Astrobiology
Origin and Evolution of Life

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Definition of Astrobiology

Astrobiology is not a discipline but an interdisciplinary activity around the question of the origin and evolution of life on Earth and its possible presence in other parts of the Universe; It covers all fields interested in this issue, from astronomy to biology, including geology and chemistry, but also history and philosophy of science.

Etimology: Exobiology and Astrobiology

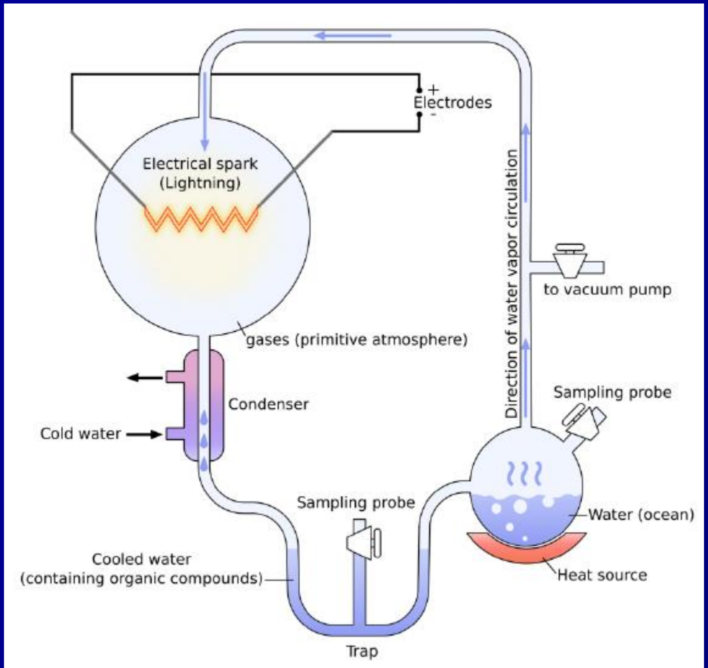
With space race and the first lunar and martian exploration missions, the risk of biological contamination appears.

First, scientists assumed that microbes were unlikely to withstand the conditions of space.

Today we know that this is not the case and, for example, tardigrades are capable of resisting extreme conditions, including those in space, and this is not an isolated case.

Water bear (tardigrade), Hypsibius exemplaris, scanning electron micrography, Bob Goldstein Vicky Madden.

Etimology: Exobiology and Astrobiology



Scheme of the Miller-Urey experiment. (Credit: La Barre, Stéphane. 2014)

With the Miller-Urey's pioneering experiment began the chemical studies for the synthesis of the first prebiotic molecules in the laboratory

A new key discipline for the search for the origin of life through space exploration appears: Exobiology, term introduced by Joshua Lederberg in 1960.

The term "Astrobiology" was adopted in 2015 by the IAU.

Astrobiology Objectives

- Define what Life is.
- Determine the origin of life.
- Look for its oldest footprints.
- Understand its evolution mechanisms on Earth.
- Search for life in the universe.

Define Life

This question requires scientific arguments, but it is also a philosophical question.

Life is a characteristic of a living organism that distinguishes the latter from a dead organism or a non-living thing, as specifically distinguished by the capacity to

- **Grow.**
- **Metabolize.**
- **Respond to stimuli.**
- **Adapt.**
- **Reproduce.**

