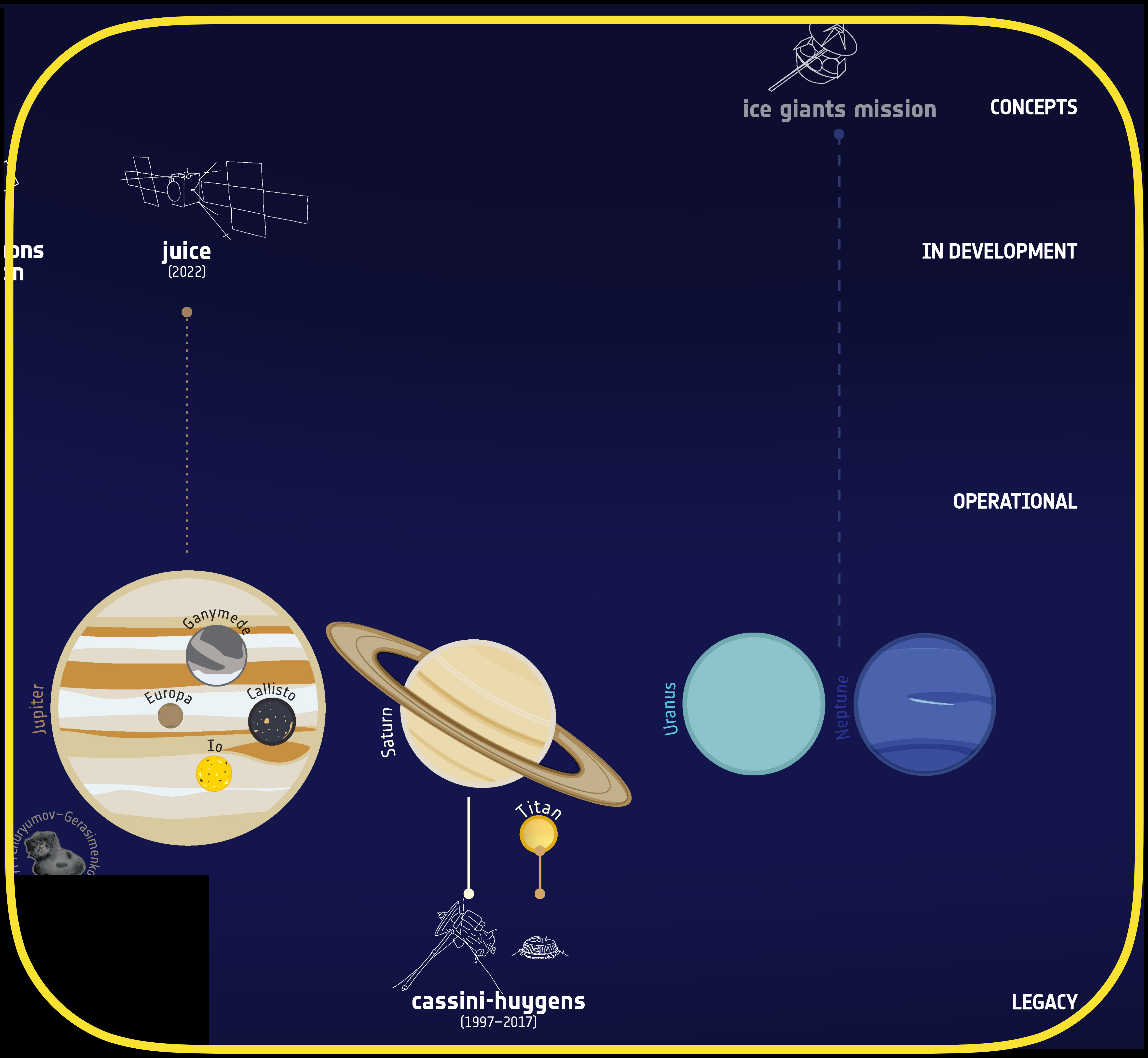
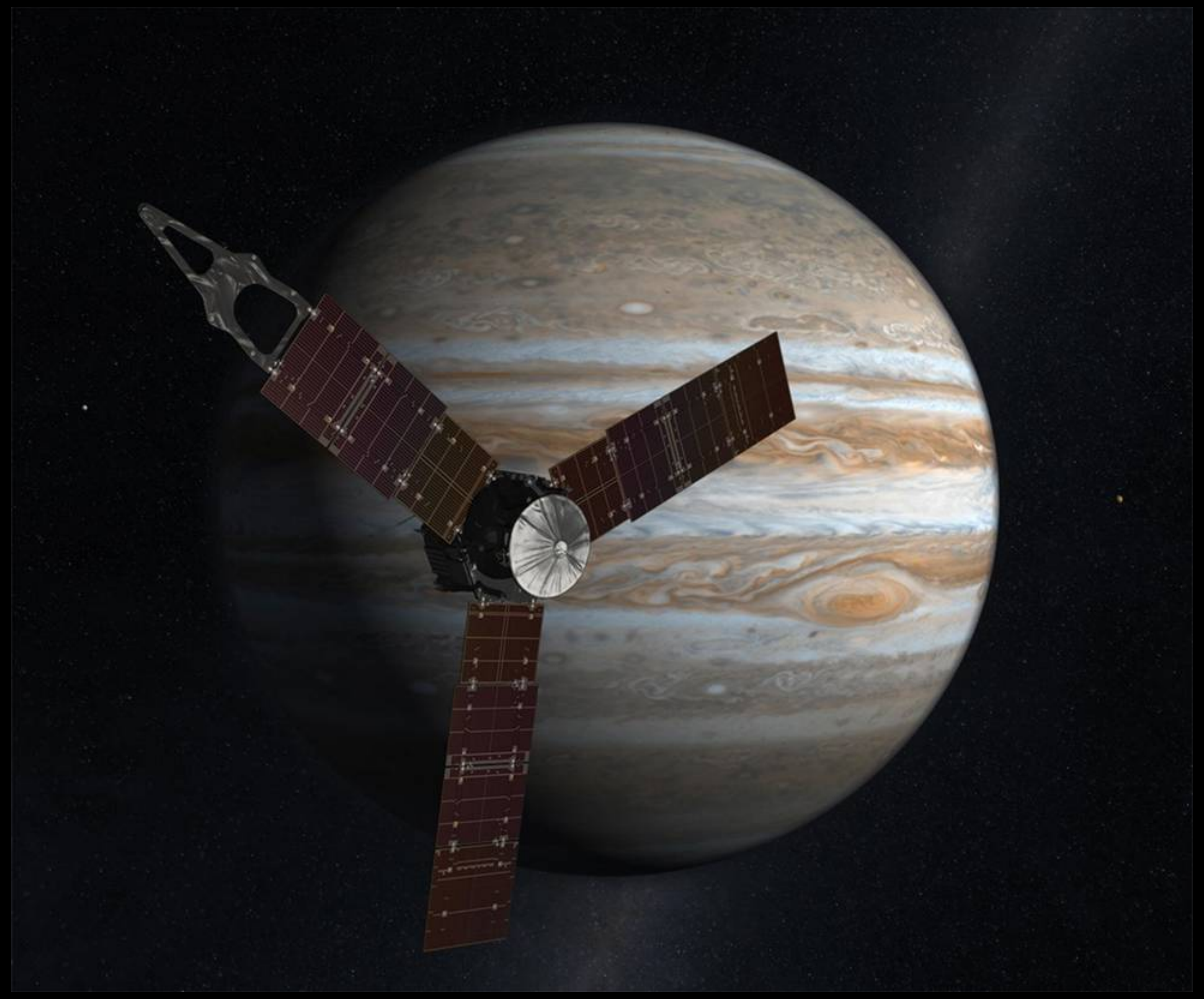
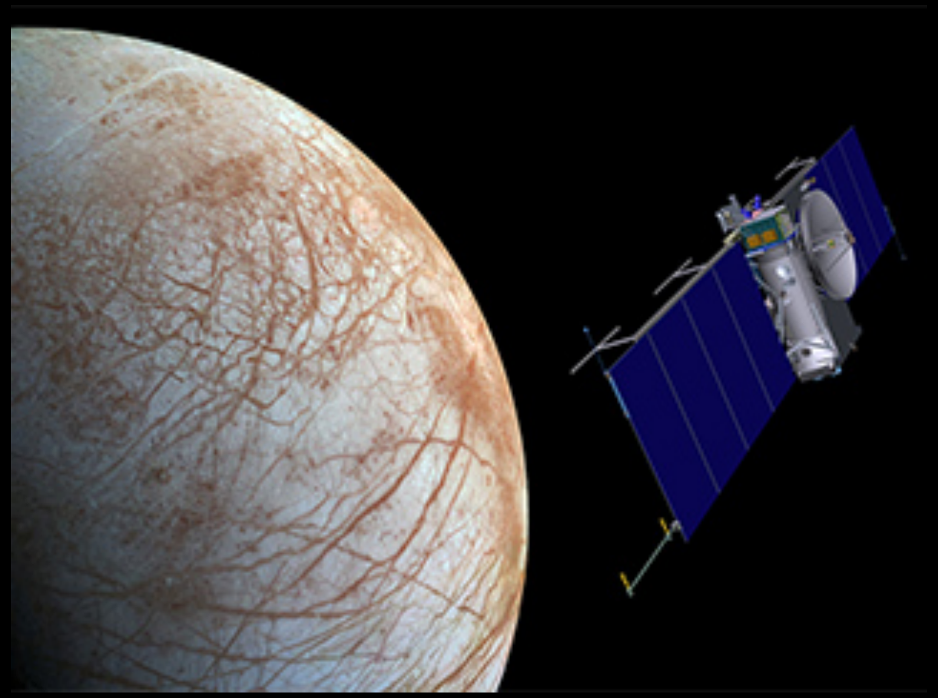
The Sun, planets, magnetosphere and plasma physics:
Outer Solar System

