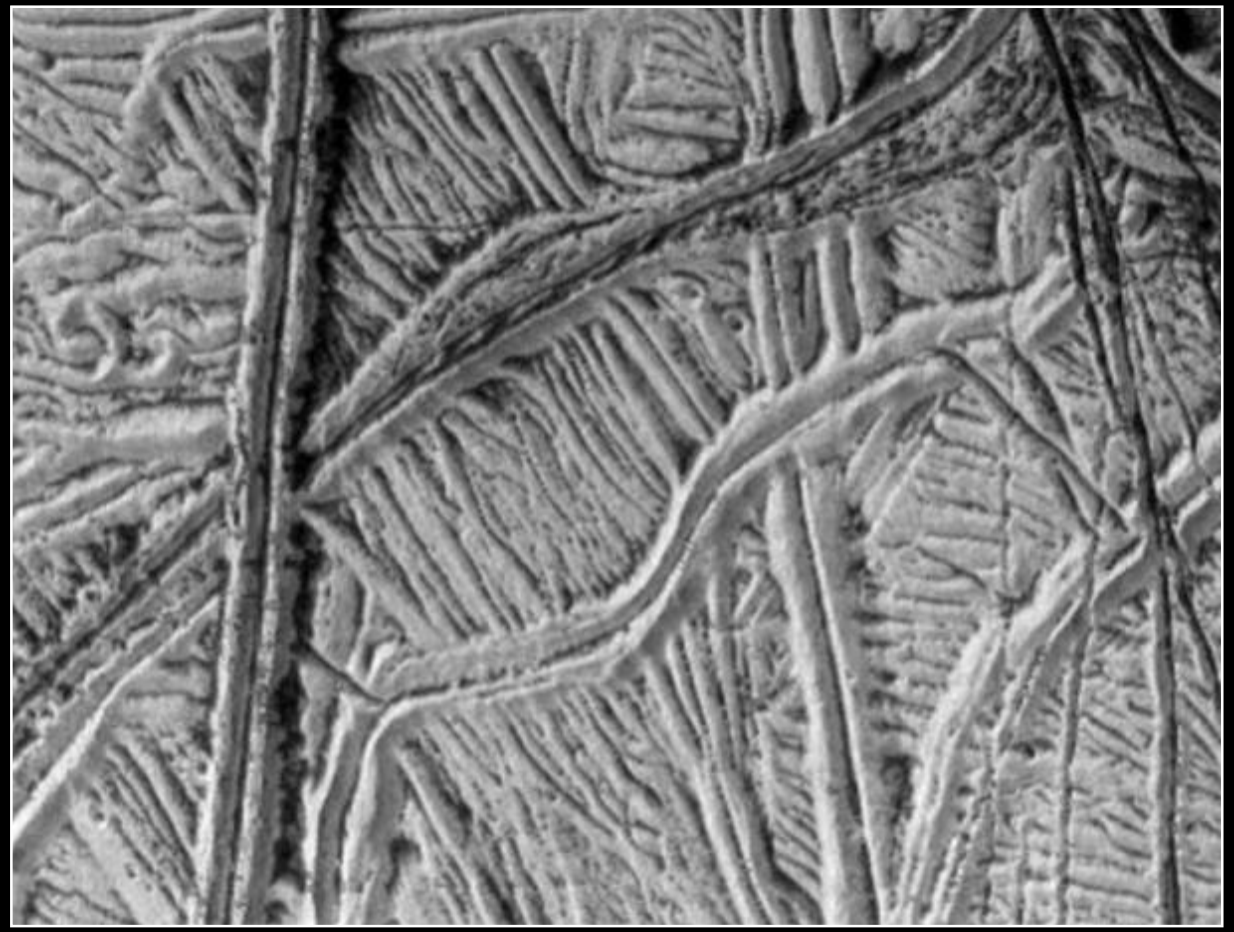
Pioneer 10

Voyager 1 (March 1979 and Voyager 2 (July 1979)

