Astrobiology
Lecture 14
The outer Solar System

Trieste University, Academic Year 2021-2022
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Life in the outer Solar System

- The outer Solar System lies far beyond the outer edge of the classic "habitable zone"
- Notwithstanding, planets and satellites of the outer Solar System have an important astrobiological potential

- Beyond the outer edge if the HZ life could be present:
  - in subsurface regions of planets or satellites where the thermodynamical conditions are compatible with the presence of liquid water
  - in the form of organisms with the capability of suspending the metabolism at very low temperatures
  - in the form of organisms that use a medium alternative to water, characterized by a low freezing point

Astrobiological relevance of giant planets

Jupiter

Sagan & Salpeter (1976) investigated the potential habitability of Jupiter's atmospheric layers

Some of the external atmospheric layers have pressure and temperature in the intervals

10^5 Pa $< p < 10^7$ Pa and $300 < T < 500$ K

In principle, these ranges of pressure and temperature allow water to be present in liquid phase in such atmospheric layers

- Hypothetical forms of life should stay suspended in those layers and resist to harsh conditions
- It is very unlikely that any type of material may stay suspended in the "habitable" layers given the presence of strong winds and convection

Giant planets are not considered to be habitable

Astrobiological relevance of giant planets

Giant planets of the outer Solar System can play a role in affecting the long term habitability of terrestrial planets

Giant planets as triggers of dynamical instabilities

Migrations of large gas giants like Saturn and Jupiter <u>scattered minor bodies rich of water and organic material, providing a potential source of prebiotic ingredients eventually delivered to the Earth</u>

Giant planets as protective shields

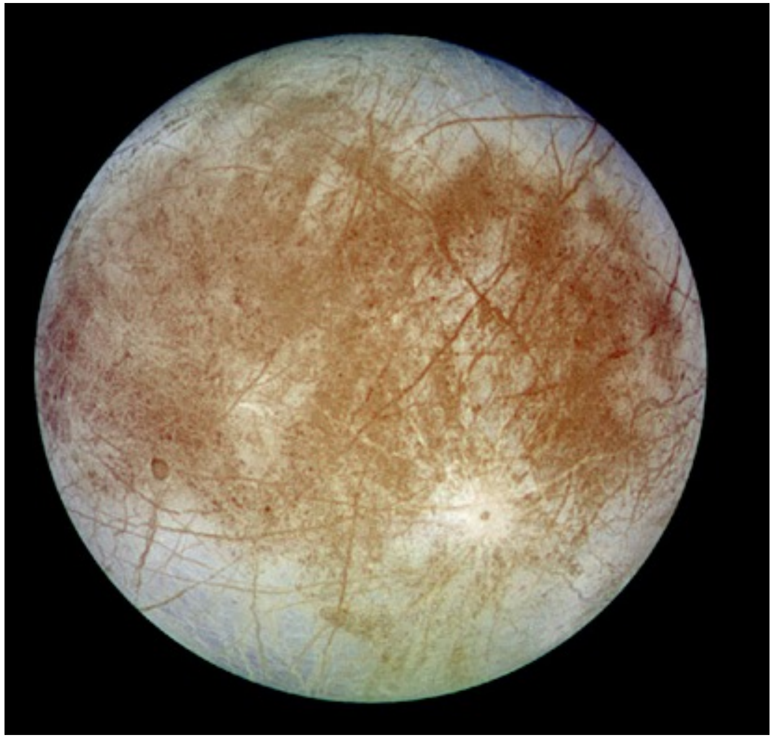
Jupiter has a role in shielding the terrestrial planets from comet impacts in the Solar System

In this sense, jovian planets may help to keep a long-term habitability for the evolution of life on Earth

Results of recent simulations (Grazier 2016) suggest that the role of "Jupiter as shield" might have been quite negligible

Life in moons and minor bodies of the outer Solar System

- Some icy moons of the outer Solar System are good candidates to search for subsurface life
- Titan, the largest moon of Saturn, is a laboratory for testing the possibility of alternative forms of biochemistry
- Minor satellites, such as Enceladus, and transneptunian objects are also being considered in astrobiological studies



Europe

One of the 4 major moons of Jupiter

– The second one in order of distance

Europes' surface is not habitable

$<T_s> = 103$ K, $p_s = 10^{-6}$ Pa

Despite the lack of surface habitability, Europe is one of the most interesting bodies in the Solar System from the point of view of astrobiology

Europe

Europe has been the target of several space missions

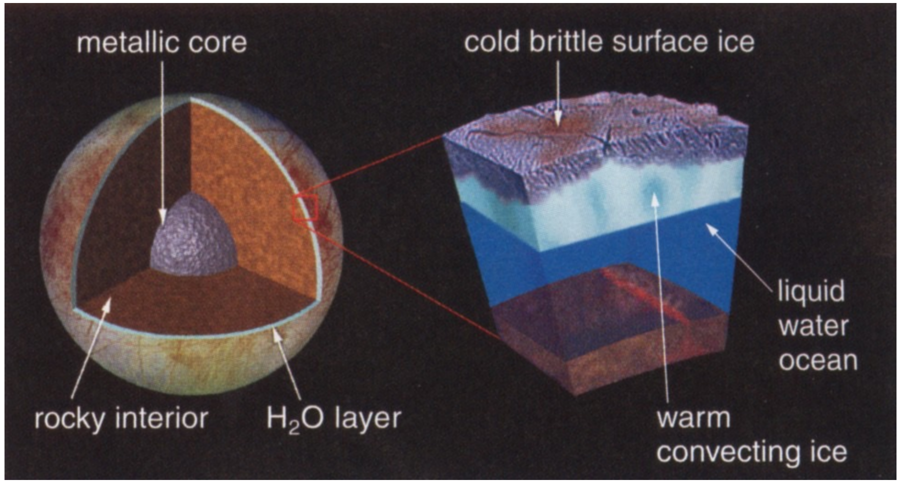
The most detailed observations have been obtained by the “Galileo” probe