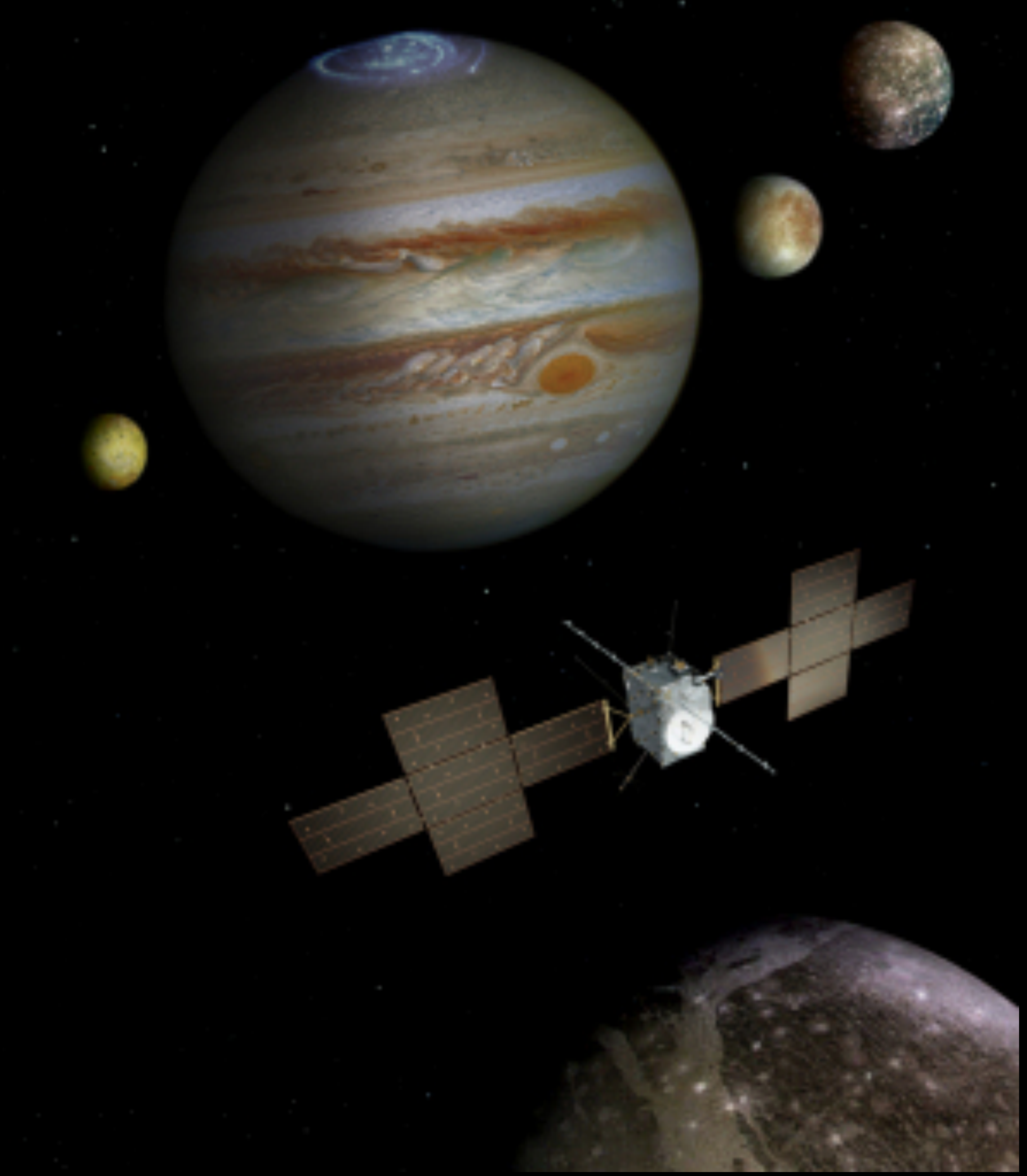
Chauffray	UV exploration of the solar system	UV telescope from Earth orbit
Roussos	The in-situ exploration of Jupiter's radiation belts	Jupiter system
Blanc	Joint Europa Mission (JEM) A multiscale, multi-platform mission to characterize Europa's habitability and search for extant life	Jupiter system
Prieto-Ballesteros	Searching for (bio)chemical complexity in icy satellites, with a focus on Europa	Jupiter system
Thomas	A Comprehensive Investigation of the Galilean Moon, Io, by Tracing	Jupiter system
Mitri	Exploration of Enceladus and Titan: Investigating ocean worlds' evolution and habitability in the Saturn System	Saturn system
Rodriguez	Science goals and mission concepts for a future orbital and in situ exploration of Titan	Saturn system
Choblet	Enceladus as a potential oasis for life: Science goals and investigations for future explorations	Saturn system
Sulaiman	Enceladus and Titan: Emerging Worlds of the Solar System	Saturn system
Mousis	In Situ Exploration of the Giant Planets	Saturn, Uranus and Neptune
Fletcher	The scientific potential of missions to the Uranus and Neptune systems	Uranus and Neptune
Guillot	Uranus and Neptune are key to understand planets with hydrogen atmospheres	Uranus and Neptune



The Jovian system







JUNO
2016-2021

- Characterise **Jupiter's atmosphere**
- Look deep into Jupiter's atmosphere !
- Map **Jupiter's magnetic and gravity fields** (planet's deep structure)
- Explore and study **Jupiter's magnetosphere near the planet's poles**, especially the auroras