Images: NASA/JPL-Caltech

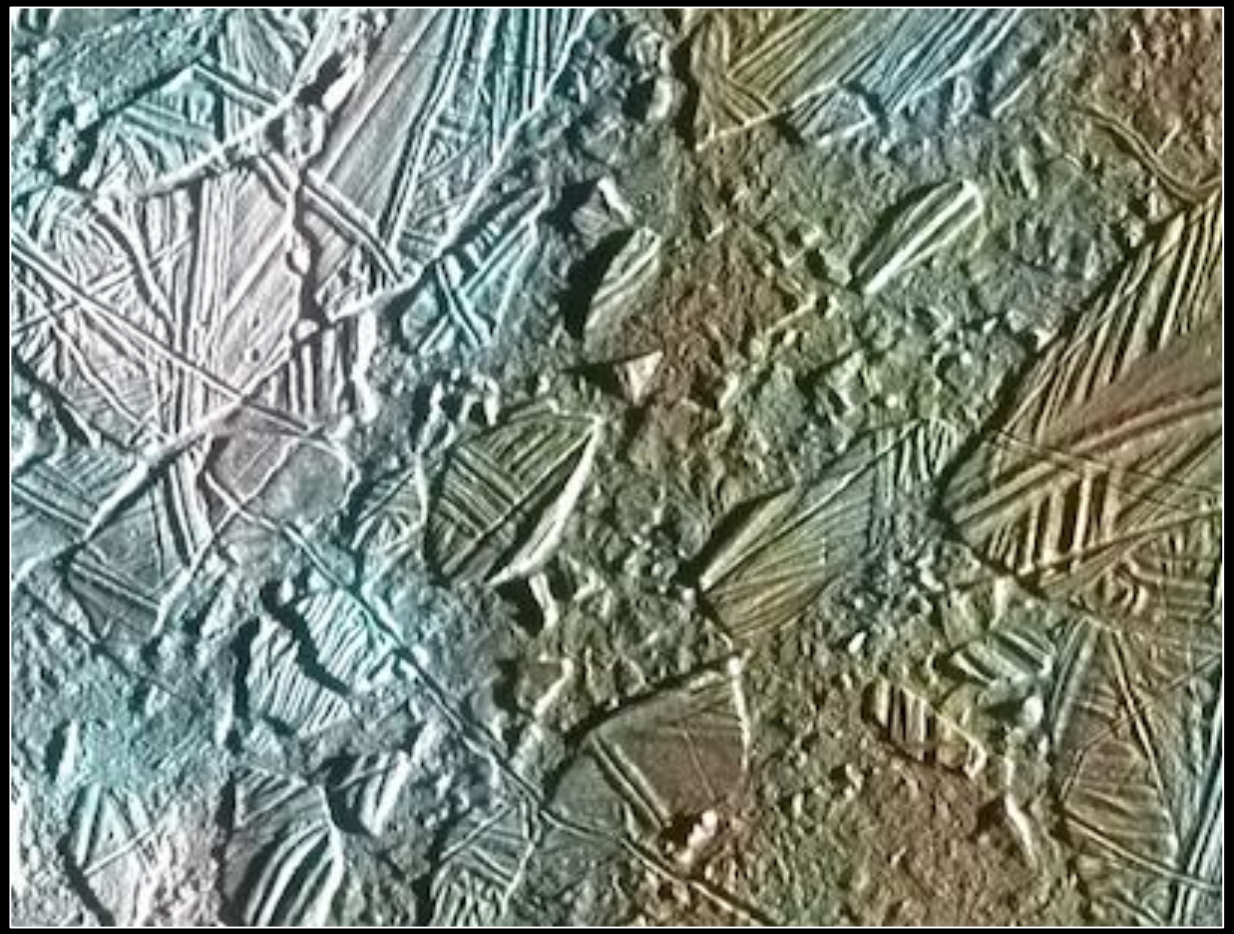
EUROPA'S SURFACE

RIDGED PLAINS



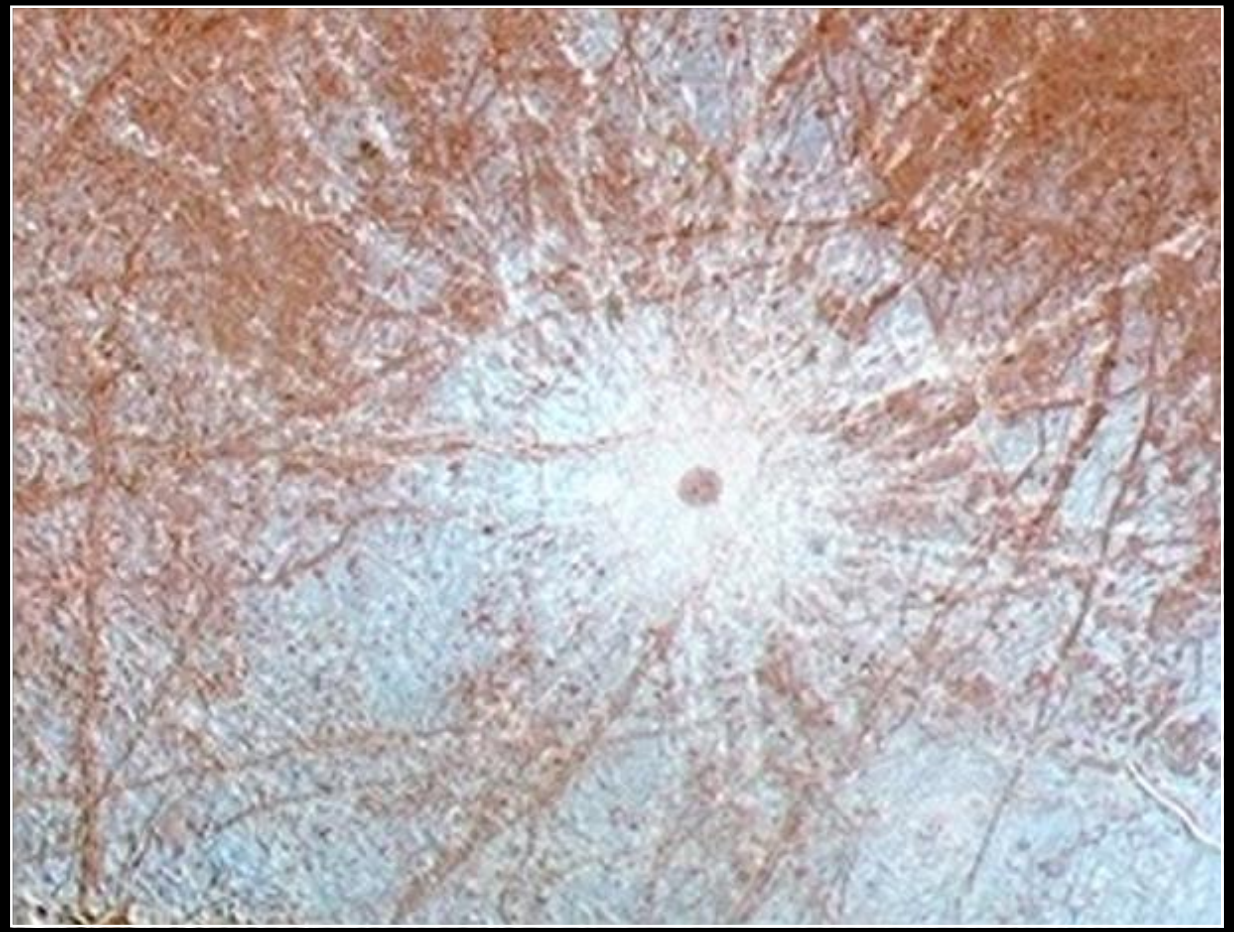
EUROPA'S SURFACE

CHAOS



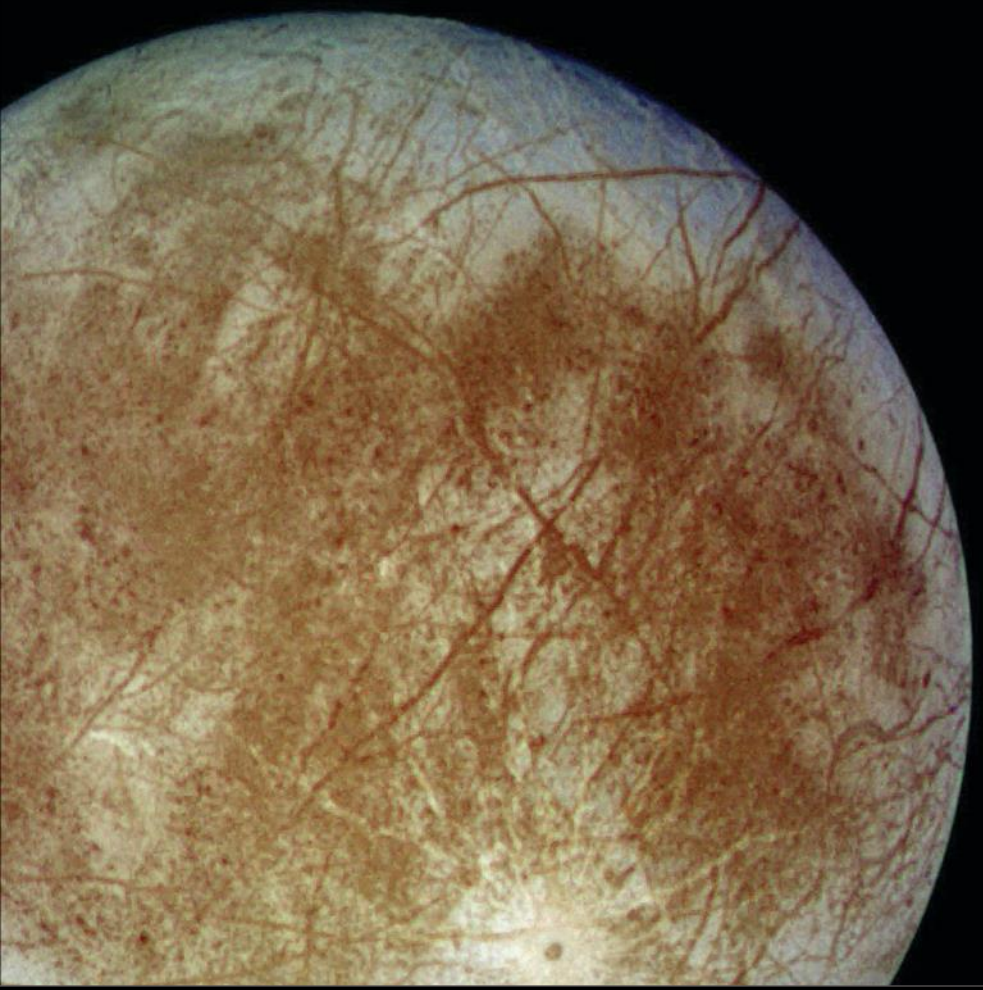
EUROPA'S SURFACE

CRATERS

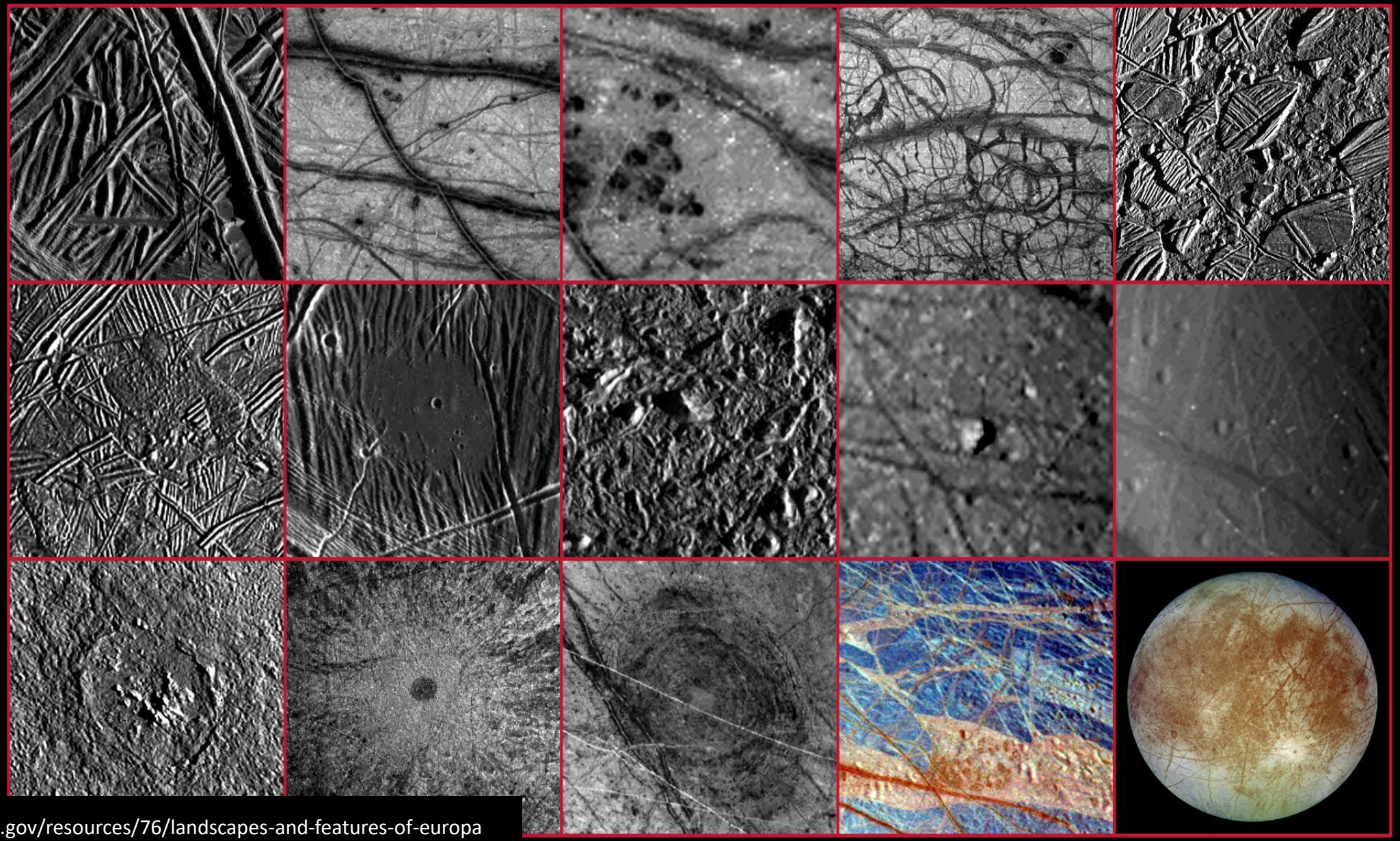


EUROPA'S SURFACE

LENTICULAE

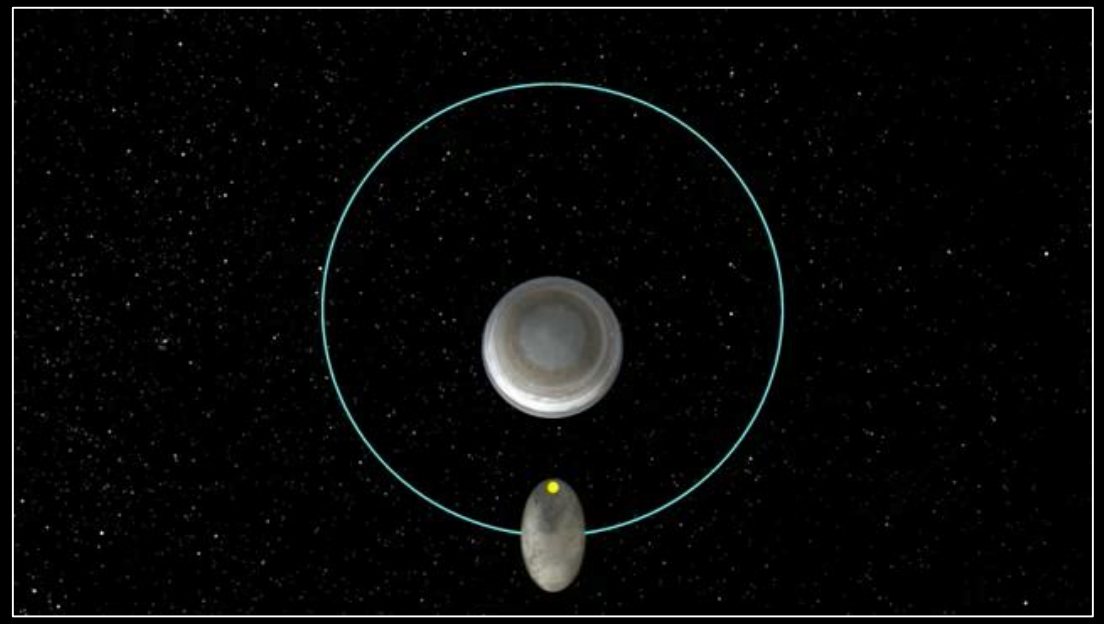


Galileo: the Spacecraft

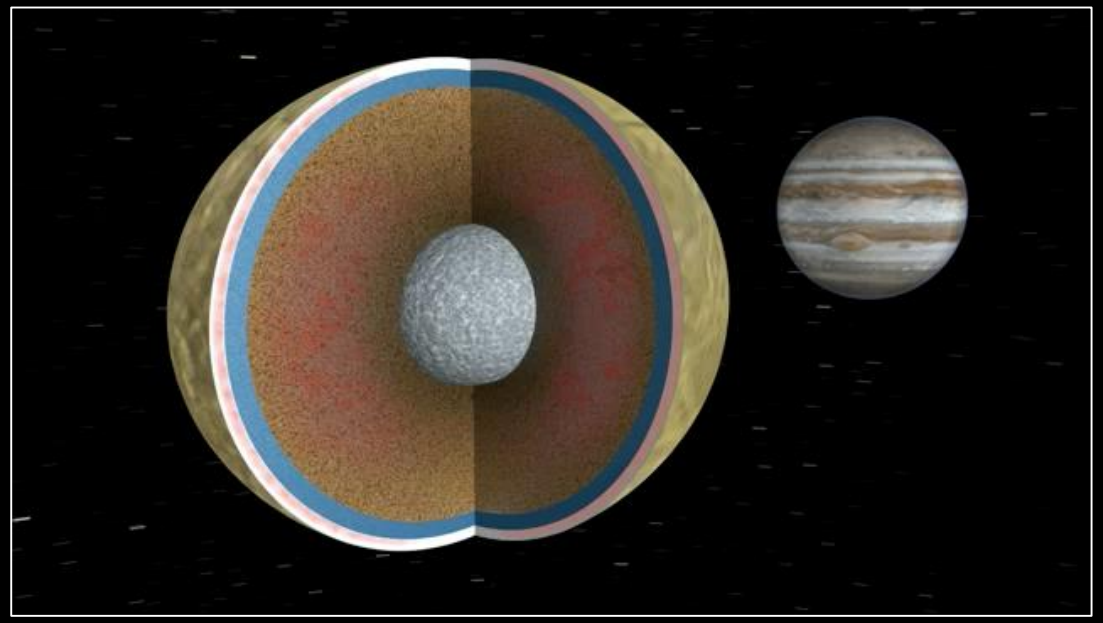


https://europa.nasa.gov/resources/76/landscapes-and-features-of-europa

TIDAL FLEXING → TIDAL HEATING and ACTIVE GEOLOGY

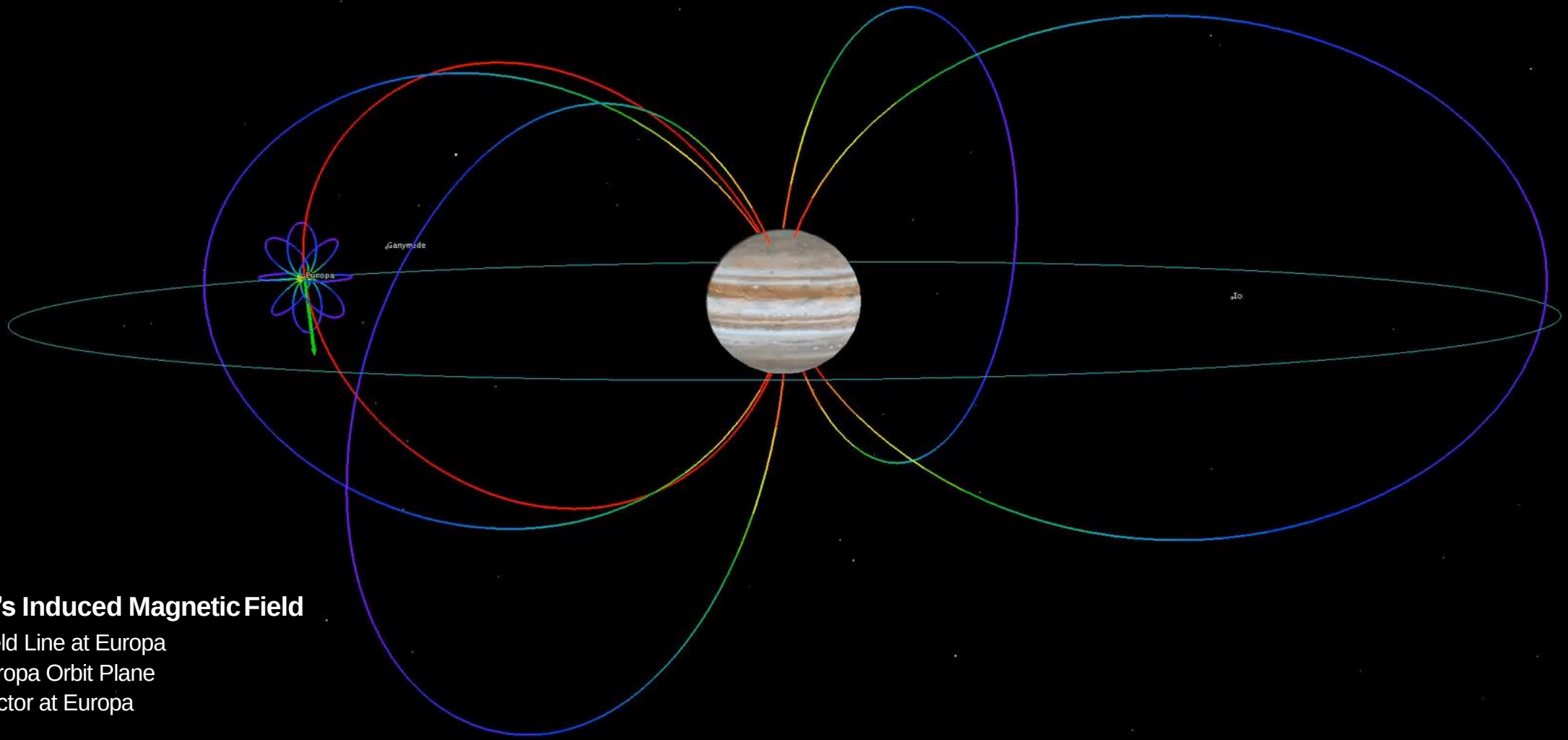


Rotation of Europa around Jupiter from above



Rotation of Europa around Jupiter from horizontal view

EUROPA'S INDUCED MAGNETIC FIELD



Europa's Induced Magnetic Field

- Field Line at Europa
- Europa Orbit Plane
- Vector at Europa

Jupiter Inertial Axes
1 Jun 2017 00:05:00.000 Time Step: 300.00 sec

Exploring Europa's Habitability: Ingredients for Life

Water:

