

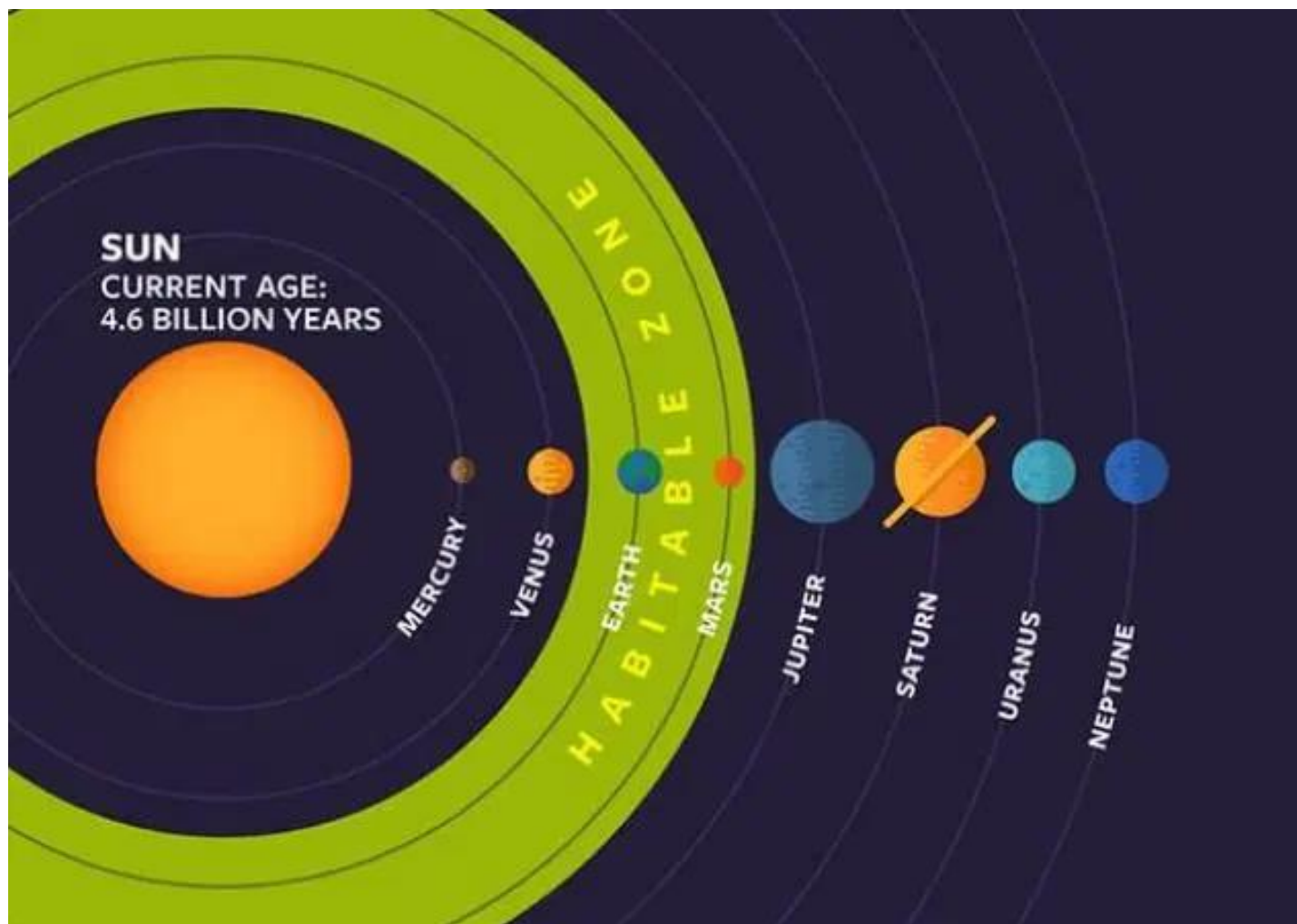
# GEO 325M Spring 2020

**Class project: Formation of chaotic terrains on Jupiter's moon Europa**

# Habitable zone

Sounds good, but is largely BS

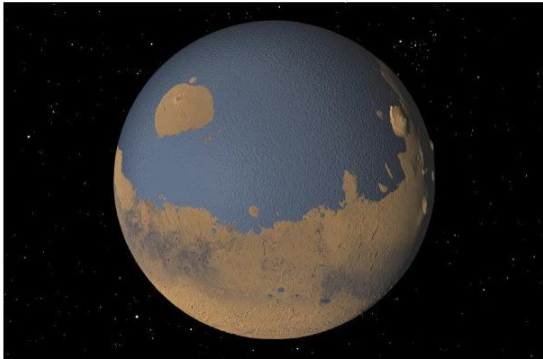
# Habitable Zone (surface water)



# Follow the water

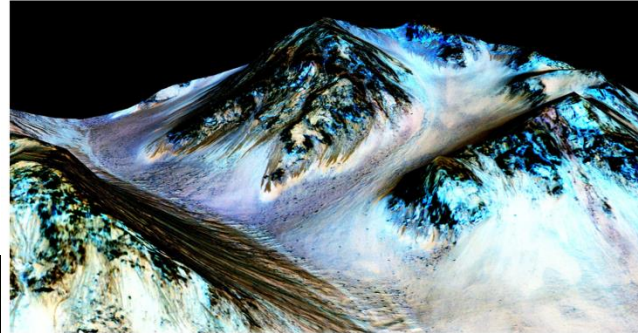
The New York Times

## *Ancient Mars Had an Ocean, Scientists Say*



The New York Times

## *Mars Shows Signs of Having Flowing Water, Possible Niches for Life, NASA Says*



Scientists say these dark, narrow, downhill streaks are evidence of flowing water on Mars. Jet Propulsion Laboratory/University of Arizona, via NASA

The New York Times

Account ▾

## *A Large Body of Water on Mars Is Detected, Raising the Potential for Alien Life*

The discovery suggests that the liquid conditions beneath the icy southern polar cap may have provided one of the critical building blocks for life on the red planet.

... but Mars is a pretty dusty place.