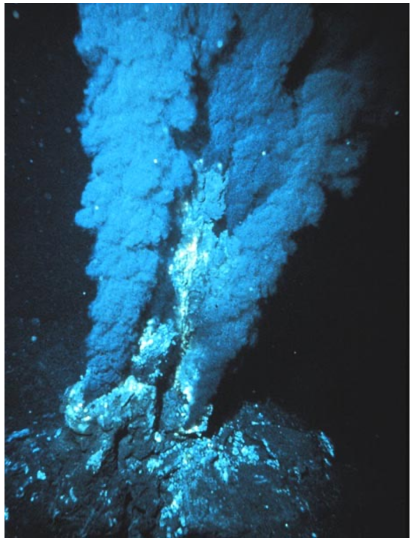
- Launched in 1989, the probe made several “flybyes” around Europe in 1997

The surface of Europe is made of H_2O ice

- The surface morphology, with relatively few impact craters, suggests that the surface is constantly being reshaped
- Different types of shallow structures can be seen on the surface
  - Their presence is emphasized by differences in albedo

Habitability of Europe's interior

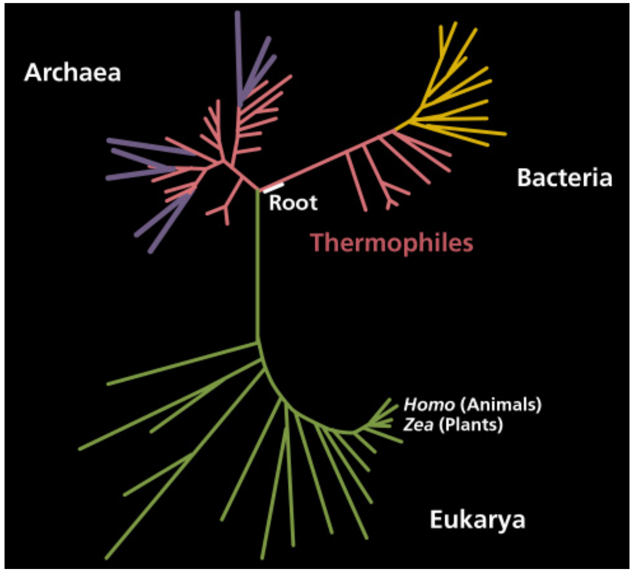


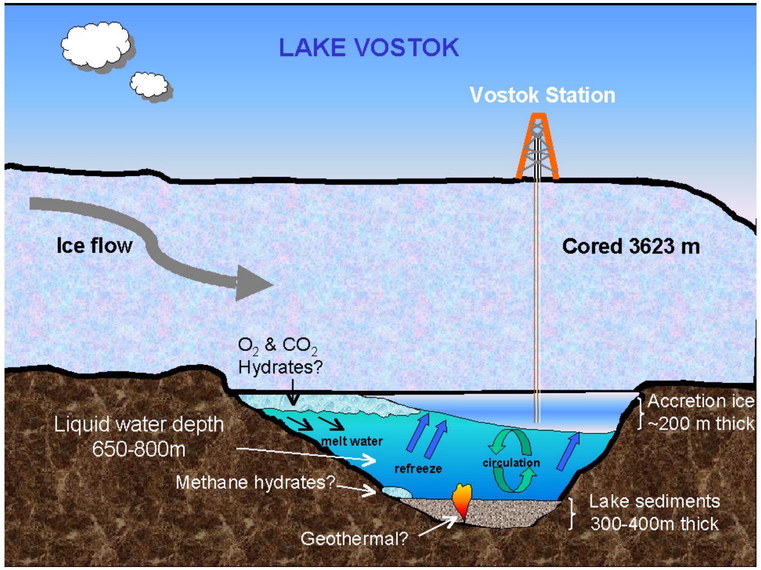


- The presence of liquid water <u>below the surface</u> makes Europe a candidate for studies of habitability outside the "circumstellar habitable zone" (which is defined according to the <u>surface habitability</u>)
- It is plausible that "hydrothermal vents", similar to those found at the bottom of the Earths oceans, may exist at the bottom of Europe's ocean
- In this case, all the main ingredients of habitability would be present:

  Liquid water, energy sources, protection from ionizing radiations

Motivations to search for life on Europe
Connection with studies in Antarctica





- The fact that Earth's termophilic organisms found around hydrothermal vents are close to the root of the phylogenetic tree (relatively close to the origin of life), provides an argument in favour of the possible presence of life
- The existence of terrestrial cryophilic organisms and the searches for life in Anctartic subglacial lakes are motivated by the similarity with Europe's conditions
- The extremophiles found in Antarctica and the technology required to carry out this type of research are all relevant for Europe's astrobiological studies

On the possibility of emergence of life in icy moons

Even if the conditions of habitability are present in the subsurface oceans of Europe, it is not clear whether life could have originated in such type of environment

The possibility of an autotrophic emergence of life in hydrothermal vents is questioned by many authors

According to Pascal (2016), the physico-chemical requirements inferred for chemical self-organization hardly support an emergence of life in the deep oceans of icy moons

The search for life in subsurface oceans is essential to prove or dismiss different scenarios proposed for the origin of life