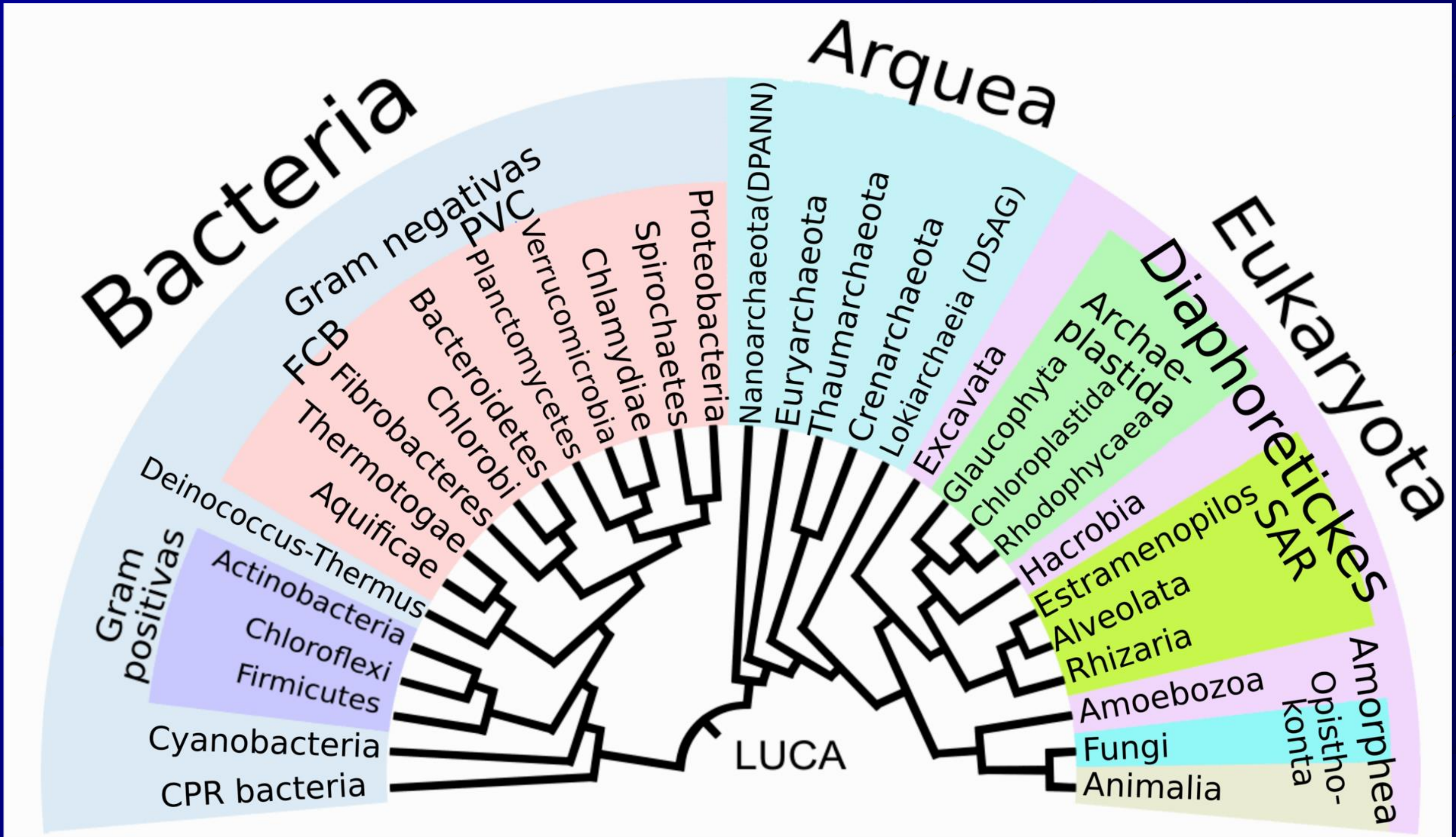
Diversity of Living Things on Earth

The only known example of life is terrestrial life.