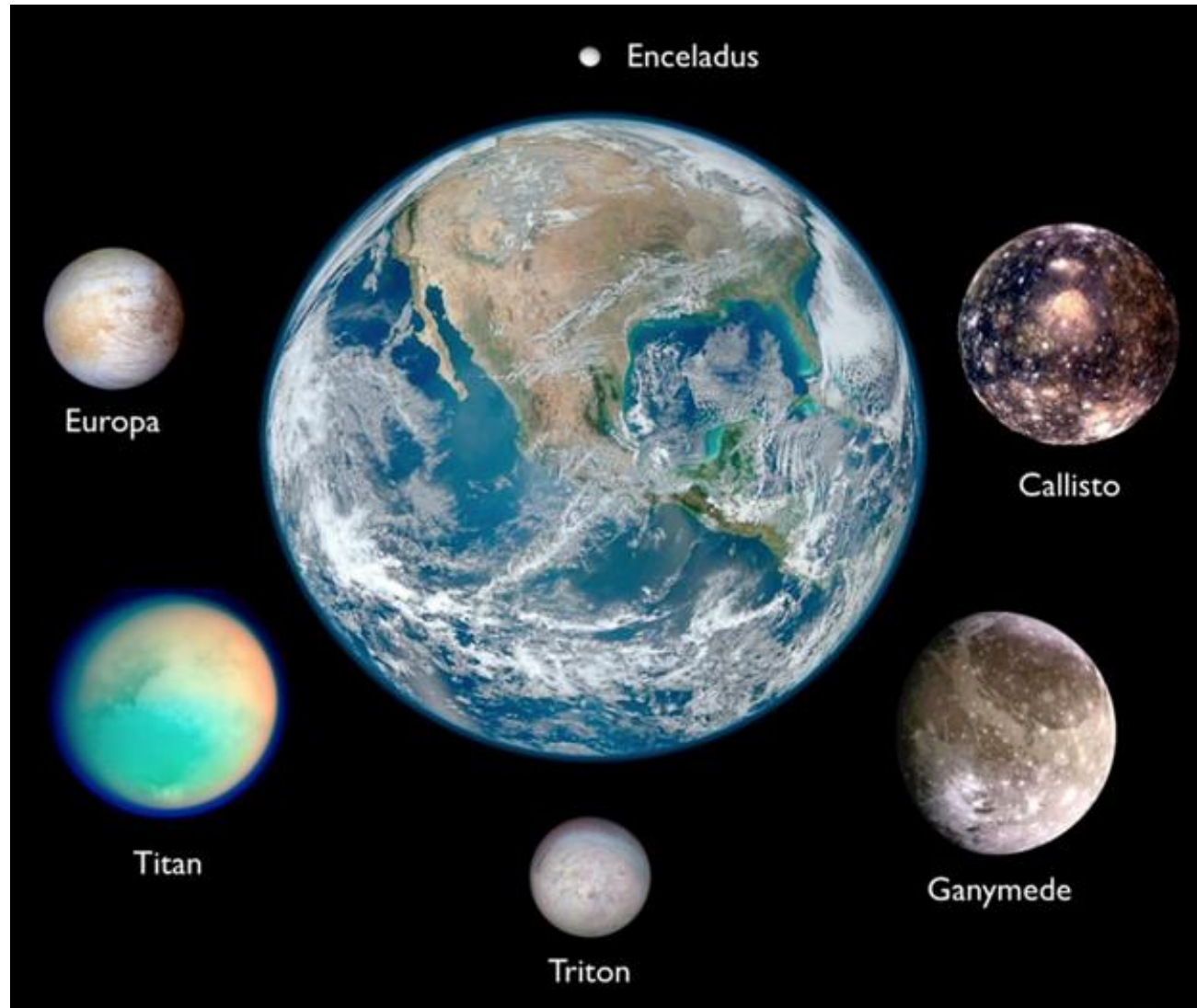


# Introduction to Icy Ocean Worlds

# Icy moons in the outer solar system



What if the water is not on the surface?





# HOW THE SOLAR SYSTEM'S LARGEST OCEAN WORLDS COMPARE IN SIZE



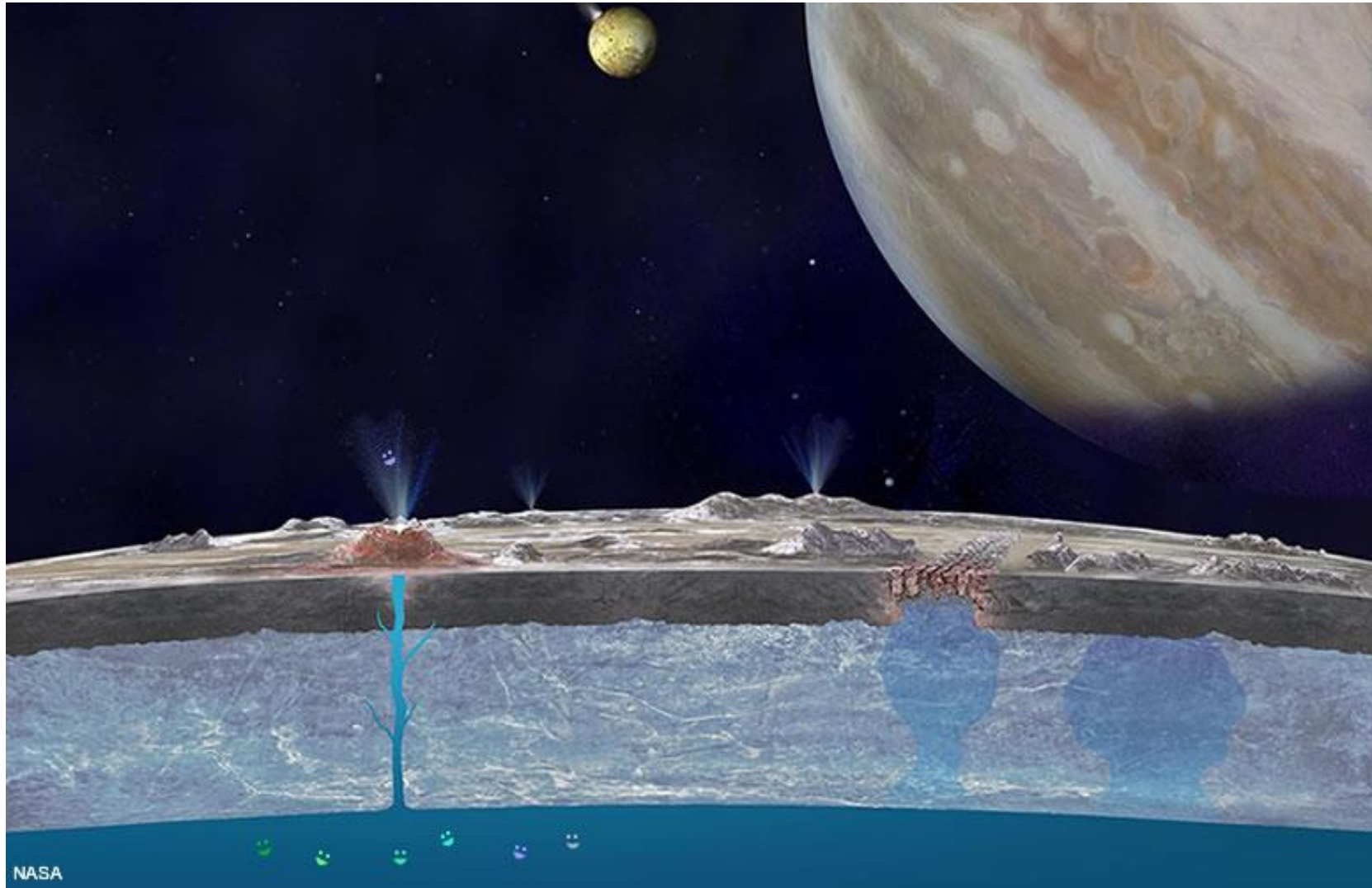
Earth has a surprisingly small amount of water compared to other worlds in the Solar System. Each measurement is the spherical radius of the world and its water (including ice):