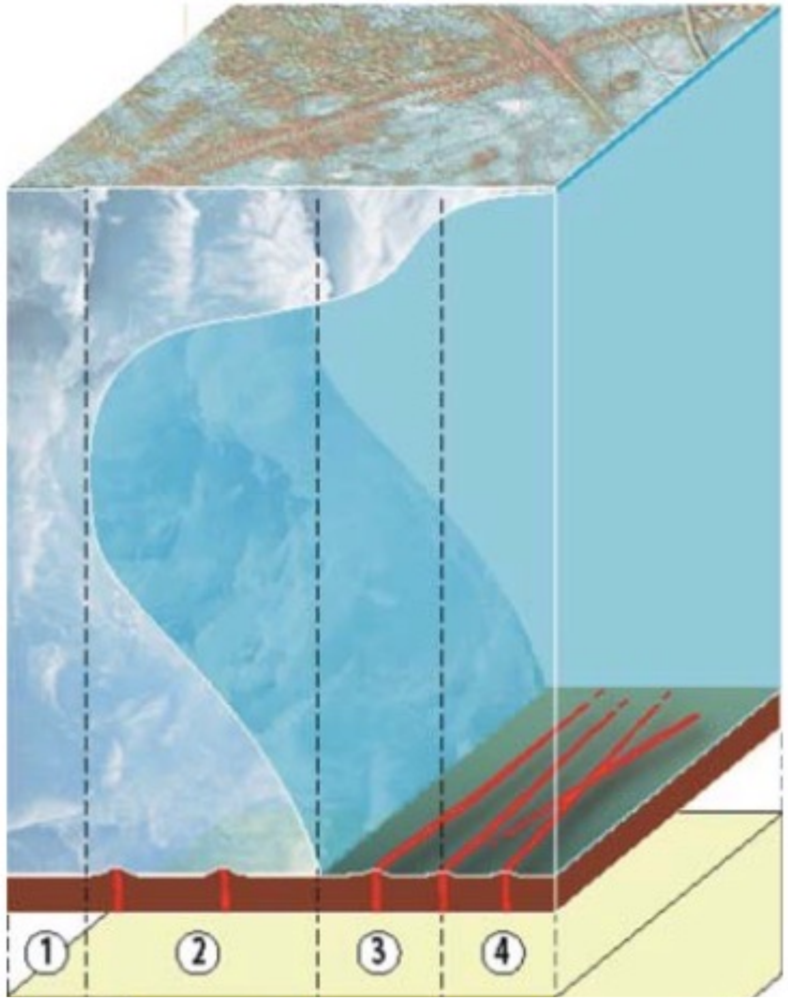
The large icy moons of Jupiter: Ganymede and Callisto

The ice layers are expected to be thicker in the large moons Ganymede and Callisto

The possible internal structure of these moons is sketched in the left of the figure (1 or 2), where internal pressures are sufficient to allow for the formation of high-pressure ice-phases

Oceans —if they exist—should be enclosed between thick ice layers (case 2 in the figure)

Moreover, Ganymede and Callisto probably undergo lower tidal heating than Europe since they lie at larger distances from Jupiter



Lammer et al. (2009)

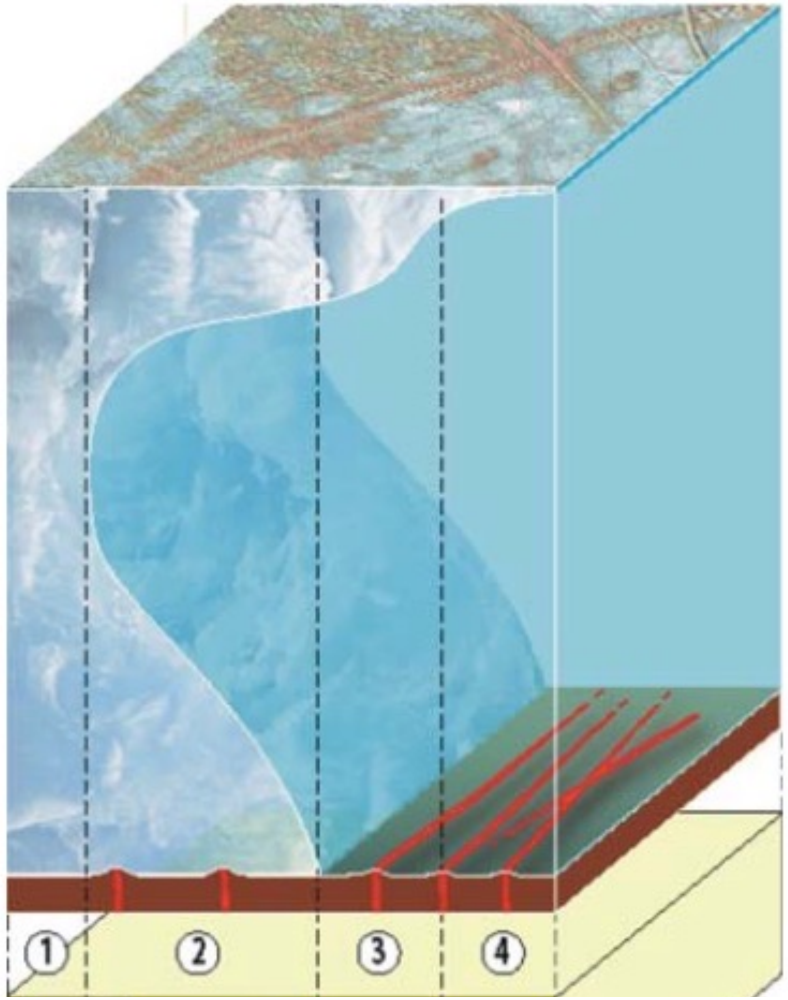
The large icy moons of Jupiter: Ganymede and Callisto

Case 2 in the figure:

