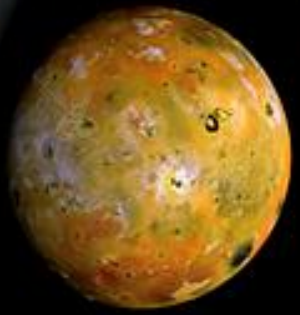
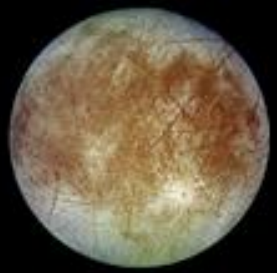
L. Alberto Cangahuala, Europa Clipper Mission System Manager
Jet Propulsion Laboratory / California Institute of Technology

The Galilean Satellites

Galileo discovered four moons around Jupiter in January 1610

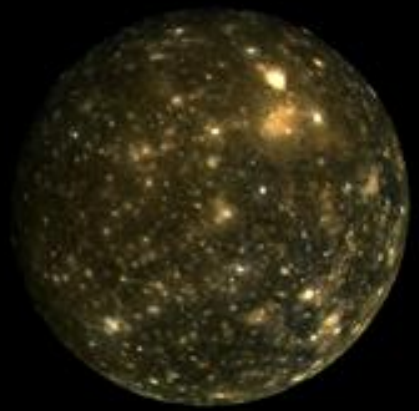


Io



Europa

Ganymede



Callisto

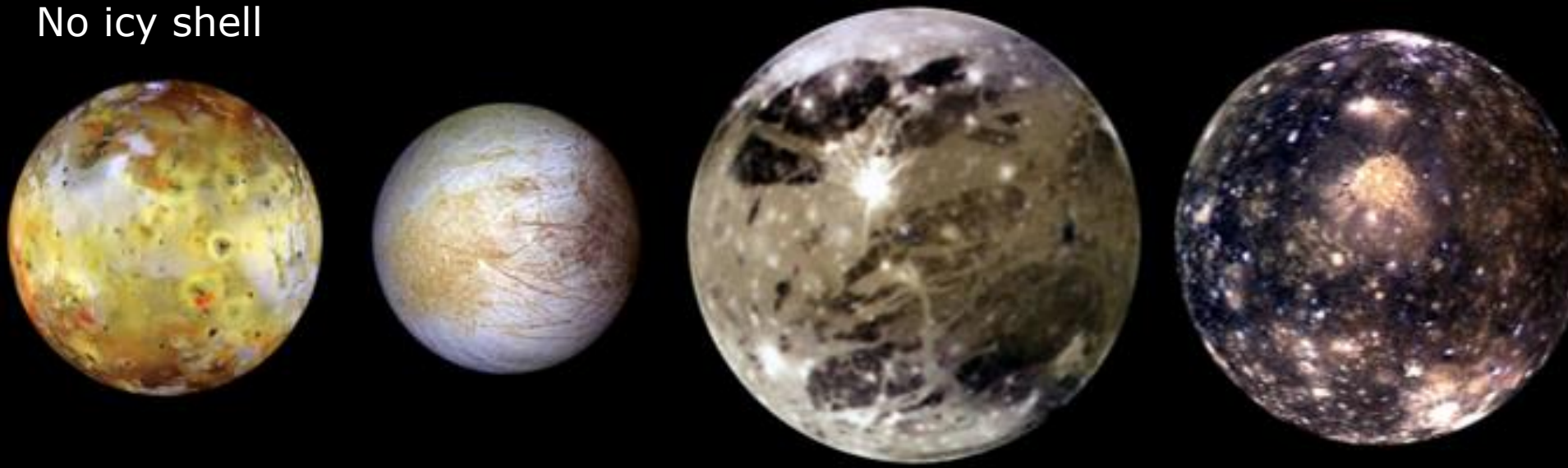
The Galilean Satellites (cont.)

As imaged last year by the Juno spacecraft on approach to Jupiter…

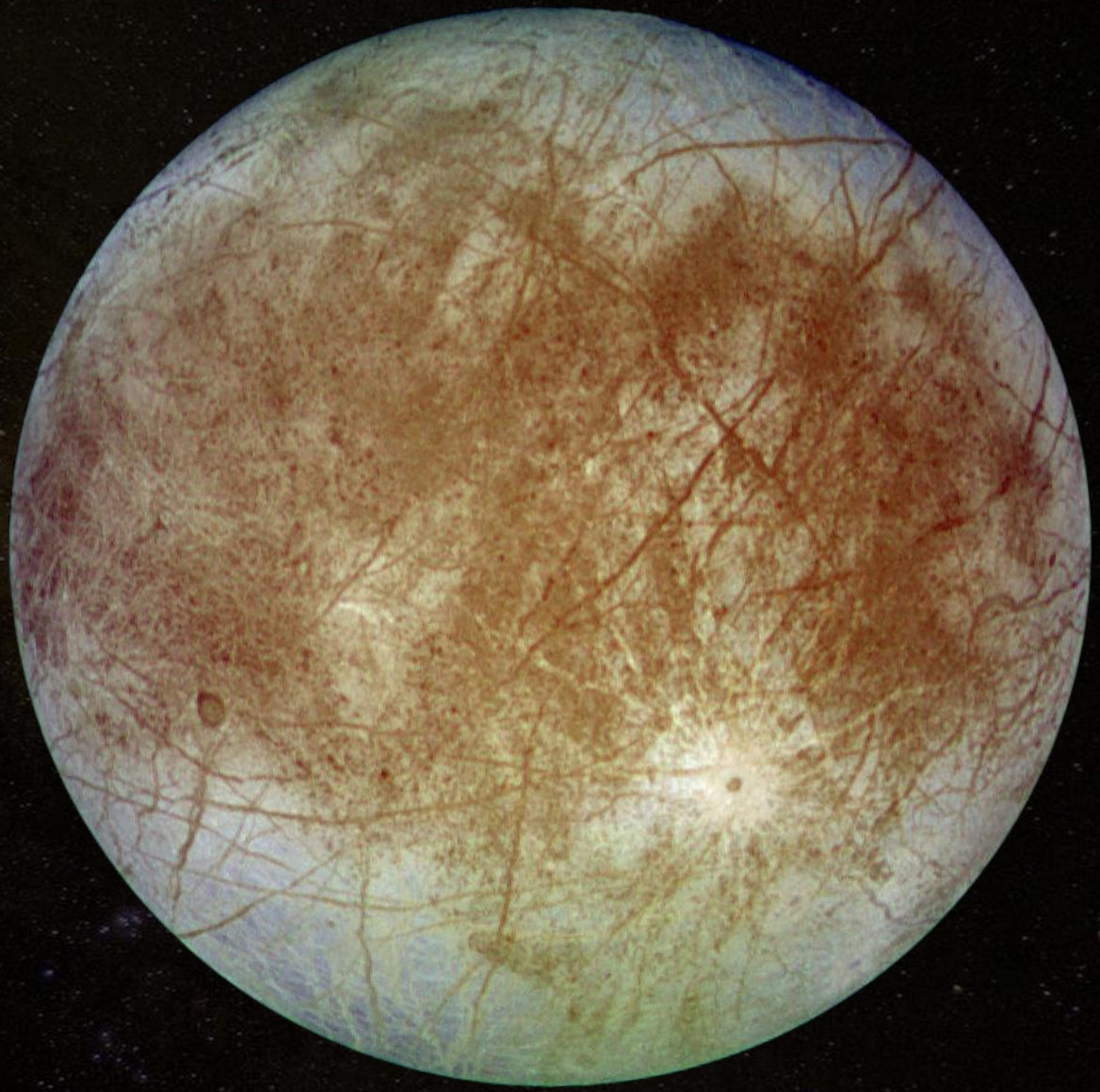
Earlier missions (Voyager, Galileo) uncovered the following…

Volcanic World
No icy shell

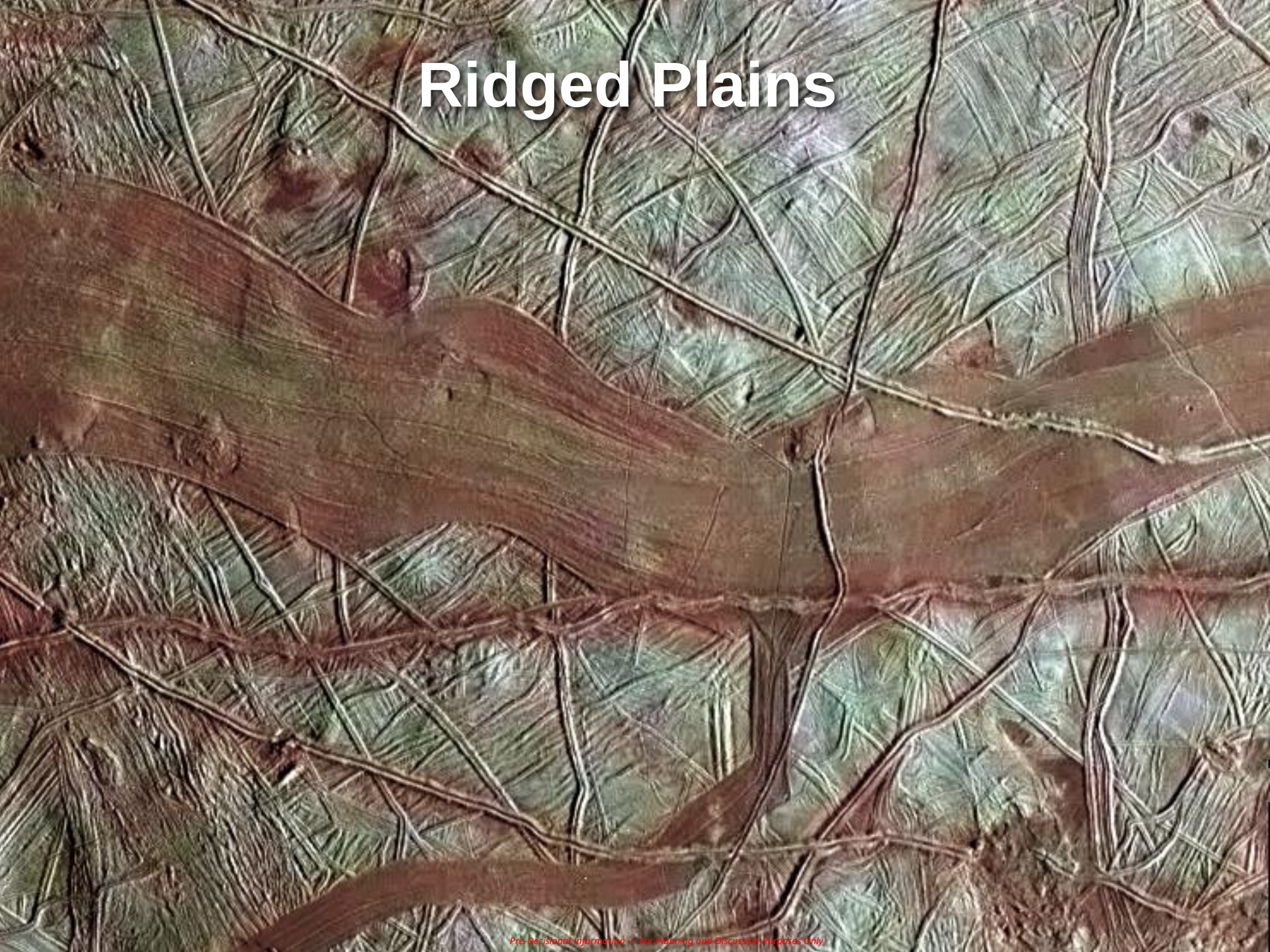
Icy Worlds – ice shells on top of oceans with rocky cores