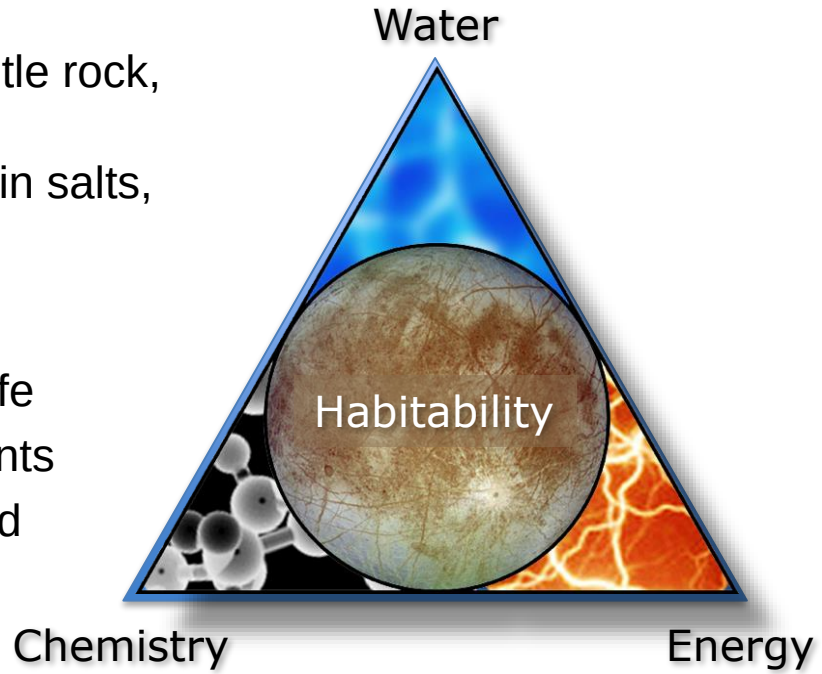
- Probable saltwater ocean, implied by surface geology and magnetic field
- Possible lakes within the ice shell, produced by local melting

Chemistry:

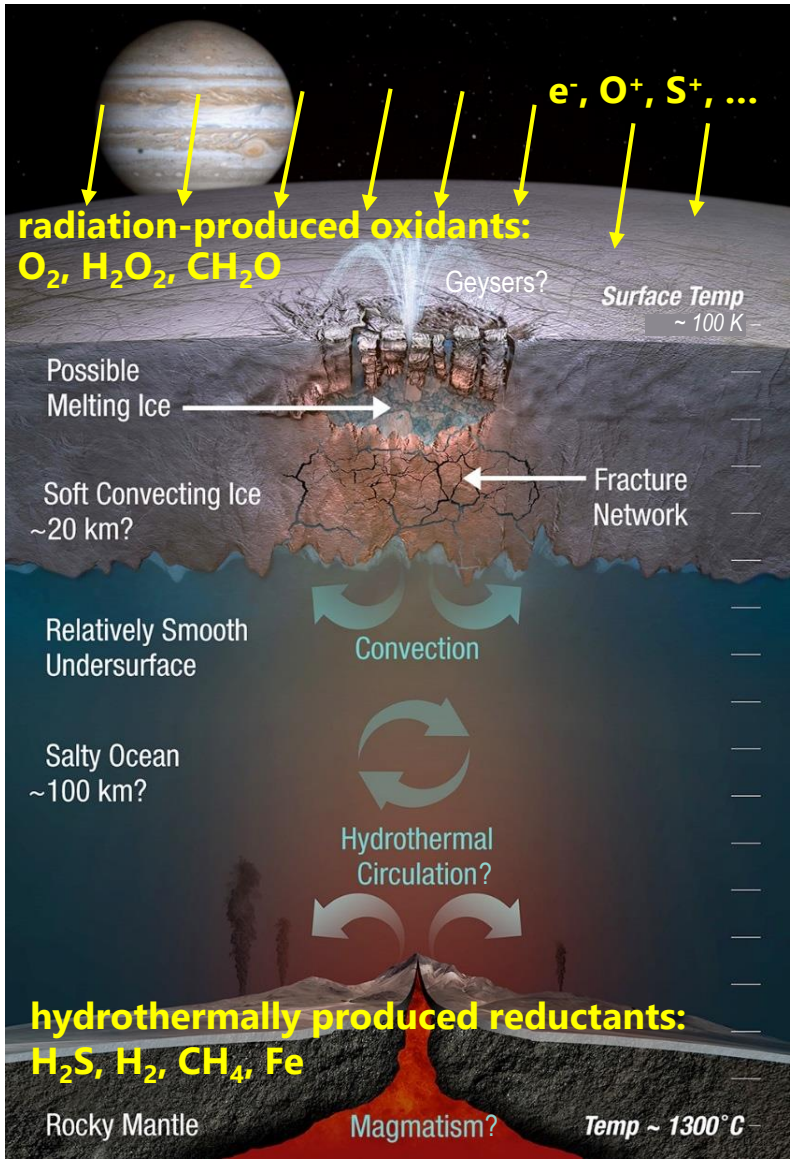
- Ocean in direct contact with mantle rock, promoting chemical leaching
- Dark red surface materials contain salts, probably from the ocean

Energy:

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

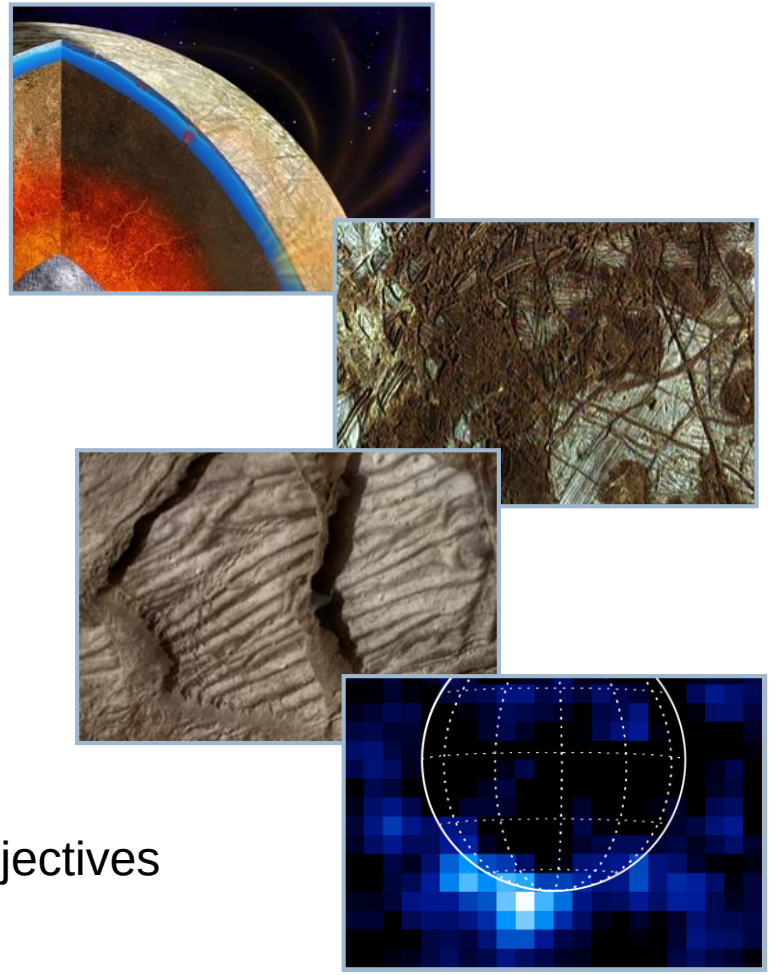


The Europa Clipper Mission will test key habitability hypotheses



Europa Clipper Science Goal and Objectives

- *Science Goal:* **Explore Europa to investigate its habitability**
- *Science Objectives:*
  - **Interior:** 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



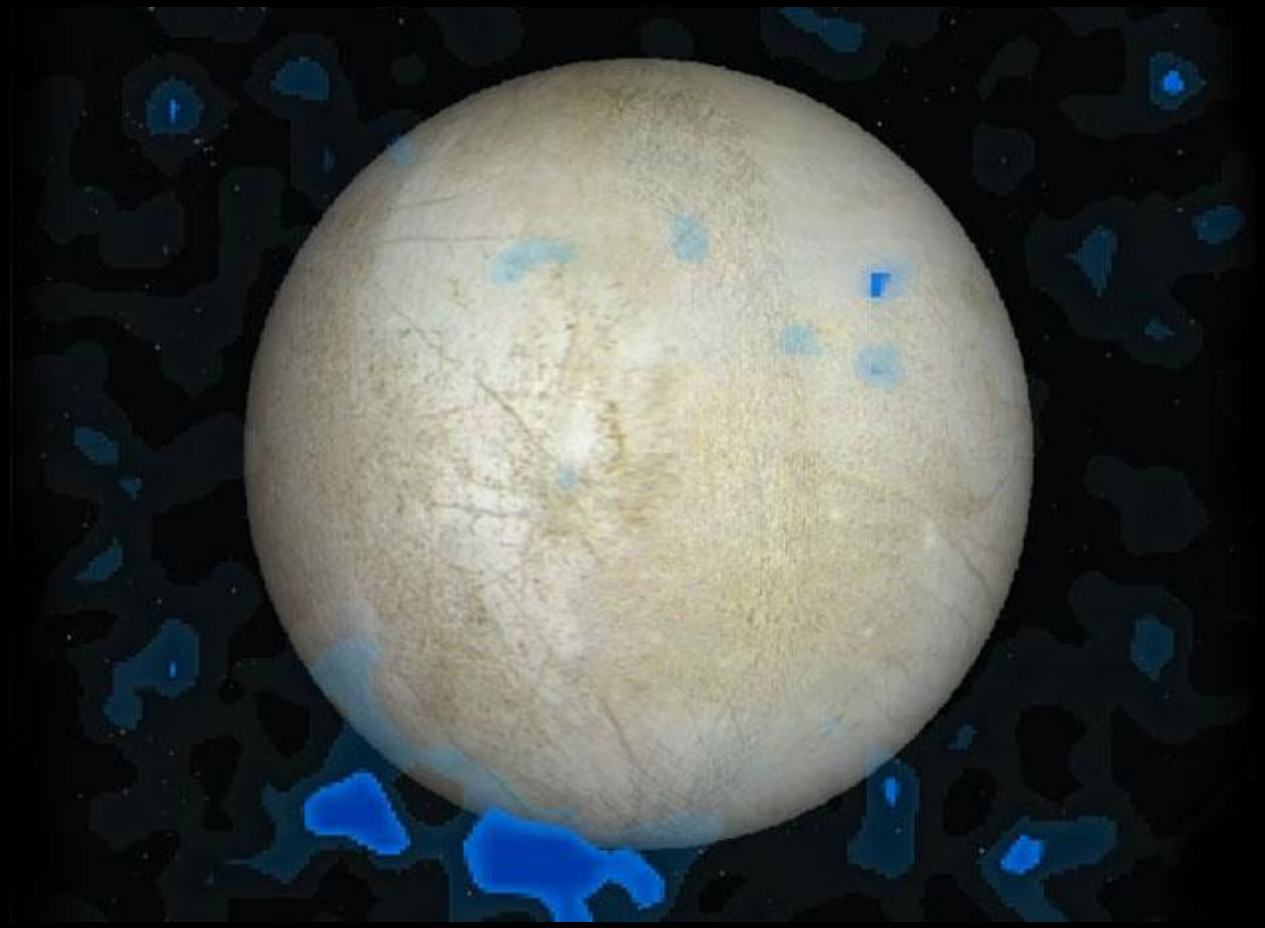
Recent Activity cross-cuts through all three principal science objectives