The bottom of the oceans is not exposed to hydrothermal vents

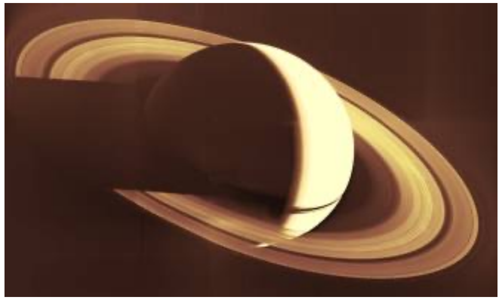
The problem of energy sources and of finding proper conditions for the origin of life is by far more complicated than in the case of Europa

This type of situation is expected to be present also in exoplanets with complete ice covers and large radii



Lammer et al. (2009)

Titan



- Largest satellite of Saturn

  Radius 40% of Earth's radius

  Non habitable surface:

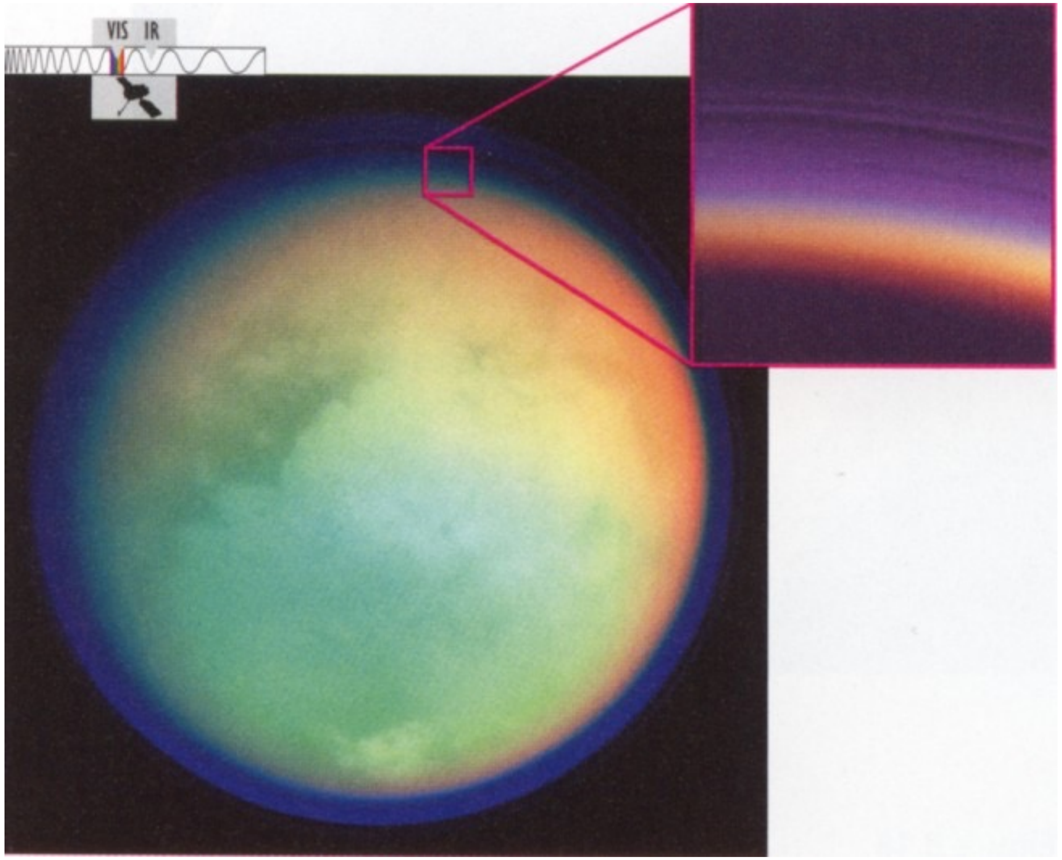
  $\langle T_s \rangle = 94$ K $\quad p_s = 1.47\ 10^5$ Pa
- Main observations from space missions

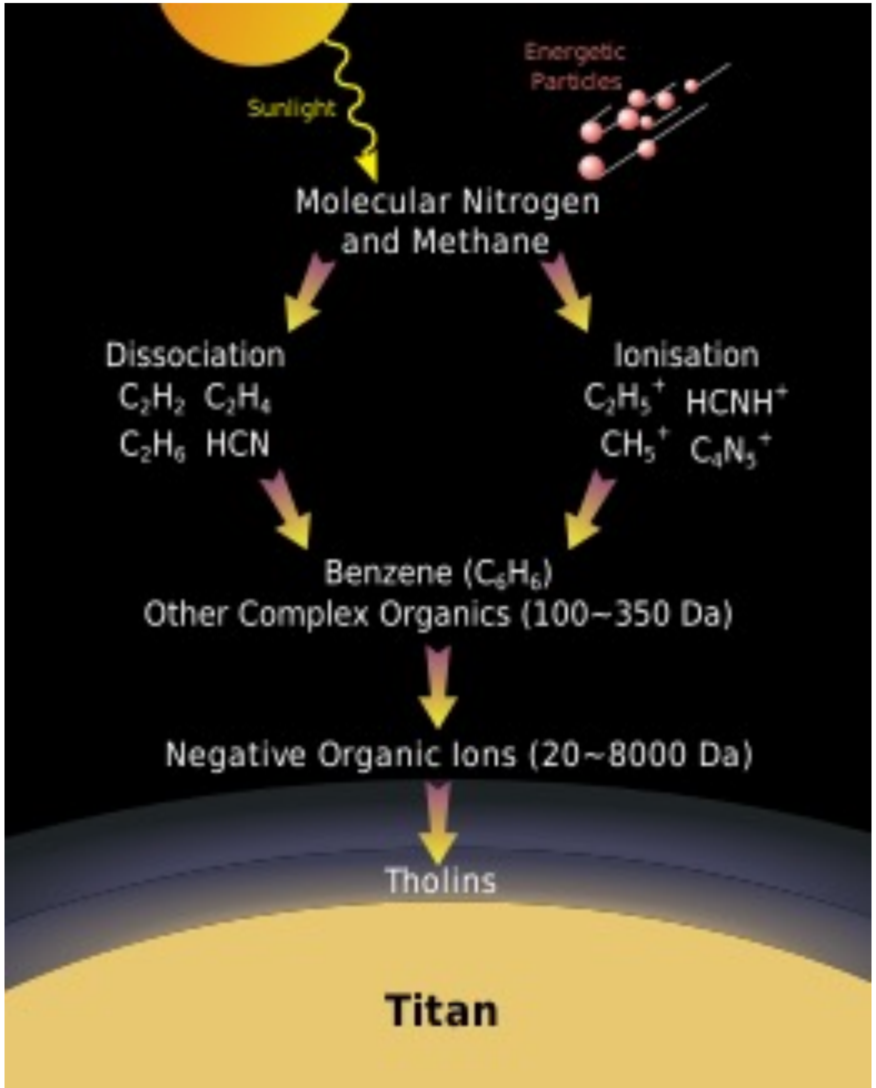
  NASA Pioneer 11, Voyager 1 and 2 between 1979 and 1982