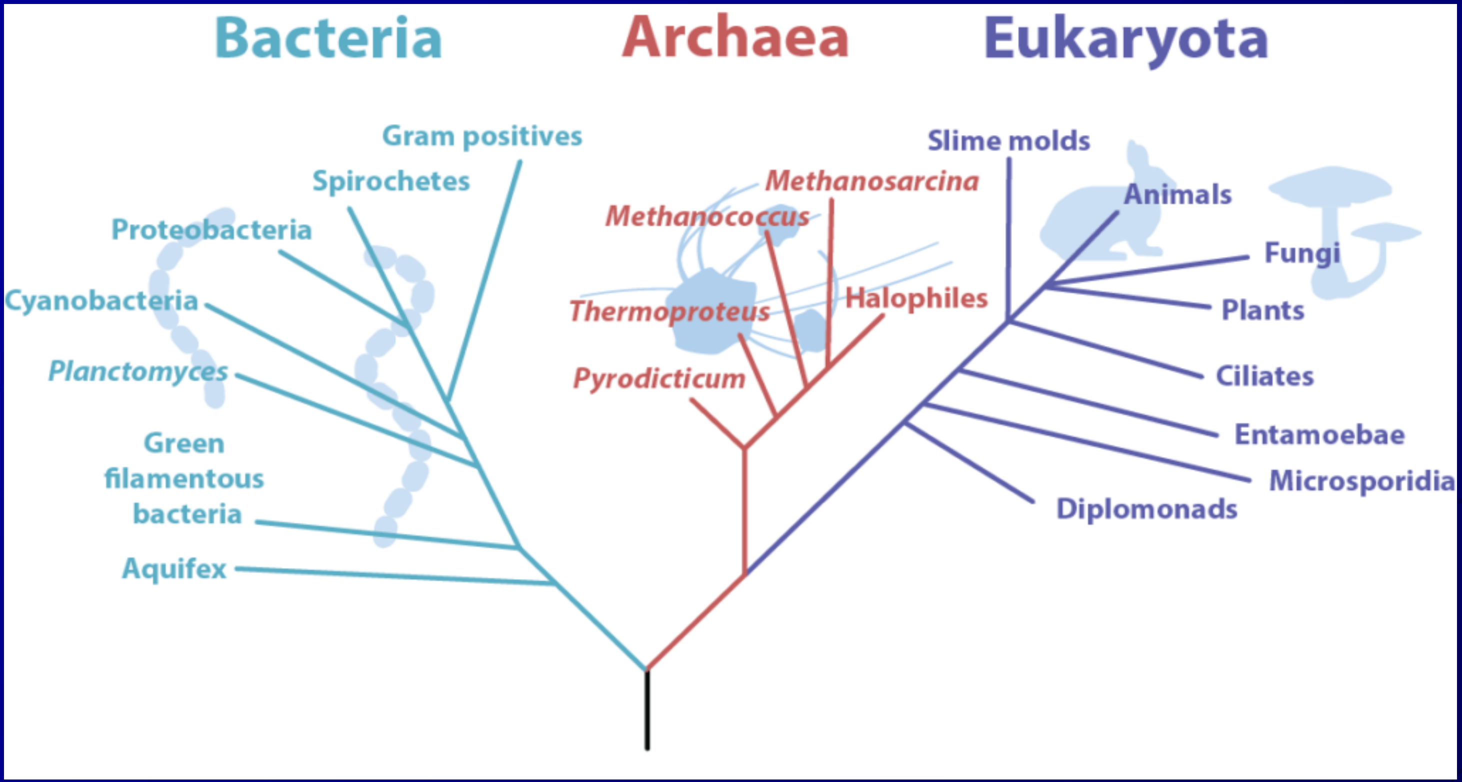
Astrobiology concentrates much of its efforts on studying terrestrial life in all environments, especially in the most extreme ones, such as underwater hydrothermal springs, brine lakes or frozen places.

This type of environment can be a good analogue for extraterrestrial locations.

To better understand the limits of living organisms and the mechanisms at work in extreme environments, scientists seek to determine the phylogenetic and metabolic diversity of living organisms.



Crédito: Wikipedia, https://es.wikipedia.org/wiki/Filogenia_bacteriana



Credit: https: //open.oregonstate.education/generalmicrobiology/chapter/archaea/

One of the branches of the tree of life that is of special interest are the archaebacteria (or archaea), different from prokaryotic bacteria due to their ribosomal RNA sequence and particularly adapted to extreme environments (in terms of pressure, temperature, salinity, nutrients , etc).

Search for the oldest traces of life on Earth: Difficulties

1) The Earth is a "living" planet (tectonics, erosion) and has therefore evolved greatly since its formation 4.5 billion years ago. Based on the genealogy of species, the first living organisms must have been single-celled beings similar to bacteria.

2) Primitive organisms had to be microscopic. The oldest proven traces of life on Earth date back 3.48 billion years and were discovered in Australia.

3) Difficulty in interpretation and comparison with abiotic systems, which could have formed fingerprints similar to biological signatures or morphologies.