Europa

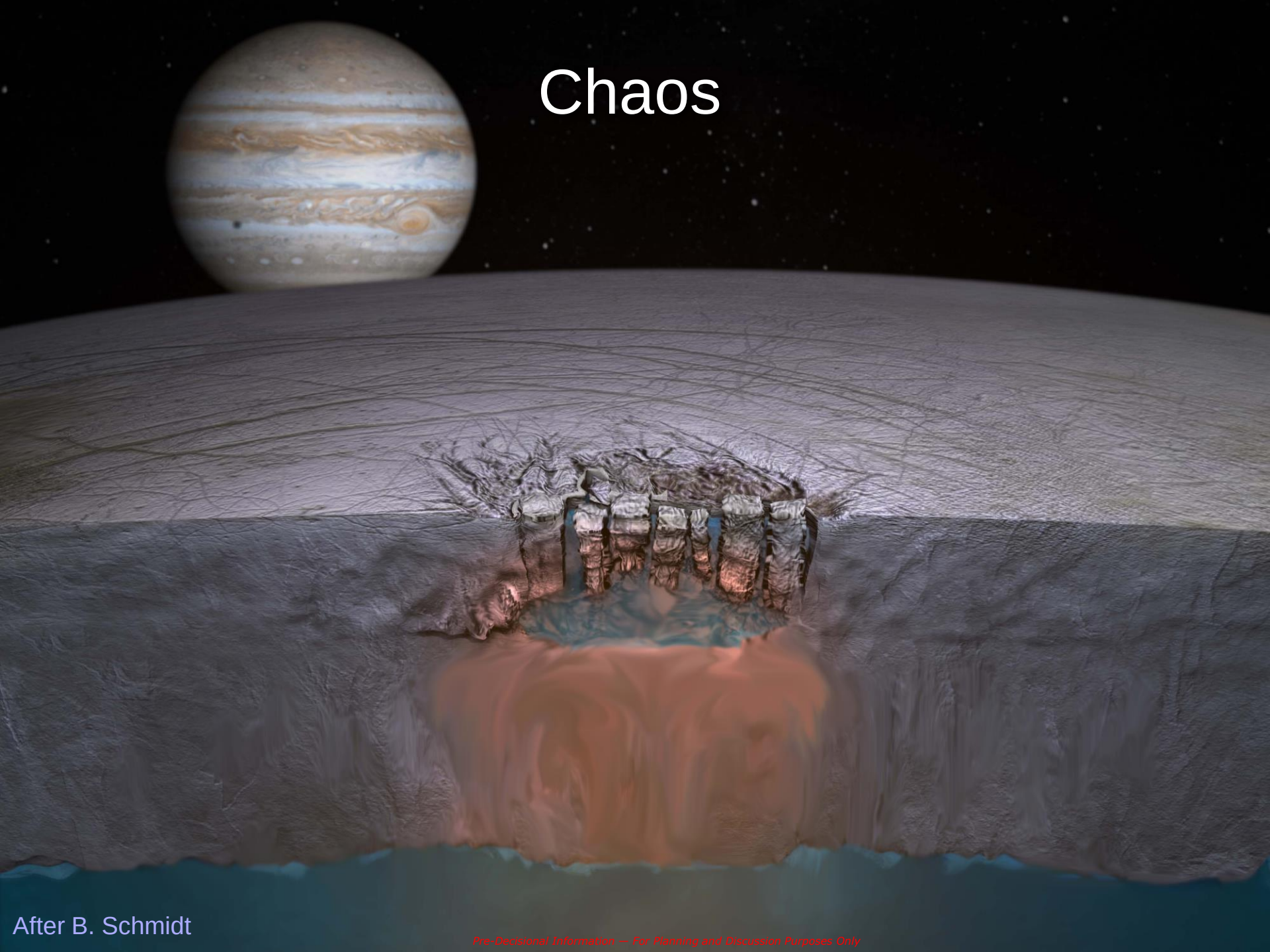


Ridged Plains



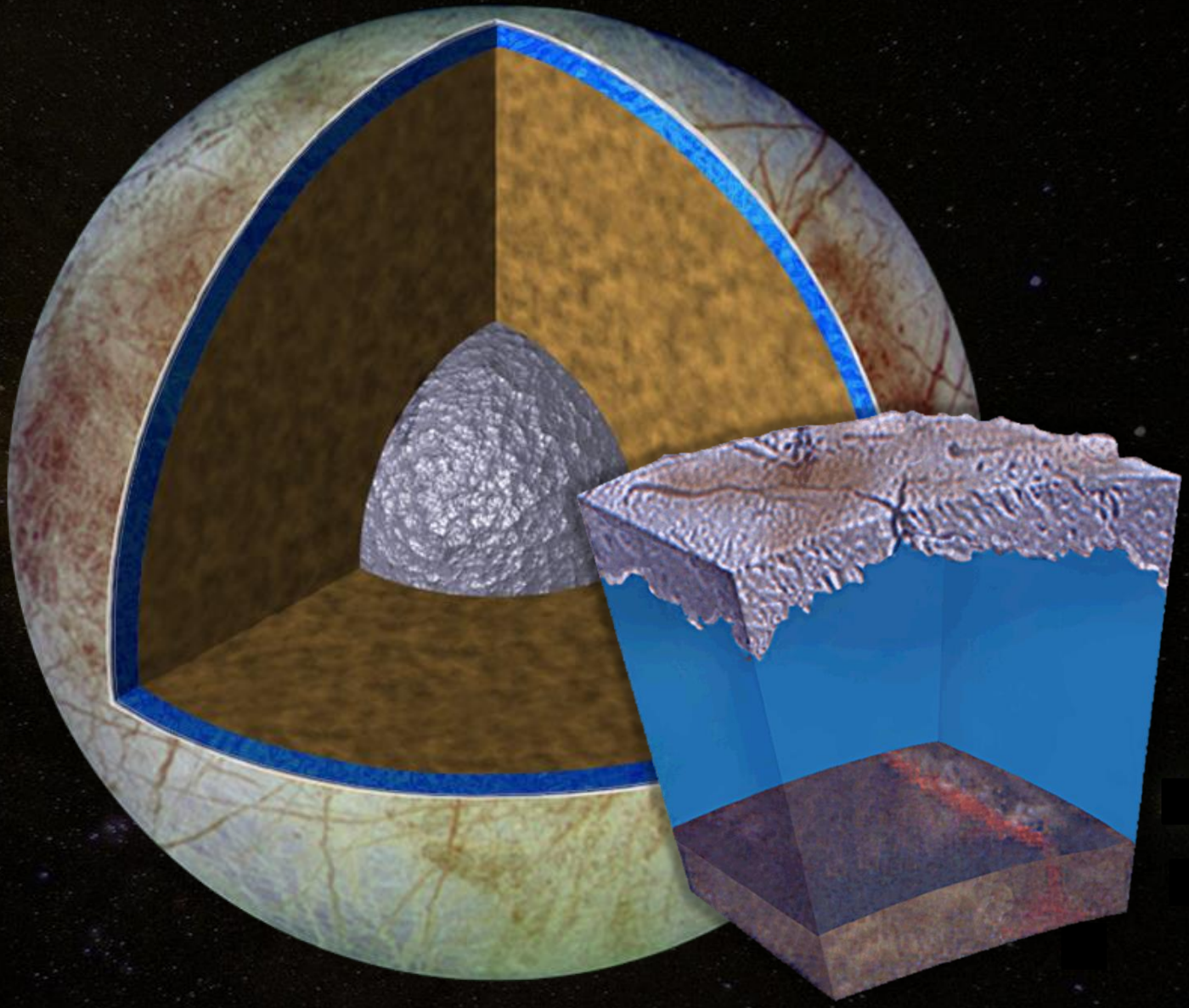
Chaos

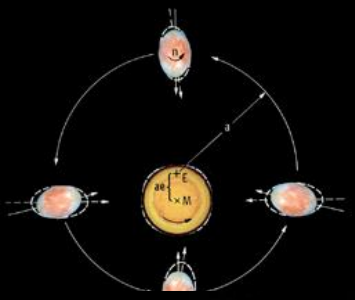
Chaos



After B. Schmidt

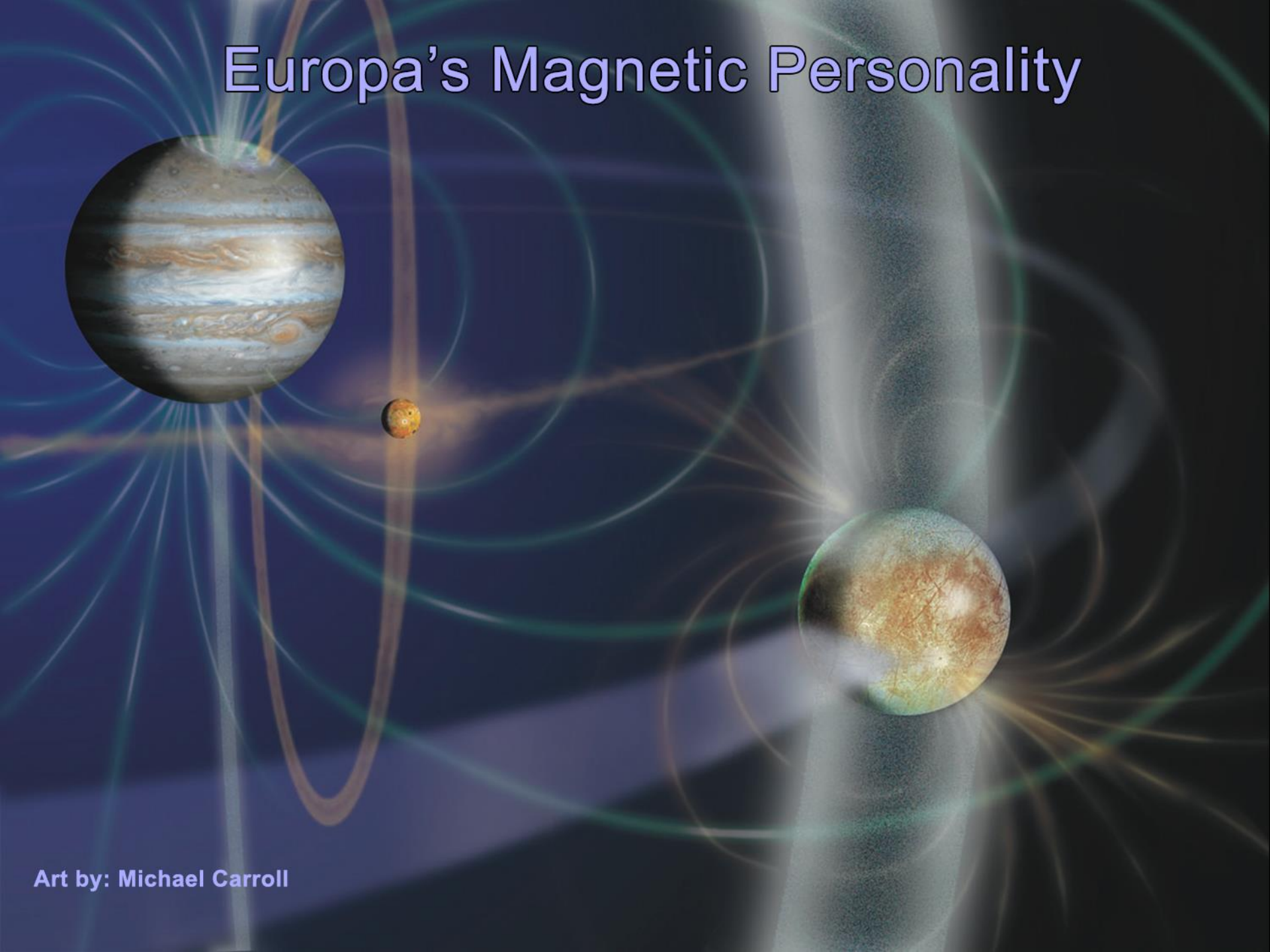
Europa's Interior





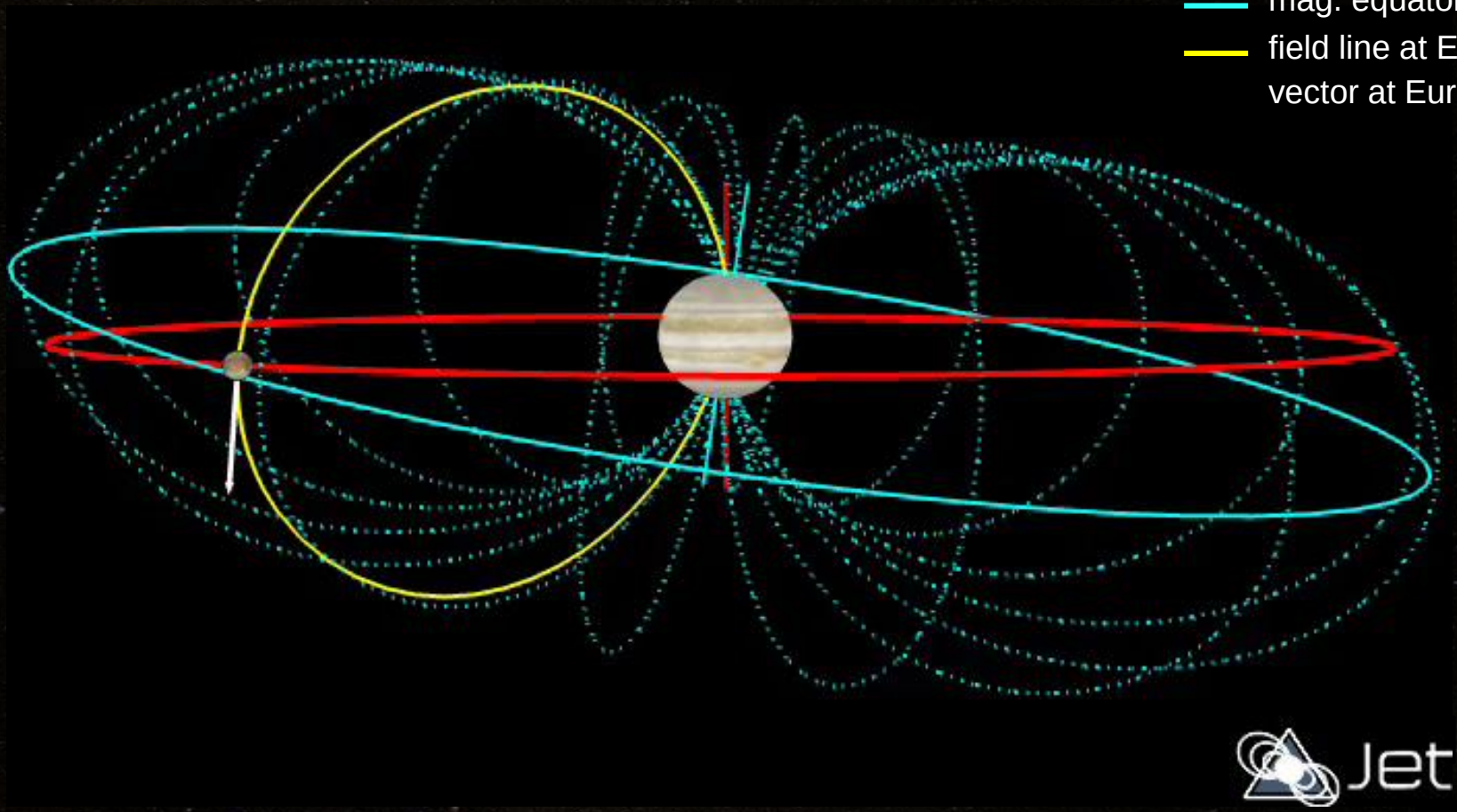
Tidal Flexing → Tidal Heating

Europa's Magnetic Personality



Art by: Michael Carroll

Europa's Induced Magnetic Field

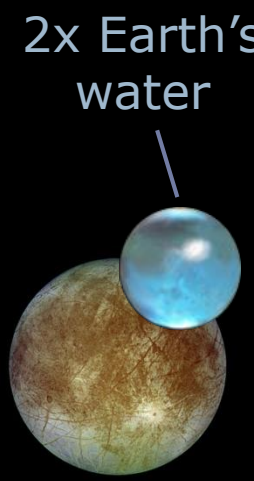


[*animation by E. Sturm using JPL's Jupiter Environment Tool*]

Water World

Earth: Known life

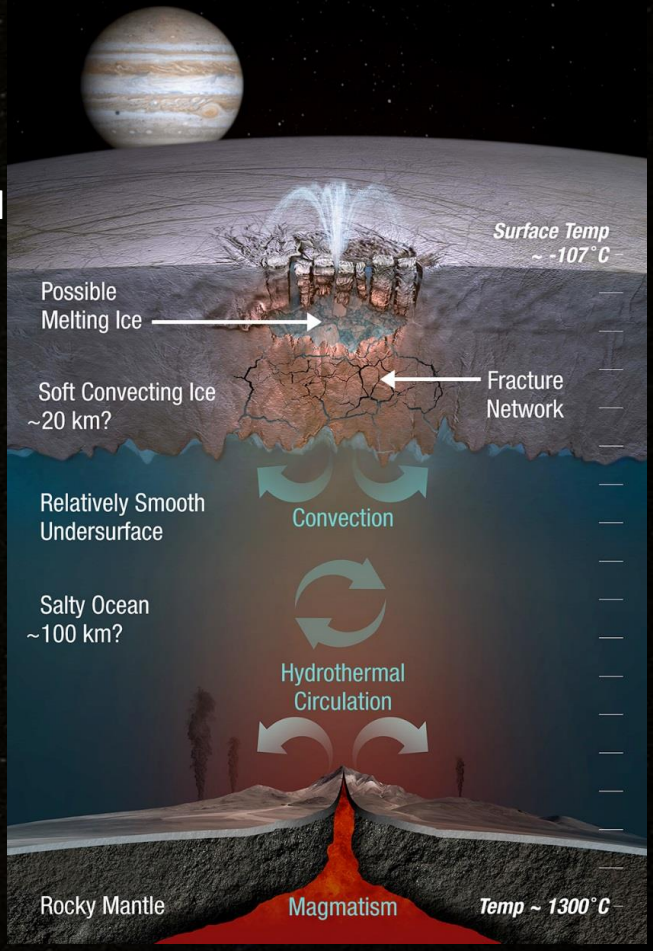
Mars: Past conditions for life



Europa: Present conditions for life?

The Big Question – Is Europa Habitable?

- **Habitability** – measure of the potential of an environment to have environments hospitable to life. (Note: Habitable environments do not necessarily harbor life.)
- From this question come the key Habitability hypotheses:
  - Water: • Probable saltwater ocean, implied by surface geology and magnetic field • Possible lakes w/in 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 rock-water reactions could create reductants
- Therefore, the Europa mission concept is designed to answer these questions:
  - How deep and salty is the ocean?
  - How thick is the ice shell?
  - How active is the ice shell?
  - Are there plumes, and if so, what is in the plumes?
  - What is in the red/brown surface features?



Forming and Proving Hypotheses - Definitions

There are two primary modes of reasoning: deduction and induction.

Deduction: teasing out implications of information already available to us.

- Examples: Crossword puzzles, Sudoku puzzles
- Example: "If B is between A and C, and A is greater than C, then B must be greater than C."

Induction: Going beyond the information contained in what we already know, potentially extending our knowledge into new areas.

- We induce using generalizations and analogies, which come through research and experience.

Generalizations: observing regularities in nature, imagining they are uniform everywhere

- In part, how we describe the so-called "laws of nature."
- Generalizations also create classes of things, such as "mammals" or "noble gases."
- We also generalize to define aspects of human behavior, including psychological tendencies and economic trends.

Analogies: claiming similarities between two things, extending this to make new knowledge.

- Example: if one finds a fossilized skull of an extinct animal that has sharp teeth, one might wonder what it ate. One looks for animals alive today that have sharp teeth and notice they are carnivores.