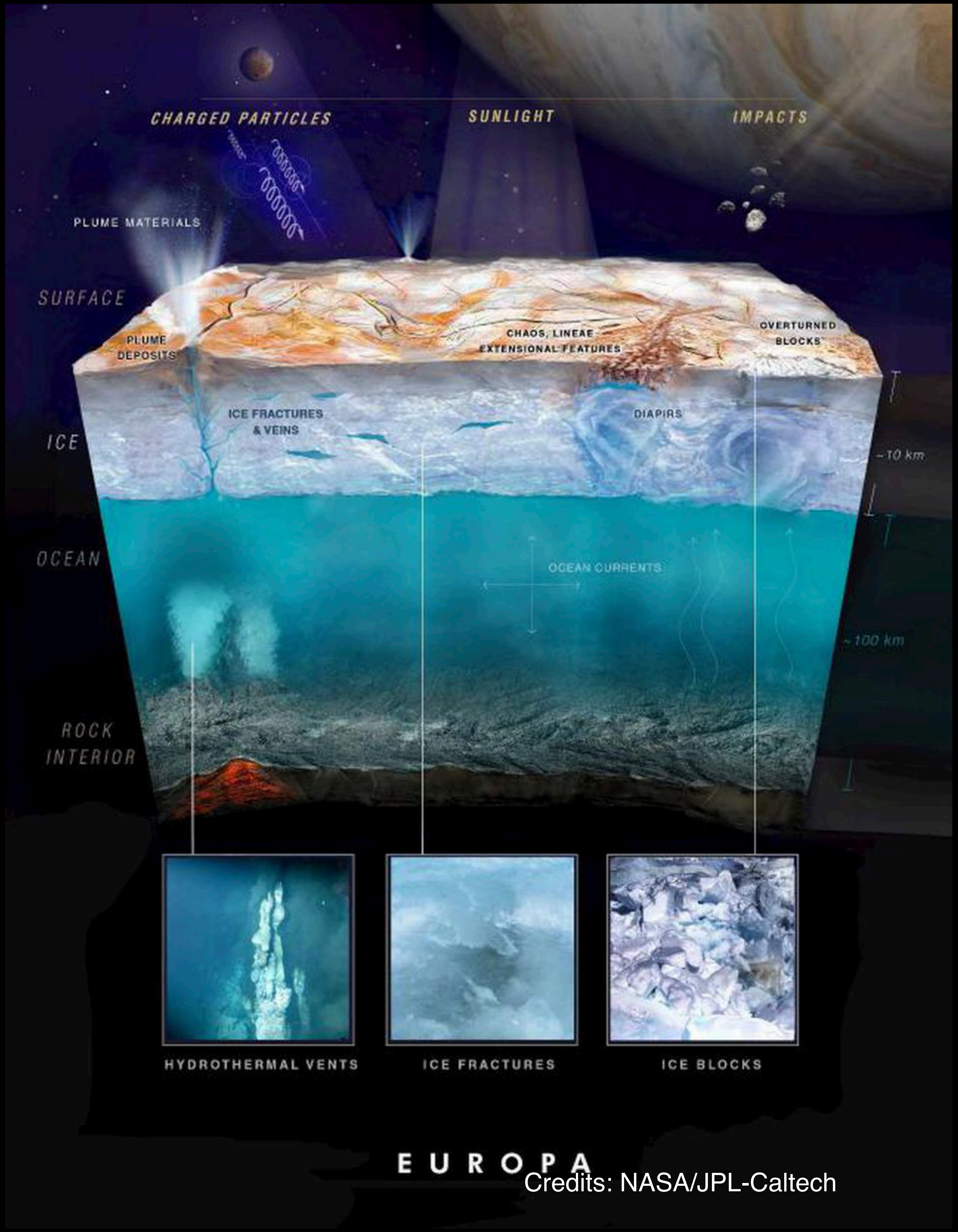
Europa Clipper
Launch 2023 ?

- to explore Europa **to investigate its habitability.**
- **not being sent to find life itself**, but will instead try to answer specific questions about Europa's ocean, ice shell, composition and geology.

JUpiter ICy moons Explorer (JUICE)
2022-2033

- detailed investigations of **Jupiter and its system** in all their inter-relations and complexity
- emphasis on **Ganymede as a planetary body and potential habitat**.
- Investigations of **Europa and Callisto**

The Jovian system in Voyage 2050: the astrobiology roadmap at Europa



Credits: NASA/JPL-Caltech

A mission dedicated to Europa only (Prieto-Ballesteros et al.)**:**
Orbiter: global characterisation+zones of interest

Lander: surface recognition, subsurface sample analysis and deep drilling (Ocean Explorer).

Jumpers: undertake geochemical and geological reconnaissance of the context around the lander at a local scale

Ocean explorer: a submersible module to have access to direct samples.

A mission dedicated to Europa in Jovian system (Blanc et al.):
Orbiter + Lander: an ESA-NASA collaboration

Focus on the AWL (Astrobiology Wet Laboratory): a liquid sample analysis facility to be developed by ESA with sensor provided by its member states.

Focus on the detection of large macromolecular material capable of structural and functional plasticity, **as well as cell-like morphologies** indicative of an extant biosphere (Prieto-Ballesteros et al.)
Understand Europa as a complex system responding to Jupiter system forcing (Blanc et al.)

The Jovian system in Voyage 2050: unknown territories - Io

A mission dedicated to Io (Thomas et al.):

- **Follow the energy**

Energy sources in the deep interior
Heat losses
Electrodynamics interactions in Io's environment

- **Follow the mass**

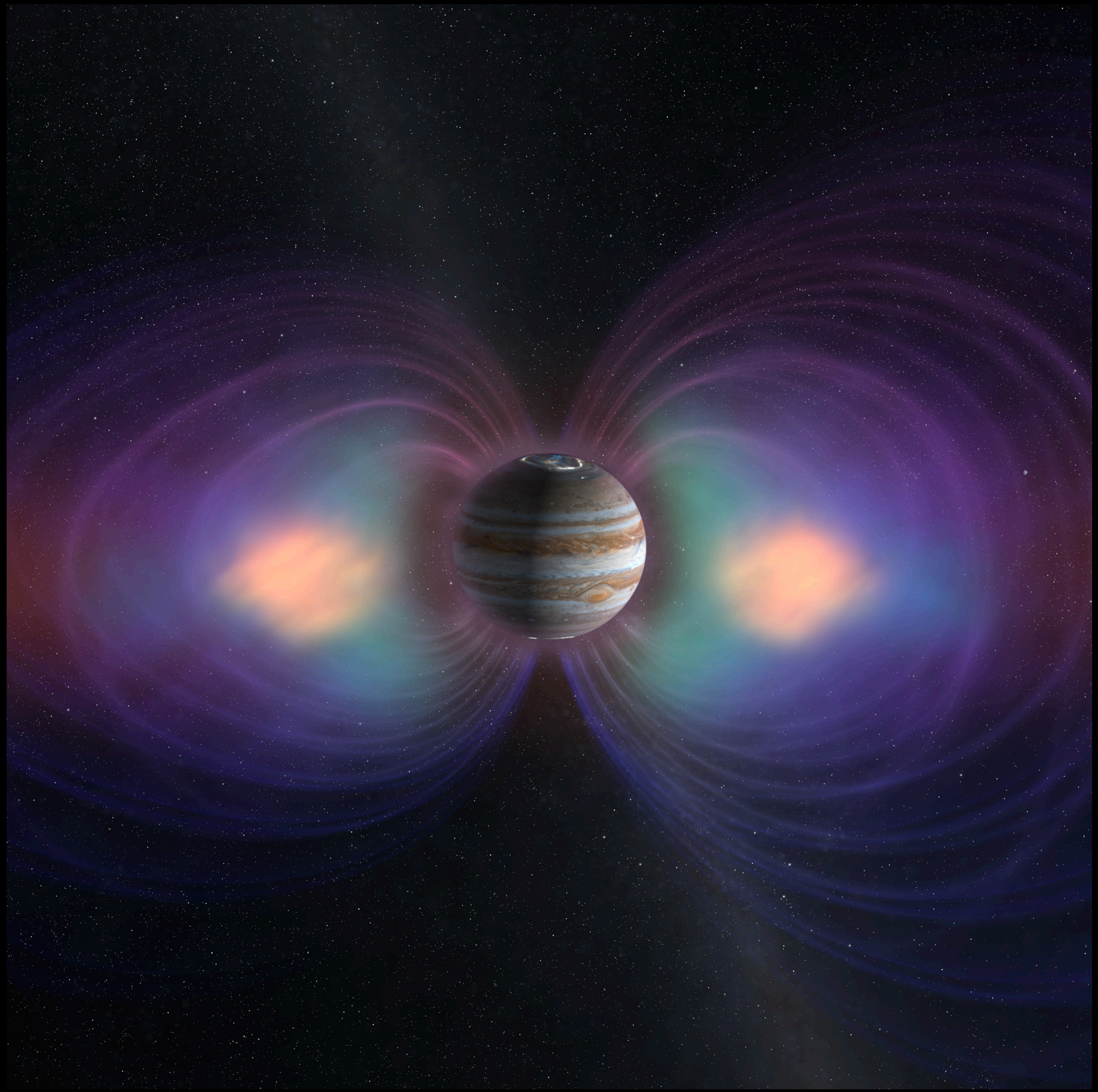
Surface changes
Volcanic losses in Io's environment
Study the species along Io's orbit

IO orbiter or IO multiple flybys

Io orbiter	ESA-only	Probably not easily achievable in an ESA context as this would require an L-class budget and major technical development.
	ESA contribution to a NASA New Frontiers-type mission	Scalable for ESA but the feasibility of a NASA-led orbiter would require significant additional study on the US side.
Multi-Io flyby	ESA-only	There would be scepticism about whether ESA could perform such a mission within an M-class budget. However, this is simpler than JUICE and proposals to NASA's Discovery programme suggest that this could be feasible with very tight cost control. It is, of course, achievable within an L-class budget.
	ESA contribution to a NASA New Frontiers-type mission	Scalable and clearly feasible should NASA decided to implement the recommendation of the last Decadal Survey through a fly-by rather than the proposed orbiter.
	ESA contribution to a NASA Discovery mission	This may be technically straightforward but politically less so given the timescales and the PI-led nature of Discovery.