ENCELADUS	DIONE	EARTH	EUROPA	PLUTO	TRITON	CALLISTO	TITAN	GANYMEDE
 Water radius: 140 mi./ 220 km.	 Water radius: 300 mi./ 480 km.	 Water radius: 430 mi./ 690 km.	 Water radius: 550 mi./ 880 km.	 Water radius: 630 mi./ 1010 km.	 Water radius: 730 mi./ 1170 km.	 Water radius: 1,120 mi./ 1,800 km.	 Water radius: 1,180 mi./ 1,890 km.	 Water radius: 1,460 mi./ 2,350 km.
World radius: 157 mi./ 252 km.	World radius: 349 mi./ 561 km.	World radius: 3,959 mi./ 6,371 km.	World radius: 972 mi./ 1,565 km.	World radius: 738 mi./ 1,187 km.	World radius: 840 mi./ 1,352 km.	World radius: 1,498 mi./ 2,410 km.	World radius: 1,601 mi./ 2,576 km.	World radius: 1,635 mi./ 2,631 km.

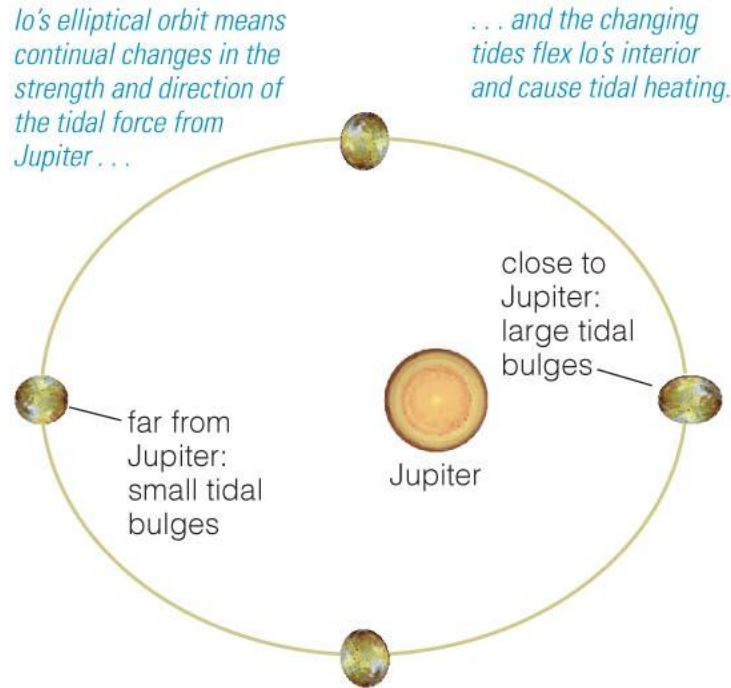
SOURCE: Steve Vance; NASA/JPL-Caltech

BUSINESS INSIDER

These are (thought to be) internal oceans!