- Reasoning by analogy, one concludes that the animal was also a carnivore.

From analogies, we can get…

Hypothesis: either a suggested explanation for an observable phenomenon, or a reasoned prediction of a possible causal correlation among multiple phenomena.

Theory: a tested, well-substantiated, unifying explanation for a set of verified, proven facts.

Forming and Proving Hypotheses: Handling Uncertainty

Using induction and inferring the best possible explanation consistent with the evidence, science teaches us more about the world than we could simply deduce.

Most of our hypotheses/theories are inductive analogies.

- The Europa Clipper hypotheses are based on our experience of wide-ranging systems on Earth.

If inputs to a particular hypothesis produce outputs that match those of the real world, then it is a good analogy, and eventually a good theory. If it doesn't match, then one must reject it, or refine or redesign the theory to make it better (more analogous).

If one gets many results of the same kind over time, one might generalize to a conclusion. But no amount of success can completely prove a theory right. Each confirming instance only increases our confidence in the idea.

- "No amount of experimentation can ever prove me right; a single experiment can [deductively] prove me wrong." – Albert Einstein

Einstein's General and Special theories of Relativity (models and therefore analogies of how the universe works) have been supported by experimental evidence many times under many conditions.

We have great confidence in these theories as excellent descriptions of reality. But they cannot be proved correct, because proof belongs only to deduction.

‘Settled’ does not mean Proved

So, while Einstein’s theories are “settled” (believed), they are not proved.

- But to plan for them not to work would be silly.
- In fact, these theories are available as a resource for further work (for example, interplanetary navigation).

We perform much of our work in a inductive manner; deductive certainty is not necessary, nor achievable.

- It’s prohibitively complicated to achieve deductive certainty, especially in solar system exploration.
- Many processes are in play, connected in various manners.
- Even when some theories may be settled, the details remain a source of lively debate.

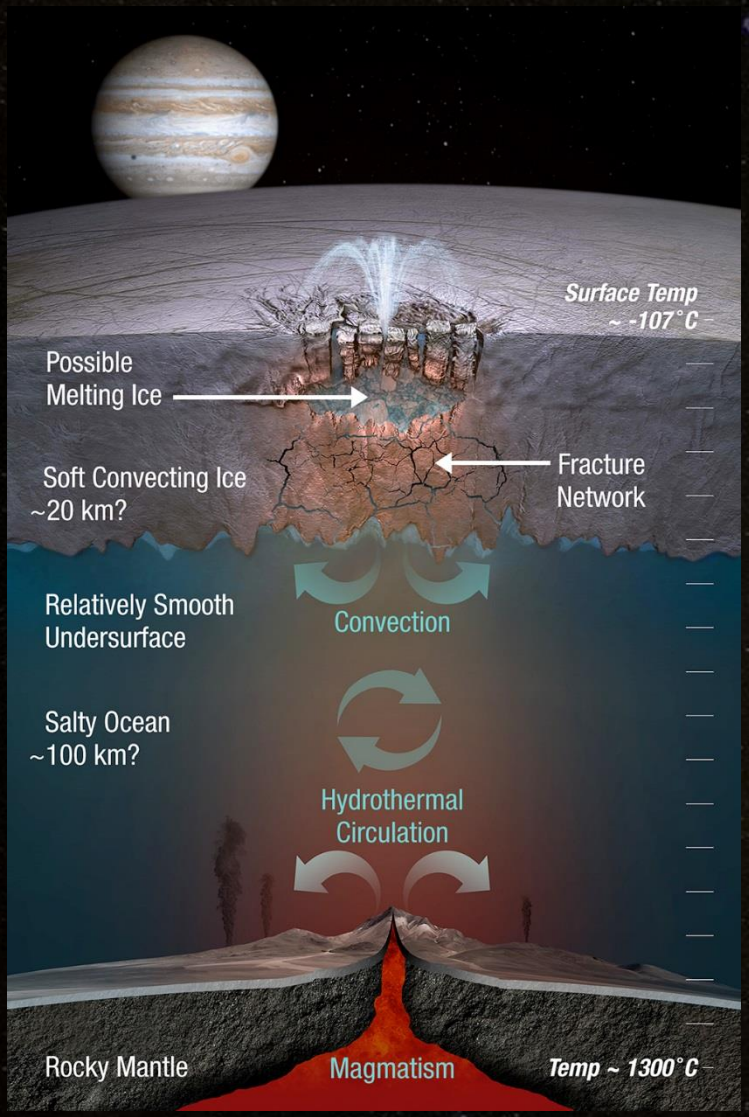
The Europa Clipper mission, and the hypotheses it will address, will set the stage for further exploration:

