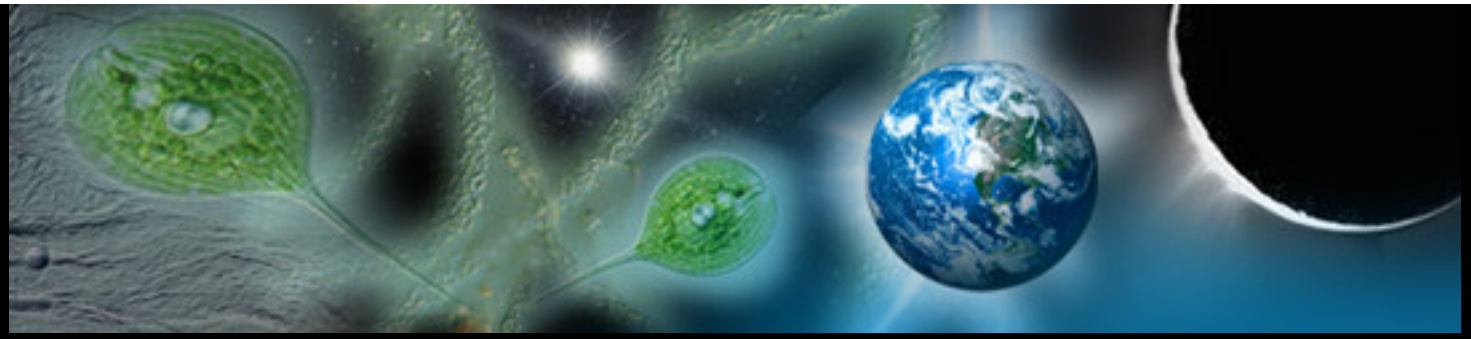


Habitability potential of icy moons around giant planets and the JUICE mission

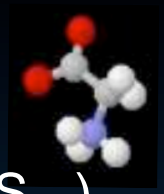
Athena Coustenis

LESIA, Paris-Meudon Observatory, France

O. Grasset, Th. Encrenaz,
H. Lammer, F. Raulin &
The JUICE SWT Team

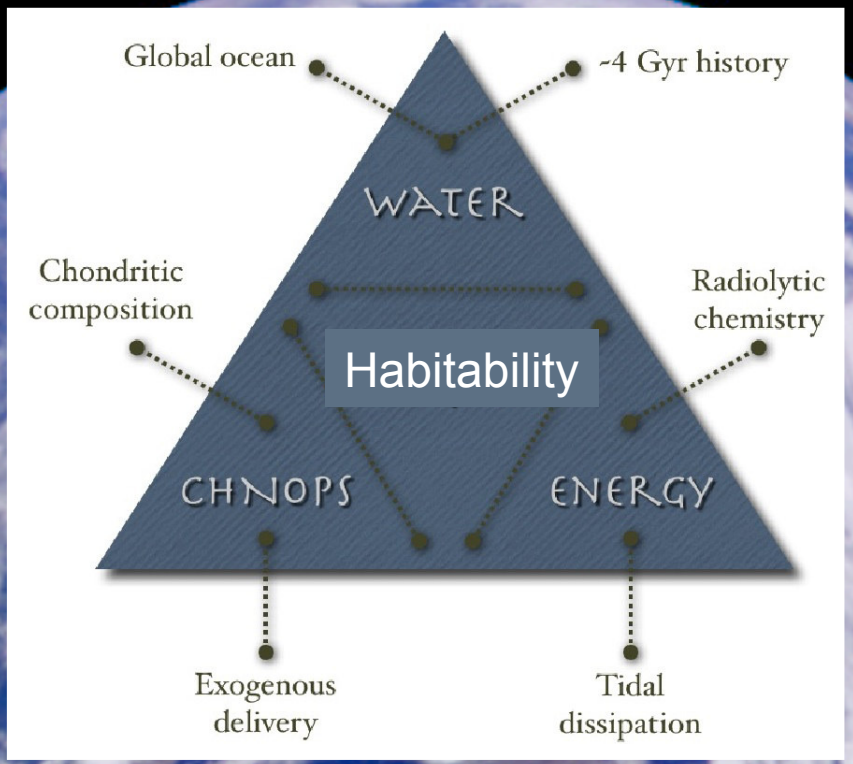
Habitability: four requirements

water 

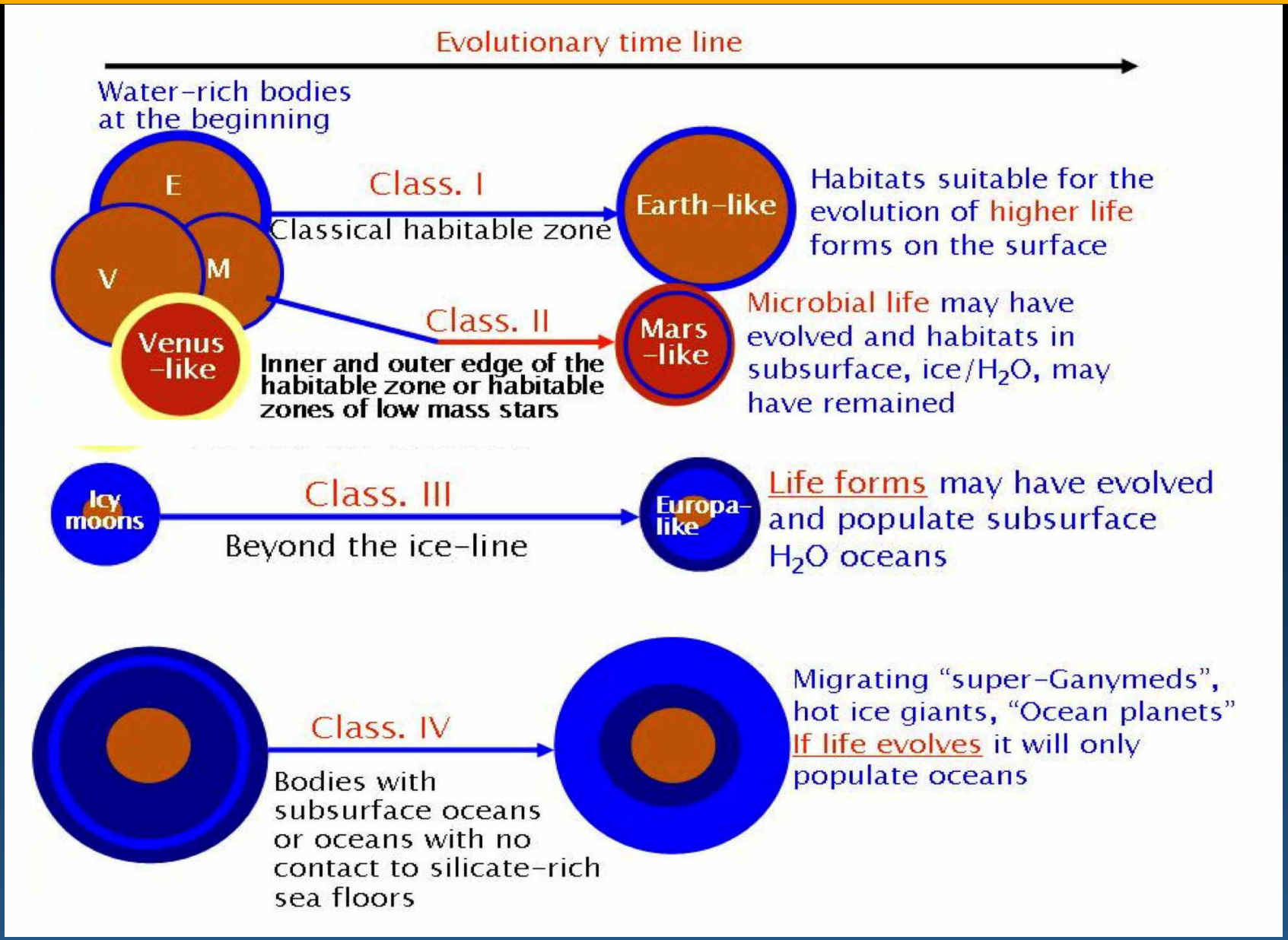
essential elements (CHNOPS...) 

chemical energy 

stable environment 

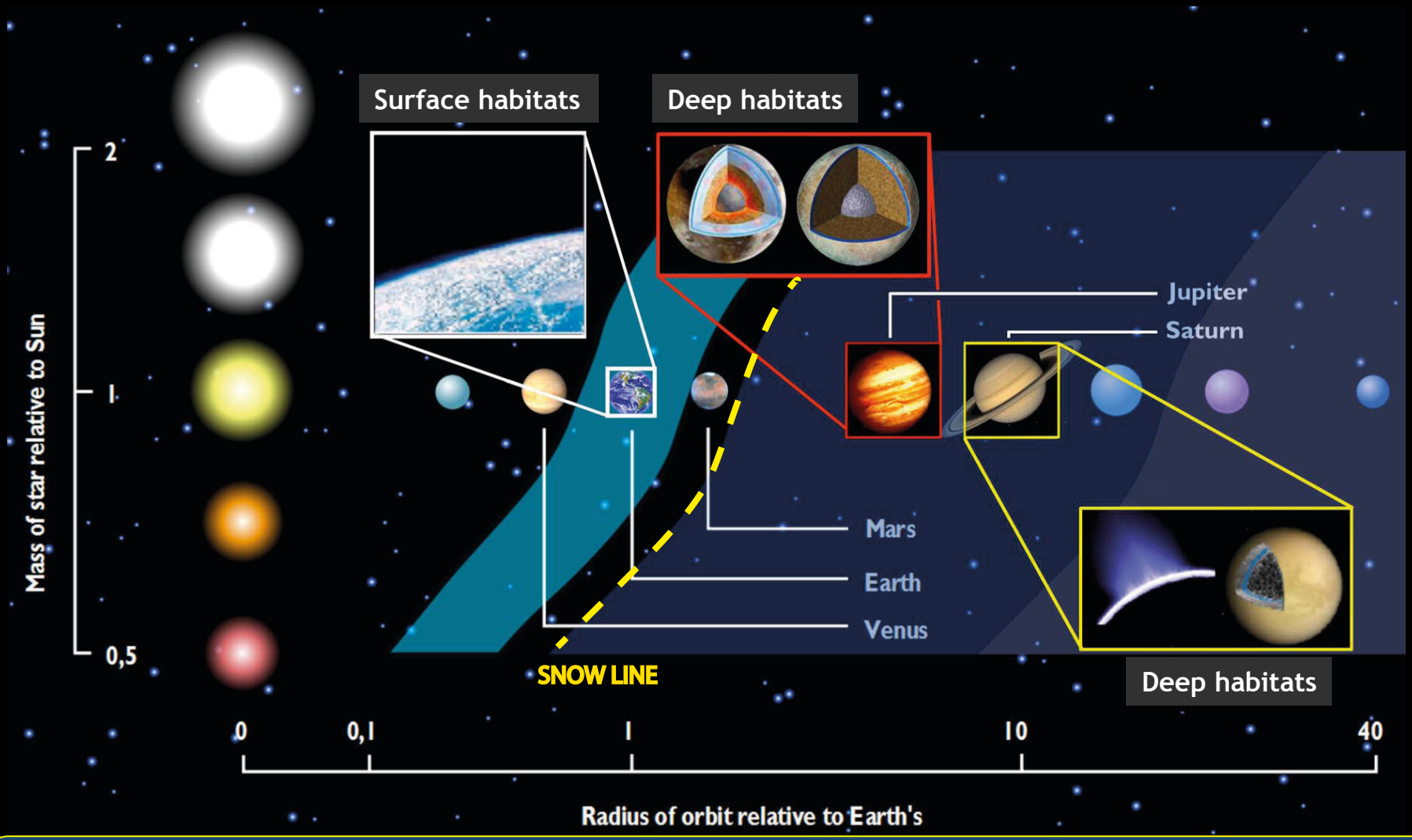


What are the habitable worlds?