  Mission NASA/ESA Cassini-Huygens, since 2004

    Close up maps obtained by Cassini

    Landing of the Huygens probe in 2005





Titan's atmosphere

The most abundant molecule is N_2, as in the Earth's atmosphere

The highest atmospheric layers are characterized by a *haze* of *tholins*

Tholins: organic compounds obtained from the processing of simple organic molecules photo-dissociated and photo-ionized

Titan's surface

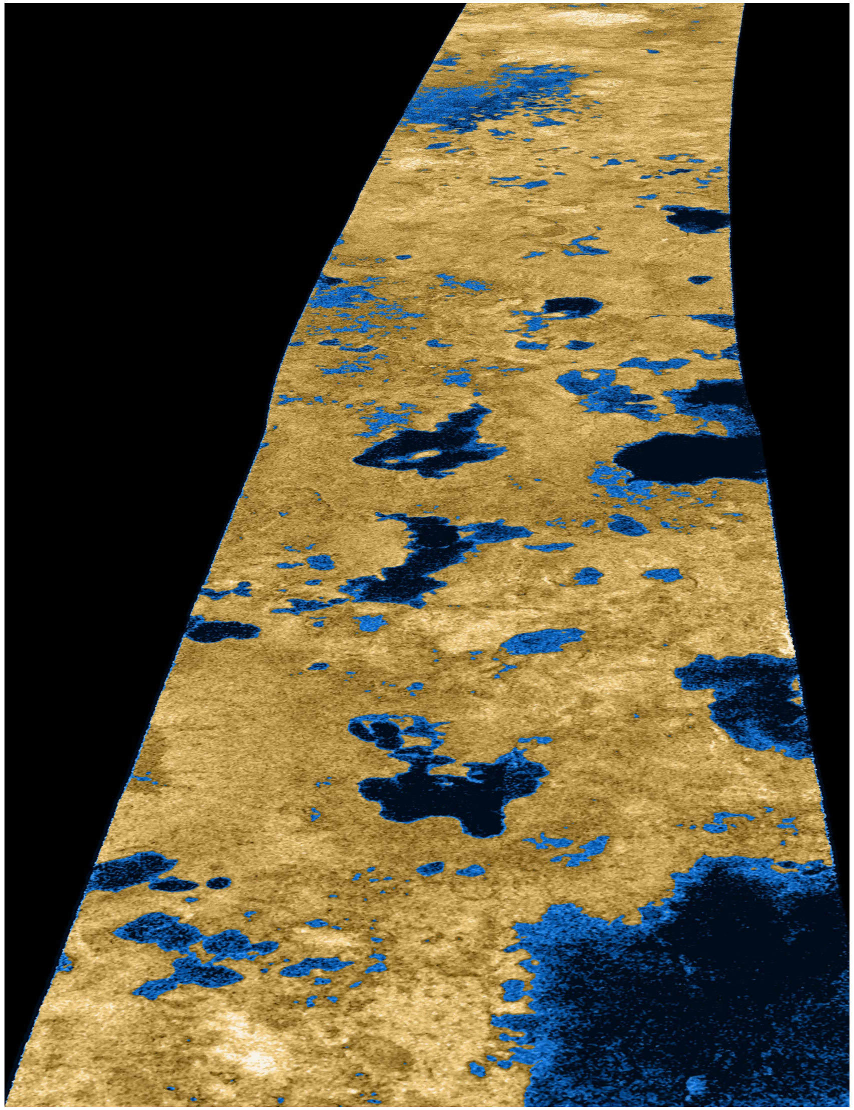
- The surface pressure is comparable to that of the Earth (50% larger)

  p_s=1.47 x 10^5 Pa

- What makes particularly interesting Titan is the presence of large amounts of organic molecules in liquid phase, forming surface lakes of hydrocarbons

  Mainly methane (CH_4) ed ethane (C_2H_6)

  The lakes have been discovered by the *Cassini* probe and, with higher detail, in the landing site of the *Huygens* module



Titan as a laboratory of astrobiology

- The presence of large quantities of organic material makes it possible the formation of complex organic molecules on Titan

  Laboratory simulations of Titan's atmosphere have shown the possibility of formation of prebiotic material, including aminoacids and nucleic acids

  Horst et al. (2010)

- Titan is an ideal laboratory to understand whether a biochemistry based on a liquid different from water, such as methane and ethane, can be possible

  However, methane and ethane molecules are not polar

  Some authors have considered the possibility that non polar liquids may give rise to some type of alternative biochemistry (Schulze-Makuch & Irwin 2004)

  The possibility of generating membranes in non polar hydrocarbons has been investigated, but the viability of an alternative biochemistry with a non-polar medium is far from being demonstrated