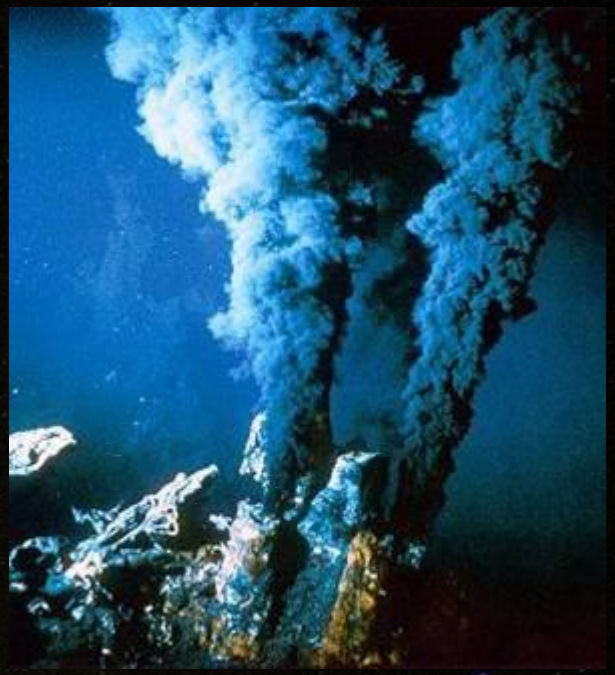
- Direct sampling of the surface and/or plumes
- Future landers or sample return missions

Our exploration path, based on inductive reasoning, is the only reasonable path forward; the science community has full confidence in it.

Learn to discern what needs to be proven from what needs to be ‘more settled,’ and support constructive investigations to further settle or disprove the unproven.