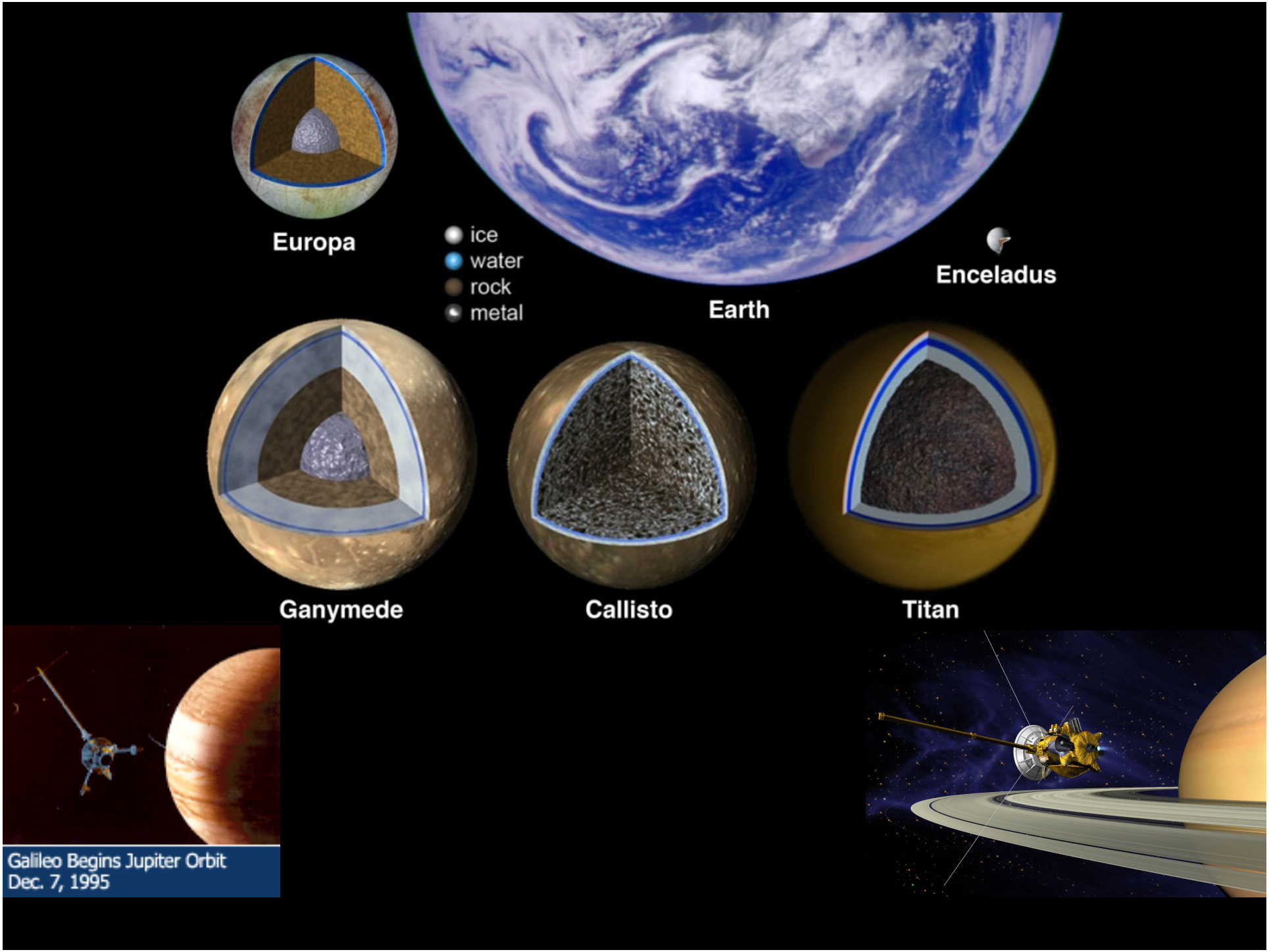


Lammer et al., 2009

Icy moons : deep habitats in the solar system



Classes I-II: habitable zones on the surface, not much water, small domain
Beyond the snow-line: deep habitats within the hydrospheres. Icy moons, Ganymede and Europa and Titan and Enceladus, are the archetypes of classes III-IV of habitable worlds

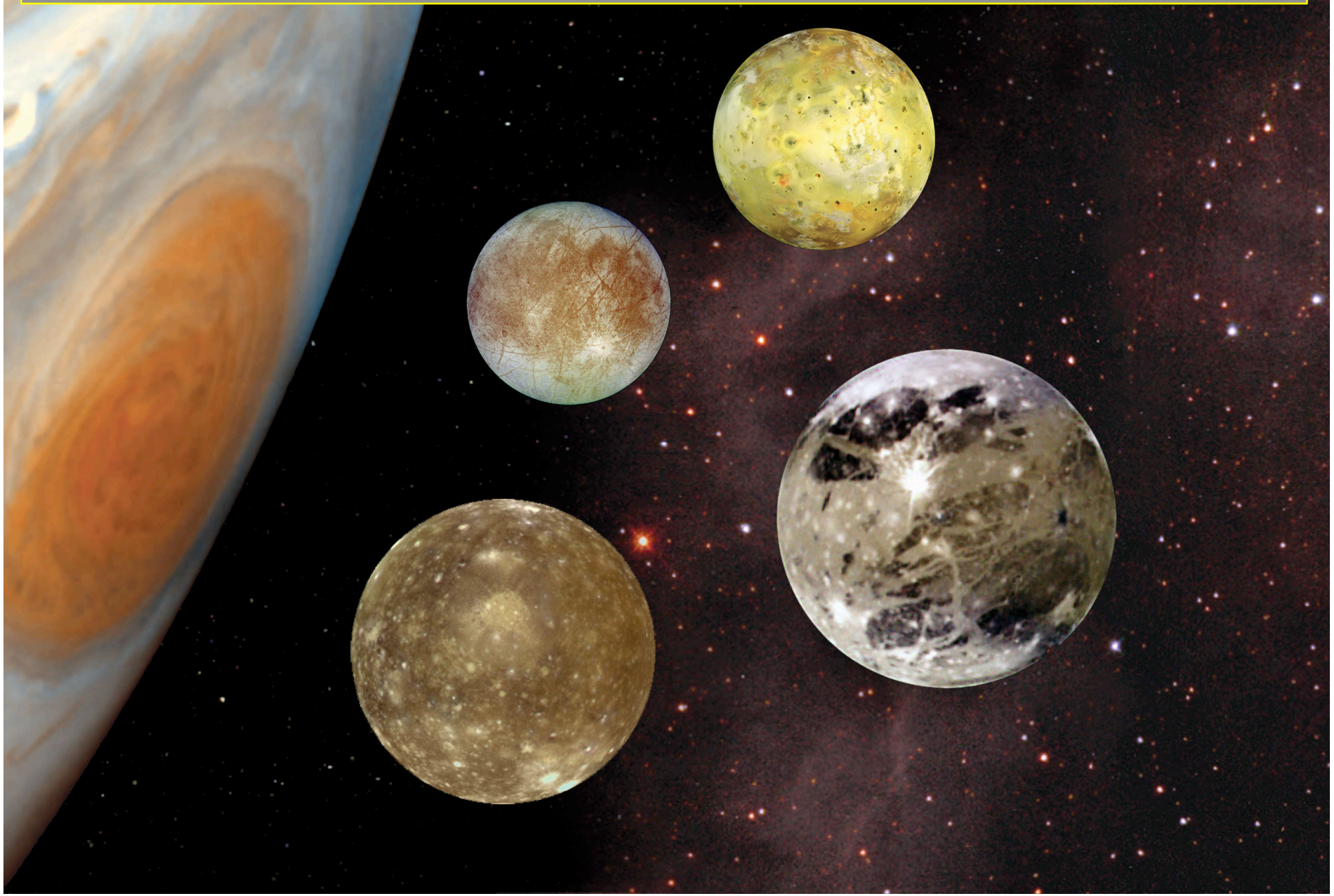

Europa
ice
water
rock
metal
Earth
Enceladus
Ganymede
Callisto
Titan
Galileo Begins Jupiter Orbit
Dec. 7, 1995

What are the habitable worlds in the outer solar system ?
Around JUPITER

Habitats in the Jupiter system

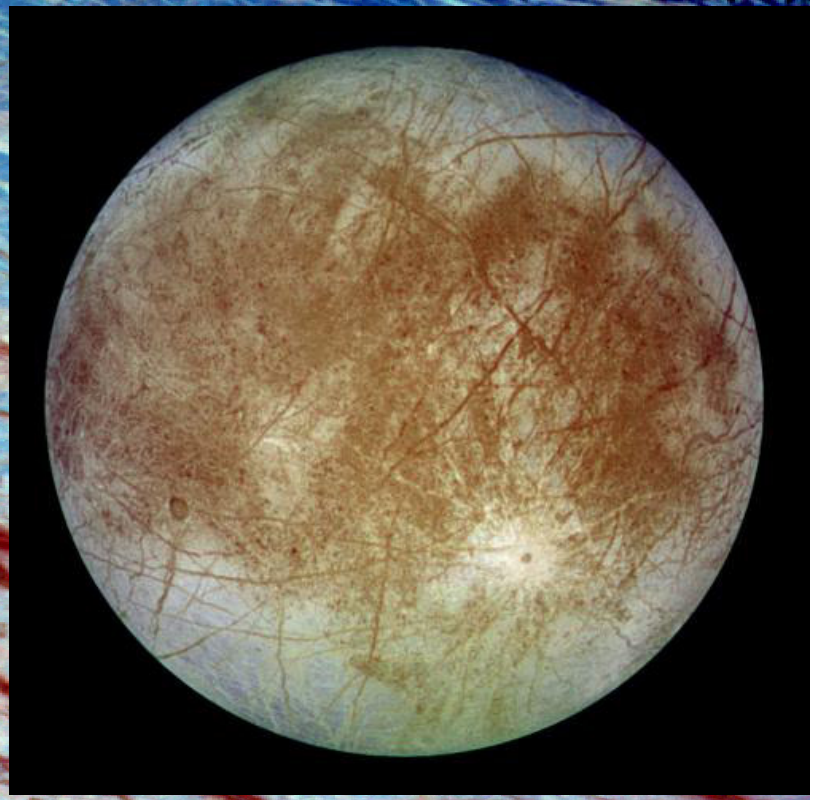
The Jupiter System

A giant planet, a giant magnetosphere, many moons including 4 giants = a mini solar system