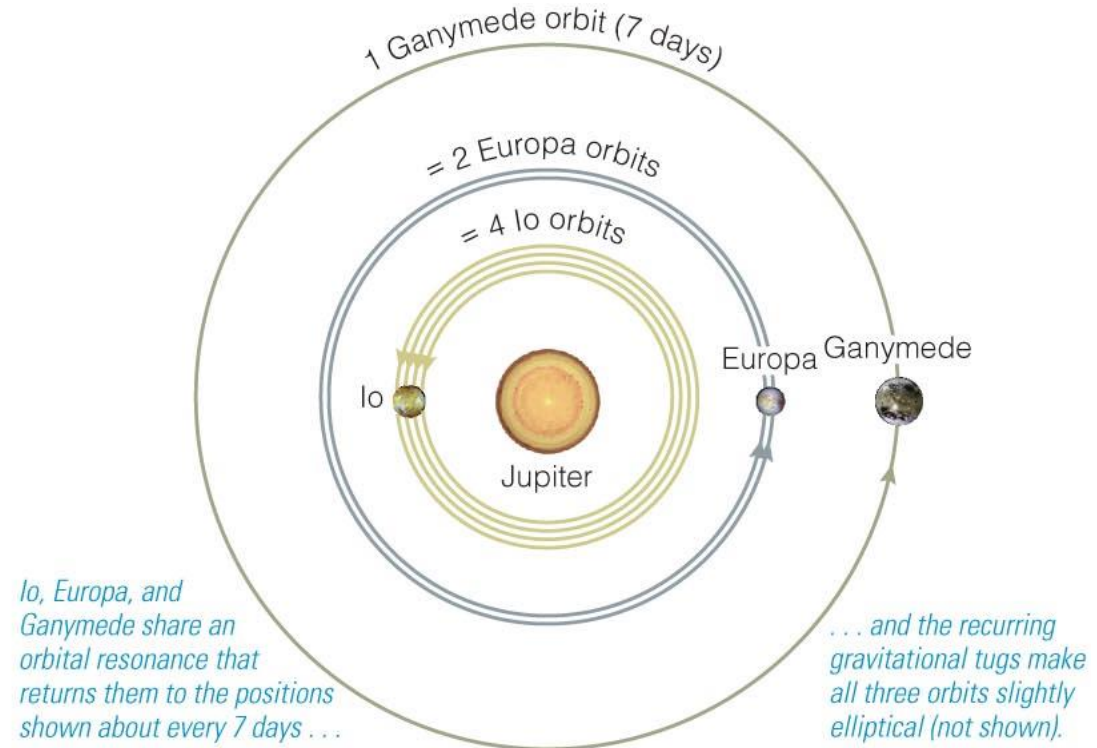


# Tidal heating of moons



**a** Tidal heating arises because Io's elliptical orbit (exaggerated in this diagram) causes varying tides.

Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

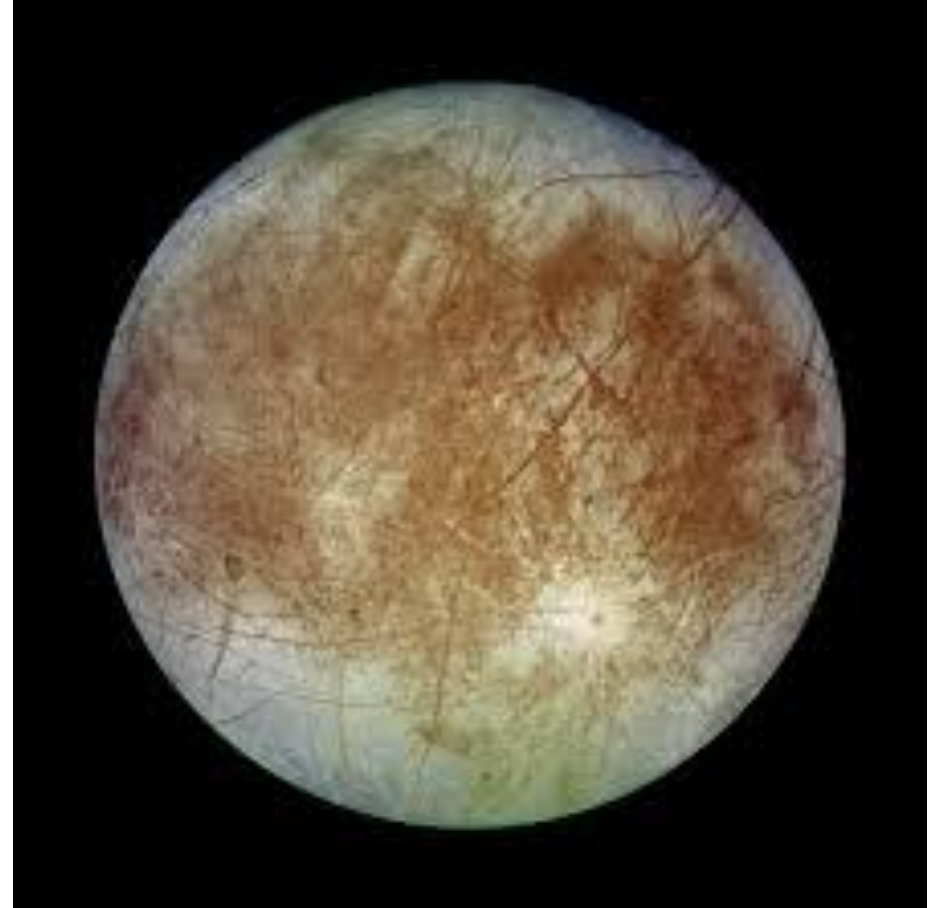