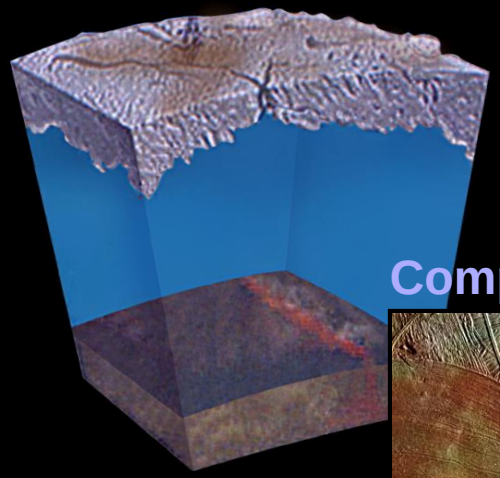
Habitability: Ingredients for Life





Europa Mission Science

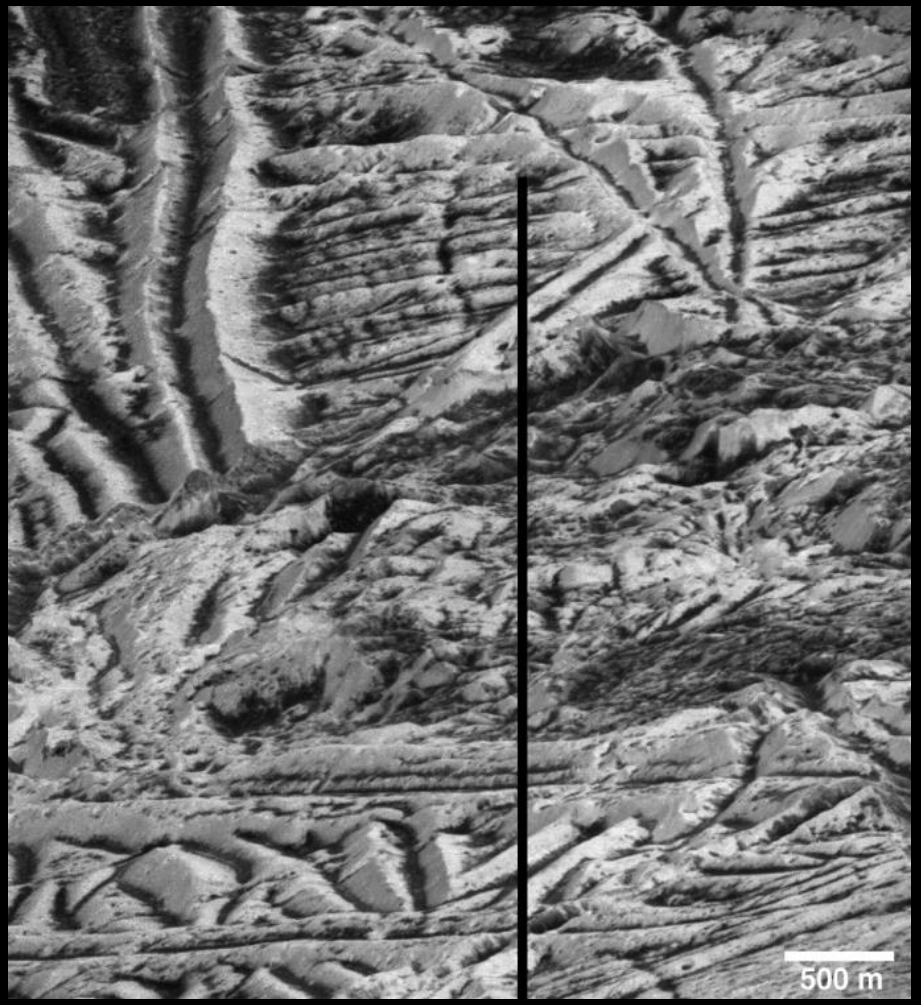
Ocean & Ice Shell



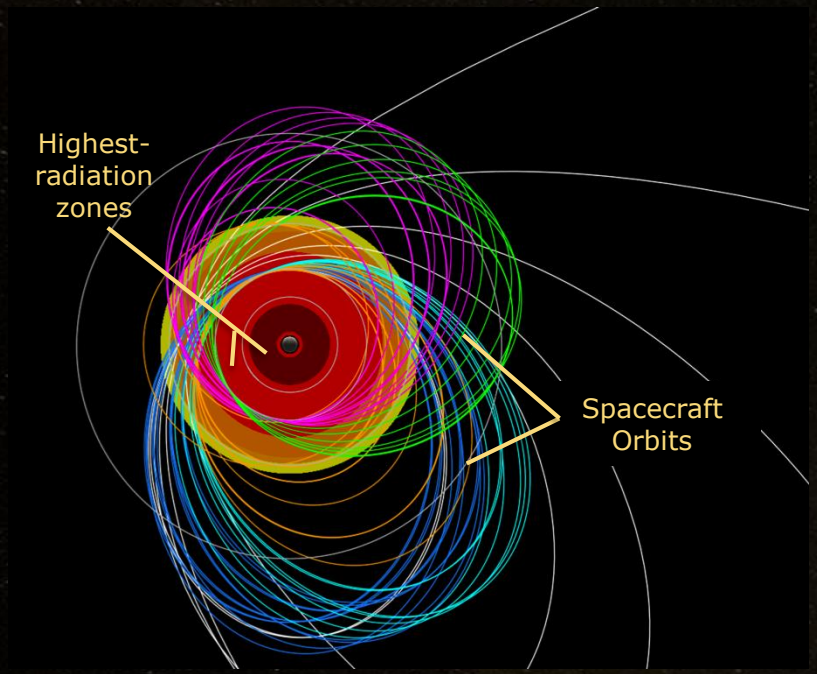
Composition

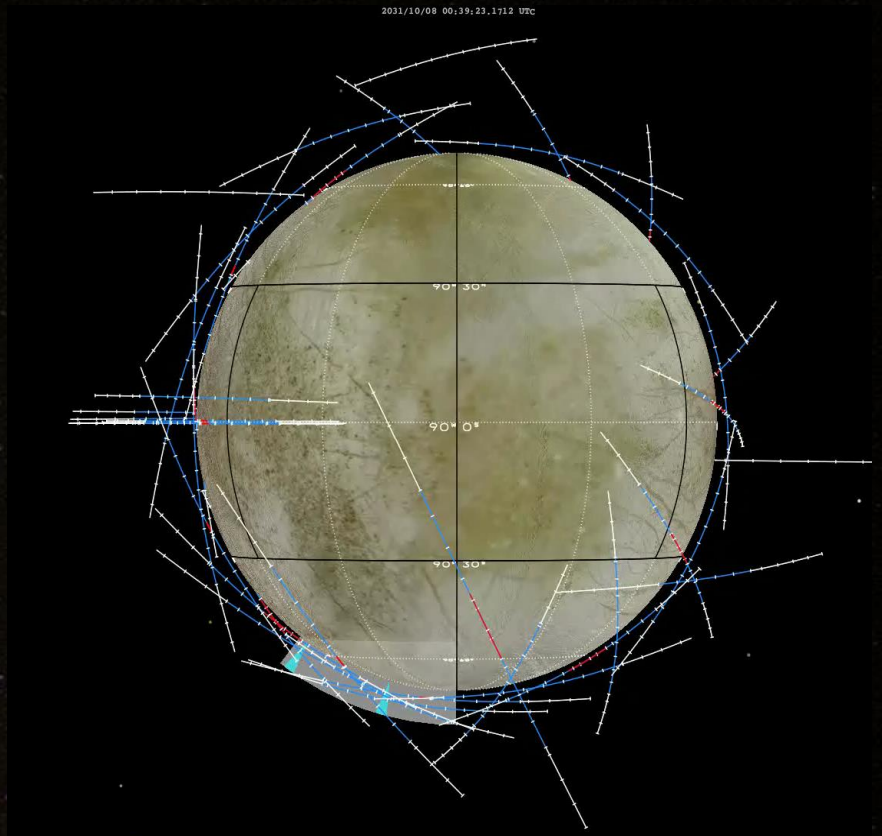
Geology

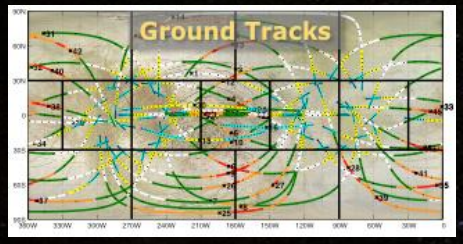
Reconnaissance

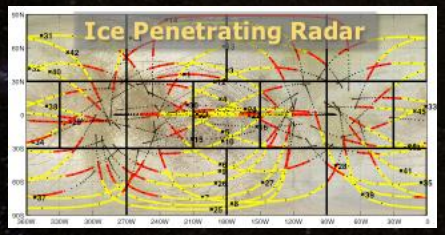


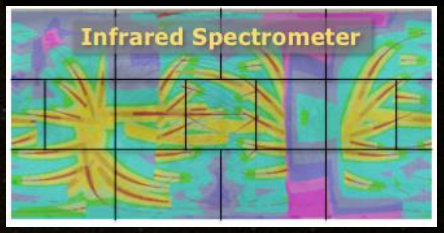
Jupiter Tour Mission Concept