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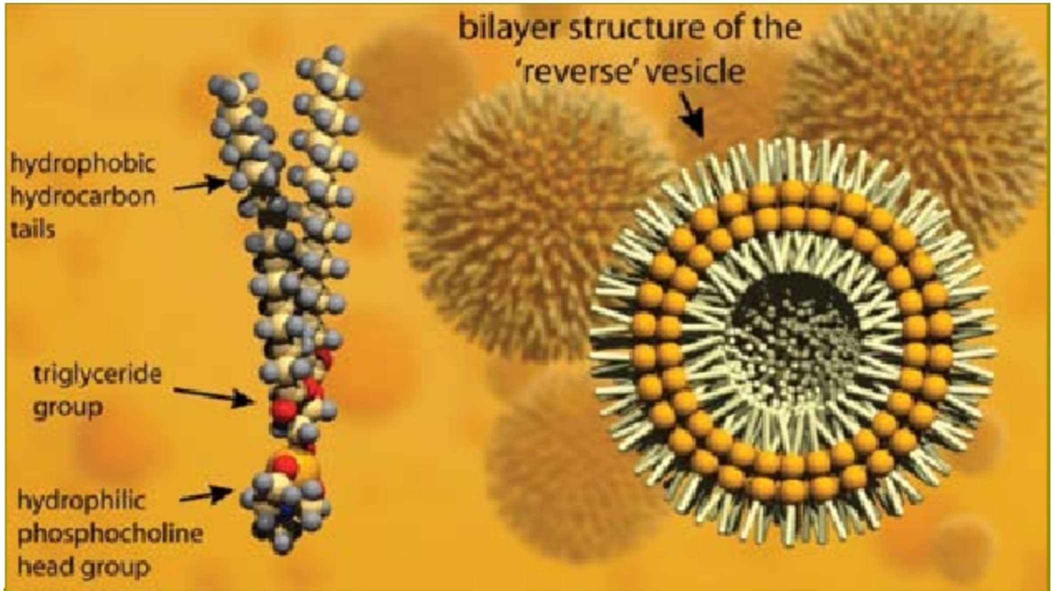


4: "Reverse" vesicle structures (right) consist of spherical bilayers of close-packed surfactant molecules (such as phosphatidylcholine, shown on the left). The hydrophilic groups (orange spheres) are packed into the centre of the bilayer, with the hydrophobic chains of hydrocarbons (pale yellow sticks) extending inwards and outwards. The phosphatidylcholine molecule shown on the left is ~25Å in length.

Hypothetical Titan biota based on hydrocarbons might adopt a modification of the arrangement of surfactant molecules in the cell membrane, forming a so called a "reverse" vesicle structure (Norman & Fortes 2011, *Astron. & Geophys.*, *52* , 1)

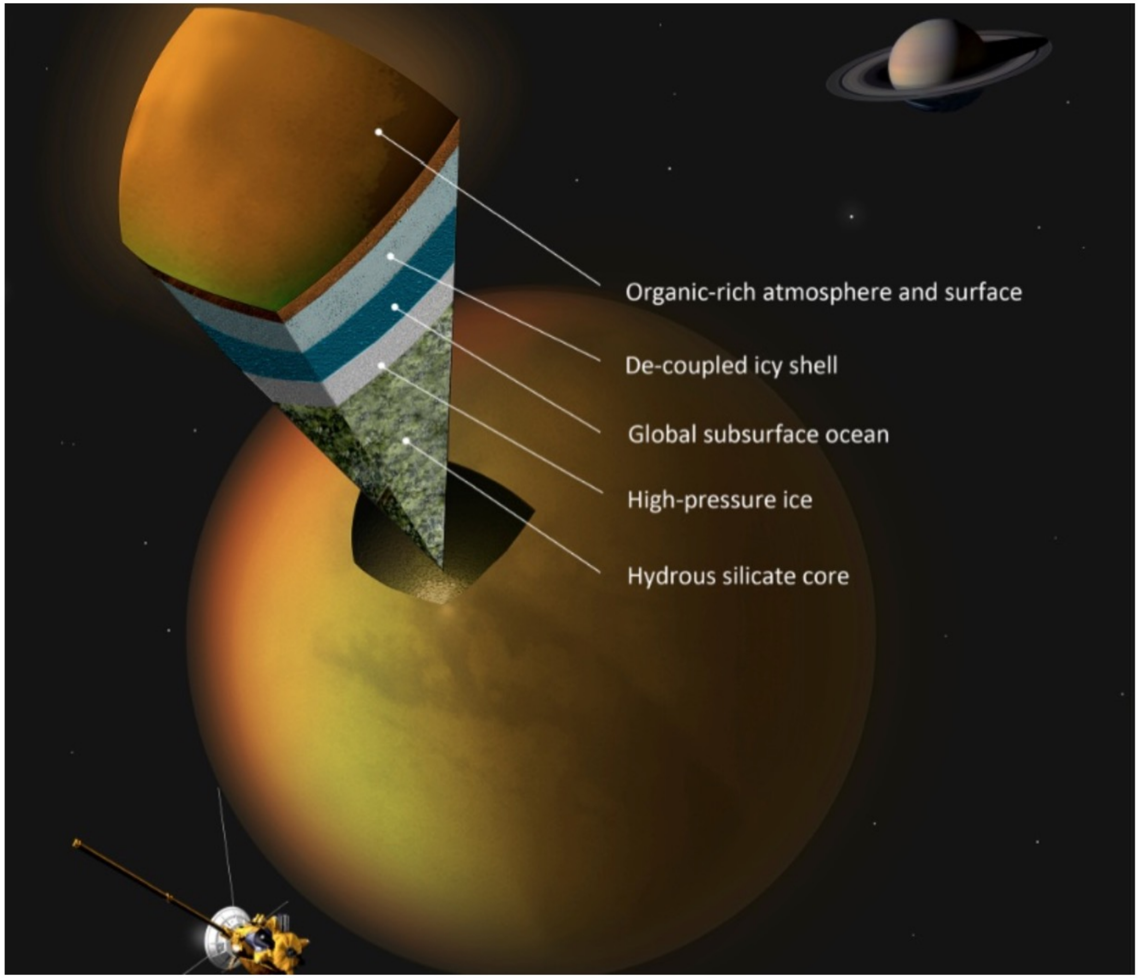
The possibility of generating membranes in non polar hydrocarbons has been investigated, but the viability of an alternative chemistry, based on liquid hydrocarbons, is far from being demonstrated