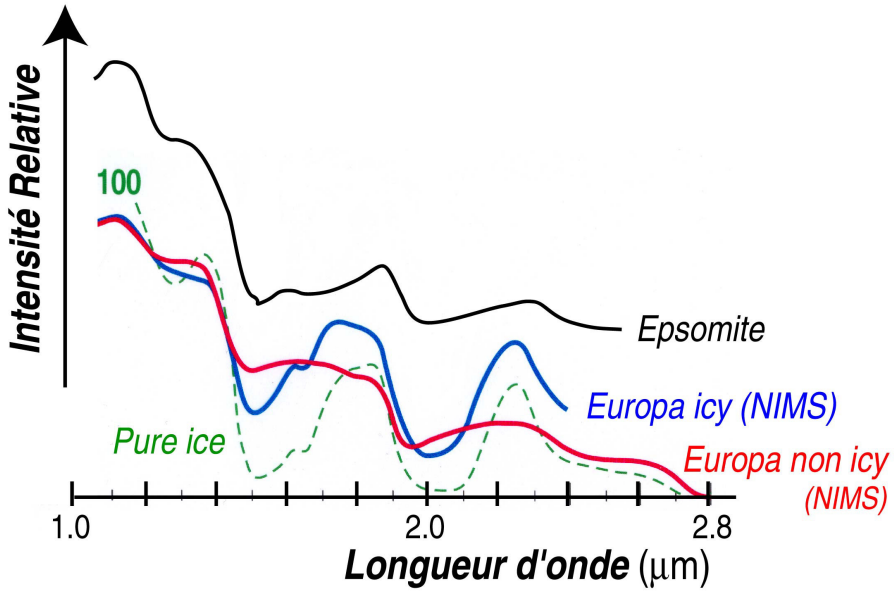


About the existence of deep liquid layers : EUROPA

Hyperspectral evidences



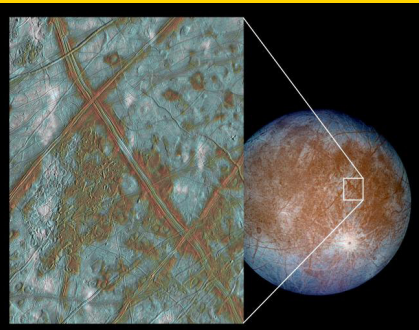
Composition of ices

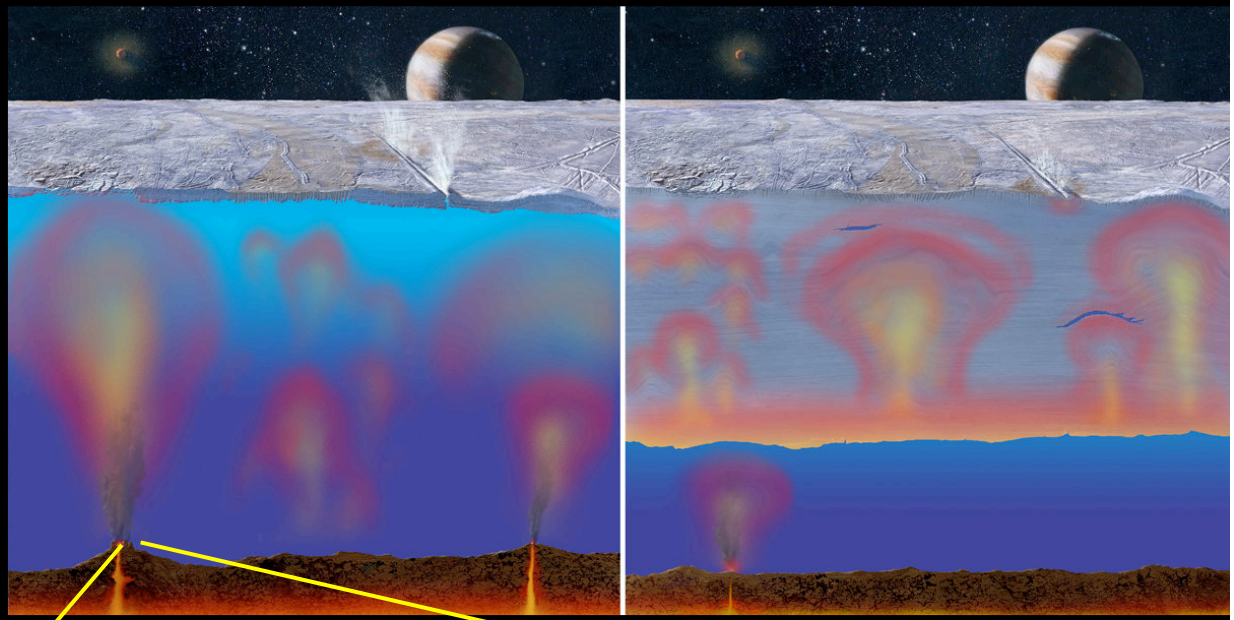


from McCord et al. (1999)

What are the habitable worlds in the outer solar system ? Around JUPITER

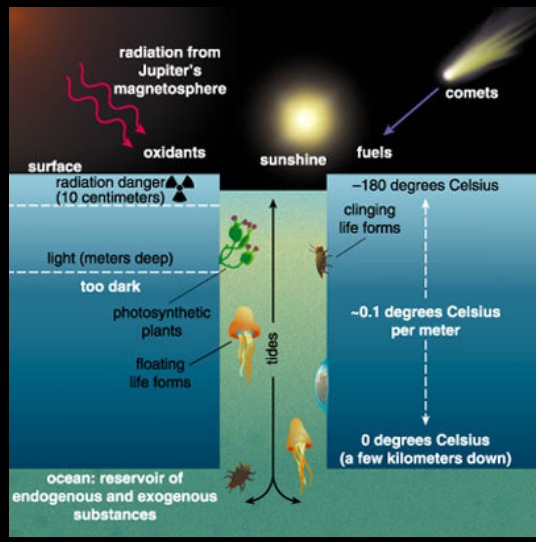
Class III : subsurface oceans in contact with silicates - Europa





Europa-like worlds:

- Water:
  - Warm salty H_2O ocean.
- Essential elements:
  - Impactors.
  - Photolysis -> O, O2
  - But radiation destroys organics in upper ~10s cm of ice.
- Chemical energy:
  - Radiation of $H_2O \Rightarrow$ oxidants.
  - Mantle contact: serpentinization and possible hydrothermal activity
- Relatively stable environment:
  - Large satellite retains heat.
  - But activity might not be steady-state.

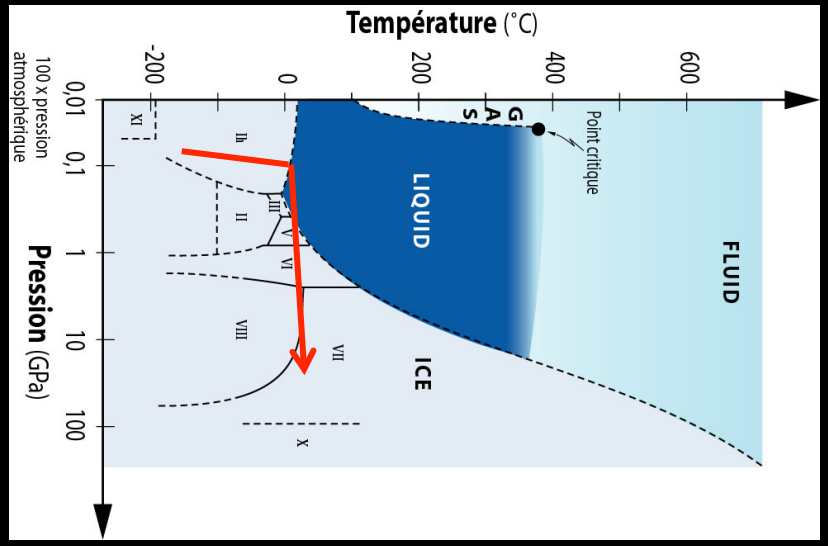


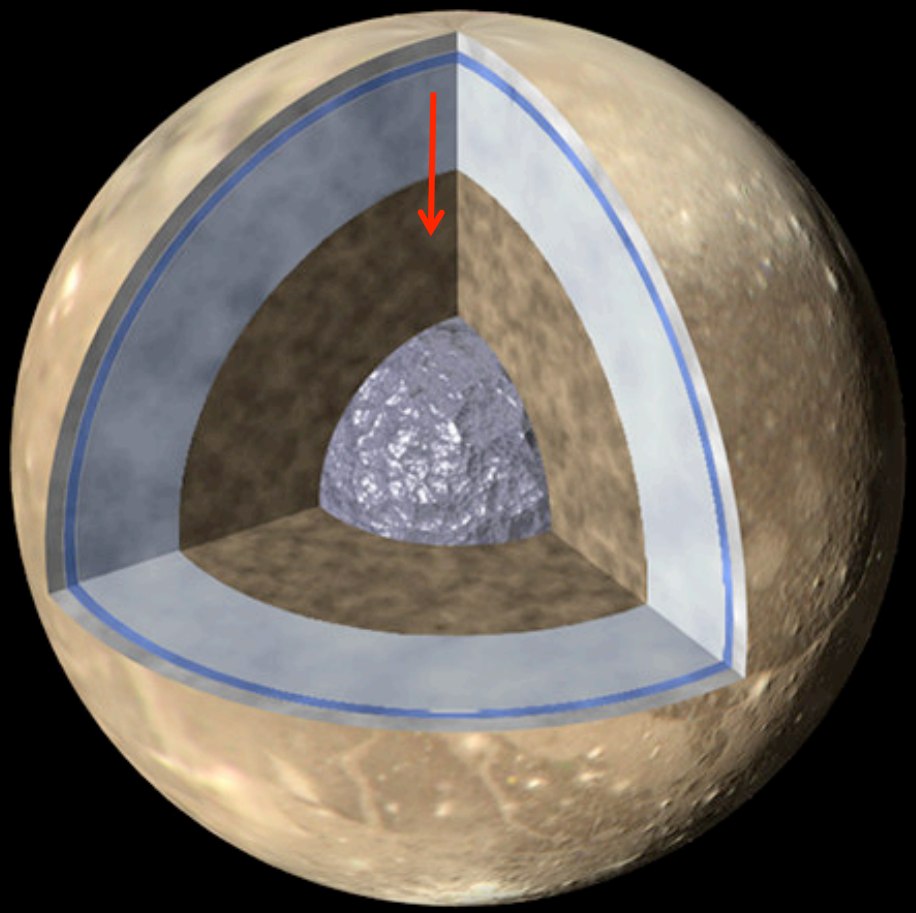
What are the habitable worlds?

Class IV : subsurface oceans without any contact with the silicates

Ganymede-like

- Liquid water
- Chemistry: silicate needed…?
- Energy: heat transfer ?
- Stable environment





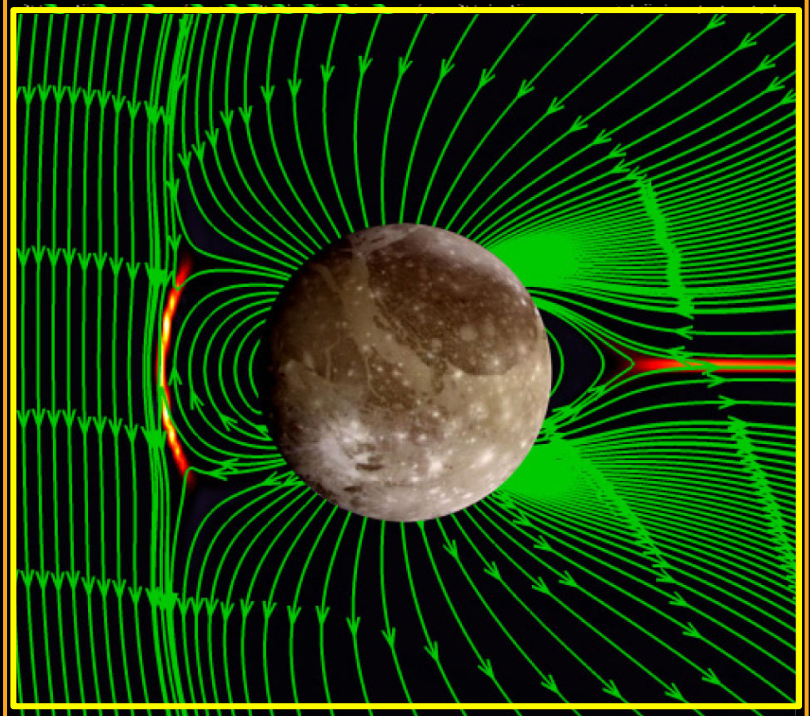
H2O ice and liquid diagram studied since 1912 (Bridgman)
Modern experiments are devoted to complex mixtures and indicate you can have liquid between ice layers.