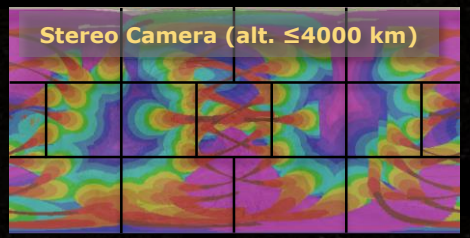




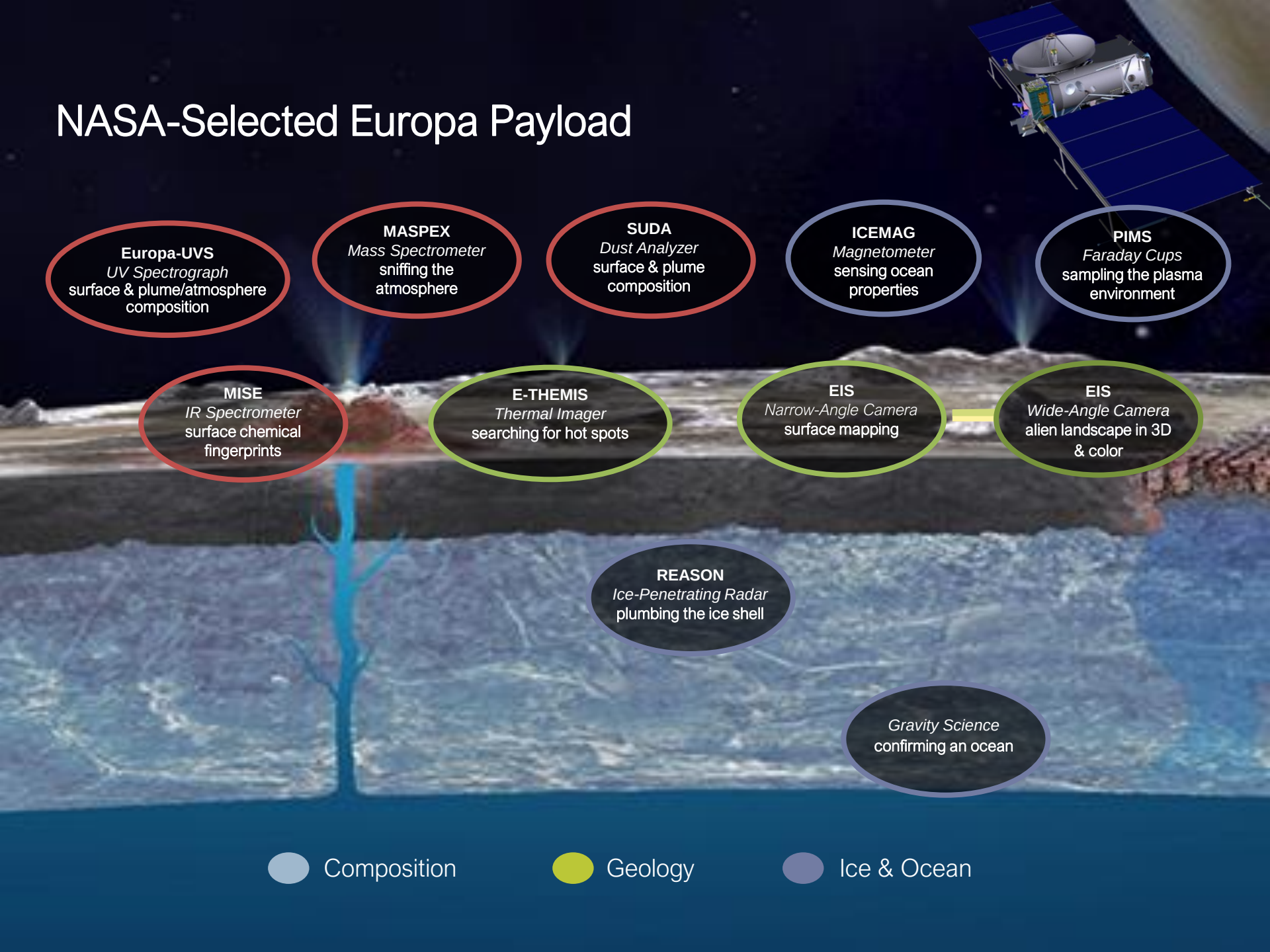




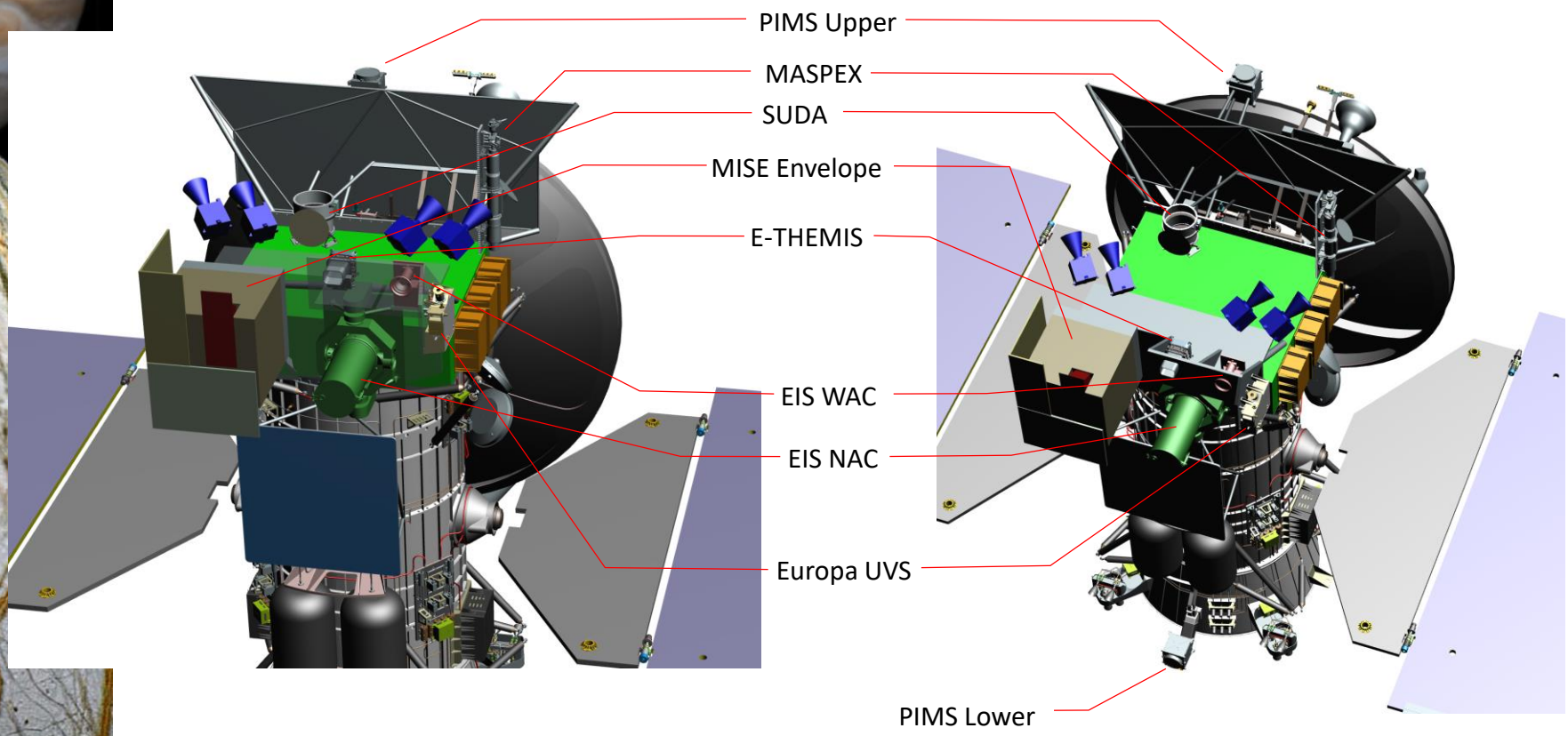




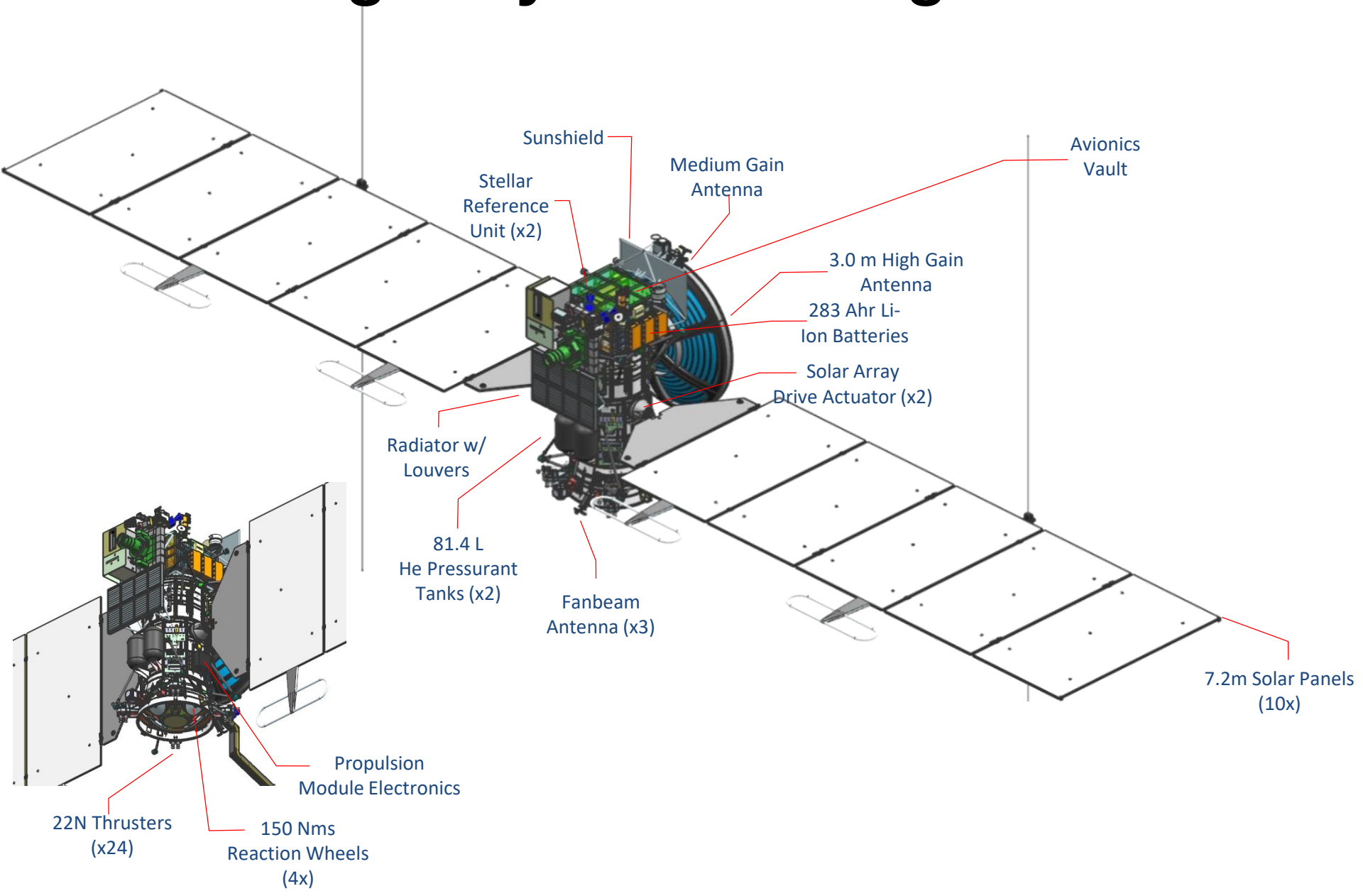
NASA-Selected Europa Payload



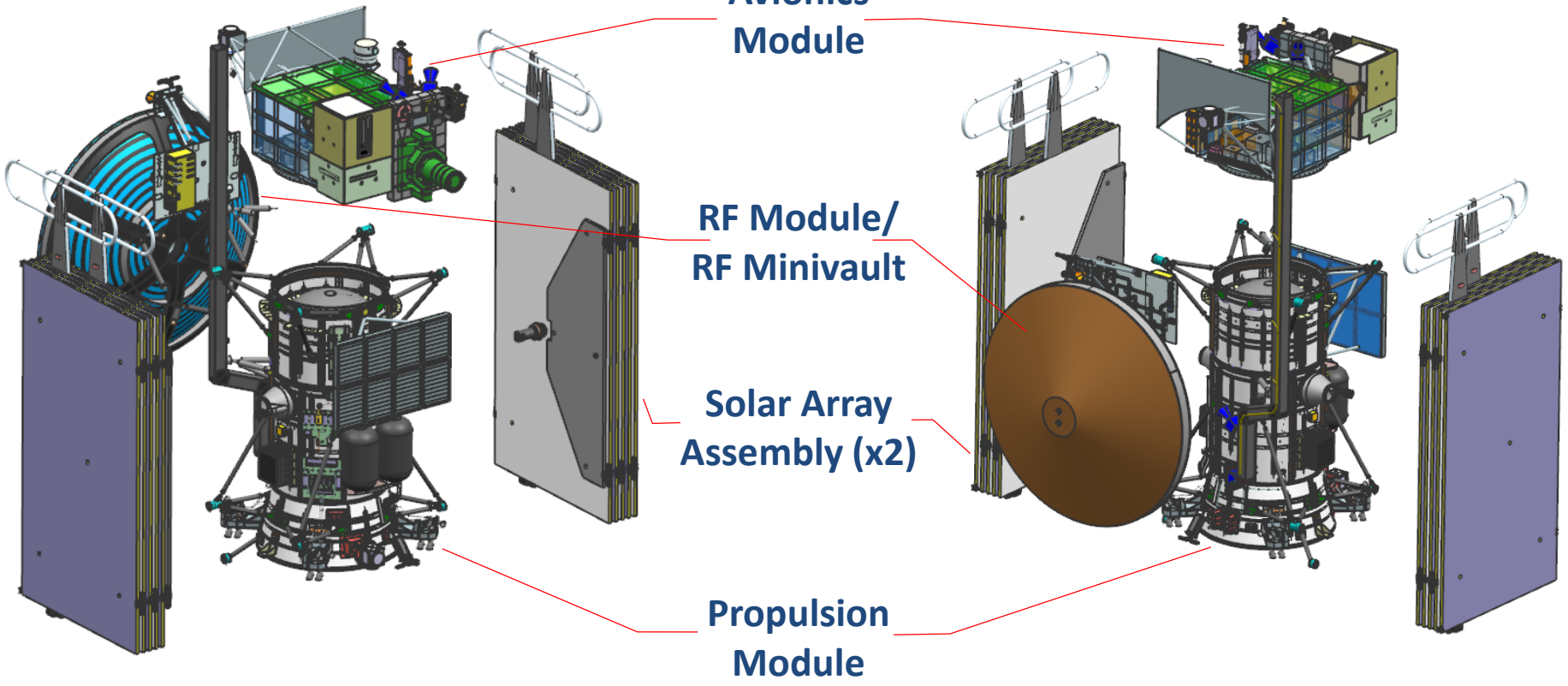
Instrument Details



Flight System Configuration

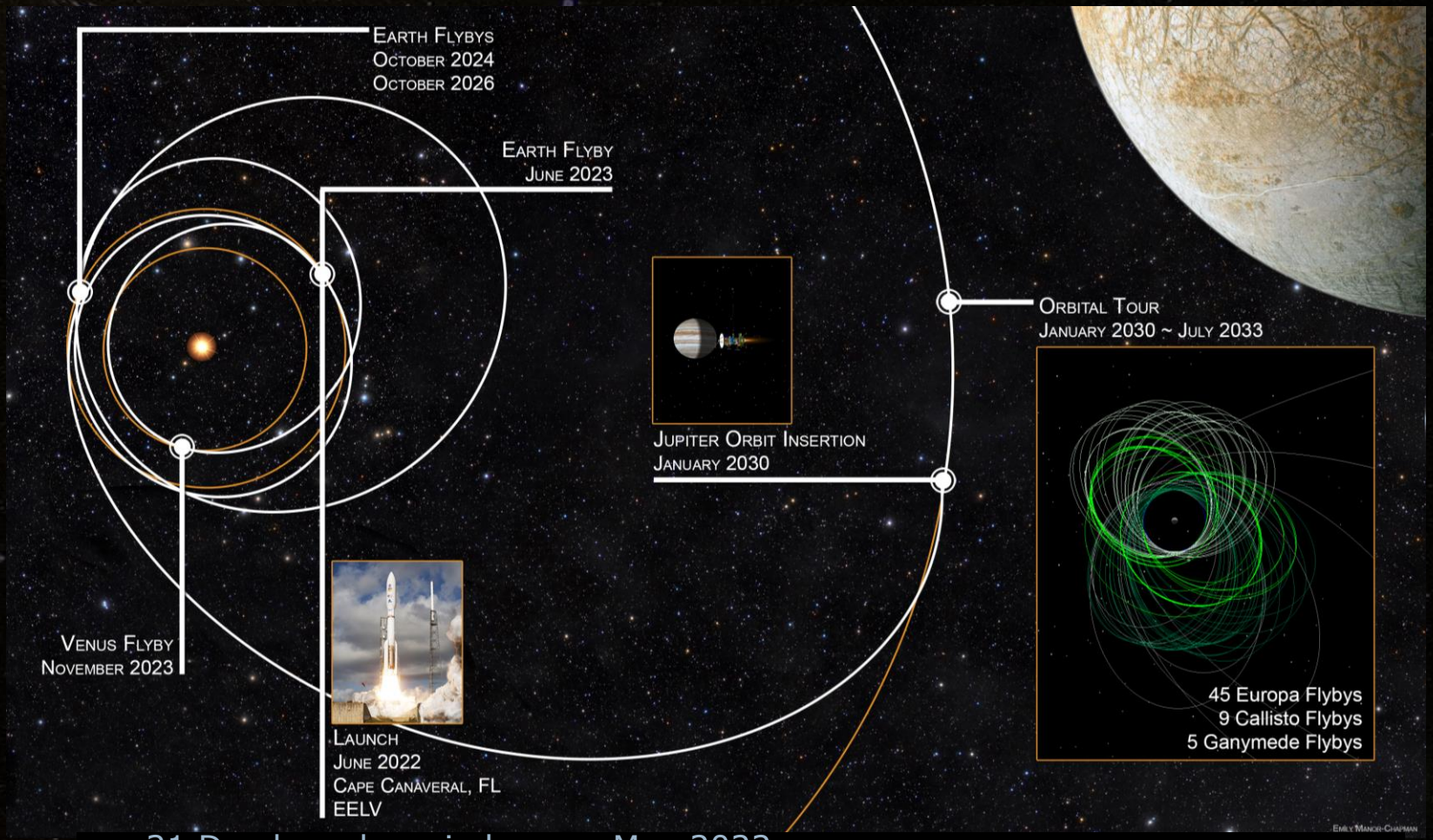


Flight System View by Module



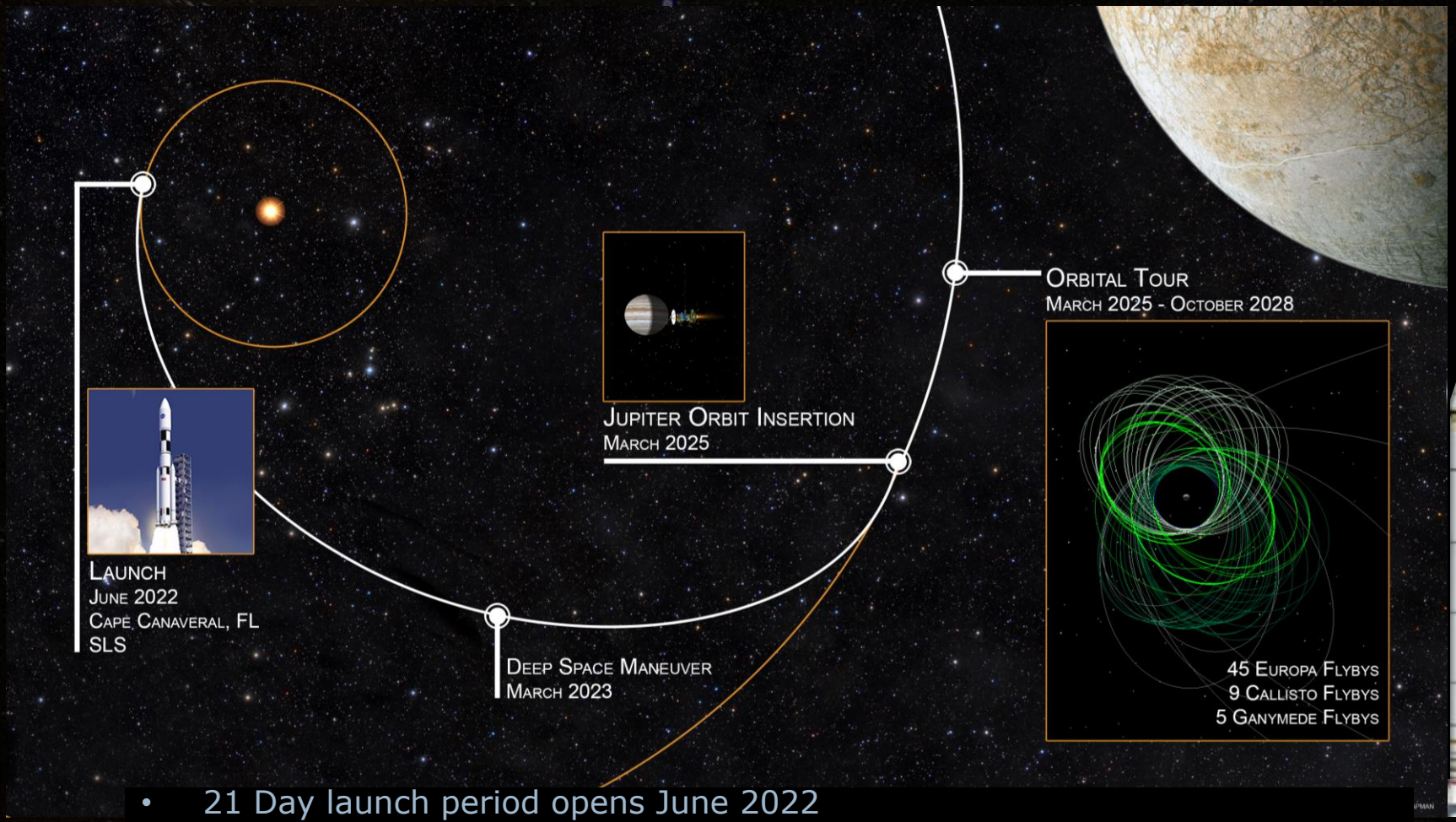
EVEEGA Interplanetary Trajectory

EELV – (ATLAS/Delta-IV/Falcon)