Europa Clipper Level 1 Science Requirements

	Mission Success	Baseline Level-1 Science Requirements	Threshold Level-1 Science Requirements
Ice & Ocean	Confirm the existence of, and constrain our knowledge of, the depth to the subsurface ocean, provide information on ocean salinity, and determine processes of surface-ice-ocean exchange.	**I1:** Map the vertical subsurface structure in regions of potential surface-ice-ocean exchange to >3 km depth along globally distributed ground tracks achieving a total cumulative length ≥30,000 km.	**I1:** Map the vertical subsurface structure in regions of potential surface-ice-ocean exchange to ≥3 km depth along regionally distributed ground tracks achieving a total cumulative length ≥10,000 km.
		I2: Constrain our knowledge of the average thickness of the ice shell, and the average thickness and salinity of the ocean, each to ±50%.	**I2:** Confirm the presence of a subsurface ocean, and determine whether the ice shell is in a “thin” (several km) or “thick” (10s km) regime.
Composition	Identify the composition and sources of key non-ice constituents on the surface and in the atmosphere, including any carbon-containing compounds.	**C1:** Create a compositional map at ≤10 km spatial scale, covering ≥60% of the surface, sufficient to identify non-ice materials, especially organic compounds.	**C1:** Create a compositional map at ≤10 km spatial scale, covering ≥40% of the surface, sufficient to identify non-ice materials, especially organic compounds.
		C2: Characterize the composition of ≥0.3% of the surface, globally distributed at ≤300 m spatial scale, sufficient to identify non-ice materials, especially organic compounds.	**C2:** Characterize the composition of ≥0.15% of the surface, regionally distributed at ≤400 m spatial scale, sufficient to identify non-ice materials, especially organic compounds.
		C3: Characterize the composition and sources of volatiles, particulates, and plasma, sufficient to identify the signatures of non-ice materials, including organic compounds, in at least one of the above forms, in globally distributed regions of the atmosphere and local space environment.	**C3:** Characterize the composition and sources of volatiles or particulates, sufficient to detect the signatures of non-ice materials, including organic compounds, in at least one of the above forms, in distributed regions of the atmosphere and local space environment.
Geology	Produce a ≤100-m spatial-scale map over ≥30% of the surface, and determine the three-dimensional characteristics of major landform types at higher resolution.	**G1:** Produce a controlled photomosaic map of ≥80% of the surface at ≤100-m spatial scale.	**G1:** Produce a controlled photomosaic map of ≥30% of the surface at ≤100-m spatial scale.
		G2: Characterize the surface at ≤25-m spatial scale across ≥5% of the surface with global distribution, including measurements of topography at ≤15-m vertical precision across ≥1% of Europa’s surface.	**G2:** Image the surface at ≤50-m spatial scale across ≥1.5% of the surface with regional distribution, including measurements of topography at ≤20-m vertical precision across ≥0.5% of Europa’s surface.
		G3: Characterize the surface at ~1-m spatial scale to determine surface properties, for ≥18 globally distributed sites.	N/A
Current Activity	Search for current activity.	**A1:** Search for and characterize any current activity, notably plumes or thermal anomalies, in regions that are globally distributed.	**A1:** Search for current activity, notably plumes or thermal anomalies.

Evidence for Activity: Hubble Space Telescope

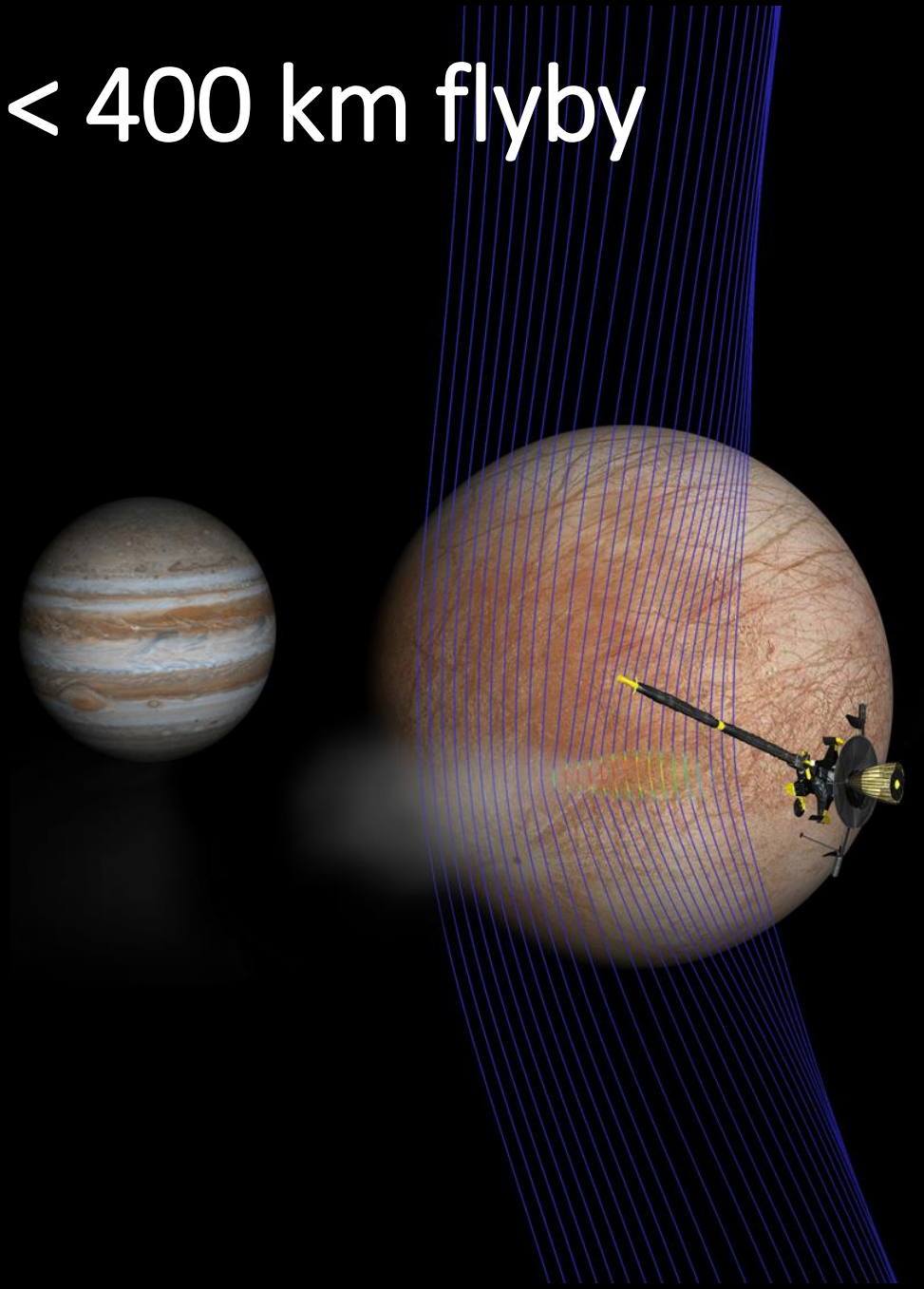
HST recorded two events, one occurring in 2012(Roth et al.) and one in 2016 (Sparks et al.); feature is about 200 km in height; many negative results, including several with James Webb Space Telescope (JWST)



Hydrogen atoms from possible ejected water originating in Europa's subsurface ocean appear as blue features
Credit: L. Roth/Southwest Research Institute and USGS

Evidence for activity: Galileo < 400 km flyby

From Jia et al. (2018): “the magnetometer recorded an approximately 1,000-kilometre-scale field rotation and a decrease of over 200 nT in field magnitude, and the Plasma Wave Spectrometer registered intense localized wave emissions indicative of a brief but substantial increase in plasma density. We show that the location, duration and variations of the magnetic field and plasma wave measurements are consistent with the interaction of Jupiter’s corotating plasma with Europa if a plume with characteristics inferred from Hubble images were erupting from the region of Europa’s thermal anomalies. These results provide strong independent evidence of the presence of plumes at Europa.”



Images: NASA/JPL-Caltech/UCLA

Europa Clipper Investigations

MASPEX
Mass Spectrometer
PI: Jim Burch, SwRI
sniffing atmospheric composition

SUDA
Dust Analyzer
PI: Sascha Kempf: U. Colorado
detecting surface & plume composition

ECM
Magnetometer
TL: Margaret Kivelson, U. Michigan
revealing ocean properties

PIMS
Faraday Cups
PI: Joe Westlake, APL
measuring plasma environment

Europa-UVS
UV Spectrograph
PI: Kurt Retherford, SwRI
seeking plume glow

EIS
Narrow-angle Camera + Wide-angle Camera
PI: Zibi Turtle, APL
mapping alien landscape

MISE
IR Spectrometer
PI: Diana Blaney, JPL
detecting chemical fingerprints

E-THEMIS
Thermal Imager
PI: Phil Christensen, ASU
searching for hot spots

REASON
Ice-Penetrating Radar
PI: Don Blankenship, UTIG
probing the ice shell

G/RS
Doppler Gravity
TL: Erwan Mazarico, GSFC
sensing interior layers

Remote Sensing In Situ

Europa Imaging System (EIS)

Zibi Turtle, Johns Hopkins U. Applied Physics Laboratory (APL)

VIS

- Characterize visible reflectance, morphology, and albedo, and color of the surface with associated topographic coverage to address:
  - global-scale distribution and regional-scale topography of geologic landforms
  - local-scale surface properties, including resurfacing and degradation processes
- Search for recent activity by searching for active plumes and characterizing albedo and color variations

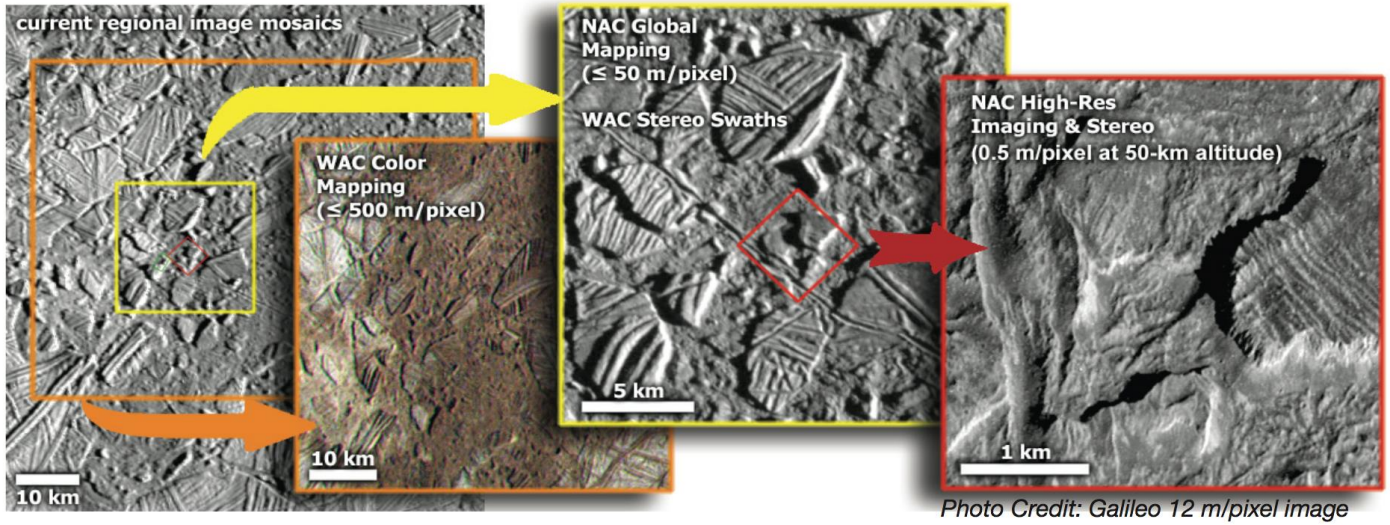


Photo Credit: Galileo 12 m/pixel image

- NAC: high-resolution, stereo imaging, color
- NAC gimbal permits independent targeting, enabling near-global mapping, including stereo, and high-phase observations to search for potential plumes
- WAC: along-track stereo & color context imaging
- WAC supports cross-track clutter characterization for ice-penetrating radar

Key Instrument Parameters

	NAC	WAC
Detector	4096 × 2048 rad-hard CMOS	
Wavelength Range	Panchromatic plus 6 filters	
	(350 – 1050 nm)	(370 – 1050 nm)
Instantaneous Field of View	10 µrad (0.5 m/pixel at 50 km)	218 µrad (11 m/pixel at 50 km)
Field of View	2.347° × 1.173°	48° × 24°

Mapping Imaging Spectrometer for Europa (MISE)