Titan as a laboratory of astrobiology

Liquid water might exist in undergound layers in Titan

There are no direct evidences, but it is plausible and it is believed to be present

The exchanges between the organic material and the liquid water may yield extremely interesting astrobiological conditions in the subsurface layers

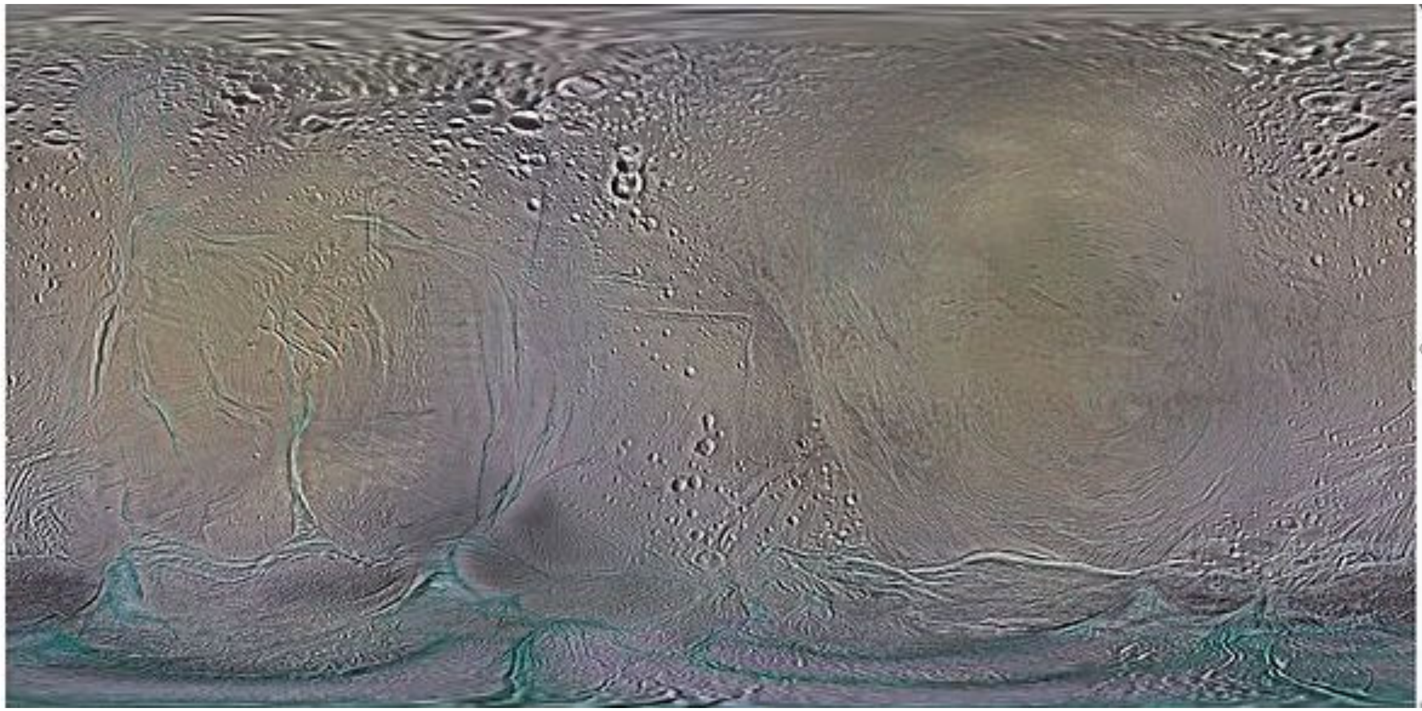


Small moons of Saturn: Enceladus

Enceladus is a moon of Saturn with radius ~250 km

Its mean surface temperature is extremely low (~ 75 K) not only because the low insolation, but also because of the very high albedo of its surface, which is mostly covered by fresh ice

In 2005, the Cassini spacecraft performed multiple close flybys of Enceladus, revealing its surface in detail; the surface shows old, heavily cratered regions, as well as young, tectonically deformed terrains