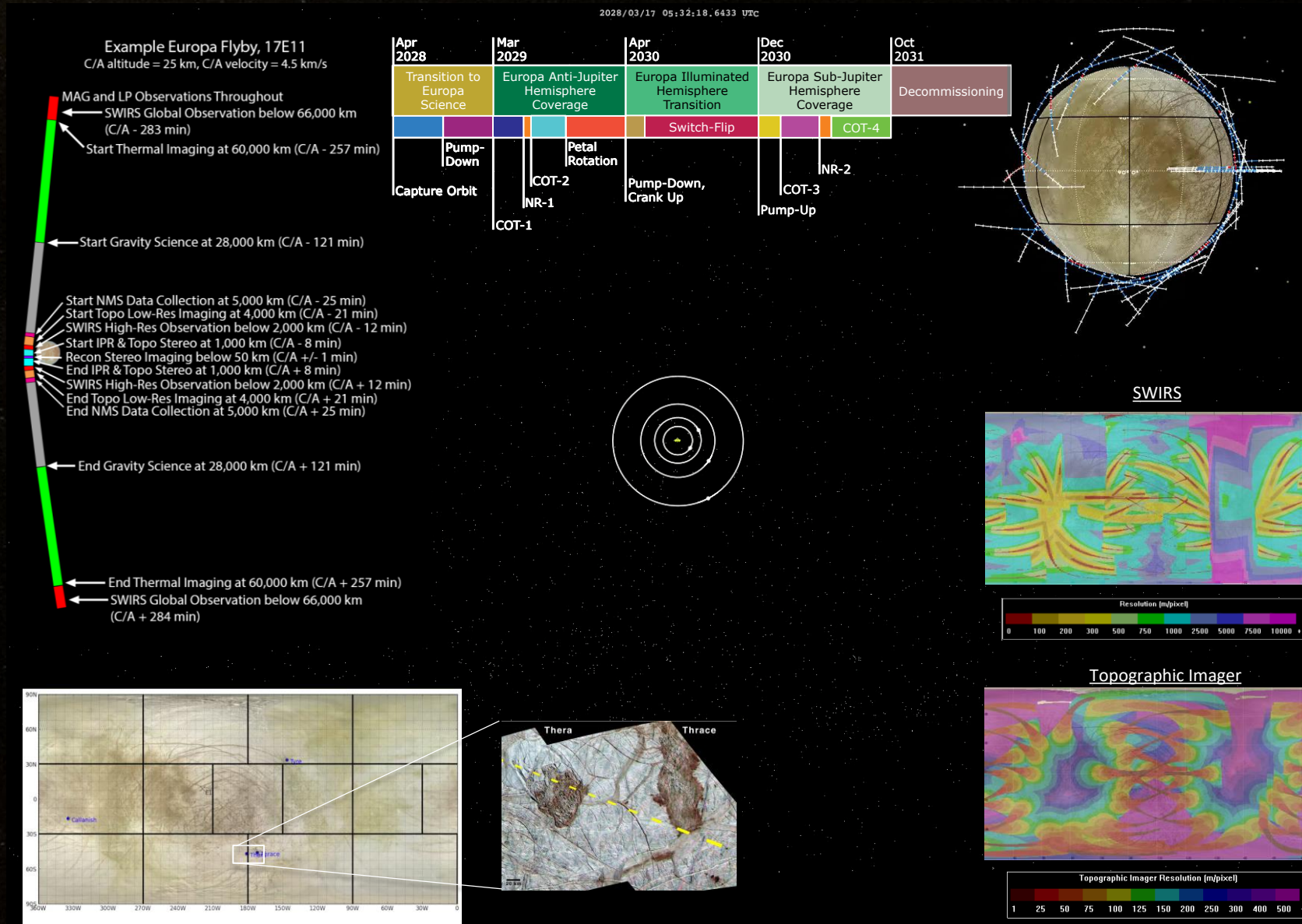
- 21 Day launch period opens May 2022
- Earth/Venus/Earth/Earth Gravity Assist
- Arrive Jovian System January, 2030 (7.5 Years)

Direct-to-Jupiter Trajectory & Jovian Tour
SLS Launch Option



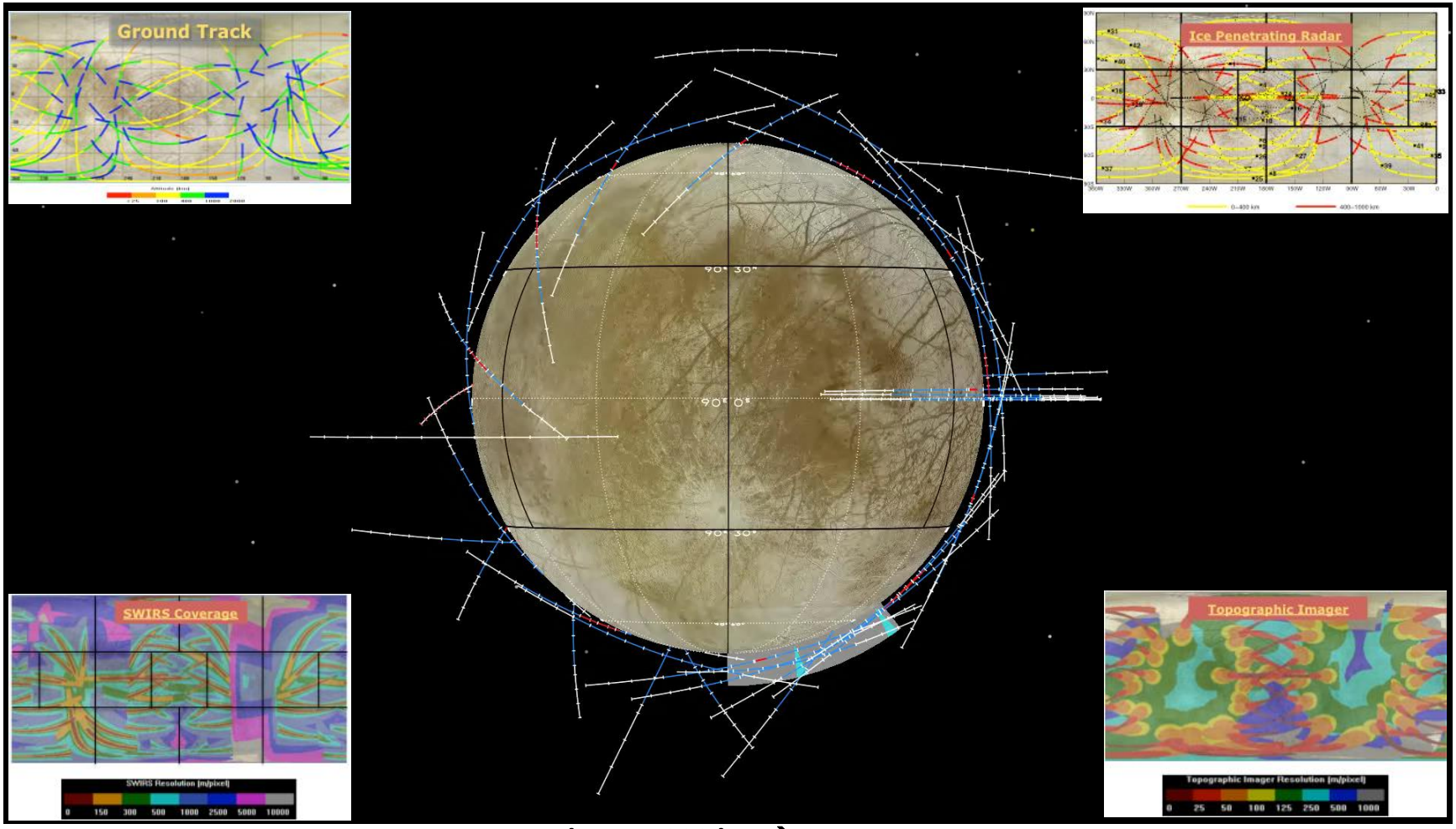
- 21 Day launch period opens June 2022
- Arrive Jovian System March, 2025 (2.7 Years)
- Tour after Jupiter orbit insertion is the same for both vehicles
- The project will maintain dual launch capability through CDR

Jovian Tour Concept



Present Coverage in Potential Plume Region

13F7-A21 Trajectory

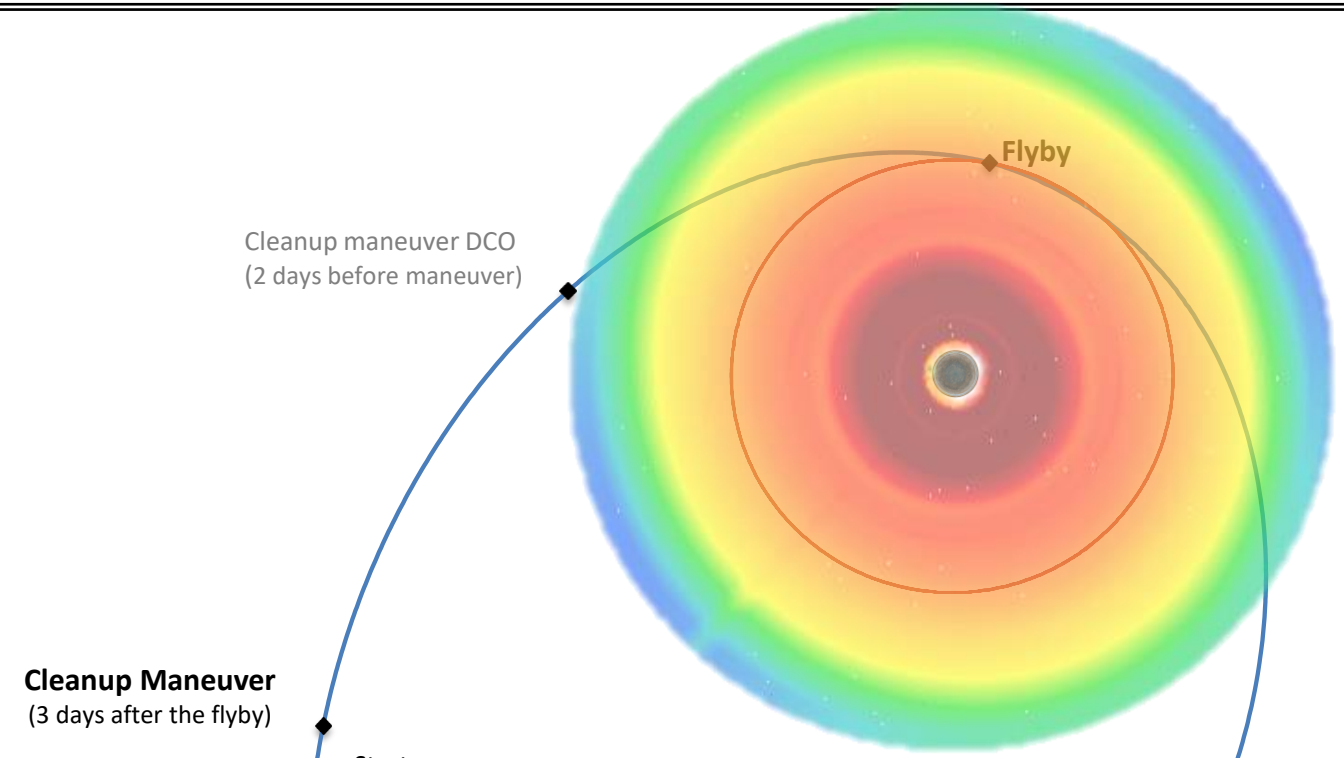


- **Above 1,000 km → 2**
- 250 km to 750 km → 6
- 80 **km to 100 km → 9**
- 50 km → 18
- **25 km → 10**

Spacecraft Trajectory

- 25 km ≤ r_{alt} ≤ 50 km
- 50 km < r_{alt} ≤ 400 km
- 400 km < r_{alt} ≤ 1000 km
- 1000 km < r_{alt} ≤ 4000 km

Europa Pedal- Jovian Orbit



Dose Rate* (rad/sec)

3.5000

0.3500

0.0350

0.0035

Cleanup maneuver DCO
(2 days before maneuver)

Cleanup Maneuver
(3 days after the flyby)

Start

Backup Approach Maneuver
(2 days before the flyby)

Targeting Maneuver DCO
(2 days before the maneuver)

Approach Maneuver
(3 days before the flyby)