**b** Io's orbit is elliptical because of the orbital resonance it shares with Europa and Ganymede.

# How do we know there is water?



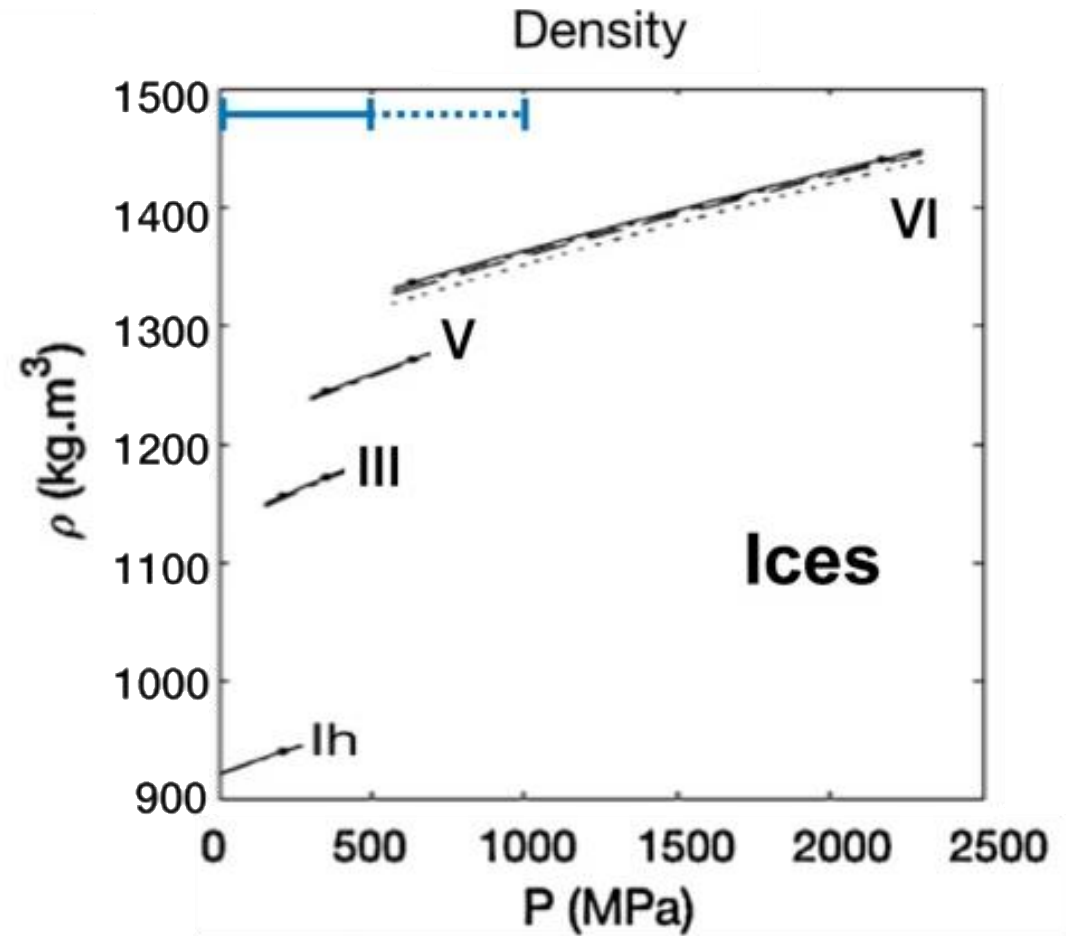
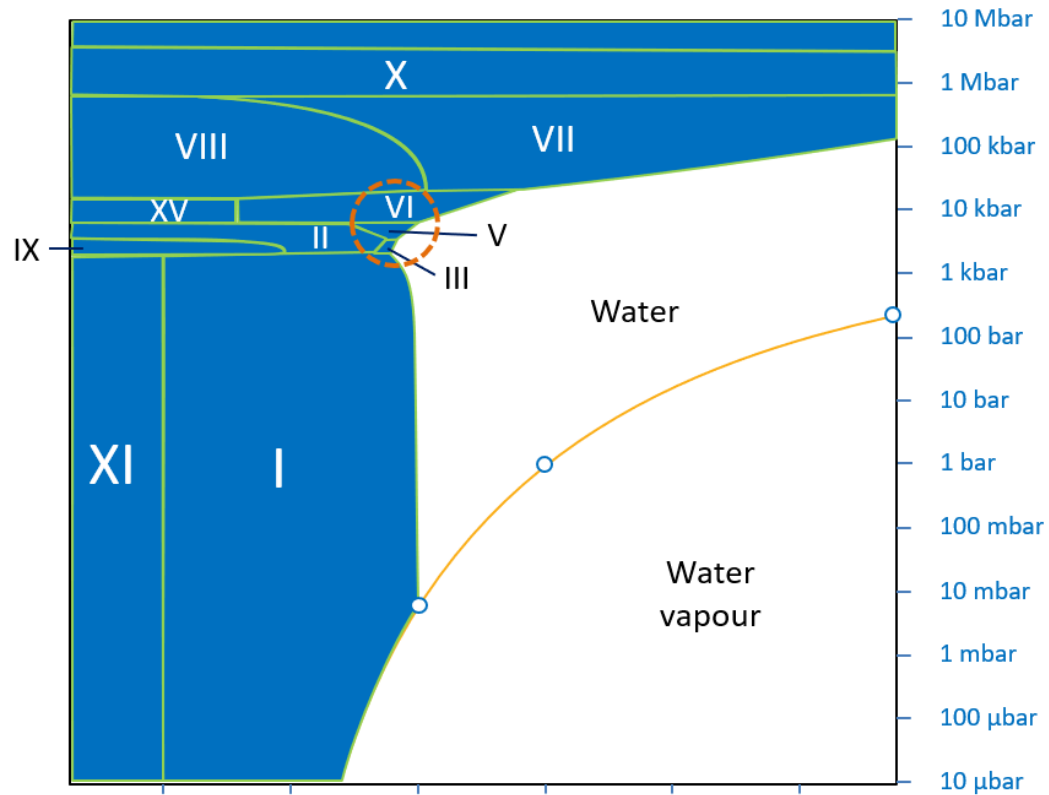
# Europa (Moon of Jupiter)