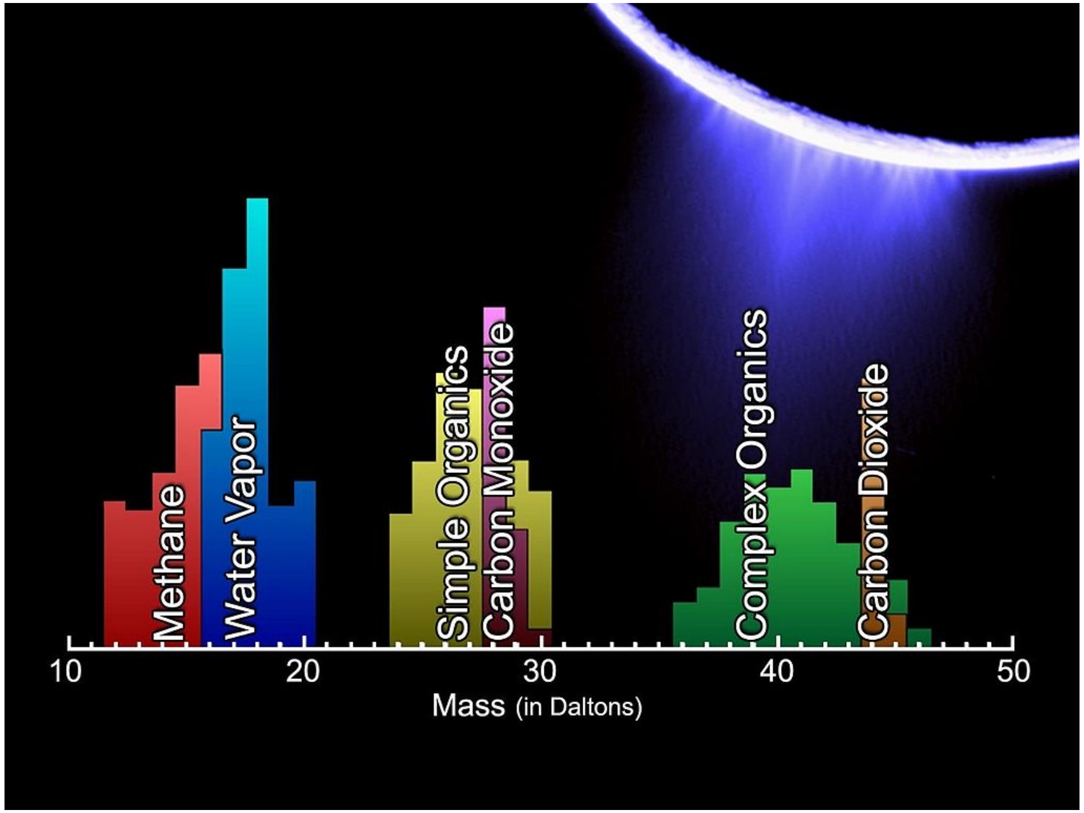


Enceladus

The astrobiological interest of Enceladus arises from the discovery of geyser-like jets of water vapor venting from the south polar region

In addition to water vapour, the jets contain methane, CO, CO_2 and organics

The geyser observations, along with the finding of escaping internal heat and the lack of impact craters in the south polar region, show that Enceladus is geologically active today

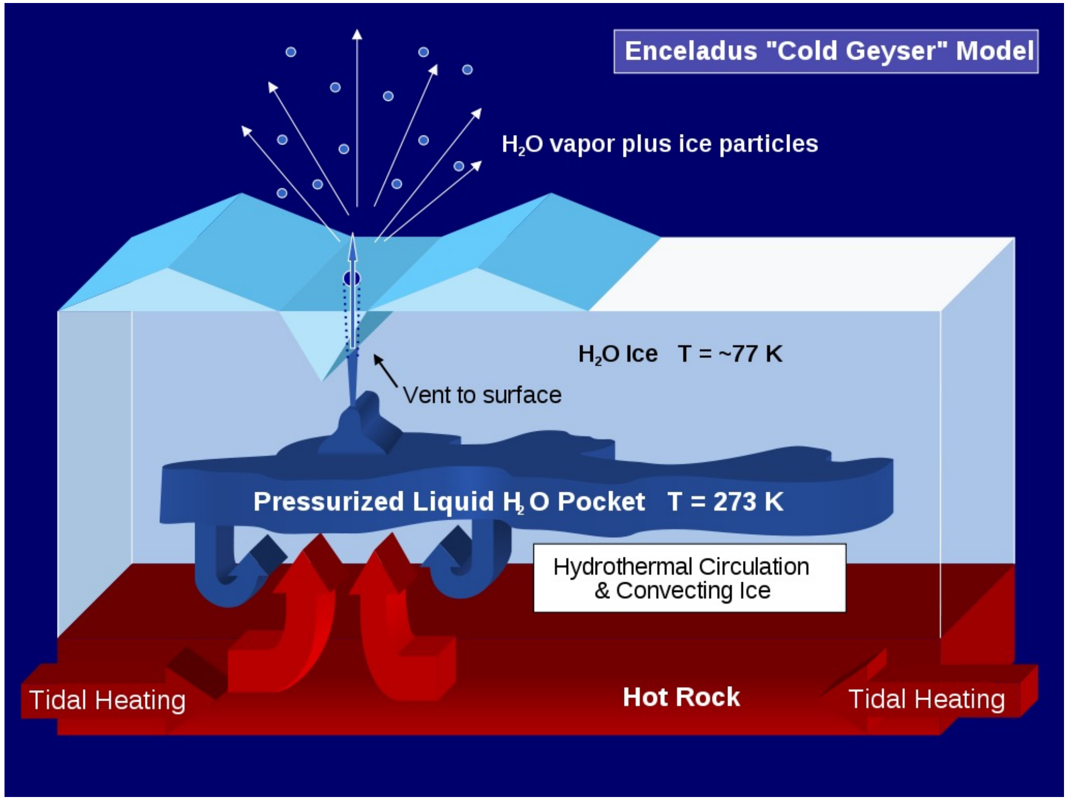


Enceladus

Enceladus is trapped in an orbital resonance with Dione; this resonance excites its orbital eccentricity, which is damped by tidal forces

The geophysical activity is probably driven by tidal heating of its interior

The existence of liquid water and organics in an ambient with internal energy and temperature gradient makes the interior of Enceladus a potentially habitable environment



Water activity in the outer Solar System:
the case of Pluto
New Horizon observations

Evidence for water-ice crust, geologically young surface units, surface ice convection, wind streaks, volatile transport, and glacial flow

Extended atmosphere with trace hydrocarbons and a surface pressure ~10 microbars; a global haze layer

The diverse surface geology and long term activity raise fundamental questions about how small planets remain active many billions of years after formation