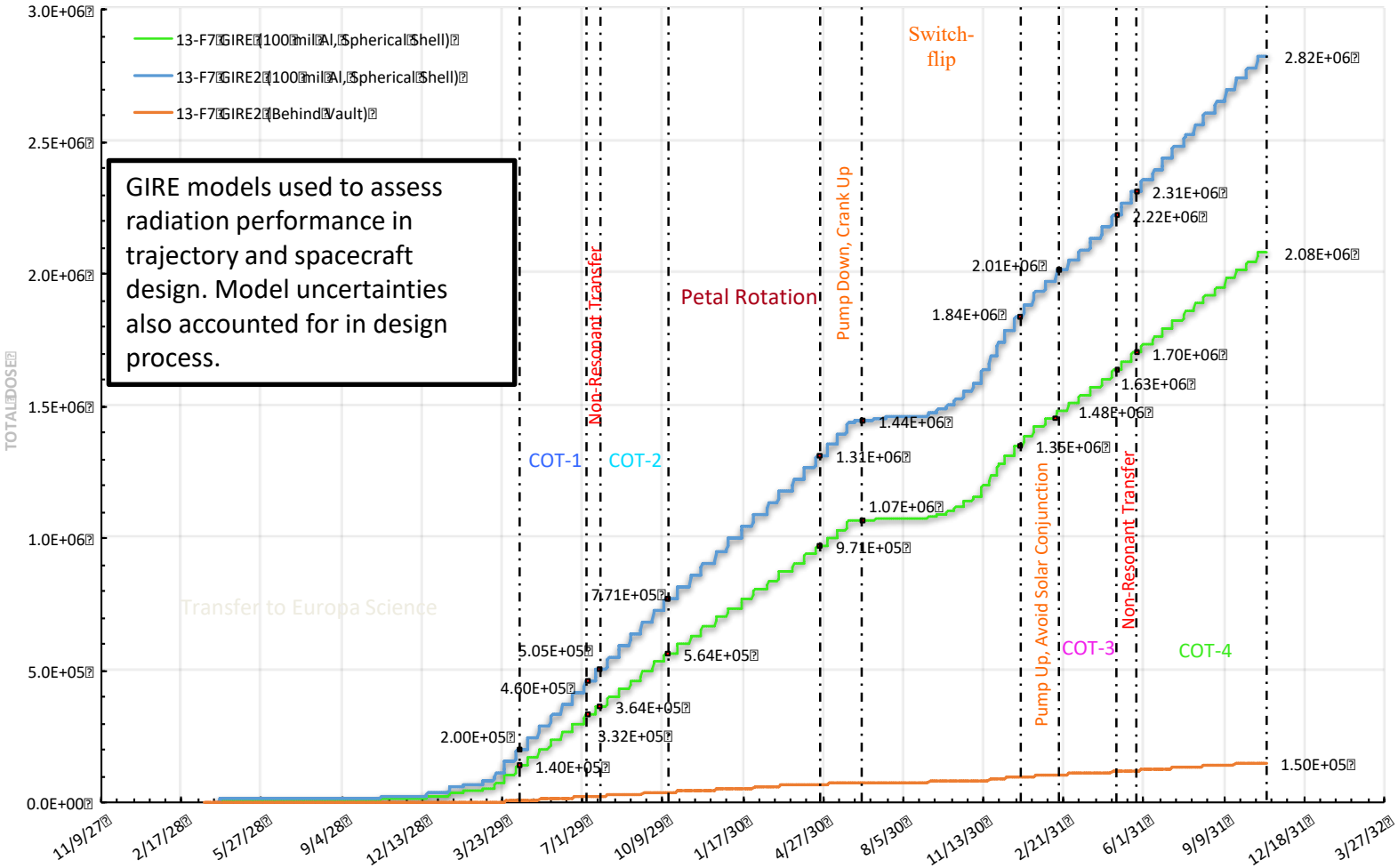
Targeting Maneuver
(near apoapsis)

Approach Maneuver DCO
(2 days before maneuver)

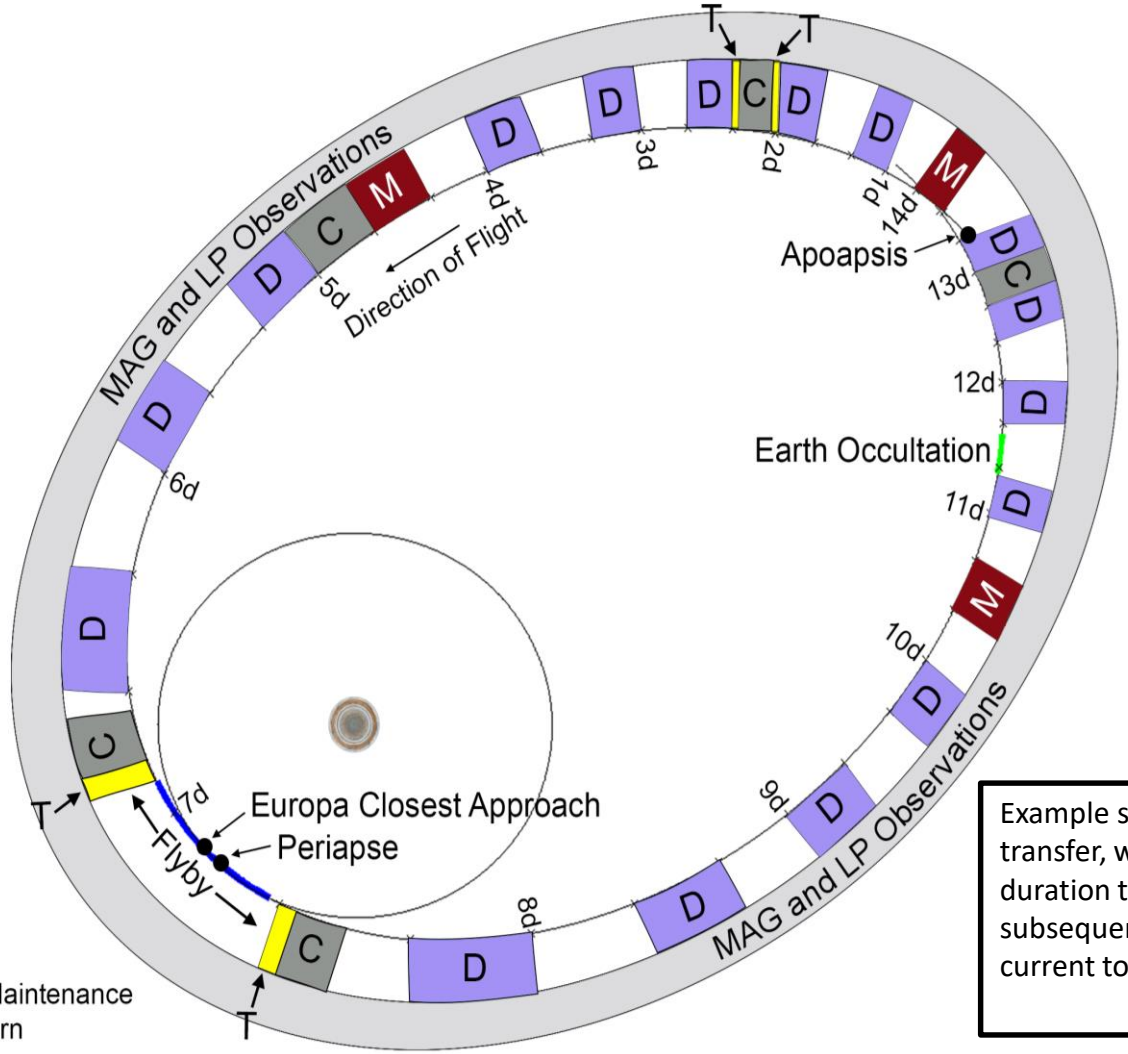
Key:
DCO: Data Cutoff

*Si behind 100 mil Al, spherical shell (GIRE2)

Radiation Modeling: GIRE (Galileo Interim Radiation Electron Model)



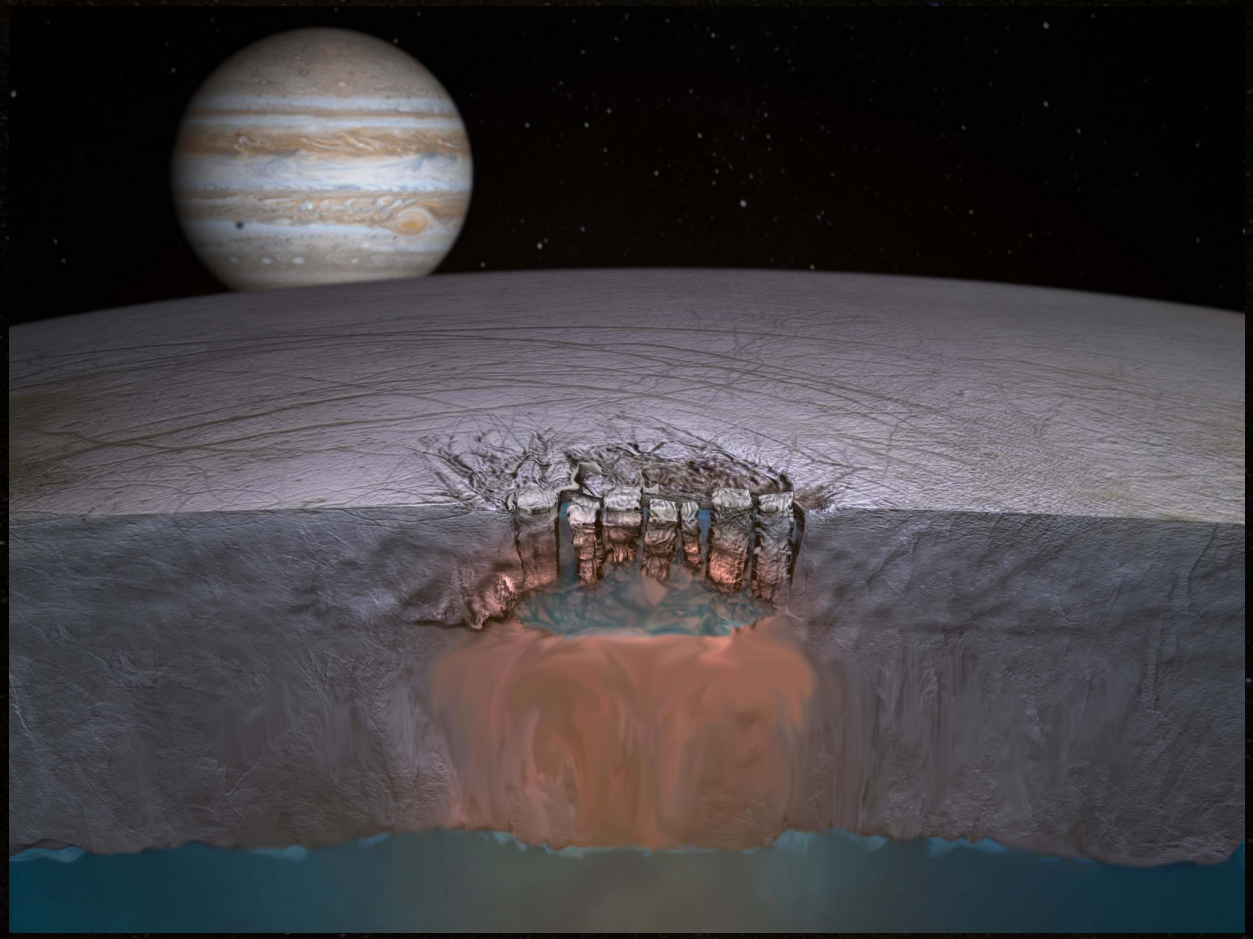
“Orbit-in-the-Life” of Europa Mission



KEY
x = 8 hour ticks
D = DSN Track
M = Manuver
C = Calibration/ Maintenance
T = Spacecraft Turn

Example shown for a 14-day transfer, which is the shortest duration transfer between subsequent Europa flybys for the current tour (13F7).

Plumes?



Summary

- Planned Europa Clipper mission verifies key habitability hypotheses
  - Water
  - Chemistry
  - Energy

- Mission concept includes studies of
  - Ocean and Ice Shell
  - Composition
  - Geology
  - Reconnaissance
- Flyby Mission architecture provides
  - Robustness against harsh environment
  - Comprehensive coverage
  - High data return
- Many science and engineering challenges remain!
- Rich fields for further innovations…
- See **http://www.jpl.nasa.gov/missions/europa-mission** for more details