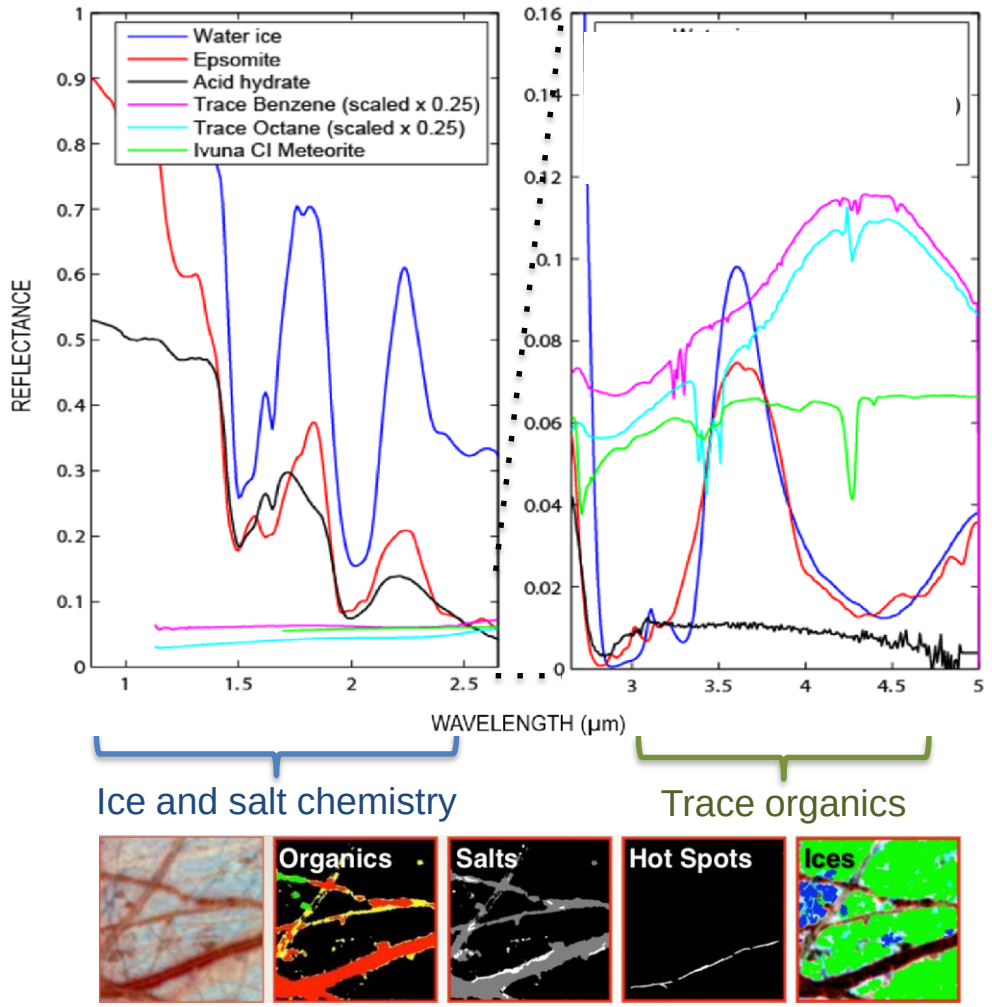
Diana Blaney, Jet Propulsion Laboratory (JPL)

IR

- Measure absorption features, due to hydrated salts, and organics, and map compositionally diagnostic properties to determine the global-scale composition and chemistry
- Measure absorption features, due to hydrated salts, and organic compounds, and map compositionally diagnostic properties to determine the regional-scale surface composition and chemistry
- Sample compositionally diagnostic properties to determine composition of individual landforms

Key Instrument Parameters	
Wavelength Range	0.8 to 5.0 µm (800 – 5000 nm)
Instantaneous Field of View	250 µrad
Field of Regard	4.3° across-track x slit width (0.01° = IFOV); along-track up to 60°
Spatial Resolution	10 km/pixel full-disk images at 40,000 km range 25 m/pixel at 100 km range
Average Spatial Sampling	10 nm/band
Spectral Cube Size	300 lines x 80 to 300 samples x 451 spectral channels
Cubes Collected	Up to 10 per flyby
Signal-to-Noise Ratio	>100:1 from 0.8–2.6 µm, 10:1 between 2.6 and 3.2 µm, >25 from >3.2 µm

Key compounds at MISE spectral resolution and sampling:



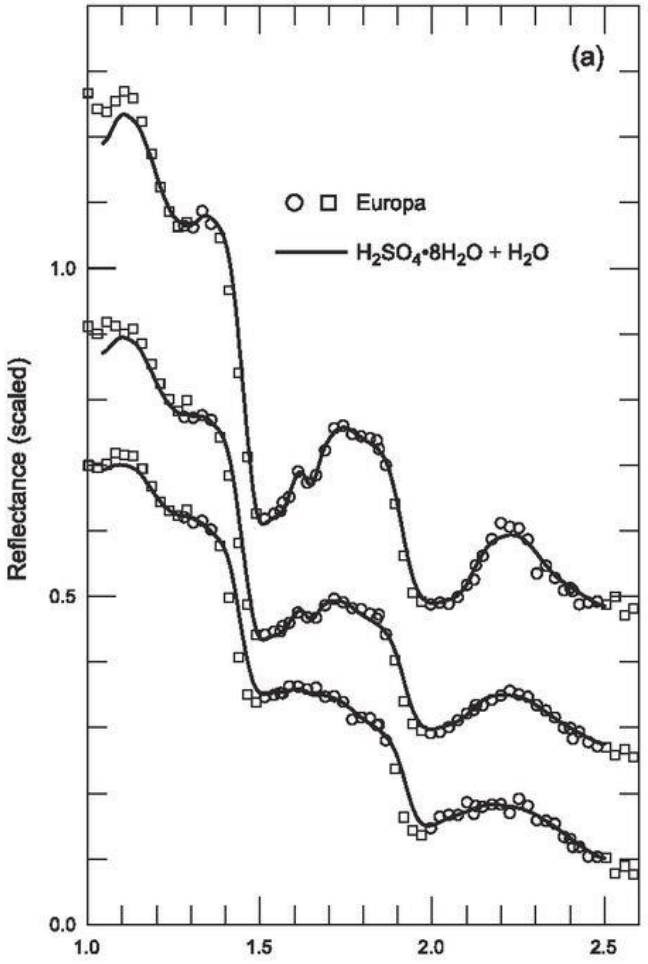
Composition

Water ice is the main component, with a rocky, possibly metallic (even iron) core.

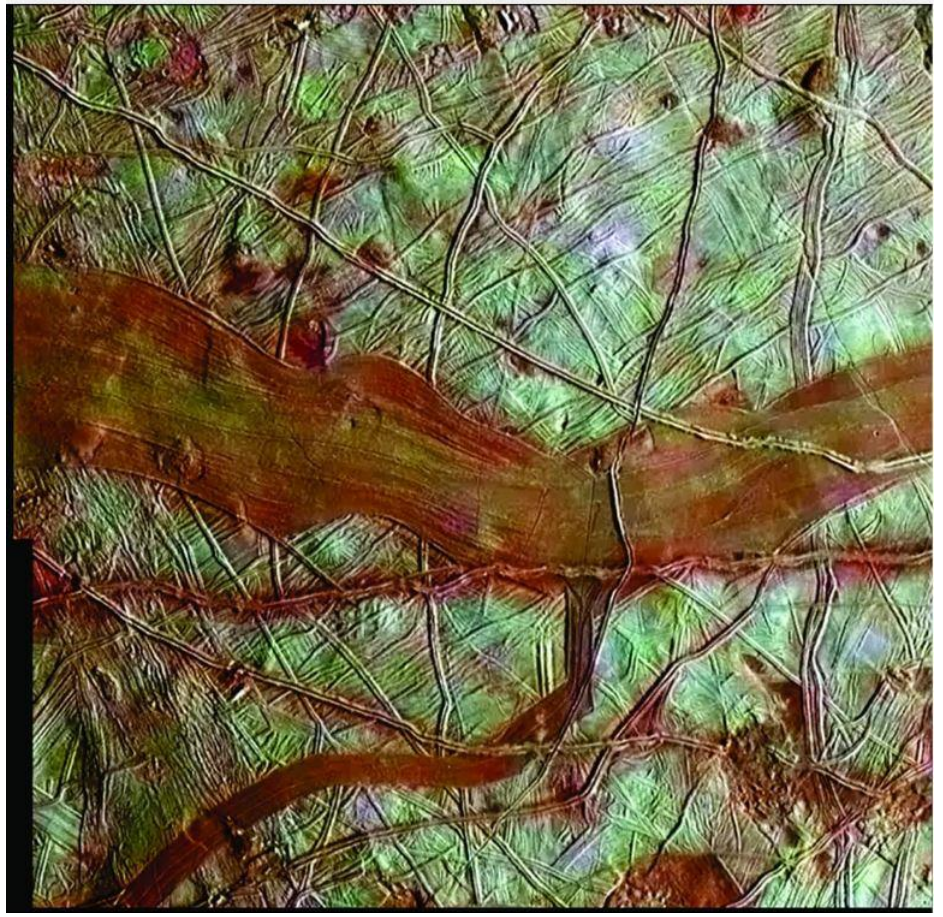
On the surface, NaCl, CO_2, possible sulfates detected (from Io)

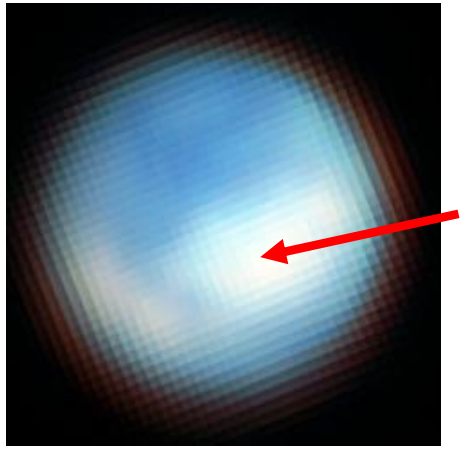
Other salts such as magnesium sulfate will be sought, as well as organic molecules, including complex ones.

Goal of mission is to map components into the context of the moon's geologic features to understand evolution



Carlson et al., 2009





James Webb Space Telescope showing CO_2 (bright) associated with the chaos terrain

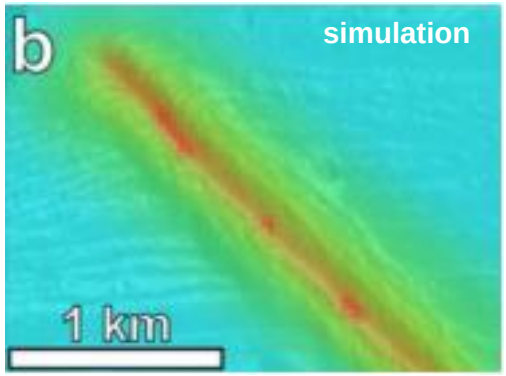
JWST (Villanueva, Trumbo & Pagan)

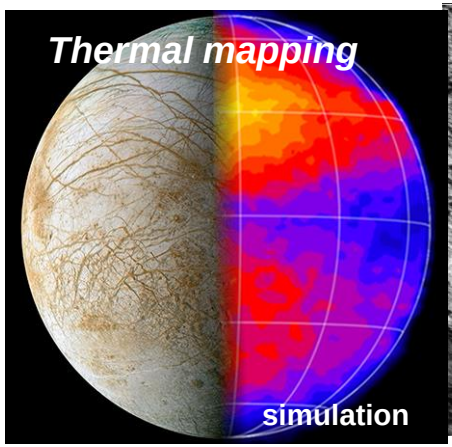
Europa Thermal Imaging System (E-THEMIS)

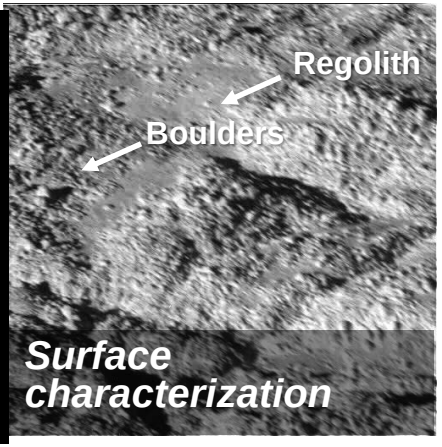
Phil Christensen, Arizona State University

MIR

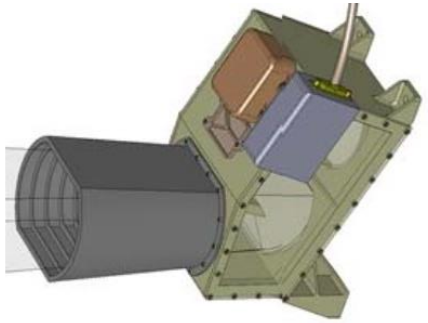
- Map daytime or nighttime temperatures to characterize the thermophysical properties indicative of erosion and deposition processes
- Map daytime and nighttime temperatures to characterize the thermal state of the ice shell and identify heat flow anomalies, regolith depth, and block abundance







- High-resolution thermal images
- Uncooled microbolometer array with three spectral channels
- Time-delay integration (TDI) for measuring low temperatures



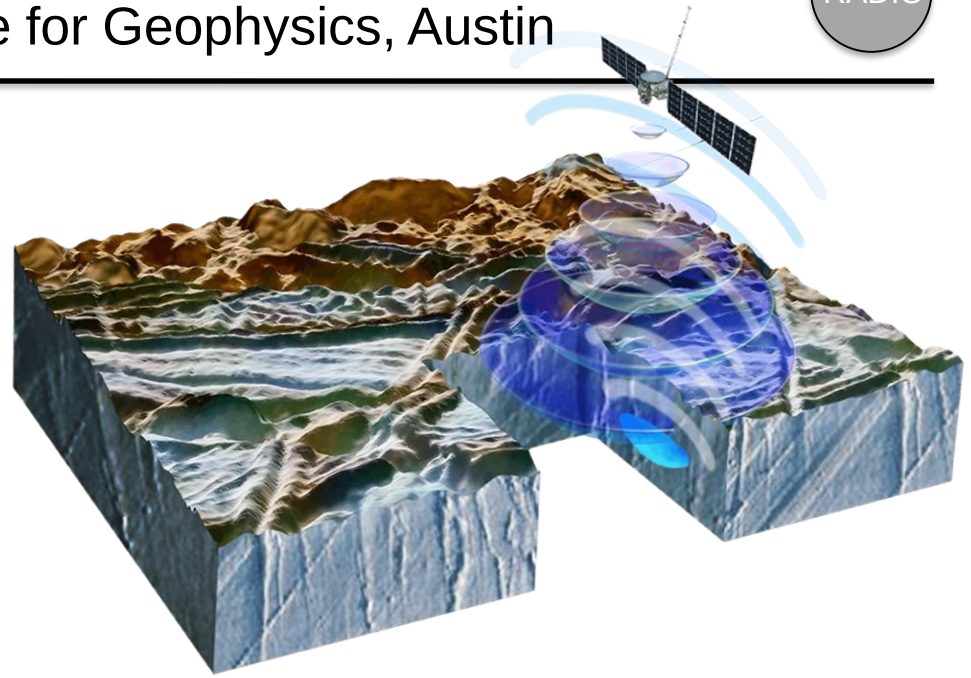
Key Instrument Parameters	
Filters	7–14, 14–28, 28–70 μm
Resolution	9 – 15 m at 25 km range
Image width	5.7° cross-track (720 pixels)
Radiometric Precision	~2 K
Radiometric accuracy	2%

Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON)

Don Blankenship, University of Texas Institute for Geophysics, Austin

RADIO

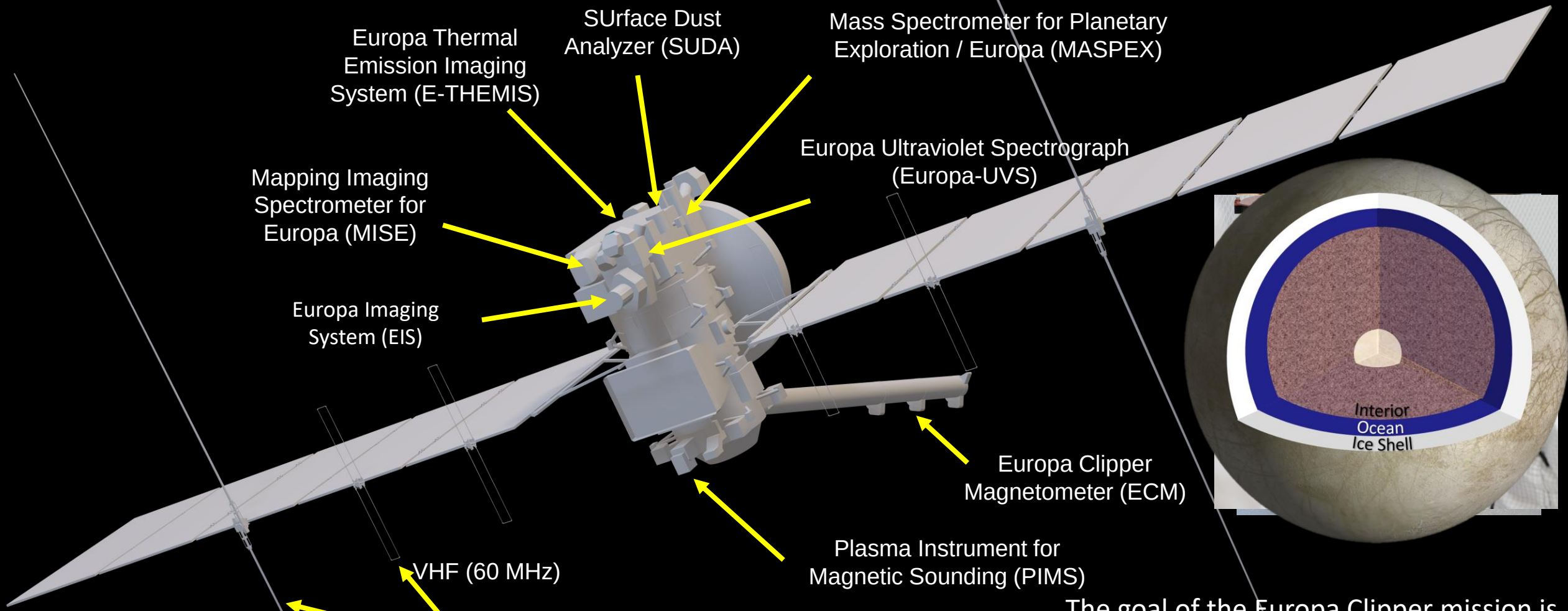
- Map the distribution of subsurface water, near-surface brines, ice shell structure, and exchange processes in the shallow subsurface
- Map the distribution of subsurface water, near-surface brines, ice shell structure, and exchange processes to address deep subsurface exchange
- Search for an ice-ocean interface by characterizing the surface elevation and ice shell thermophysical properties, as well as searching directly for any ice-ocean interfaces
- Determine regolith cohesiveness, thickness, and subsurface layering; surface roughness and slopes; and the distribution of blocks



- Simultaneous high resolution, shallow sounding, altimetry, and reflectometry along with lower resolution full-depth sounding of the ice shell and plasma measurements

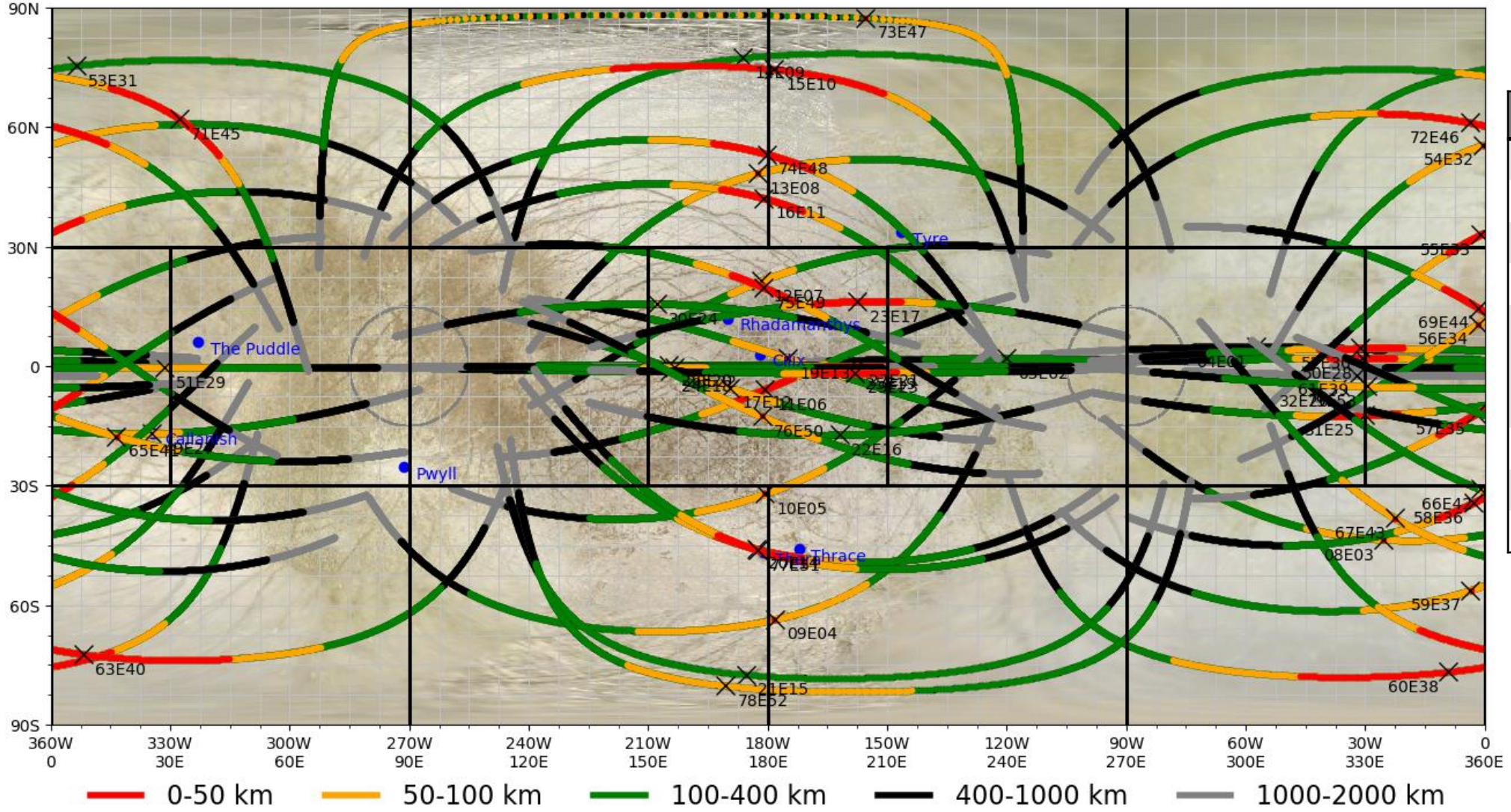
Key Instrument Parameters	
Dual Frequencies	60 MHz (λ = 5 m) Very High Frequency (VHF) globally, and 9 MHz (λ = 33.3 m) High Frequency (HF) anti-Jovian
Vertical Resolution	*Shallow sounding*: VHF with <30 m resolution from depths down to 3 km; *Full-depth sounding*: VHF (coarser) or HF with <300 m resolution and VHF (finer) with < 30 m resolution from 3 to 30 km depths; *Altimetry*: VHF with <15 m resolution
Antenna	2 deployable HF and 4 VHF dipole antennas mounted on solar array
Radiated Power	10 - 30 W

EUROPA CLIPPER SPACECRAFT



The goal of the Europa Clipper mission is to determine the habitability of Europa's subsurface ocean

Europa Clipper Tour Operations: Flyby Groundtracks
(21F31_v4)



Tour Parameter	21F31_V4
Launch Date	**10/10/24**
Arrival Date	**4/10/30**
Tour Duration (yr)	**4.27**
Europa Resonance	**6:1, 4:1**
Number of Flybys Europa Ganymede Callisto	 **49** **7** **9**
Jupiter Orbits	**79**
Max. Inclination (deg)	**7.5**
Disposal Body	**Ganymede**