About the existence of deep oceans : GANYMEDE

Galileo evidences

- **Induced magnetic field from interaction of jovian magneto with conducting layer (ocean?)**

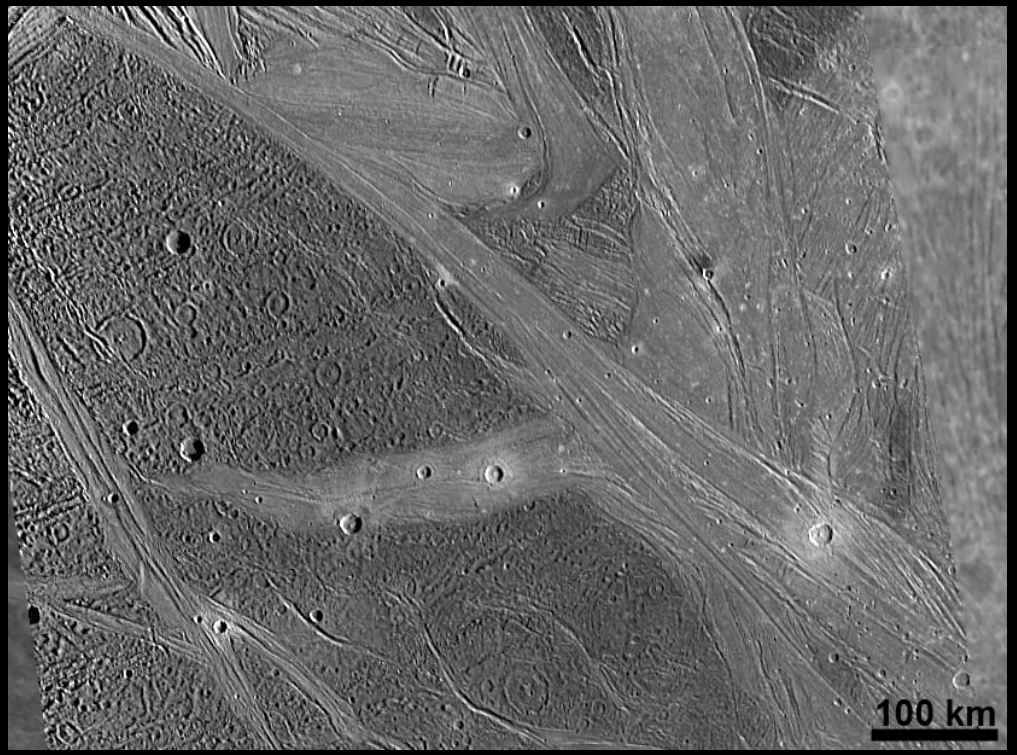
Observed but not characterised



- Own internally-driven dipole magnetic field
- Interaction of Ganymede's mini-magnetosphere with Jupiter's

Geologic activity

Indications for young surface from water flooding



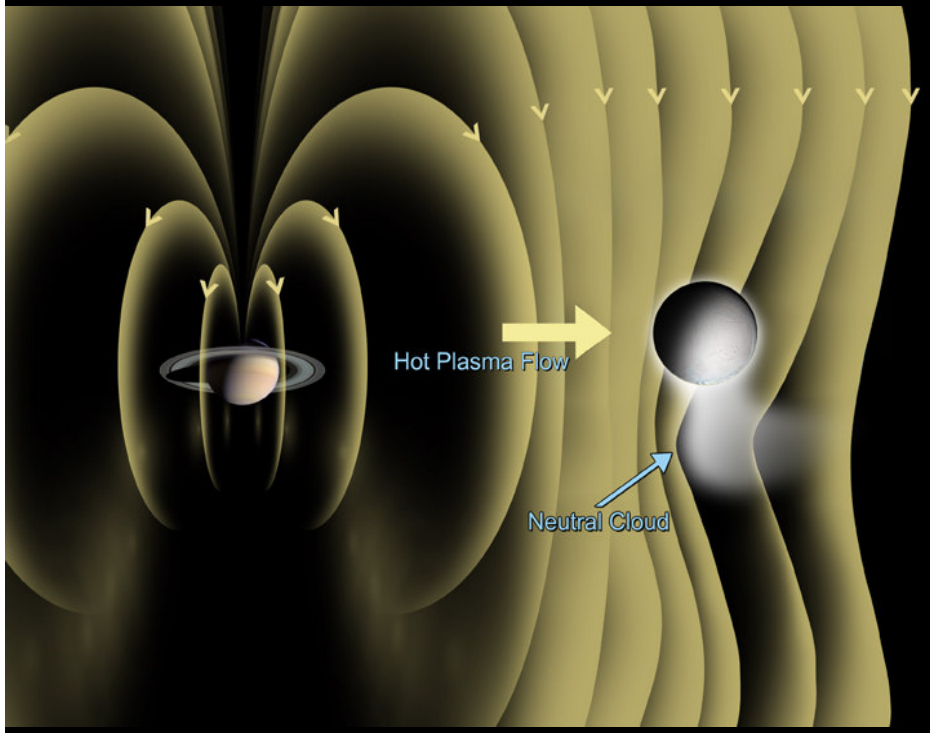
Questions

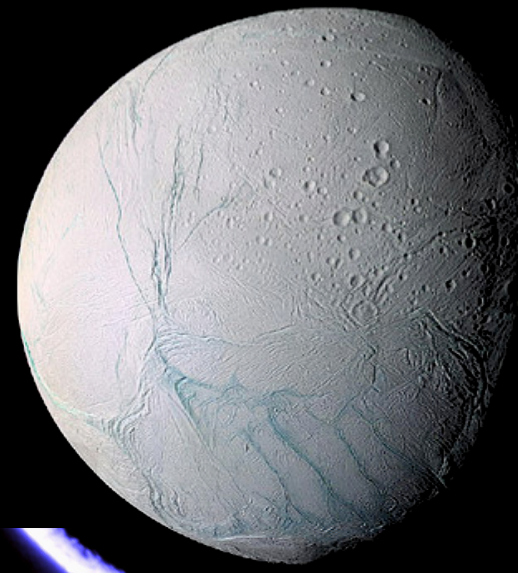
- ✧ **Which depth?**
- ✧ **Which size?**
- ✧ **What is its composition?**

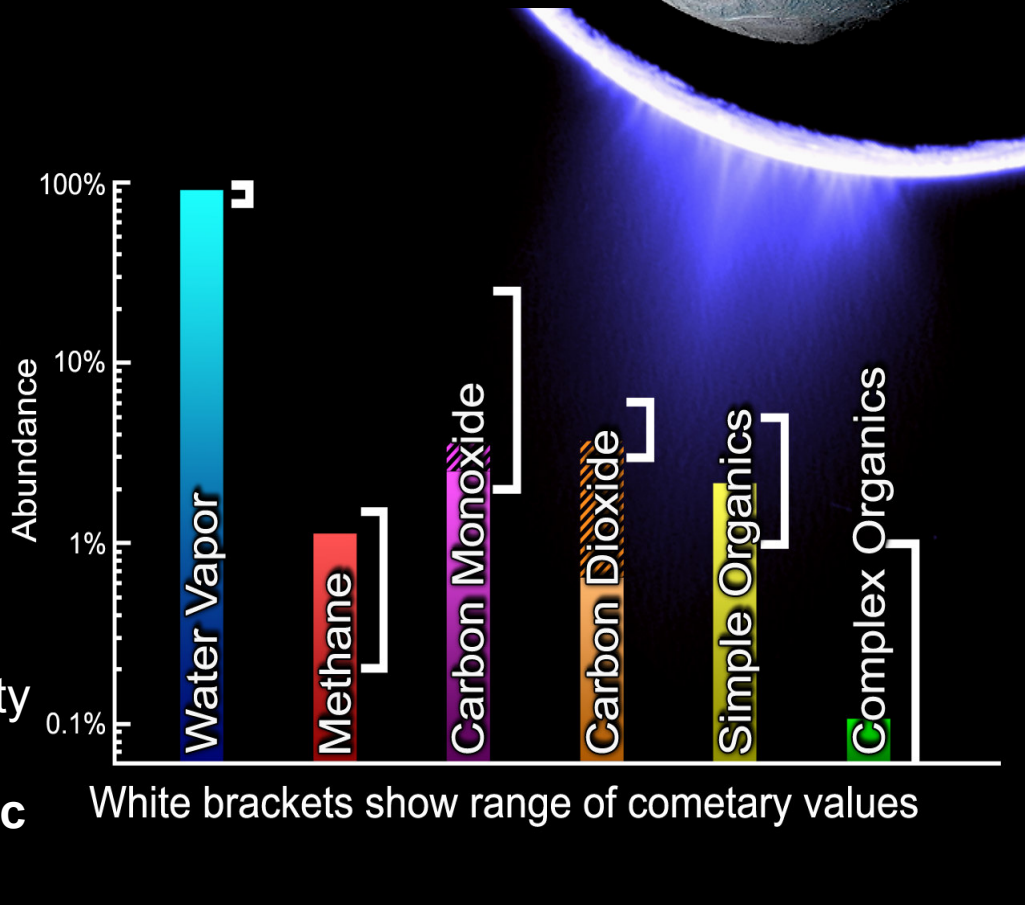
What are the habitable worlds in the outer solar system ?
Around SATURN

Habitats in the Saturnian system

Enceladus plumes





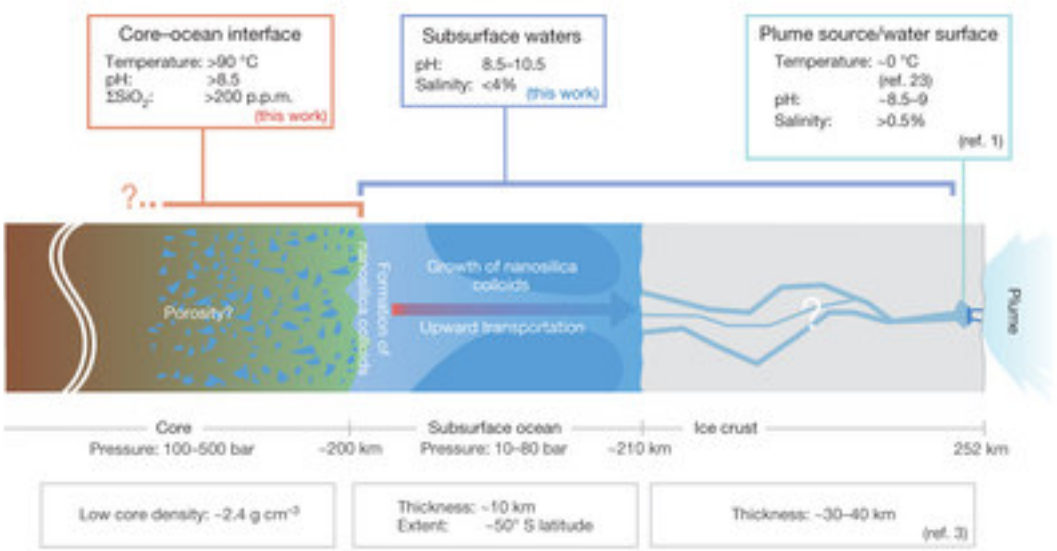


- **What is the origin of the plumes**
- **Replenishment of E-ring?**
- **Water vapor ejecta far away from the Sun** (strong implications for the habitability zones)
- **Indications for the presence of organic chemistry**

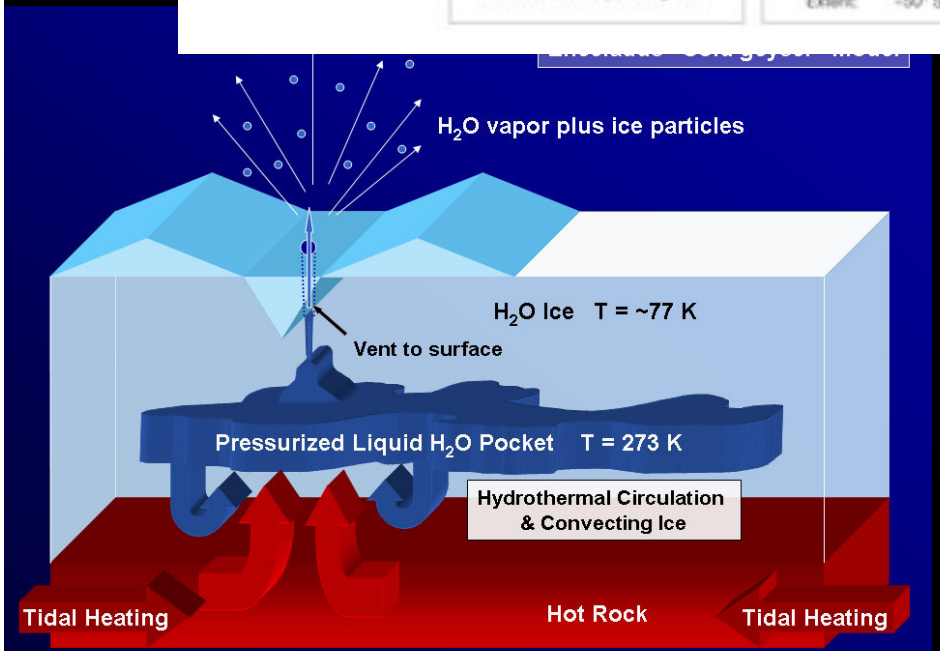
What are the habitable worlds in the outer solar system ? Around SATURN

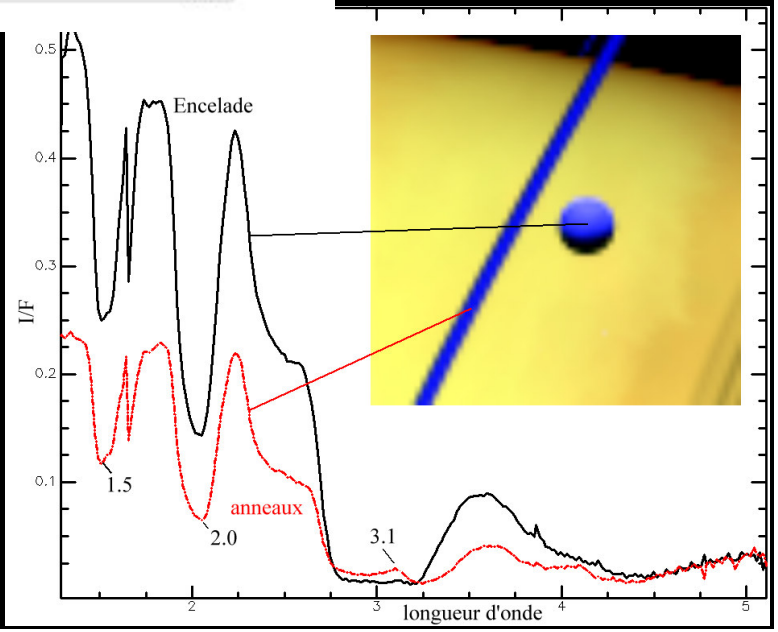
Class III : subsurface oceans in contact with silicates –Enceladus

: A schematic of Enceladus' interior.