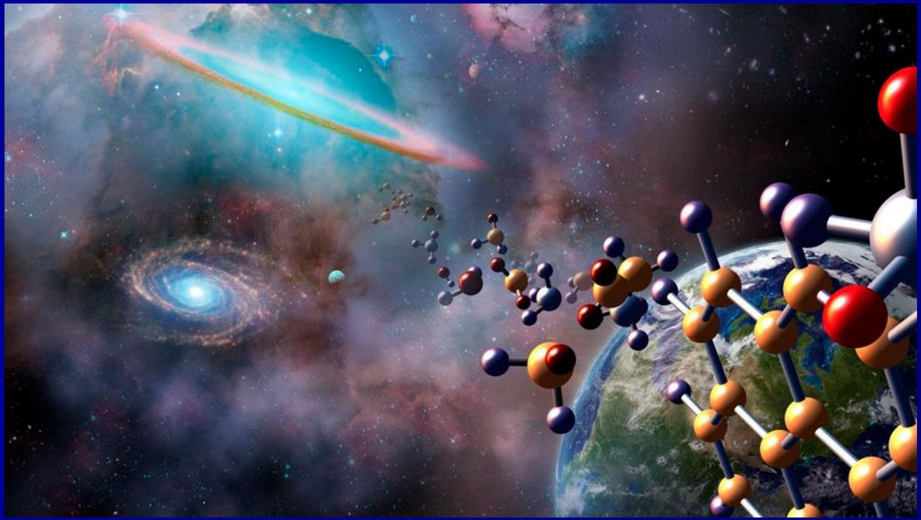
Prebiotic chemistry and the transition from non-living to living

Today, in all living species on Earth, among all the existing diversity, there are elementary blocks made of C, H, N and O

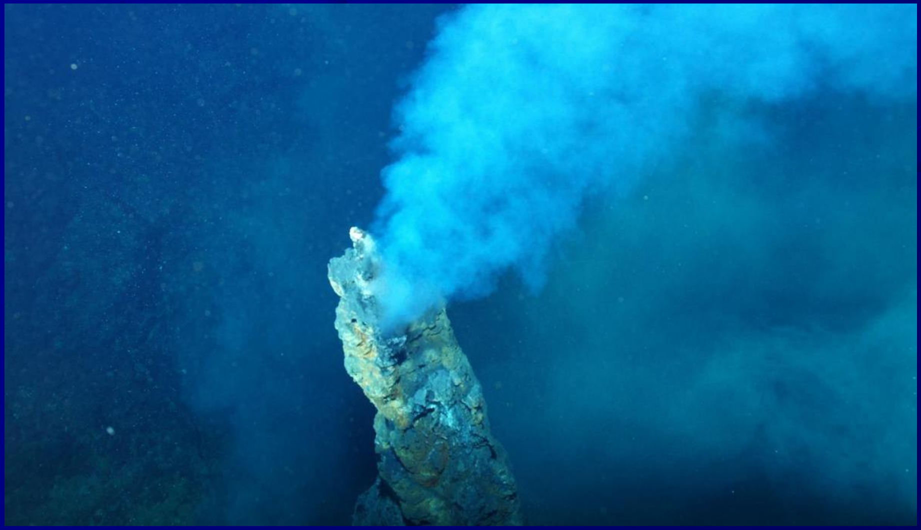
These blocks are proteins, the basis of replication, DNA (deoxyribonucleic acid), which carries genetic information, and amphiphiles, which constitute cell walls for compartmentalization.

The elemental bricks that every living species on Earth has are, therefore, five types of molecules (sometimes called the bricks of life), amino acids, nitrogenous bases, sugars, phosphorus, lipids (or fatty acids).