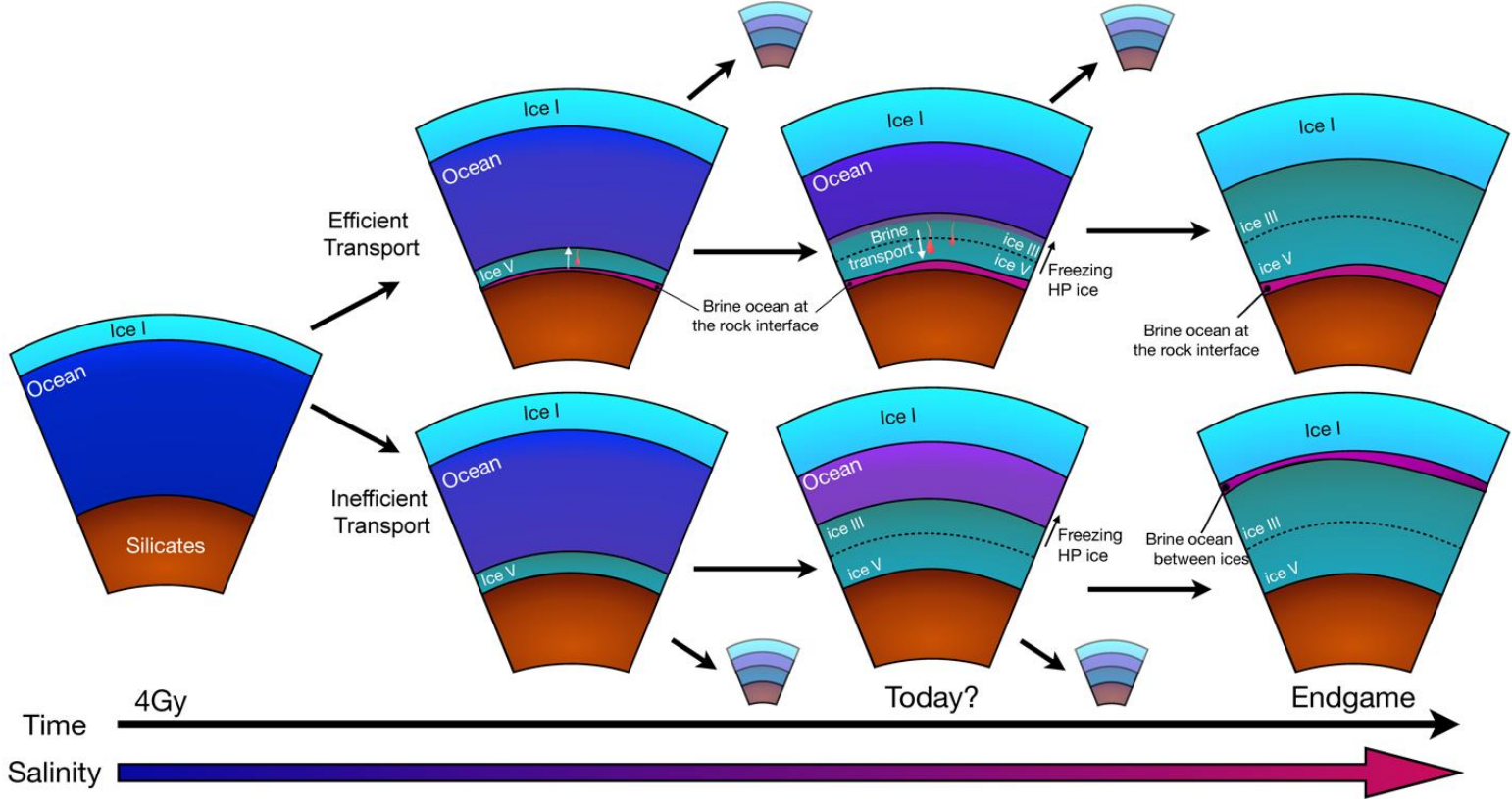
# Three upcoming space missions!

1. Europa Clipper (NASA - JPL): Europa  
<https://www.jpl.nasa.gov/missions/europa-clipper/>  
Launch: 2022, Arrival:
  2. JUICE - Jupiter Icy Moons Explorer (ESA): Callisto and Ganymede  
<https://sci.esa.int/web/juice>  
Launch: 2022, Arrival: 2030
  3. Dragonfly (NASA-APL): Titan  
<https://dragonfly.jhuapl.edu/>  
Launch: 2026, Arrival: 2034
- ⇒ Exciting area to get involved in now.