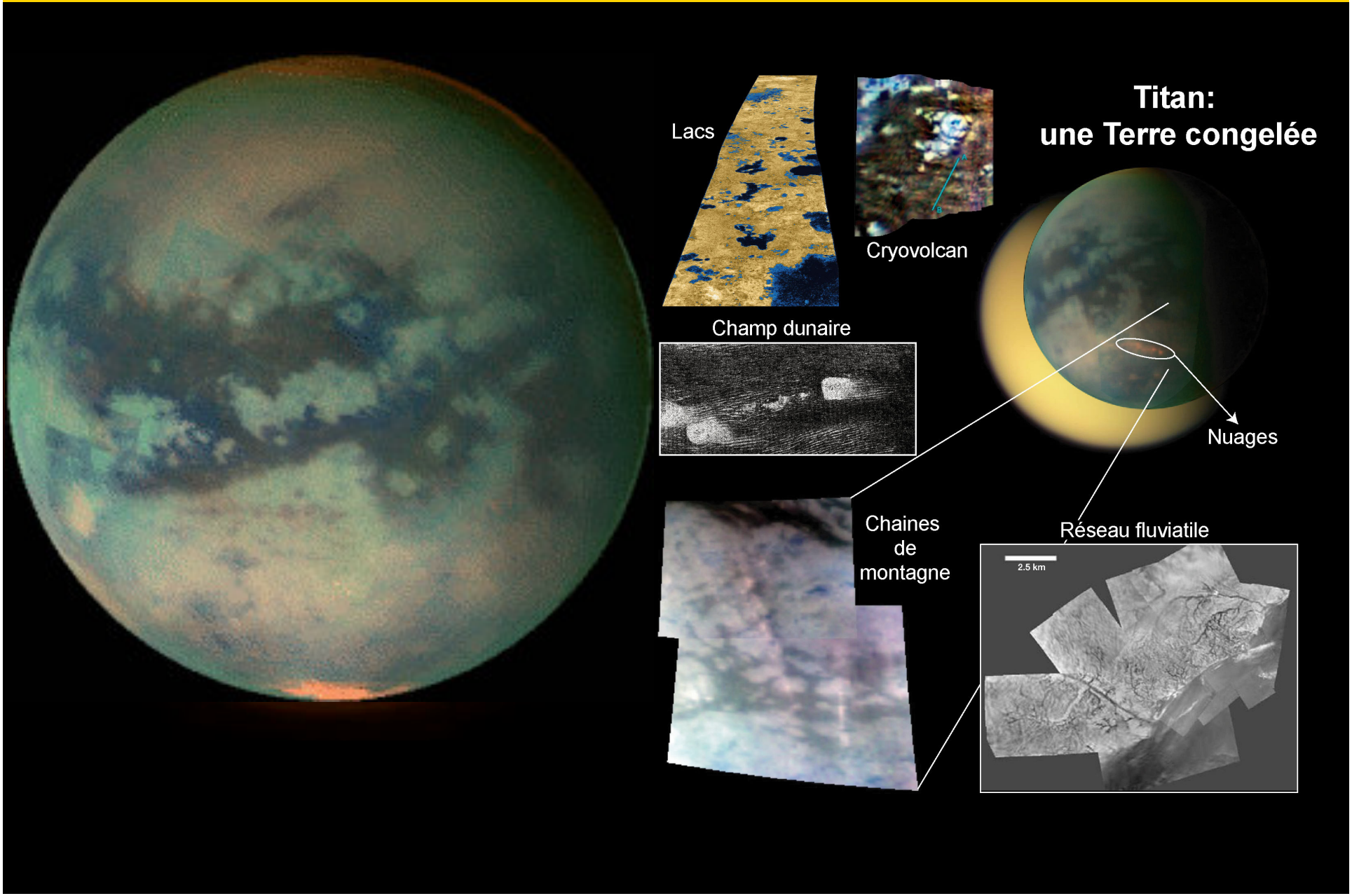
From Hsu et al. 2015





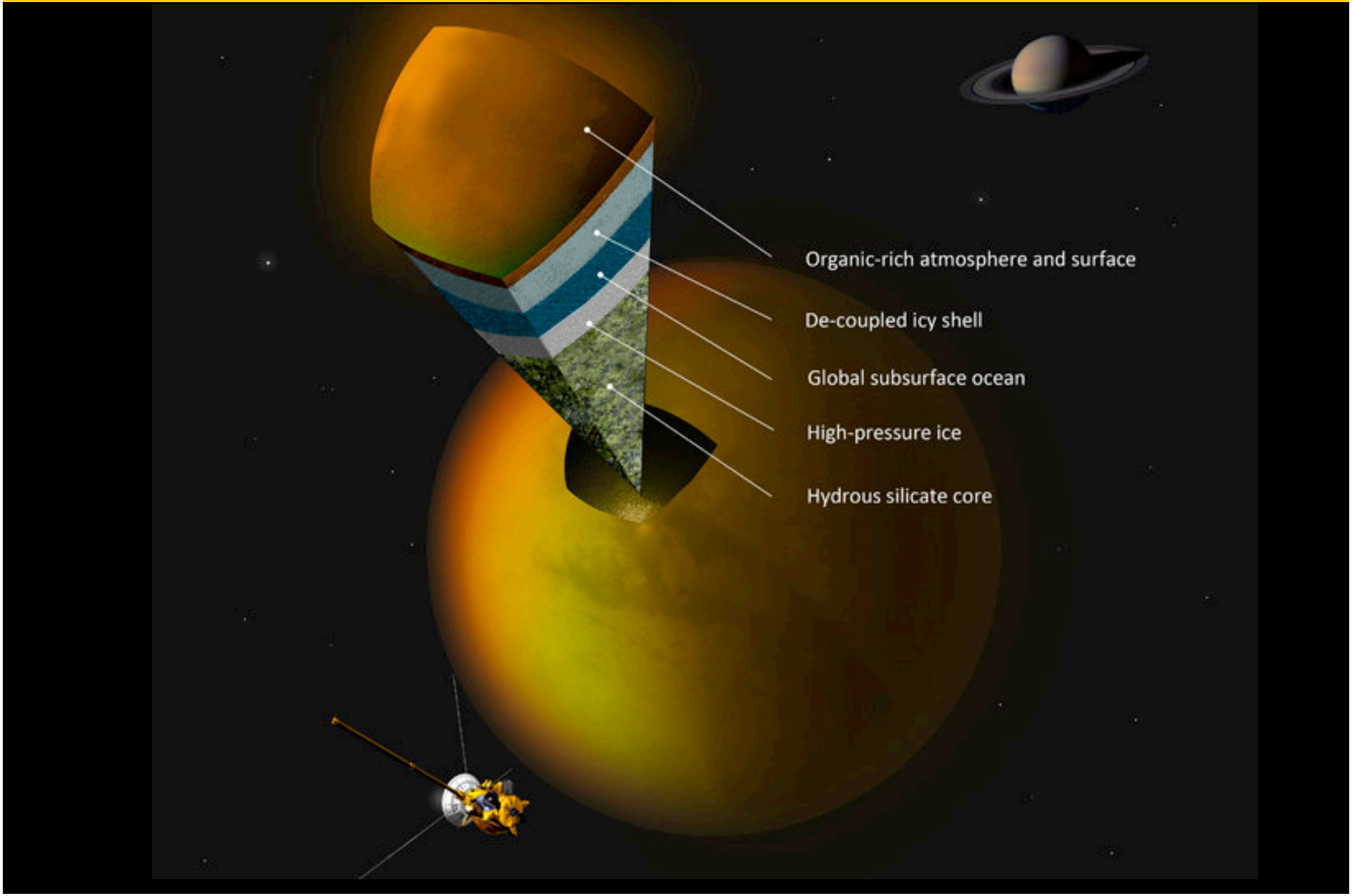
What are the habitable worlds in the outer solar system ? Around SATURN

Class IV : subsurface oceans without any contact with the silicates – Titan



What are the habitable worlds in the outer solar system ? Around SATURN

Class IV : subsurface oceans without any contact with the silicates - Titan



Habitable worlds in the outer solar system ?

Future exploration

Need for further in-depth and in situ exploration of the deep habitats and the extended habitable zone around gas giants

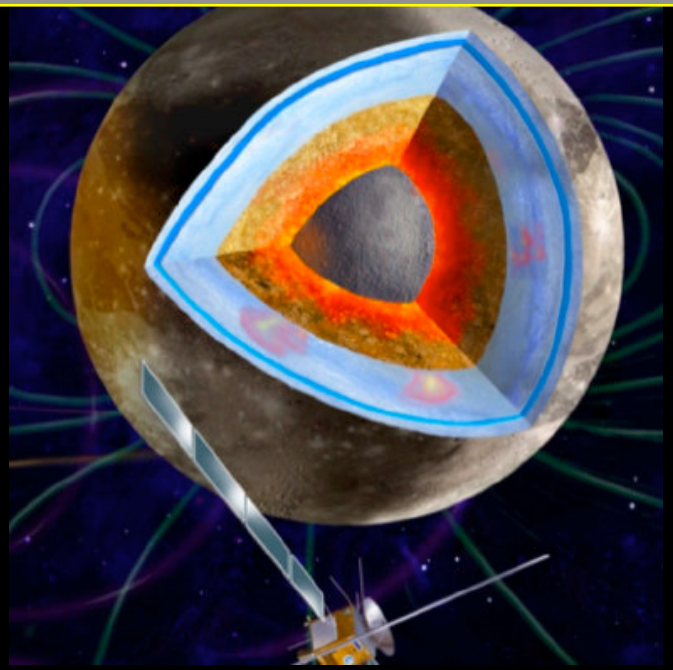
Emergence of the habitable zone around Jupiter

Three large icy moons to explore

Ganymede - class IV

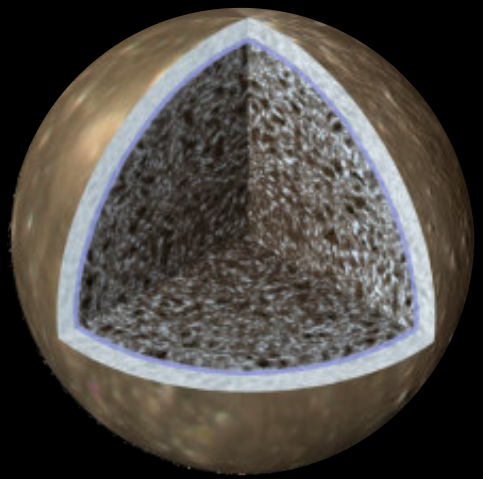
- Largest satellite in the solar system
- A deep ocean
- Internal dynamo and an induced magnetic field – unique
- Richest crater morphologies