Final trajectory is currently in work

SIZE OF EUROPA CLIPPER SPACECRAFT

NASA SLS Block I

Statue of Liberty

93 m / 305 ft

6 stacked School Buses

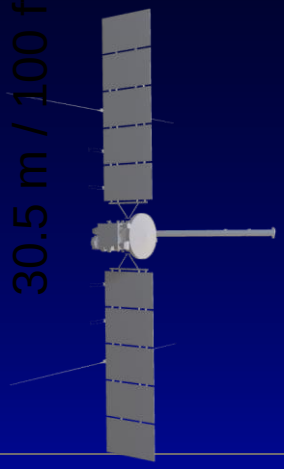
72 m / 236 ft

Space X Falcon Heavy

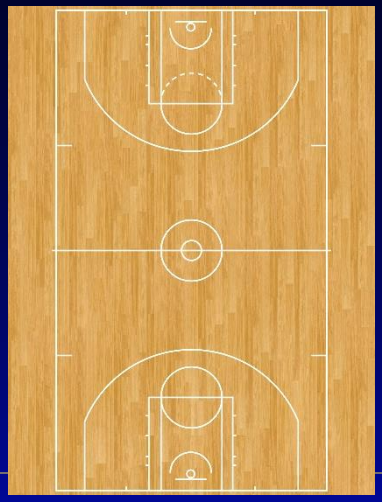
70 m / 230 ft

Europa Clipper

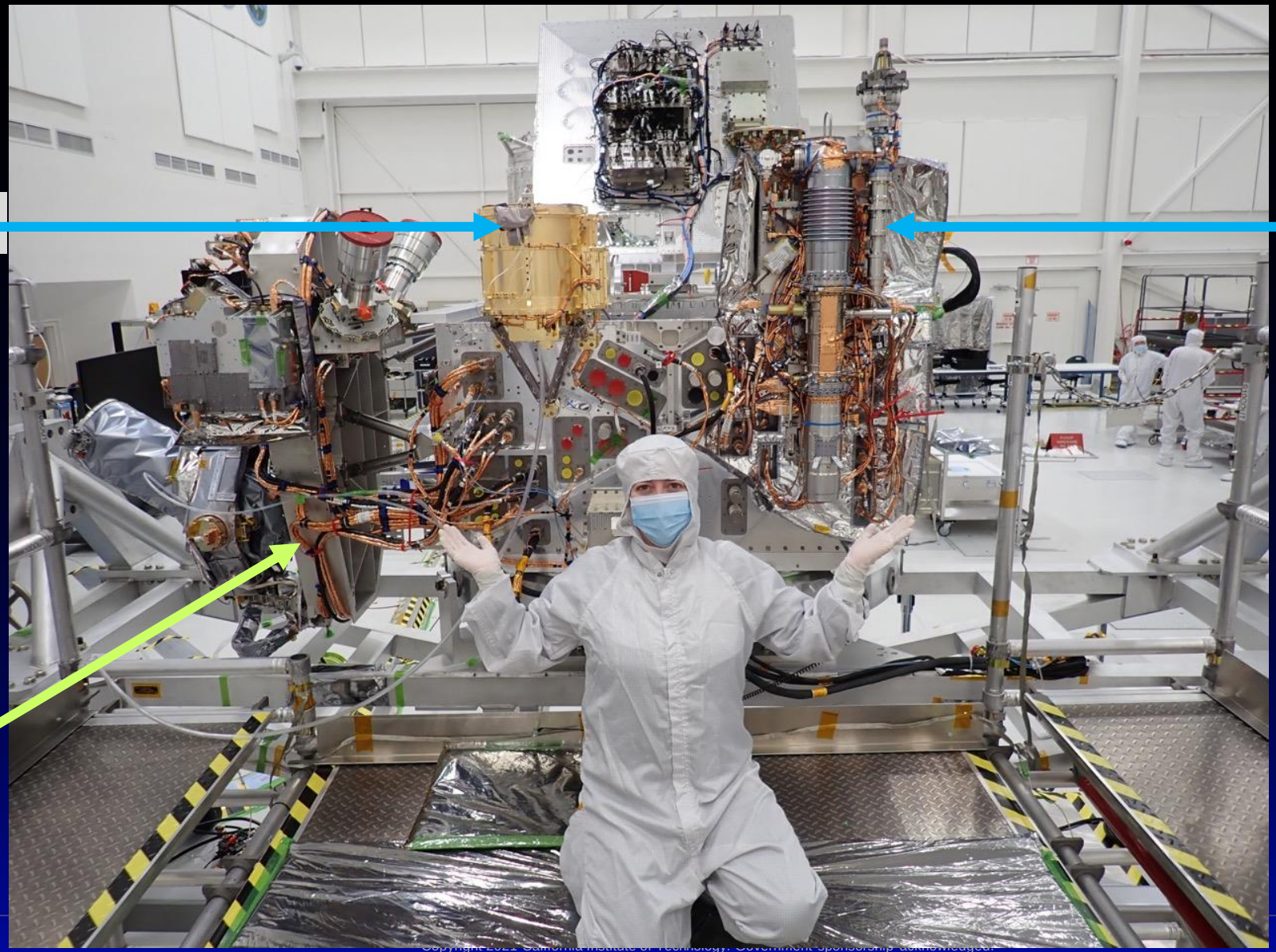
30.5 m / 100 ft



Basketball Court

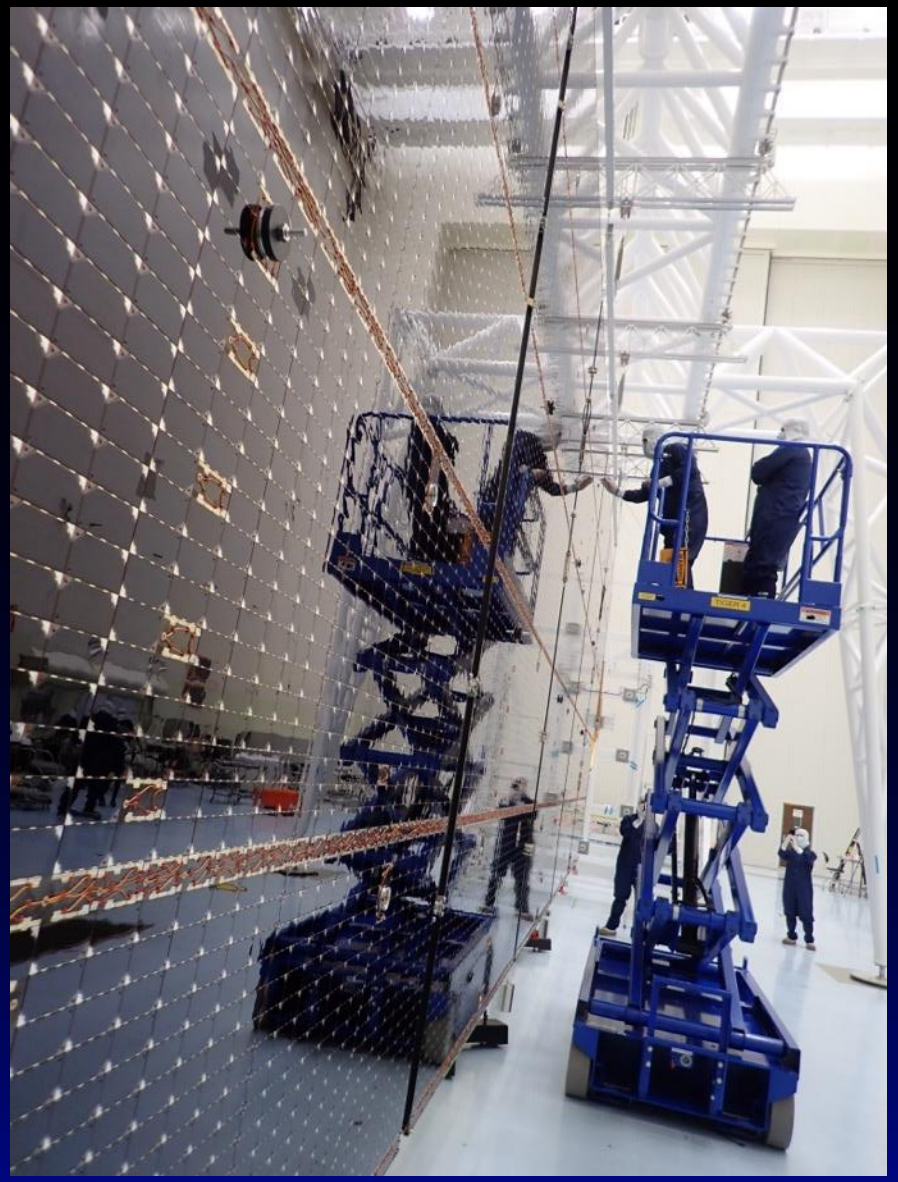


INSTRUMENTS INSTALLED ON THE VAULT

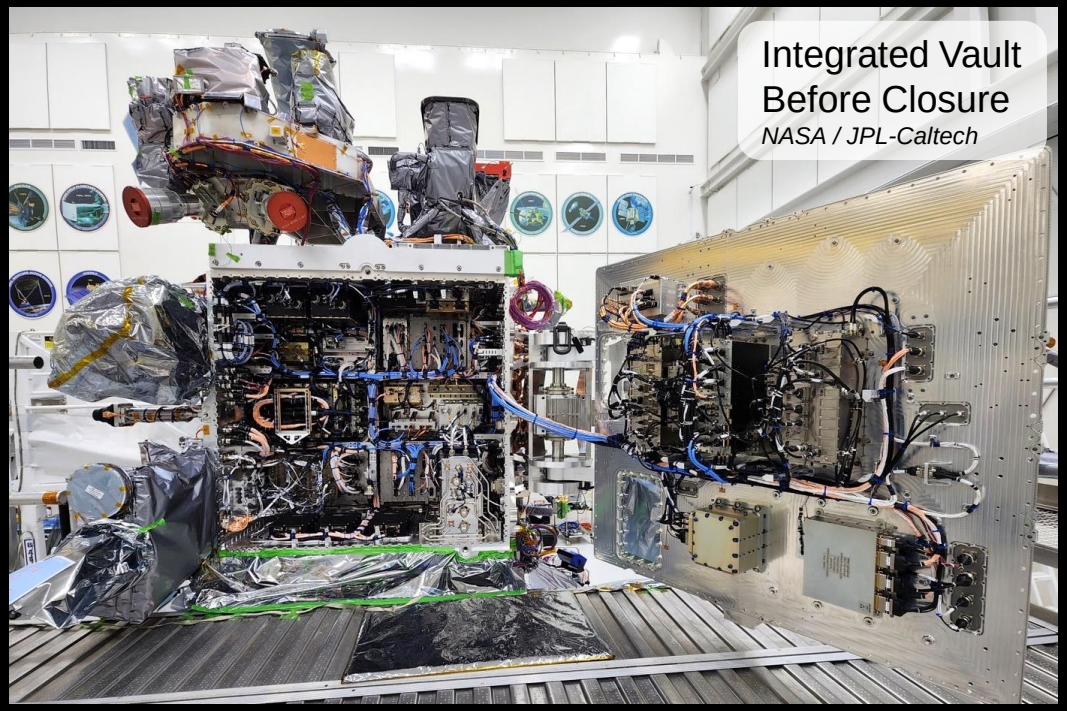


SOLAR ARRAYS

IN TESTING AT KENNEDY SPACE CENTER

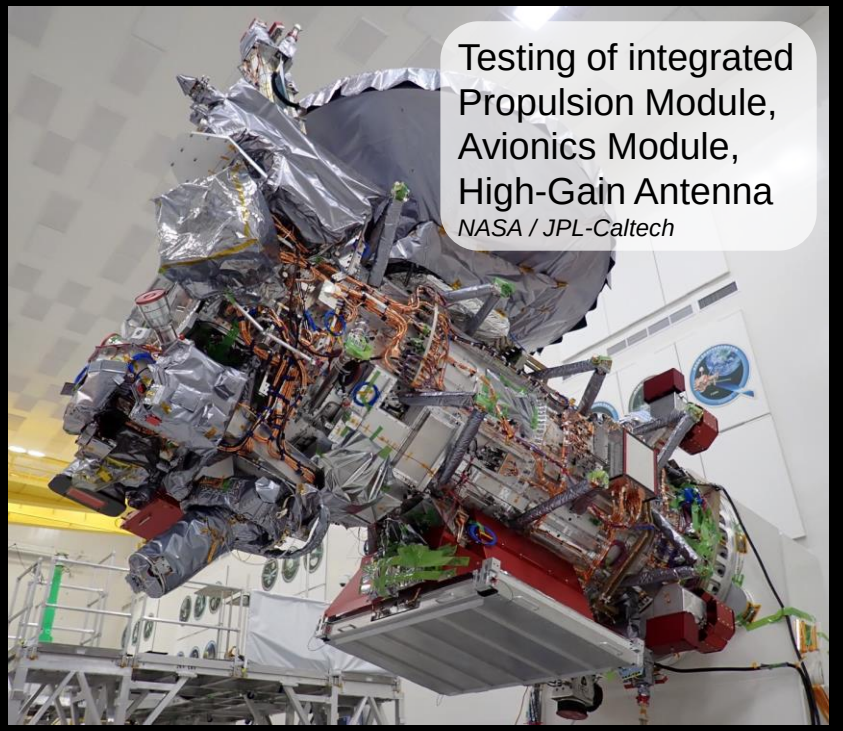


Spacecraft Integration



Integrated Vault Before Closure
NASA / JPL-Caltech

Clipper with Solar Array Mass Simulators
NASA / JPL-Caltech



Testing of integrated Propulsion Module, Avionics Module, High-Gain Antenna
NASA / JPL-Caltech

Mag Boom Deployment Test
NASA / JPL-Caltech

Solar Arrays
Airbus, Netherlands

30

EUROPA CLIPPER SPACECRAFT

CURRENT CONFIGURATION

COMPLETED SUCCESSFUL TESTING IN THERMAL VACUUM CHAMBER AT JPL

FINAL TESTING AND ASSEMBLY IN CLEAN ROOM AT JPL

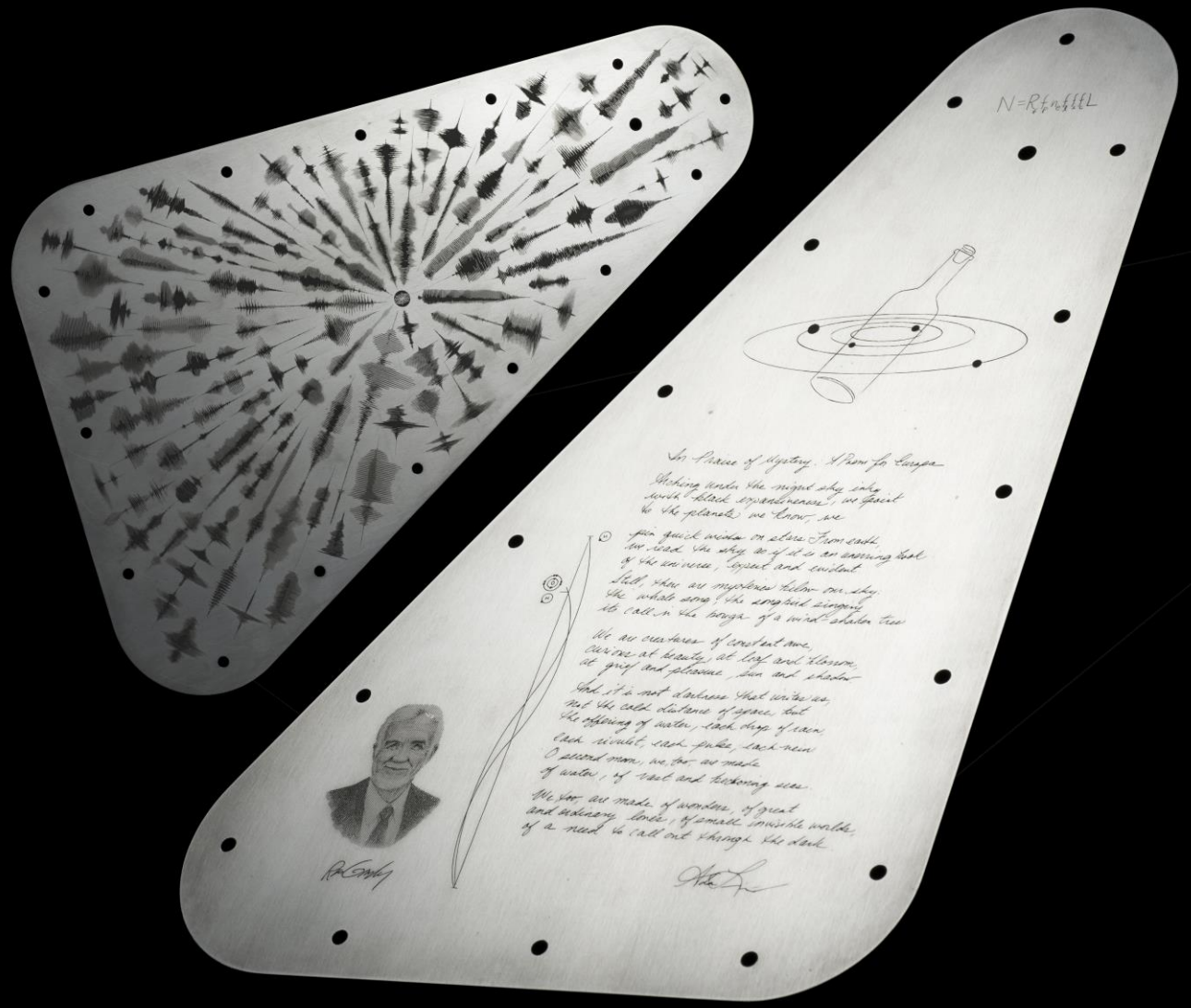
EUROPA CLIPPER VAULT PLATE

Inward-facing side: *In Praise of Mystery: A Poem for Europa* in Ada Limón's handwriting; cosmic message bottle and chip with 2.6 million names; Drake Equation in Frank Drake's handwriting; hand-drawn portrait of Ron Greeley; OH and H radio waves