A comprehensive investigation of the Galilean moon Io: **tracing the mass and energy flows in the Io-Jupiter system.**

The Jovian system in Voyage 2050: unknown territories - Jupiter Radiations Belts

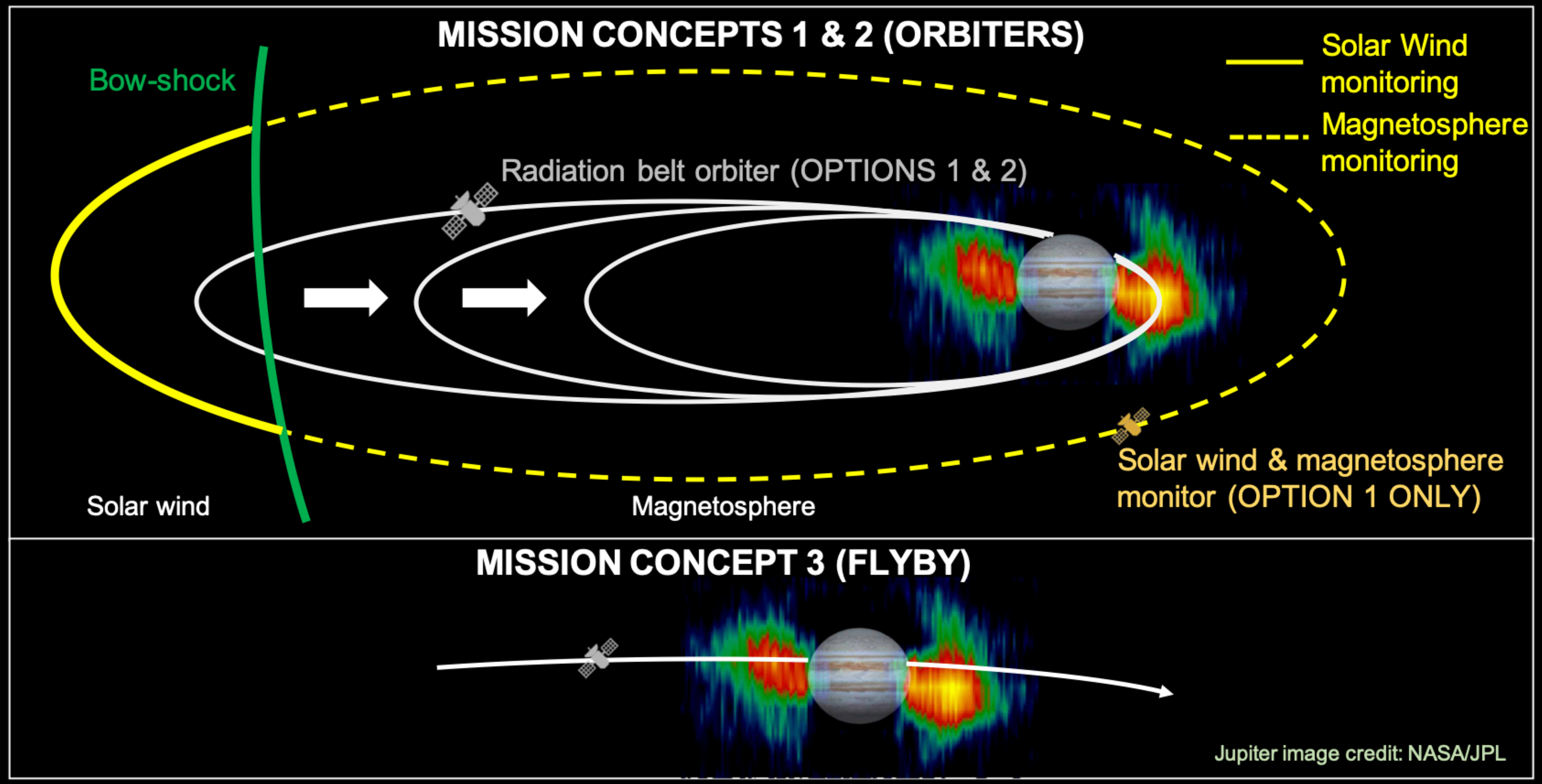


A mission dedicated to the radiation belts (Roussos et al.):

Objectives:

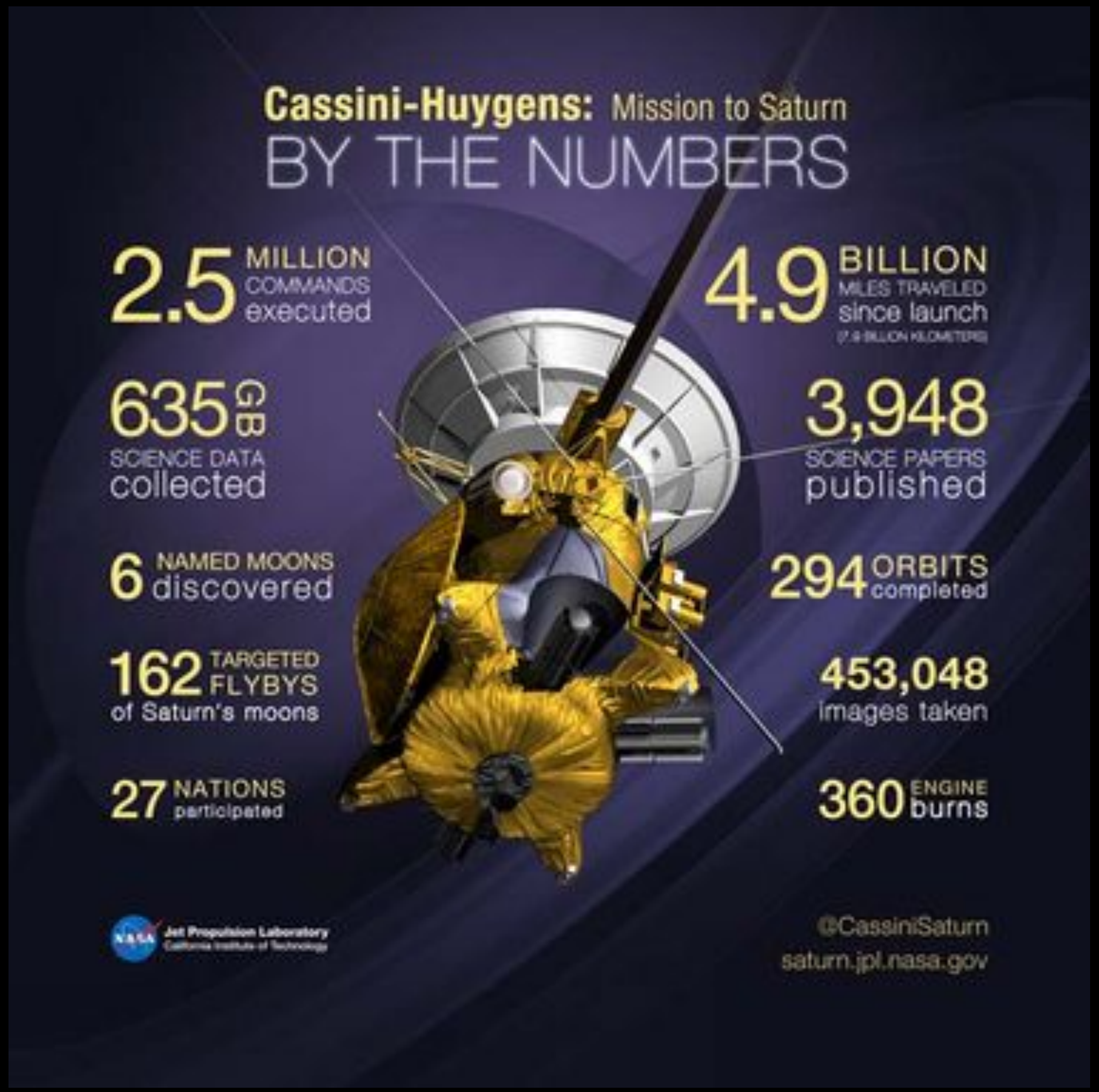
- Adiabatic electron heating vs local electron radiation belt sources and losses
- Cosmic ray albedo neutron decay as universal proton radiation belt source
- Origin of heavy and light ion radiation belts
- High latitude charged particle acceleration as a radiation belt source
- The space weather of Jupiter's radiation belts
- Radiation processes of moon surface material