- Best example of liquid environment trapped between icy layers



Callisto - class IV

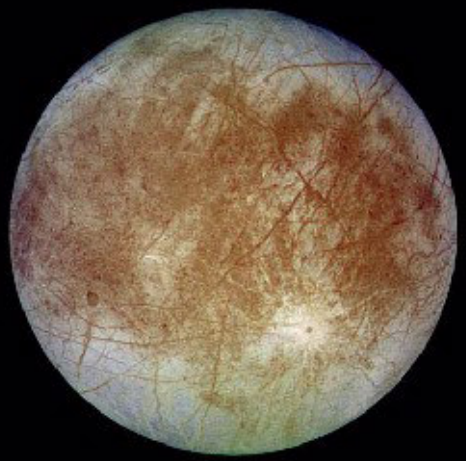
- Best place to study the impactor history
- Differentiation – still an enigma
- Only known example of non active but ocean-bearing world
- The witness of early ages



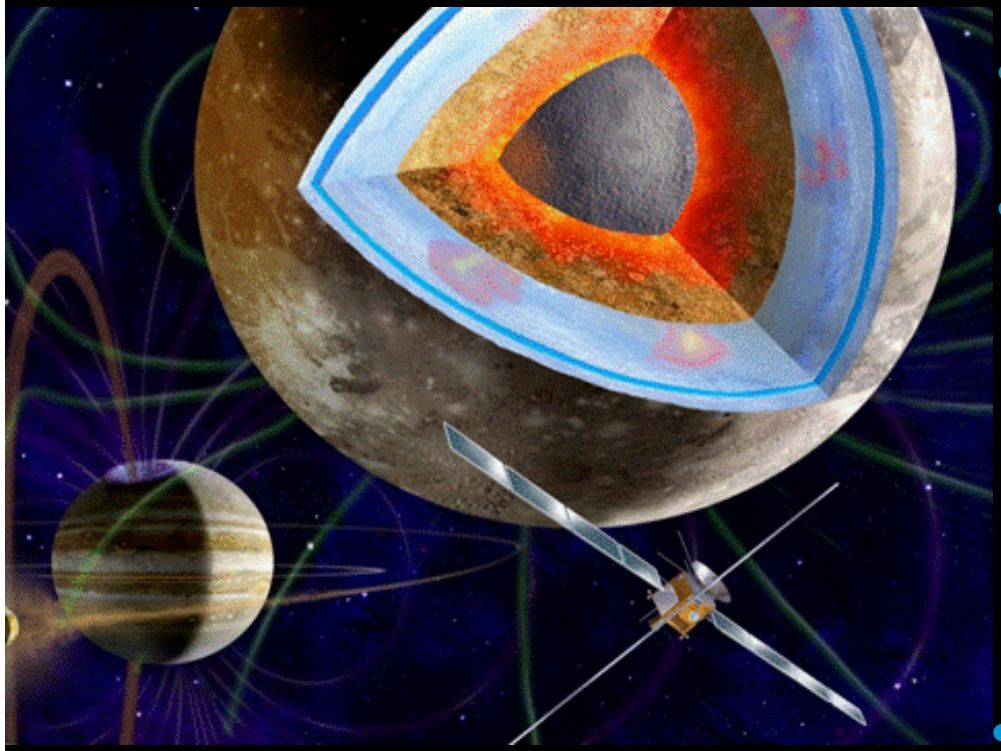
Europa - class III

- A deep ocean
- An active world?

- Best example of liquid environment in contact with silicates

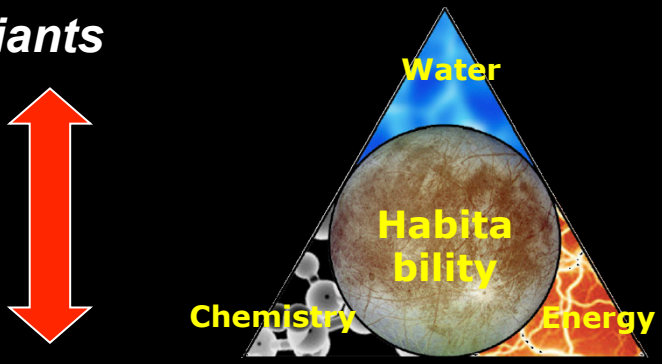


JUICE: JUpiter Icy moons Explorer



JUICE Science Goals

- *Emergence of habitable worlds around gas giants*
- *Jupiter system as an archetype for gas giants*



Cosmic Vision Themes

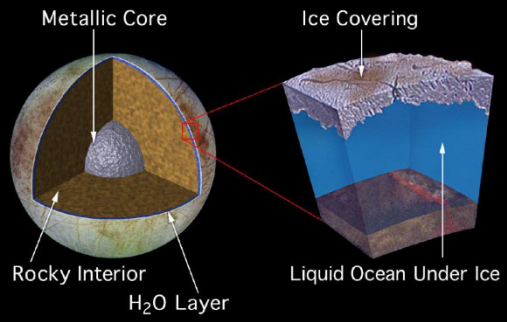
- *What are the conditions for planetary formation and emergence of life?*
- *How does the Solar System work?*

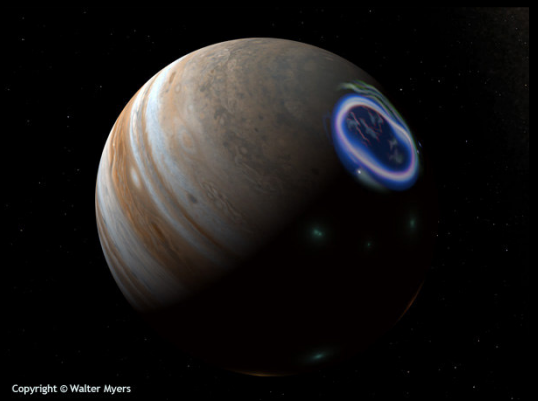
JUICE : the 1st Large CV mission concept

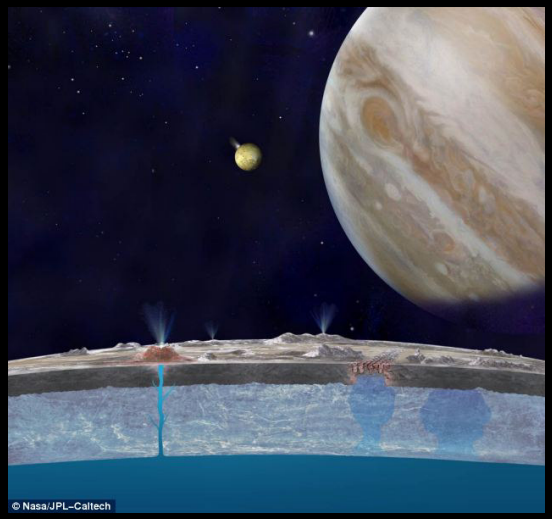
- *Single spacecraft mission to the Jovian system*
- *Investigations from orbit and flyby trajectories*
- *Synergistic and multi-disciplinary payload*
- *European mission with international participation*

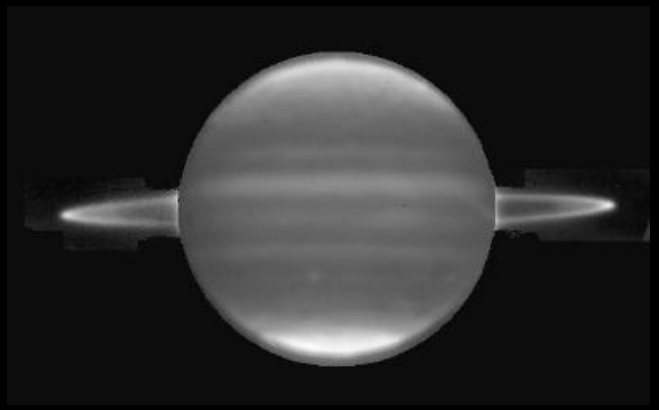
Topics:
Planet, moons, rings, magneto

- Interior
- Subsurface
- Geology
- Atmosphere
- Plasma
- Habitability
- Link to exoplanets





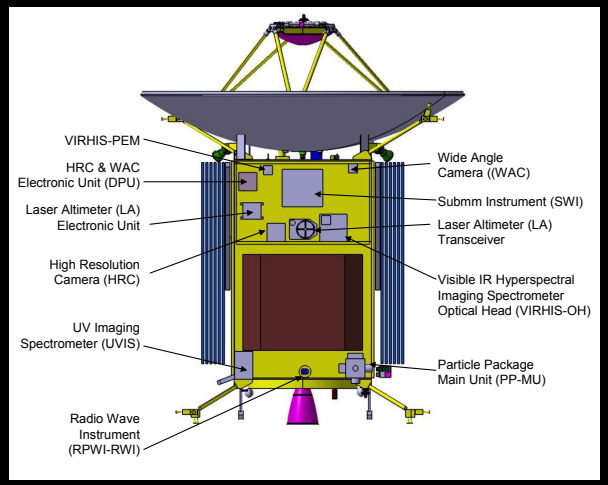


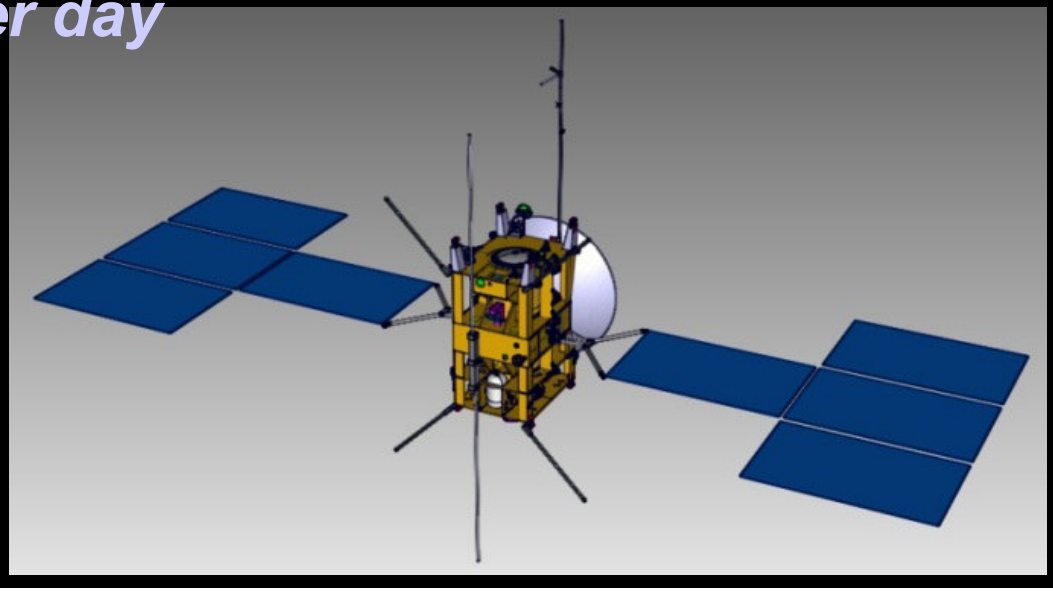


Jupiter system: largest planet, largest storm, fastest rotation, largest magnetic field, largest moon, largest moon system, most active moons

Main features of the spacecraft design

- *Dry mass ~2000 kg, propellant mass ~3000 kg*
- *Launcher - Ariane 5 ECA (mass : 5-5.5 tons), High Δv required: 2600 m/s*
- *Payload ~110 kg, ~ 150 W*
- *3-axis stabilized s/c*
- *Power: solar array ~ 70 m², ~ 700 W*
- *HGA: ~3 m, fixed to body, X & Ka-band*
- *Data return >1.4 Gb per day*