# High pressure ice structures

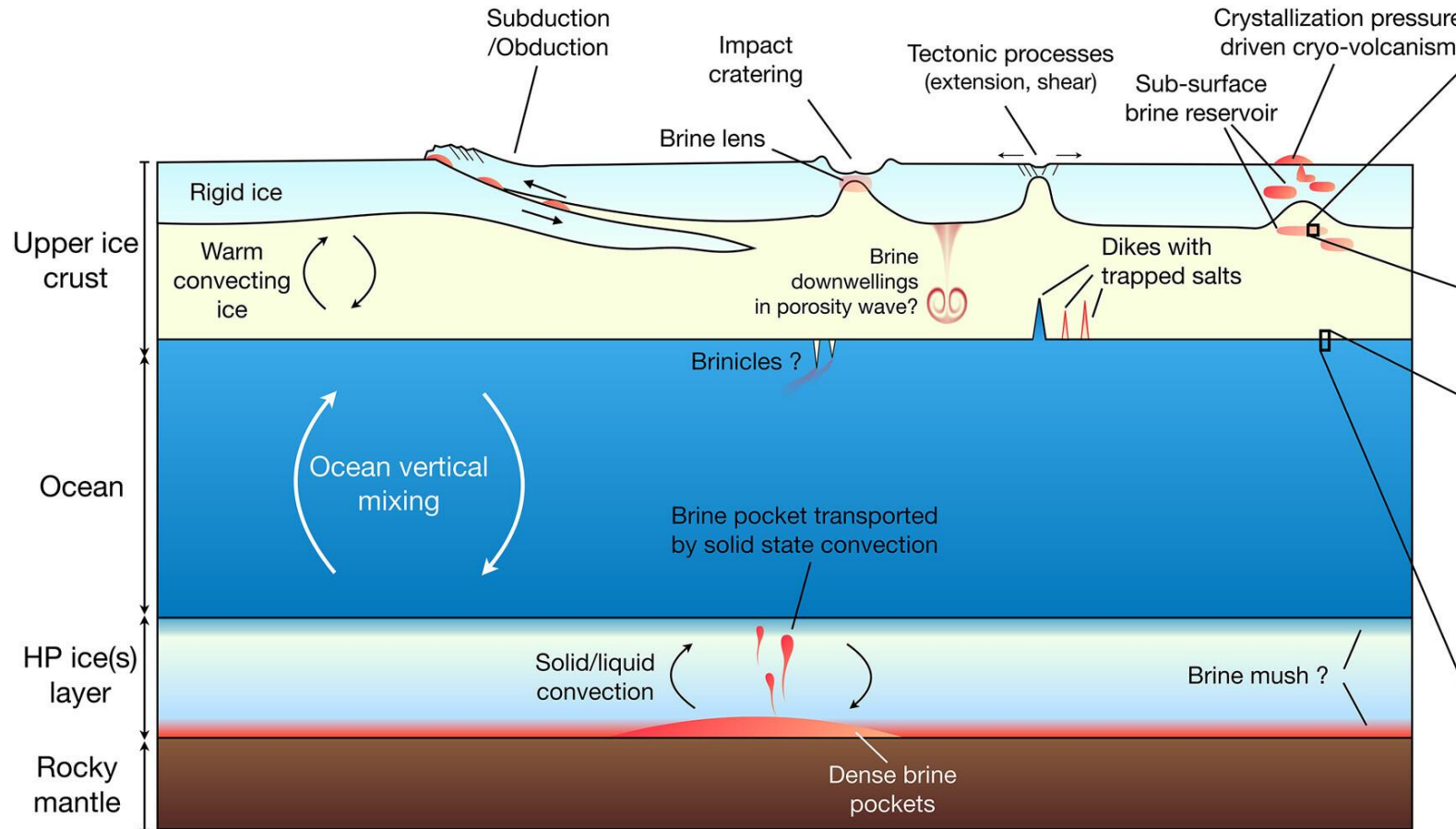


# Evolution of Callisto's Ocean

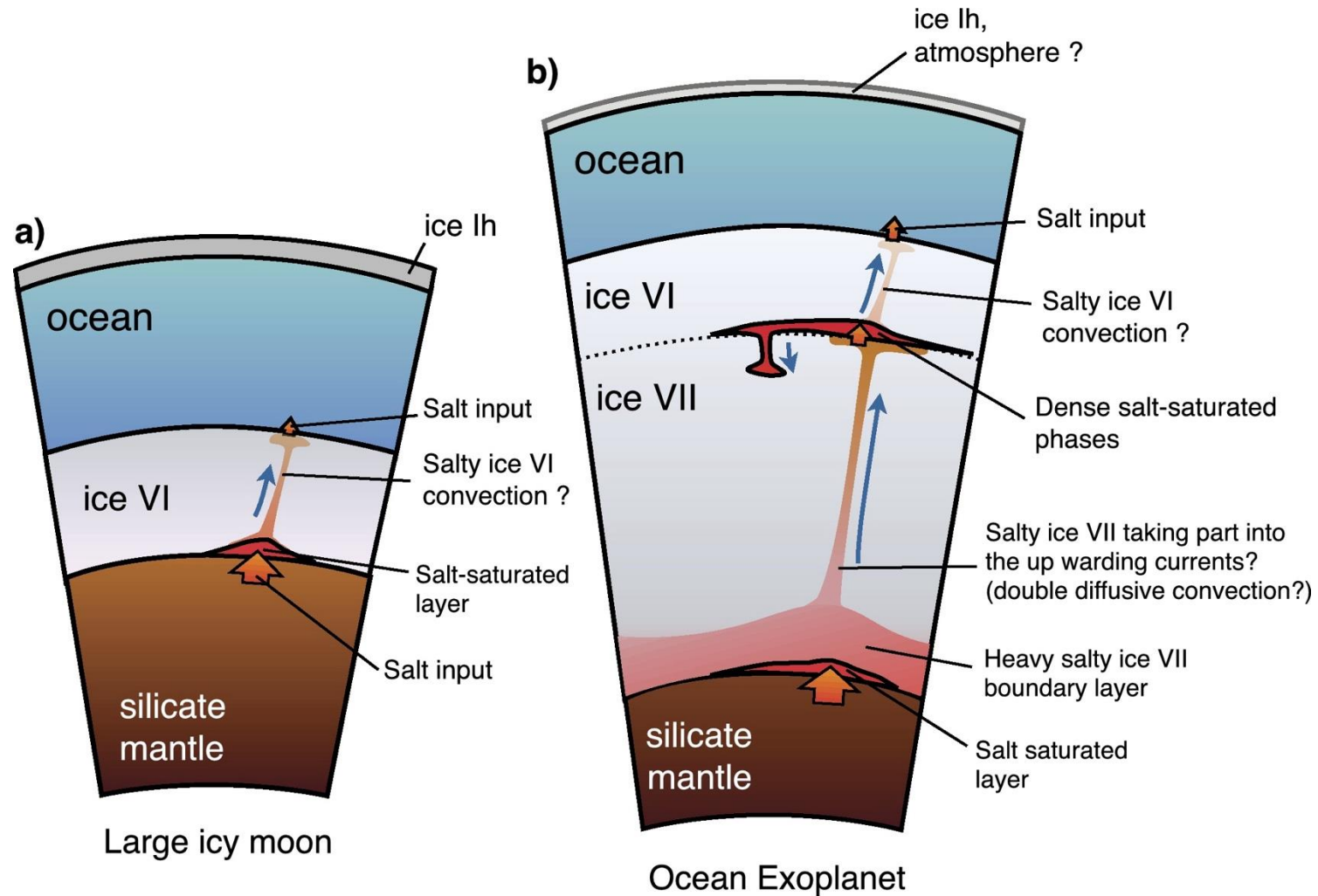


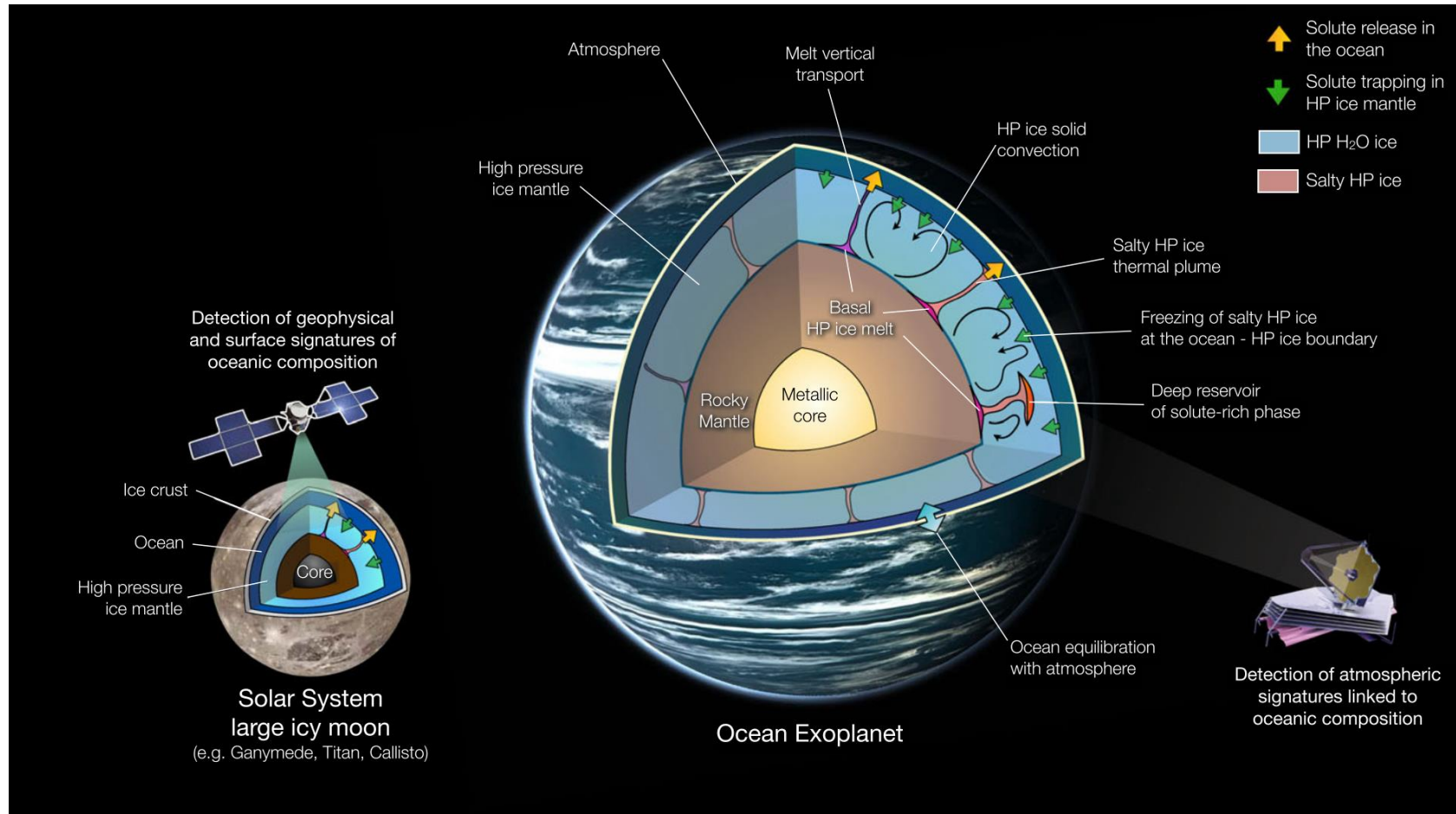


# Internal Ocean between two ice layers

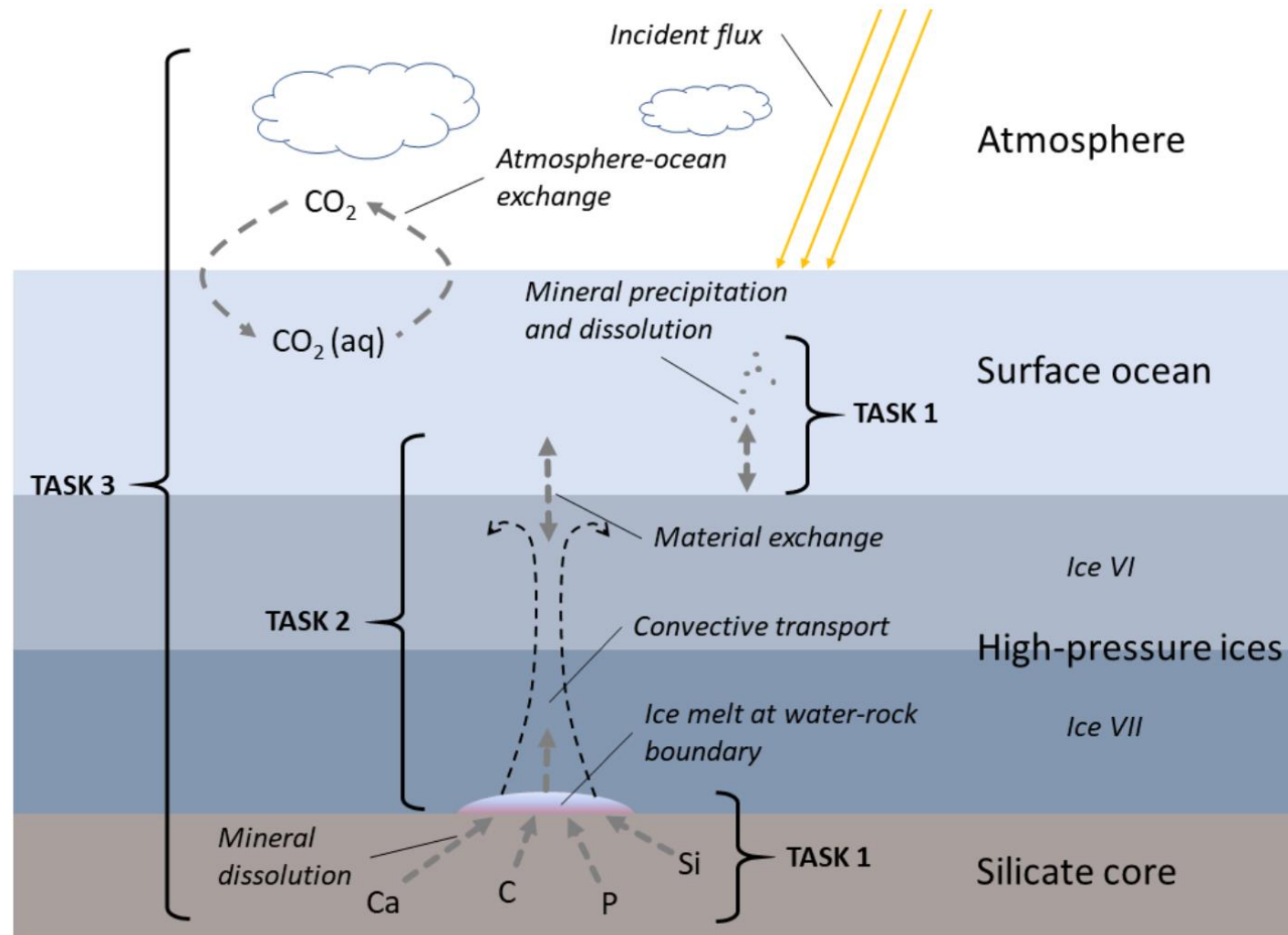


# Mass transport across high-pressure ice





# Water-rich exoplanets?



# Basic Research Questions

- Mass and energy transport across the ice
- Solubility differences between ices - > salt accumulations
- Feedback between salt and partial melting
- Wholesale exchange between ocean and (formerly) dense ice