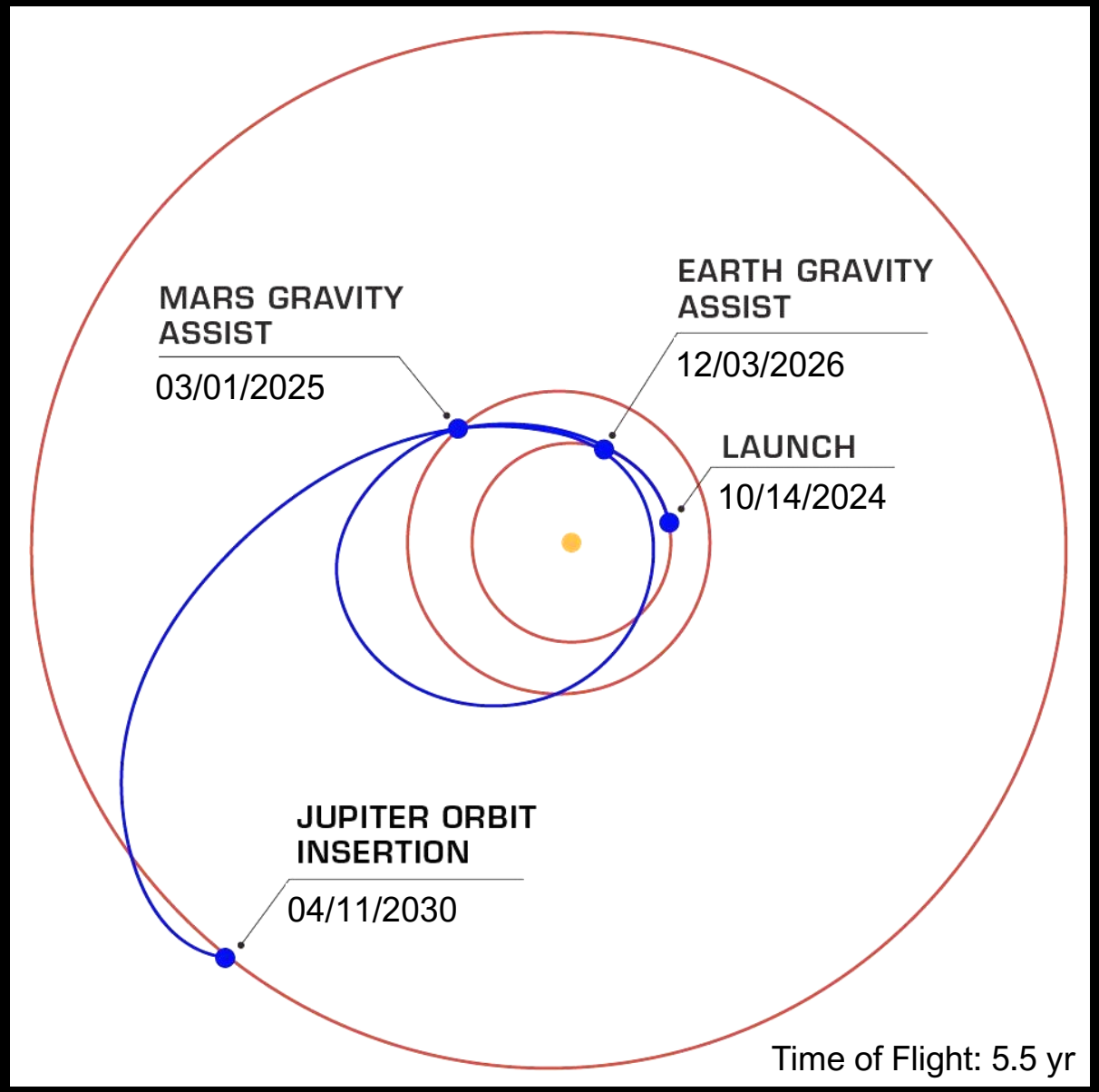
Outward-facing side: spoken words for water in 104 languages from across the globe, shown as waveforms

The engraved designs on the vault plate represent human connections: between each of us on Earth, between Earth and Europa, and between humankind and the cosmos, as we seek to learn about the possibilities of life beyond Earth. Each element is derived from human voices or drawn by hand.

To learn more: visit go.nasa.gov/MakeWaves



Interplanetary Trajectory: Mars-Earth Gravity Assist (MEGA)



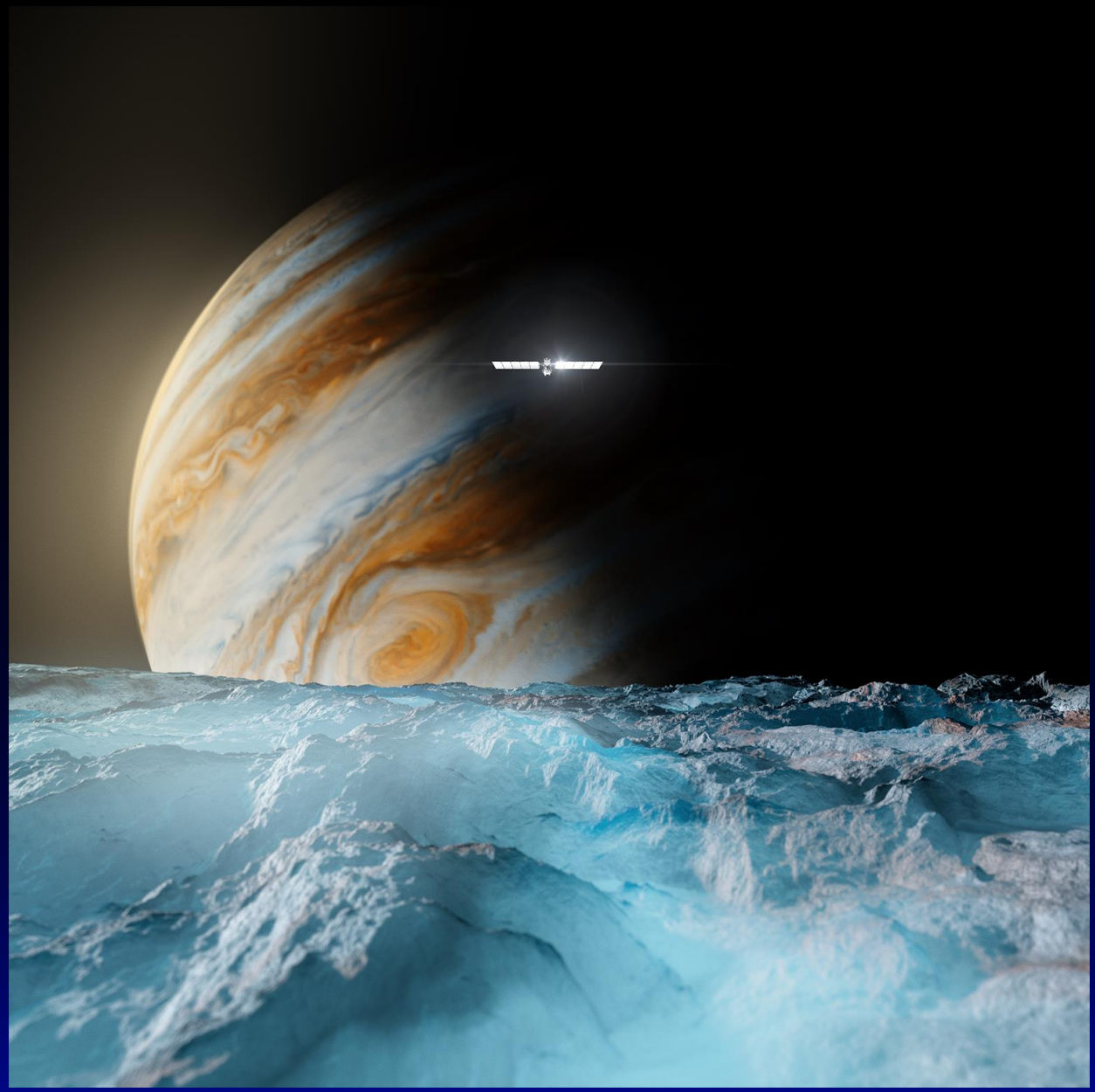
GET INVOLVED

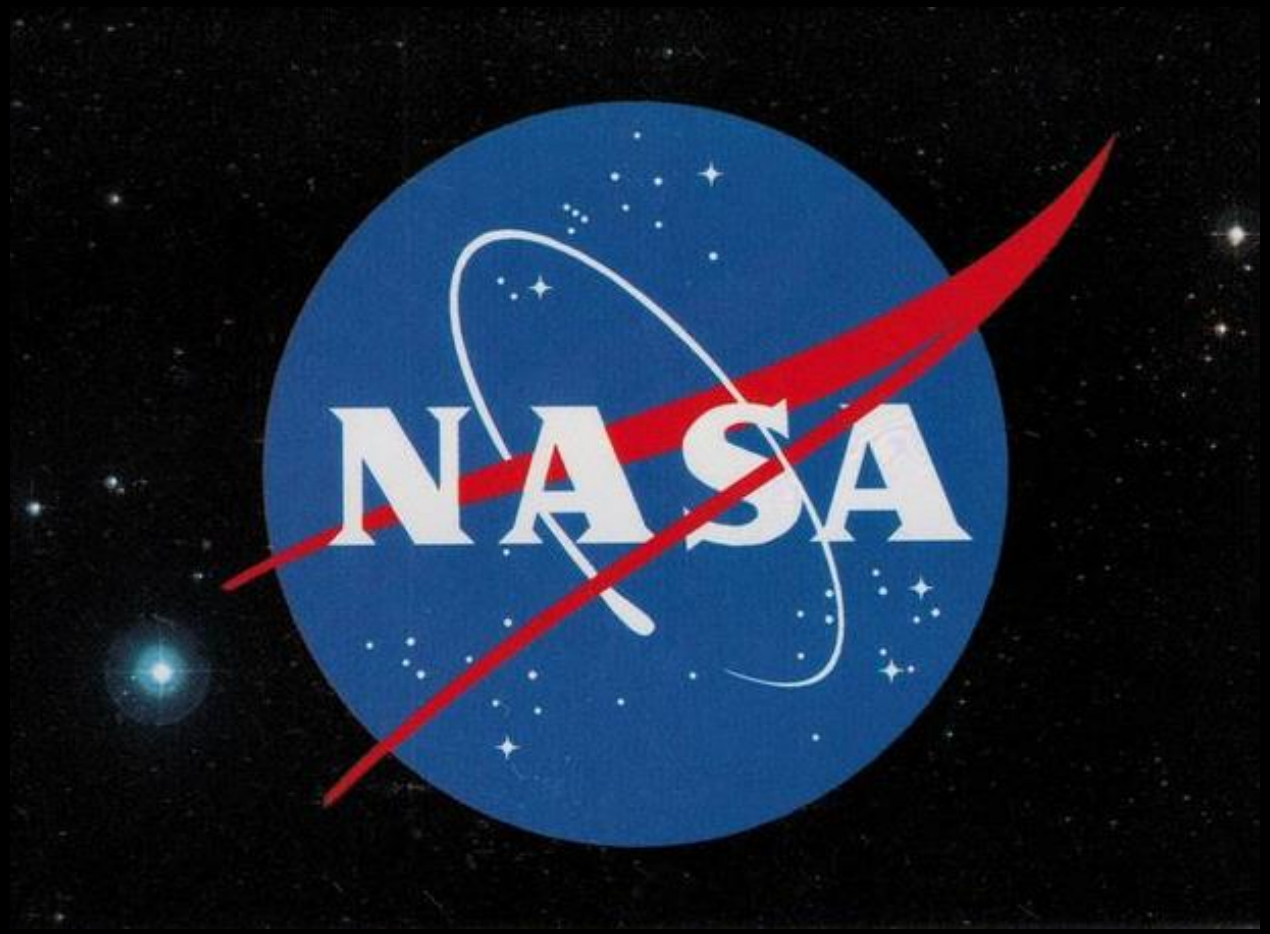
europa.nasa.gov

@EuropaClipper

www.facebook.com/NASAEuropaClipper

@NASASolarSystem




NASA