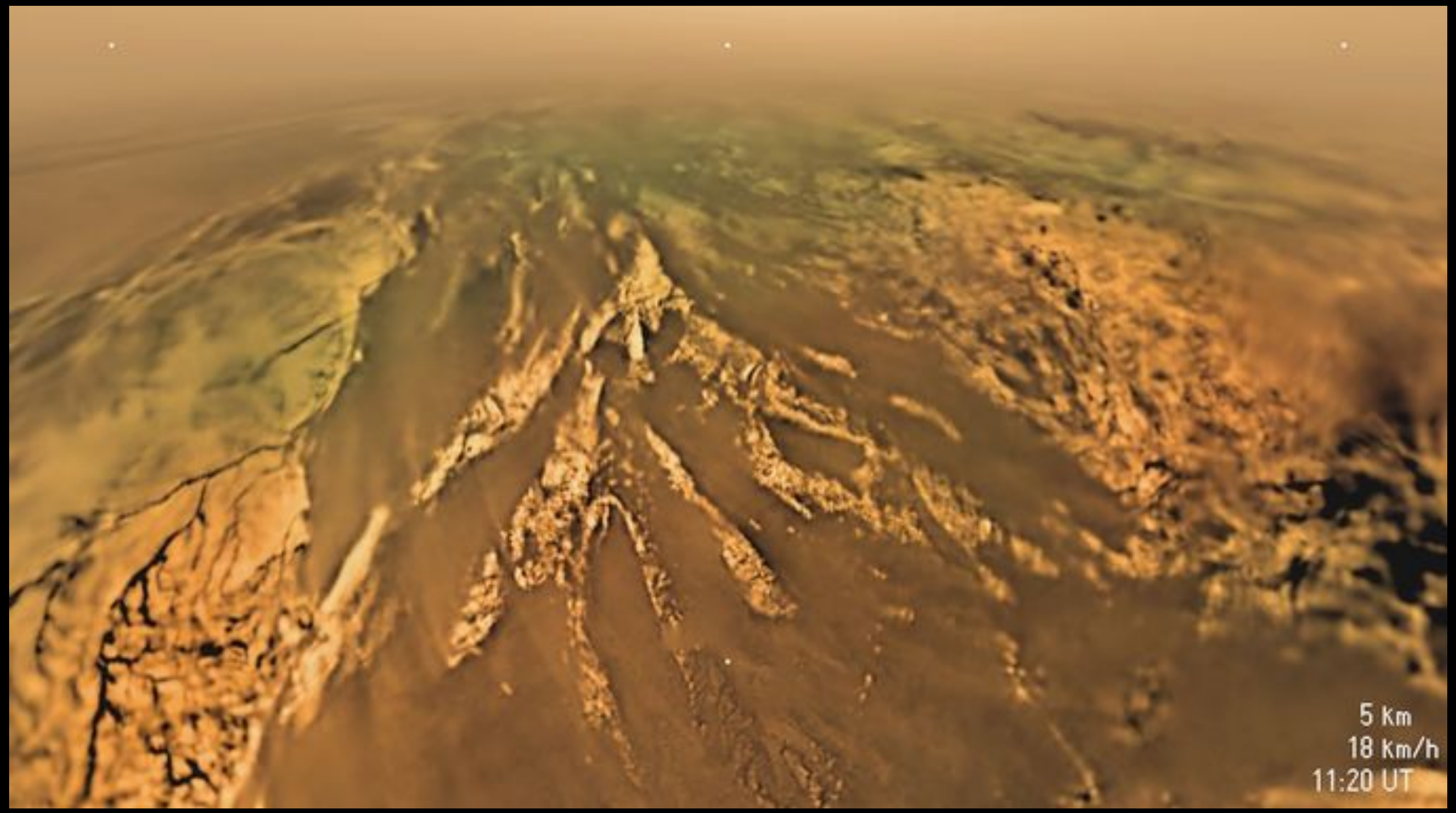
Mission concepts



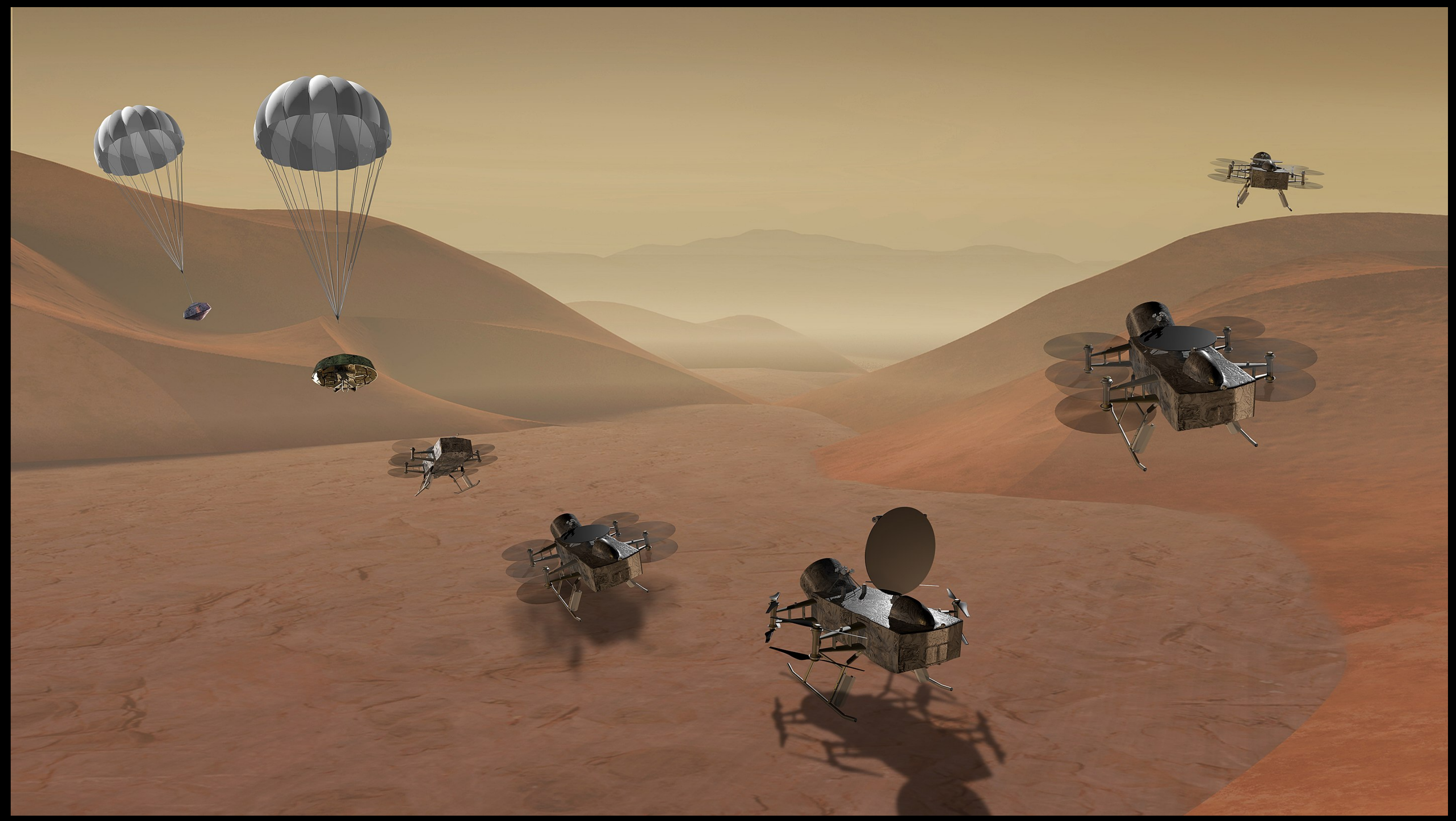
Uniqueness of Jupiter's radiation belts: Why don't we go and explore what we have tried to avoid in (almost) all previous missions?