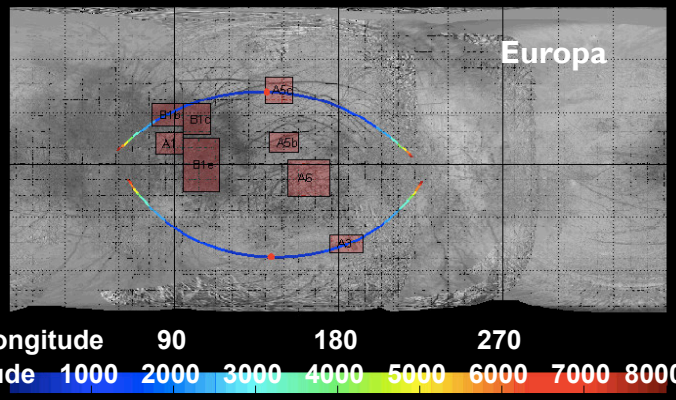
JUICE Payload

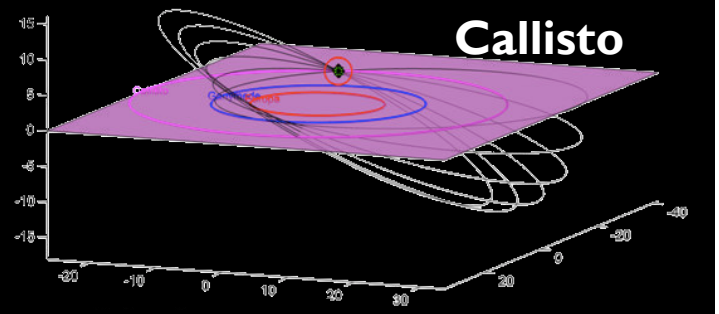
Acronym	PI	LFA	Instrument type
Remote Sensing Suite			
JANUS	P. Palumbo	Italy	Narrow Angle Camera
MAJIS	Y. Langevin G. Piccioni	France Italy	Vis-near-IR imaging spectrometer
UVS	R. Gladstone	USA	UV spectrograph
SWI	P. Hartogh	Germany	Sub-mm wave instrument
Geophysical Experiments			
GALA	H. Hussmann	Germany	Laser Altimeter
RIME	L. Bruzzone	Italy	Ice Penetrating Radar
3GM	L. Iess	Italy	Radio science experiment
PRIDE	L. Gurvits	Netherlands	VLBI experiment
Particles and Fields Investigations			
PEP	S. Barabash	Sweden	Plasma Environmental Package
RPWI	J.-E. Wahlund	Sweden	Radio & plasma Wave Instrument
J-MAG	M. Dougherty	UK	Magnetometer

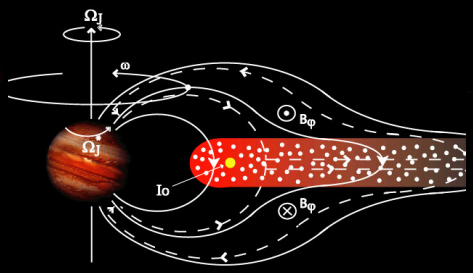
Mission design

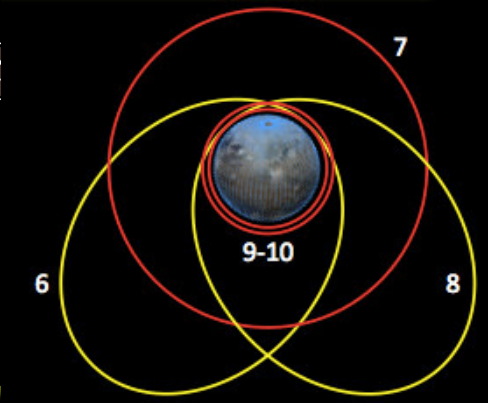
JUICE

Spacecraft Design	Model instruments	Mission phases
Launch	June 2022	
Interplanetary transfer (Earth-Venus-Earth-Earth)	7.6 years (8 years)	
Jupiter orbit insertion and apocentre reduction with Ganymede gravity assists	11 months	
2 Europa flybys	36 days	
Reduction of v_{inf} (Ganymede, Callisto)	60 days	
Increase inclination with 10 Callisto gravity assists	200 days	
Callisto to Ganymede	11 months	
Ganymede (polar) 10,000x200 km & 5000 km 500 km circular 200 km circular	 150 days 102 days 30 days	
Total mission at Jupiter	3 years	









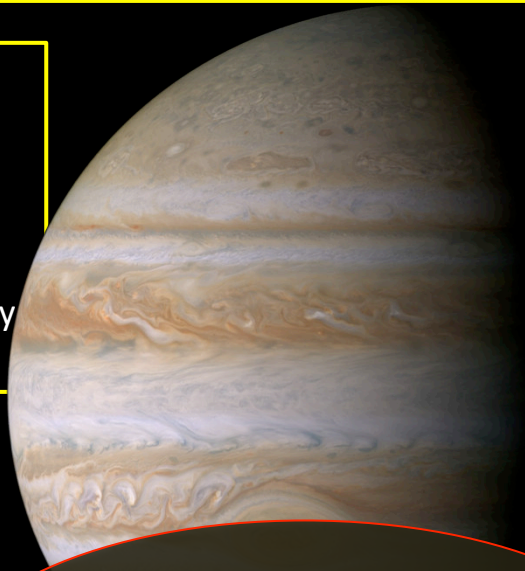
Exploration of the Jupiter system

JUICE

The biggest planet, the biggest magnetosphere, and a mini solar system

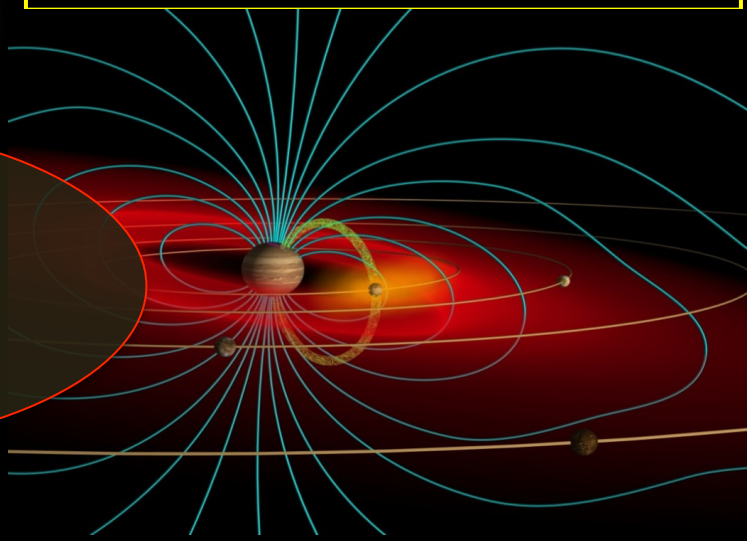
Jupiter

- Archetype for giant planets
- Natural planetary-scale laboratory for fundamental fluid dynamics, chemistry, meteorology,...
- Window into the formational history of our planetary system



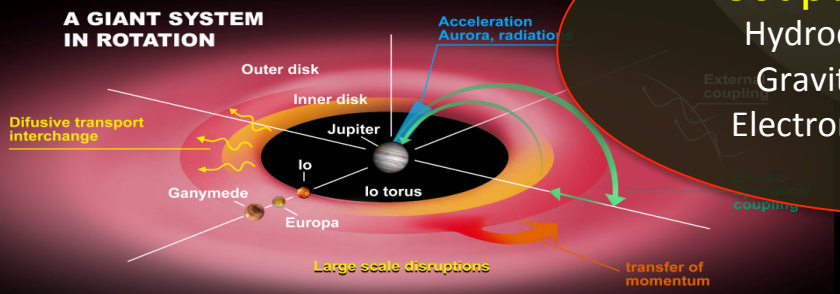
Magnetosphere

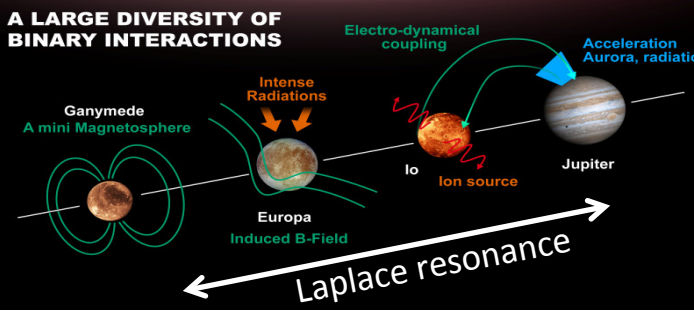
- Largest object in our Solar System
- Biggest particle accelerator in the Solar System
- Unveil global dynamics of an astrophysical object



Coupling processes

Hydrodynamic coupling
Gravitational coupling
Electromagnetic coupling





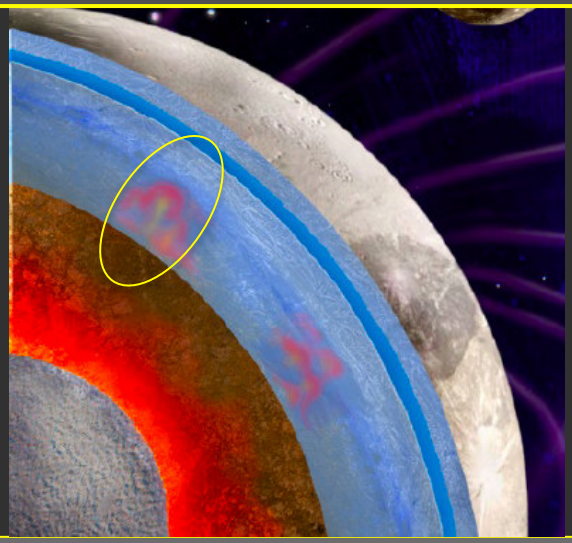
Satellite system

- Tidal forces: Laplace resonance
- Electromagnetic interactions to magnetosphere and upper atmosphere of Jupiter

From the Jupiter system to extrasolar planetary systems

Waterworlds and giant planets | Habitable worlds | Astrophysics Connection

Waterworlds: If habitable, the liquid layers are trapped between two icy layers

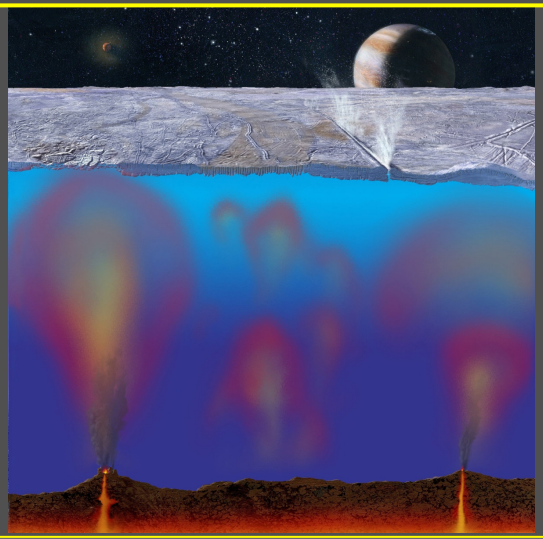


Occurrence:
Largest moons, hot ice giants, ocean-planets…
Most common habitat in the universe ?

Key question:
Are these waterworlds habitable ?