The Saturnian system





Huygens descent: 2004



Cassini-Huygens
1997-2017

- Characterise **Saturn's atmosphere**
- Explore **Saturn's magnetosphere**!
- **Titan** as a planetary object
- Study the icy moons (**Enceladus**!)
- Study the **rings**

DragonFly (NF4)
Arrival @ Titan - 2034

- Sample surface material to **identify the chemical components and processes** producing biologically relevant compounds
- Measure **bulk elemental surface composition**
- Monitor **atmospheric and surface conditions**
- characterize **geologic features**
- detect subsurface activity and structure

The Saturnian system in Voyage 2050: a mission to Titan

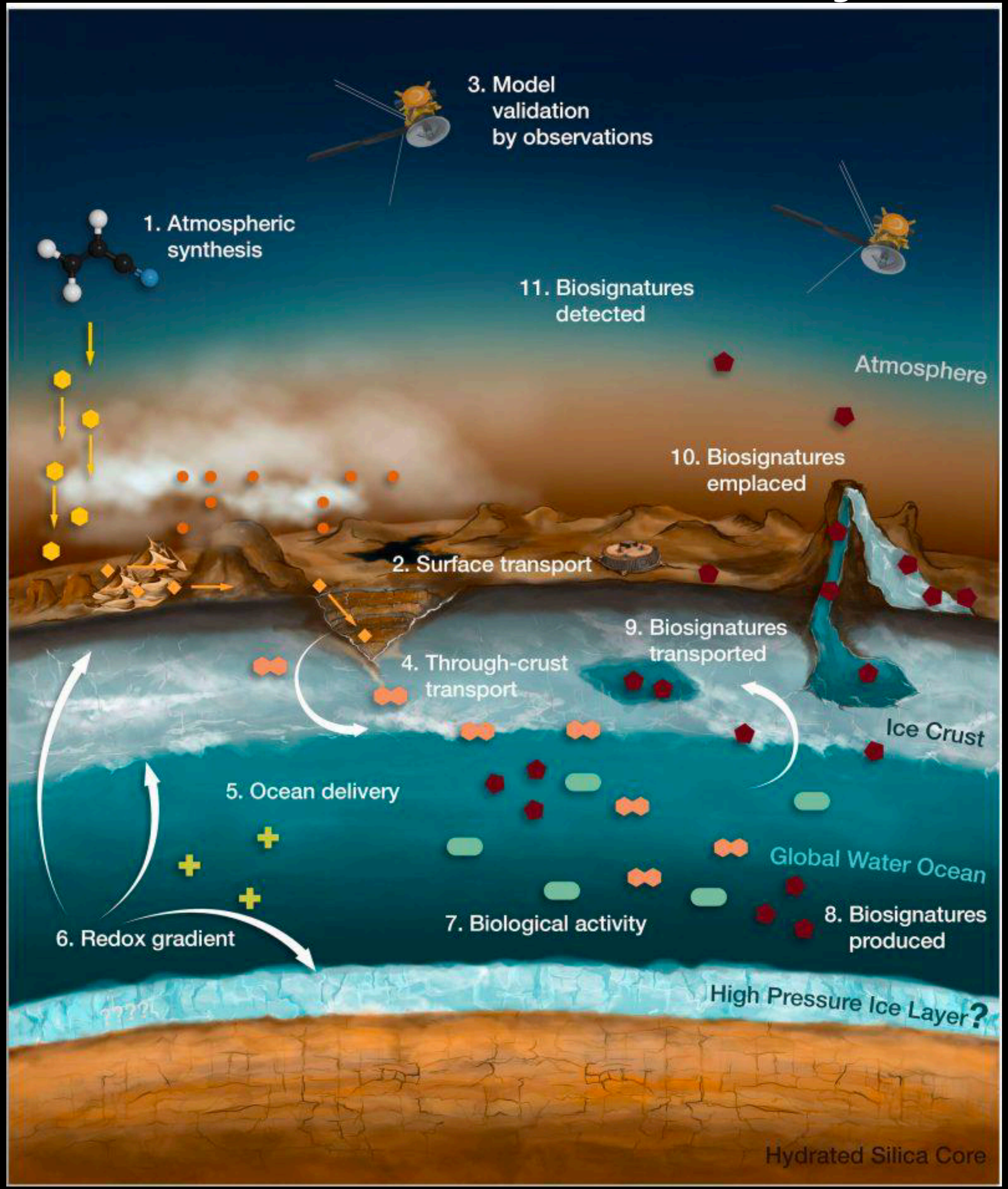


Image Credit: A. Karagiotas/T. Shalamberidze/NAI/JPL

(Rodriguez et al.):

- Titan's atmosphere
- Titan's geology
- Titan's habitability

(Sulaiman et al.):

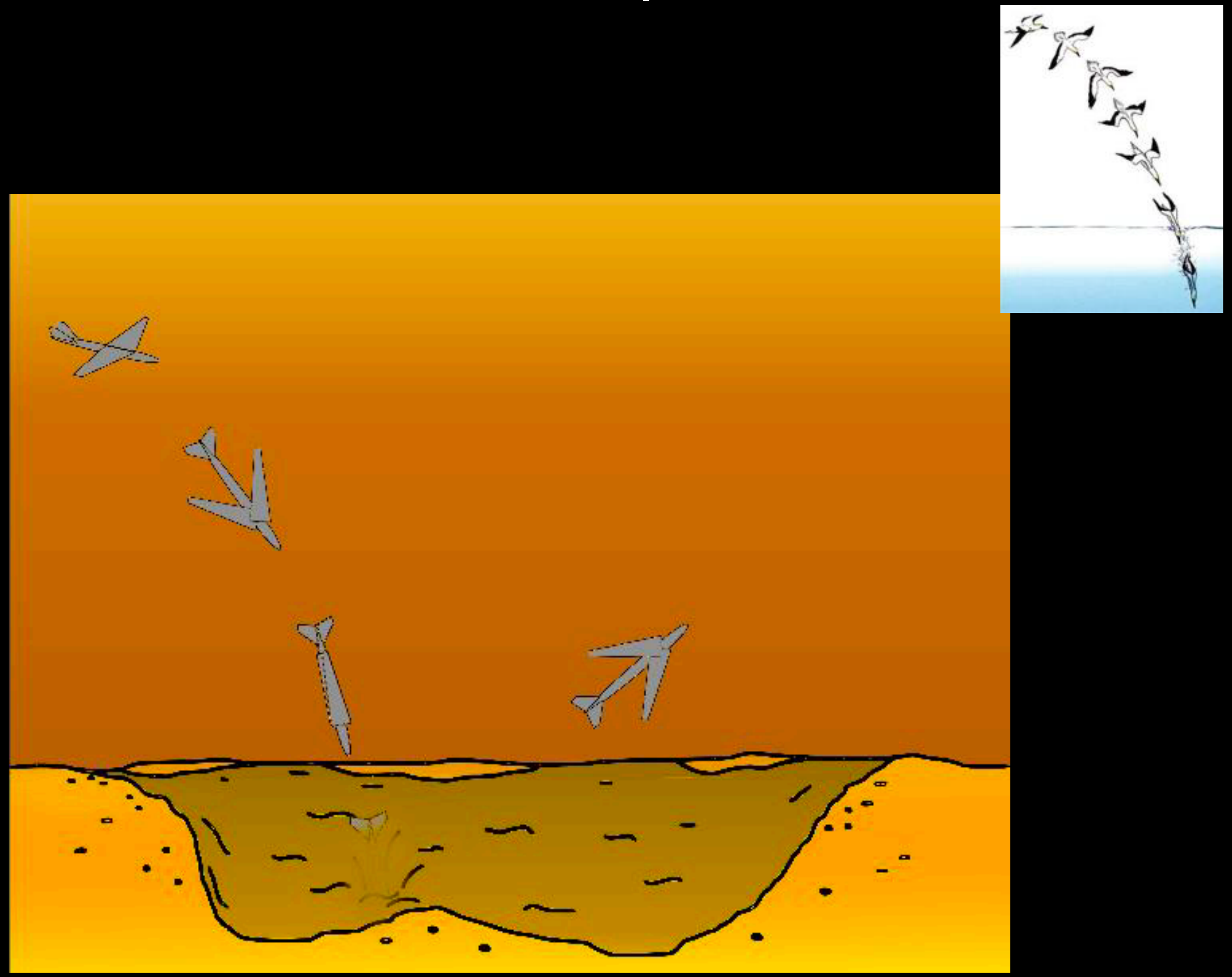
- Titan's atmosphere
- Titan's Energy Budget
- Titan's Geology and Interior
- Titan's Interaction with Saturn's Magnetosphere

(Mitri et al.):

- Origin and evolution of the moon
- Habitability and potential for life of the deep ocean.
- Origin and evolution of Titan's lakes and seas
- Habitability and potential for life of Titan's lakes and seas
- Interior structure and processes of Titan

Mission(s) profile(s) - TBD

- An orbiter
- At least one surface element
  - Lander
  - Drone/mini-drones
  - Plane
  - …



Impression of a 'plunge diving' manoeuvre by an aerial-aquatic aircraft inspired by thegannet seabird (inset).Insetadapted from Liang et al. (2013).