What JUICE will do:
Via characterisation of Ganymede, will constrain the likelihood of habitability in the universe

Europa-like: If habitable, the liquid layers may be in contact with silicates as on Earth



Occurrence:
Europa, Enceladus
Only possible for very small bodies

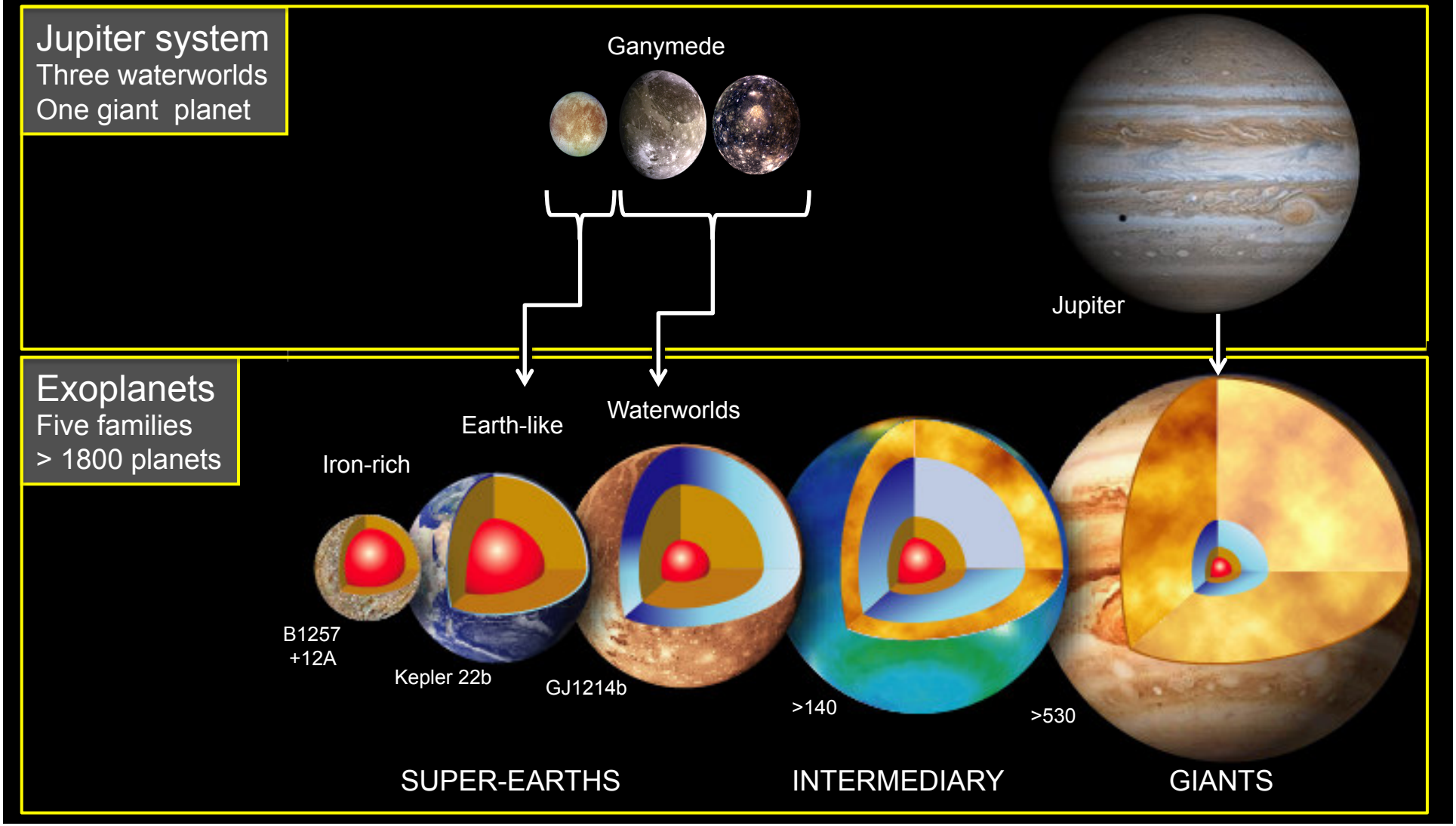
Key question:
How are the surface active areas related to potential deep habitats?

What JUICE will do:
Pave the way for future landing on Europa
Better understand the likelihood of deep local habitats

From the Jovian system to extrasolar planetary systems

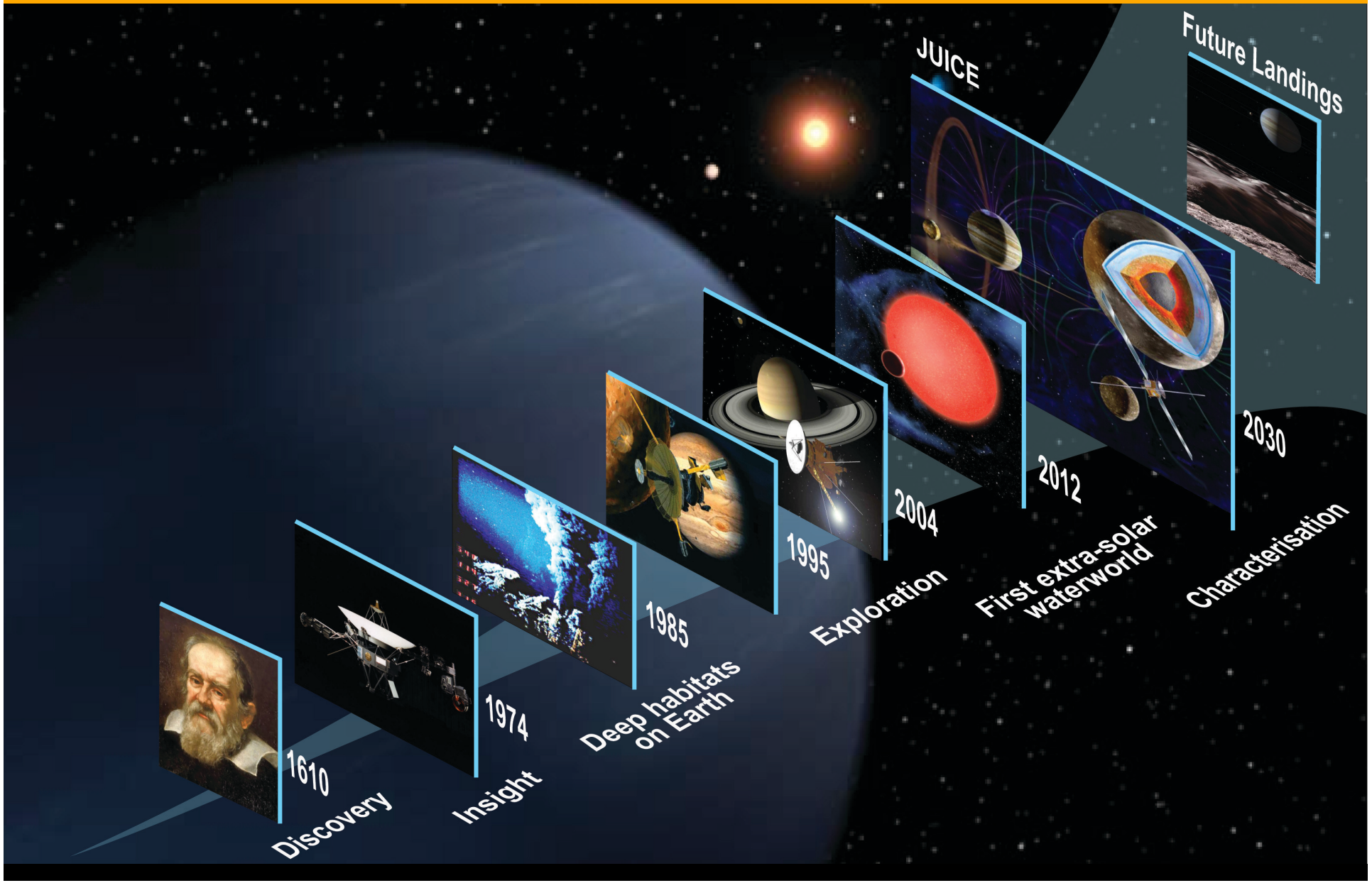
Waterworlds and giant planets | Habitable worlds | Astrophysics Connection

By studying Ganymede, we can characterise an entire family of exoplanets: the waterworlds.

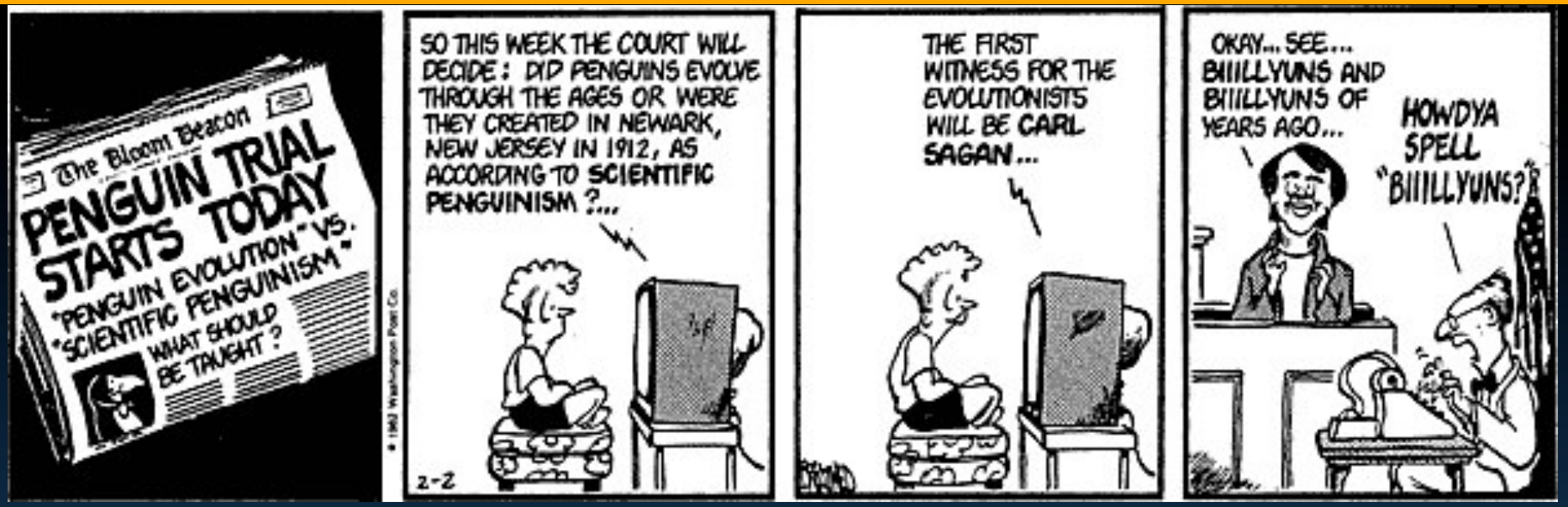


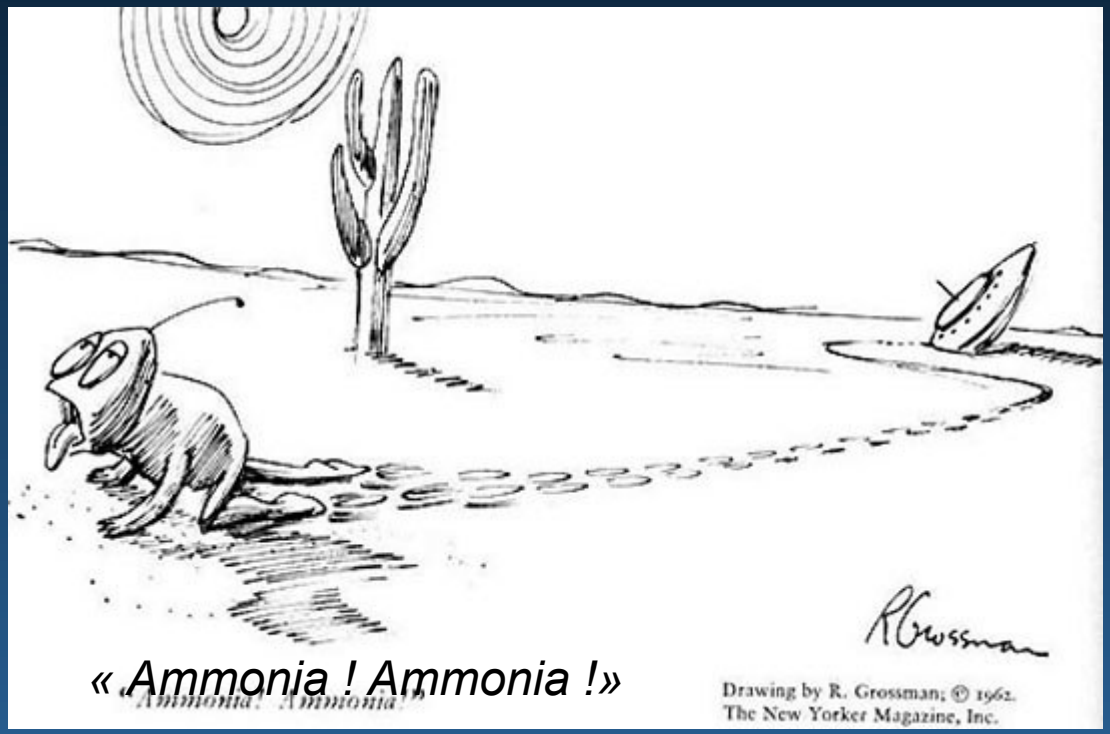
THE FUTURE OF EXPLORATION

Rich future for exploration of habitable worlds in the outer solar system with JUICE as L1 and more : missions to Europa, Titan, Enceladus, and exoplanets (CHEOPS+PLATO+ARIEL at ESA)



OTHER LIFE FORMS AND THE LOOK FOR HABITATS





« Ammonia ! Ammonia !»

Drawing by R. Grossman; © 1962. The New Yorker Magazine, Inc.

Thank you
and au revoir !