Which roadmap for Titan after Cassini-Huygens and Dragonfly?: **its astrobiological potential,** together with **its complexity as planetary object**, induces a strong interest from the community

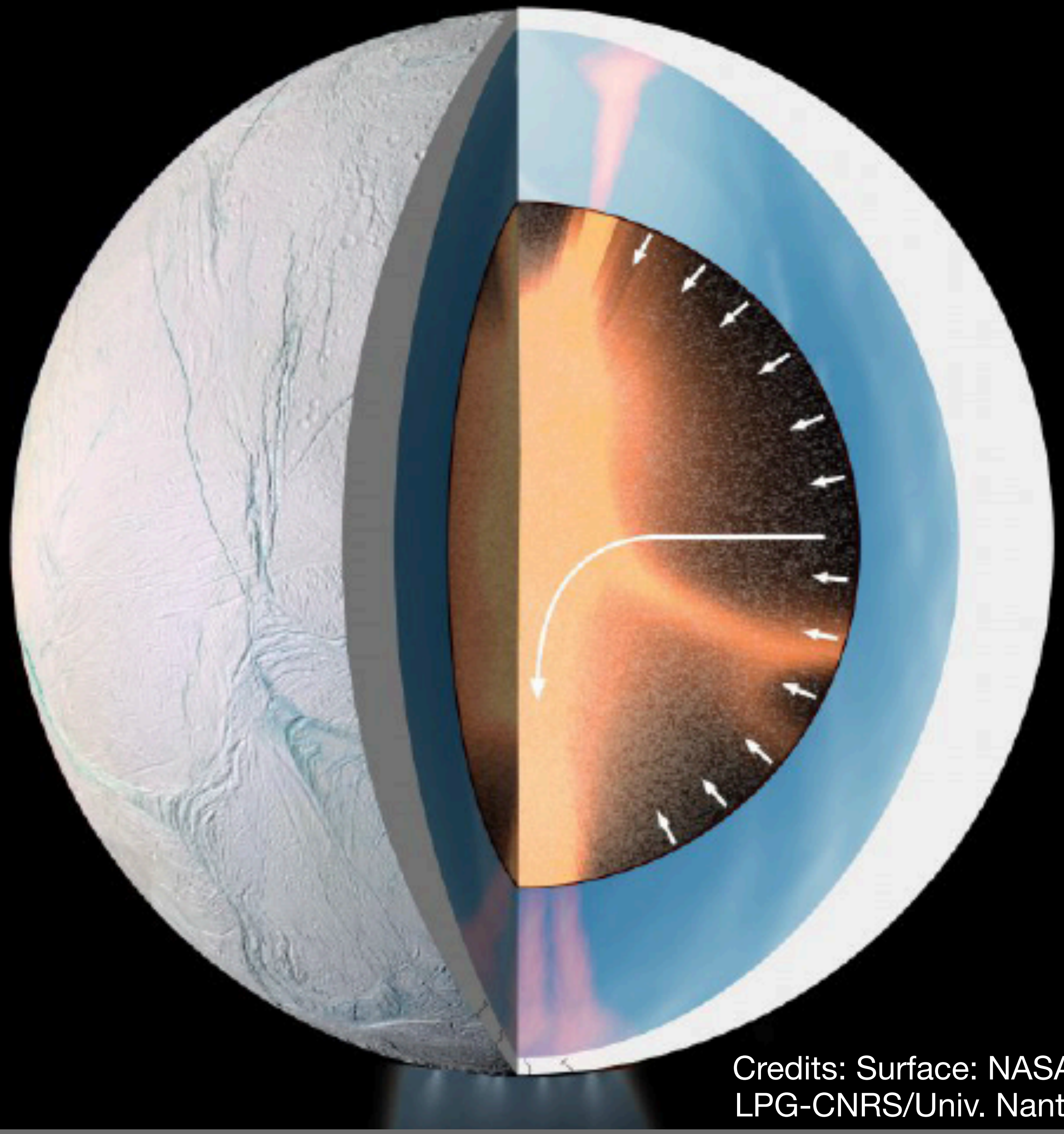
The Saturnian system in Voyage 2050: a mission to Enceladus

(Choblet et al.):
- Emergence of an habitable world
- A global hydrothermal system
- Dynamics and exchange processes from the ocean to space
- Plume material as a window on the origin of life

(Sulaiman et al.):
- Enceladus's plume
- Enceladus' Interaction with Saturn's Magnetosphere
- Titan's Interaction with Saturn's Magnetosphere

of Choblet et al. (2017), (Credits: Surface: NASA/JPL-Caltech/Space Science Institute; interior: LPG-CNRS/U. Nantes/U. Angers. Graphic composition: ESA)

(Mitri et al.):
- Origin and evolution of the moon
- Habitability and potential for life of the deep ocean.
- Interior structure and processes of Enceladus



Credits: Surface: NASA/JPL - Caltech/Space Science Inst.; Interior: LPG-CNRS/Univ. Nantes/Univ. Angers. Graphics composition: ESA

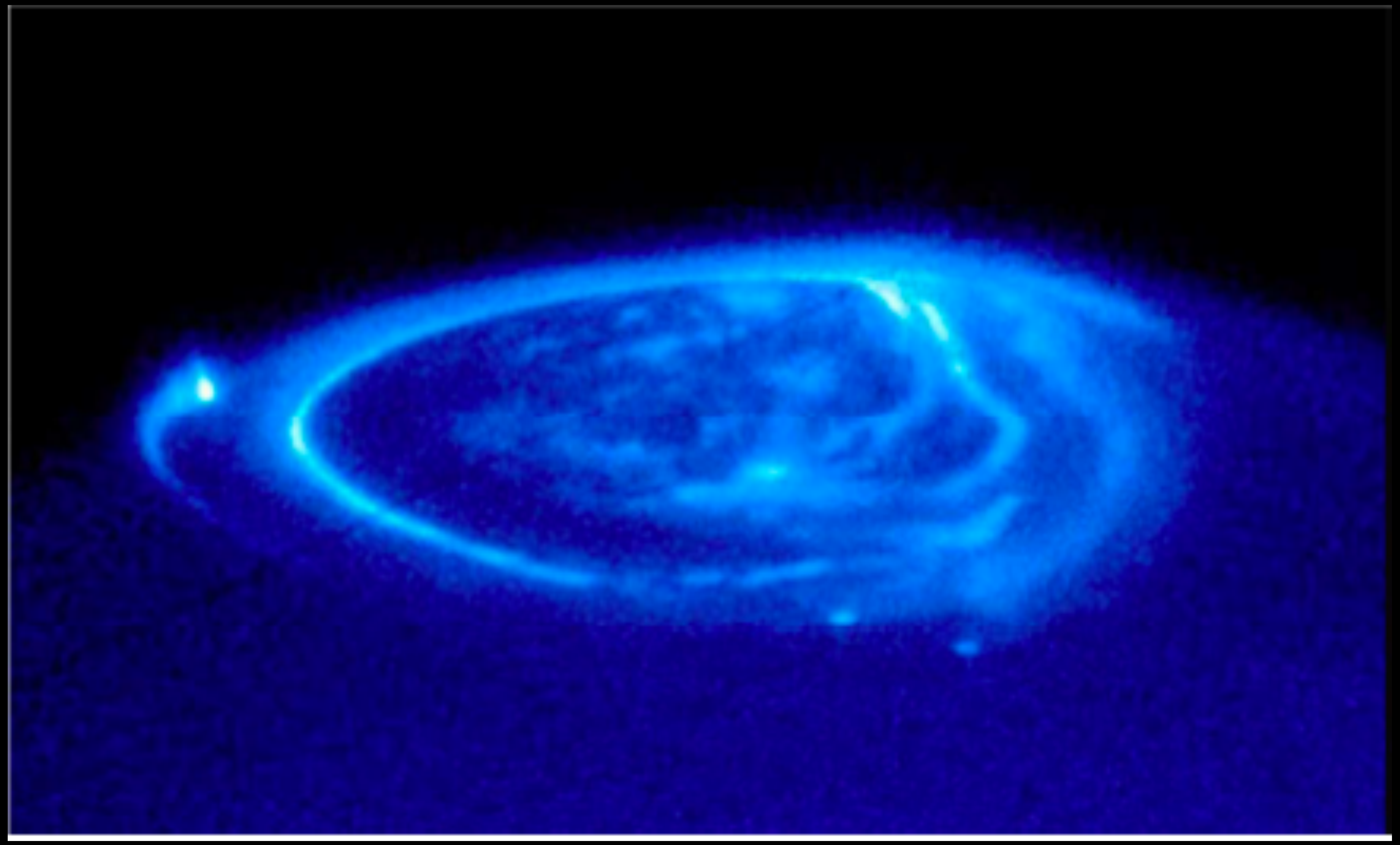
Mission(s) profile(s) - TBD
- Multiple Flybys
- Enceladus Orbiter
- Orbiter + Lander
- Sample return?

	Multiple flybys		Enceladus orbiter	Lander(s)		Sample return	Enceladus orbiter	
				single	multi		Lander(s)	Sample R
1-Origin in the Saturn system	M-class	L-class	Saturn tour				Saturn tour	Saturn tour
2-Hydrothermal context								
3- From ocean to space				SPT landing				
4- Biosignatures in plume materials								
Mission profiles	*ESA-led M- or L-mission*		*ESA-led L-mission*	*- ESA-led L mission - ESA M-Mission + int. partner*		*ESA M-mission + int. partner*	*- ESA-led L mission + int. partner contr. - Int. partner-led mission + ESA M-class mission*	

Relevant for science questions : Not | Partly | Mostly | Fully

Which roadmap for Enceladus after Cassini-Huygens?: **its astrobiological potential** induces a strong interest from the community

Voyage 2050: what about the giant planets?



(Chaufray et al.): **a new multi-object UV observatory after Hubble**

- Planetary surfaces (mostly Mars and Venus)
- Planetary atmospheres (includ. Titan and Pluto) with **a focus on the Lyman-alpha bulge at Jupiter**
- **Planetary magnetospheres and auroral emissions of giant planets**

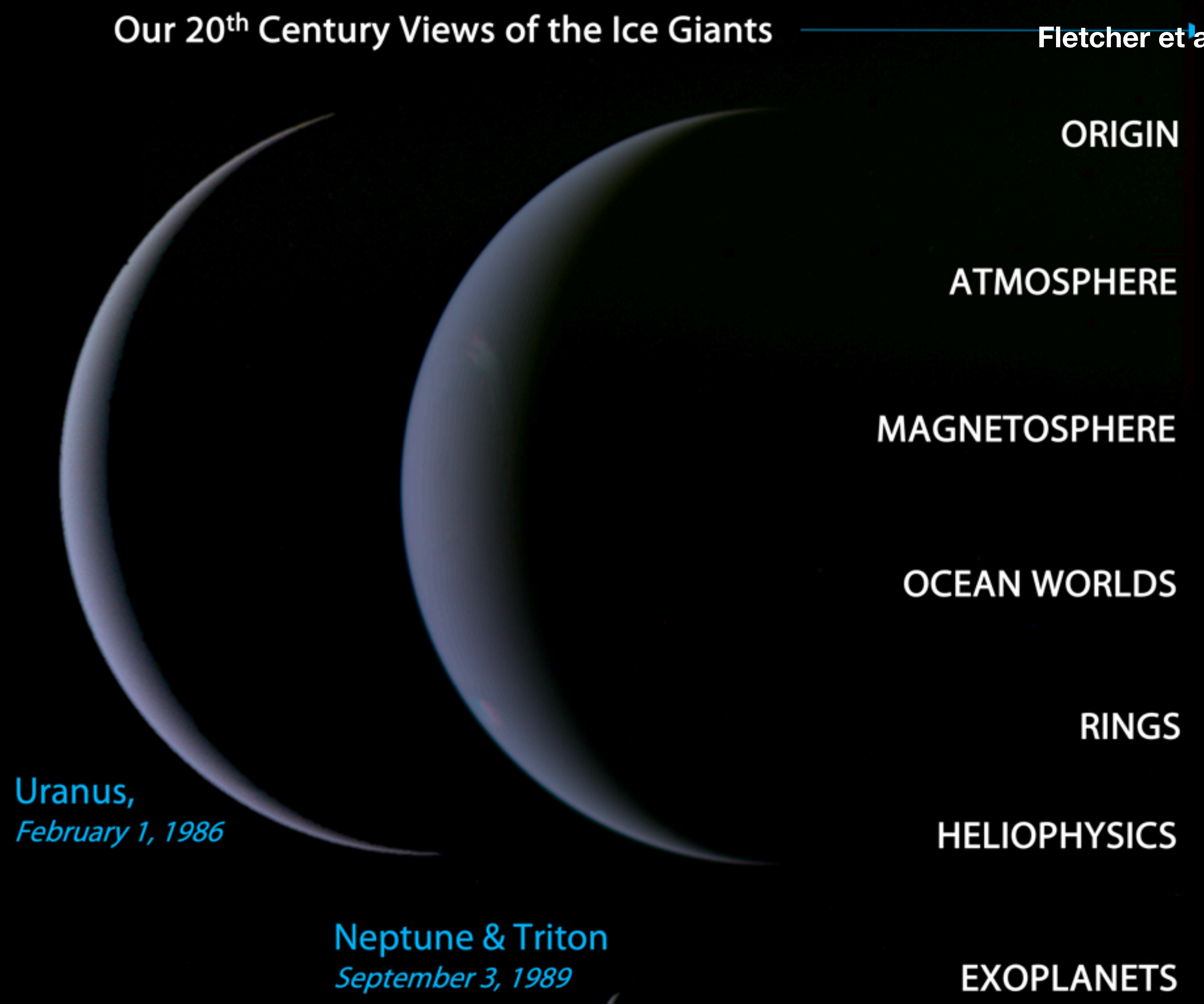
(Champain et al.) : **build a THz observatory on the moon** to observe the atmosphere of planets and satellite

Which roadmap for giant planet exploration?
is *in situ* exploration the only « missing clue » for these planets?

Mousis et al. WP

Voyage 2050: Uranus and Neptune science cases

Fletcher et al.



Credit: NASA/JPL/E. Lakdawalla

Guillot

Transport processes in hydrogen atmospheres

Structure, interior composition and dynamo

Provide keys to understand the origin of the solar system

Relations to exoplanets

A mission to these remote systems: orbiter, lander, probe…?

The Sun, planets, magnetosphere and plasma physics: Outer Solar System

UV telescope
THz observatory on the moon

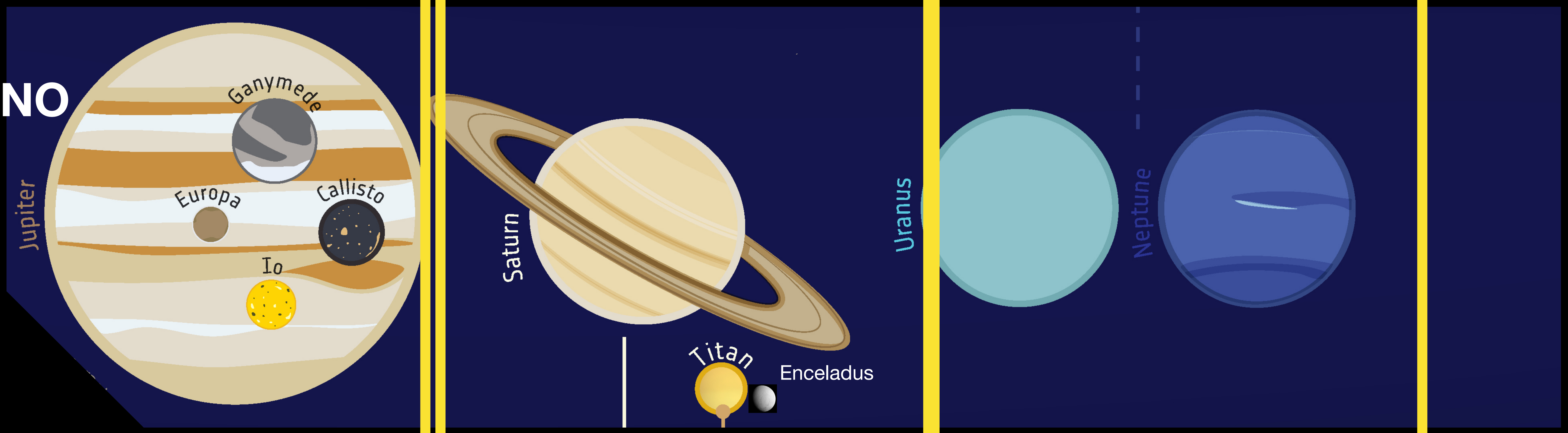
JWST

Hubble Space Telescope

Europa missions
Io orbiter/clipper
Radiation belts explorer

JUICE
Europa Clipper

JUNO



Galileo
...

Titan missions
Enceladus missions
Saturn's probes

Dragonfly

Cassini-Huygens
...

Orbiters,
Probes

Voyager

Voyage 2050

In development

Operational

Legacy