Prebiotic chemistry and the transition from non-living to living



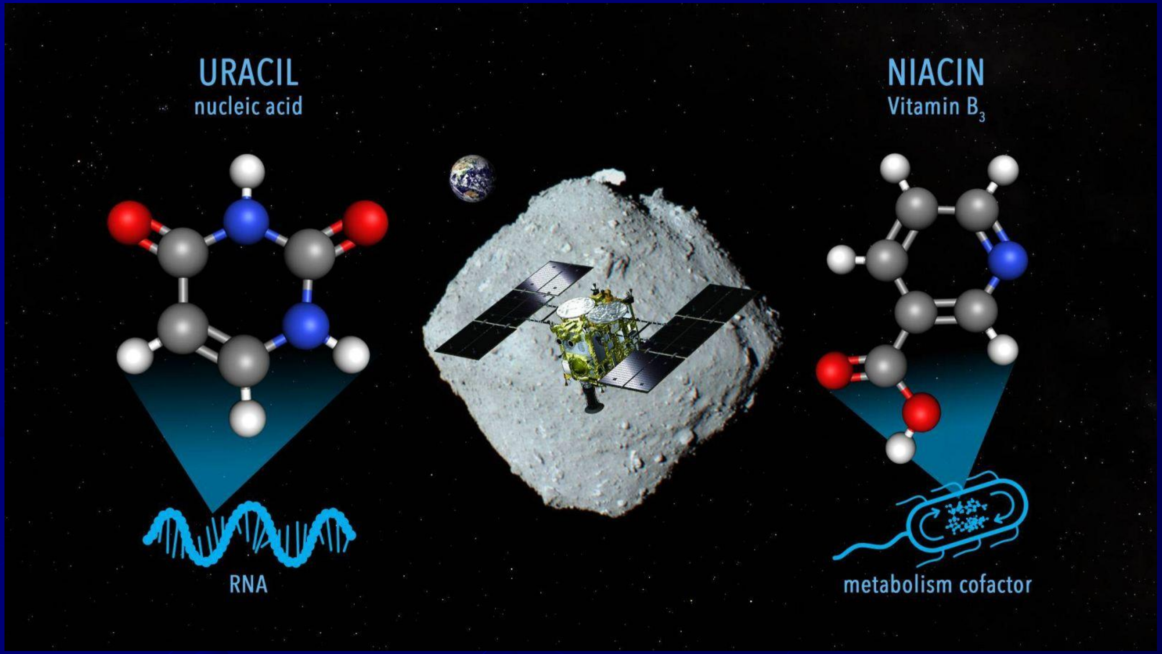
These elements are essential for terrestrial life and the study of their origin allows us to give more limitations to the origin of life itself.



Abiotically, these molecules could have formed in the Earth's atmosphere, but also in hydrothermal vents.

Prebiotic chemistry and the transition from non-living to living

Another hypothesis proposes that these molecules could have been brought by celestial objects (meteorites), coming from asteroids and comets: meteorites have proven to have great organic richness.



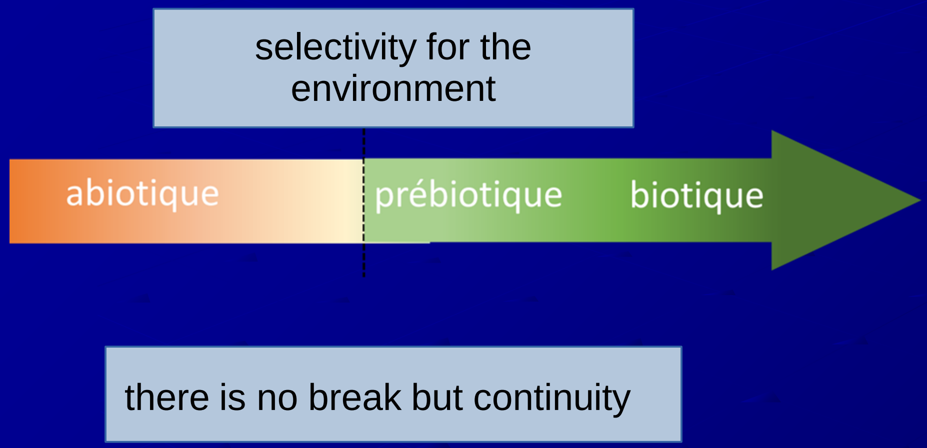
Representation of the asteroid Ryugu and the materials found in samples taken in 2019, NASA Goddard/JAXA/Dan Gallagher

Prebiotic chemistry and the transition from non-living to living

When falling to Earth, the meteorites could have transported part of the water and siderophile elements found on their surface after differentiation 4.5 billion years ago.

No life form has yet been found in these objects, but they contain thousands of molecules as diverse and varied as those necessary in abiotic synthesis.

Prebiotic chemistry and the transition from non-living to living

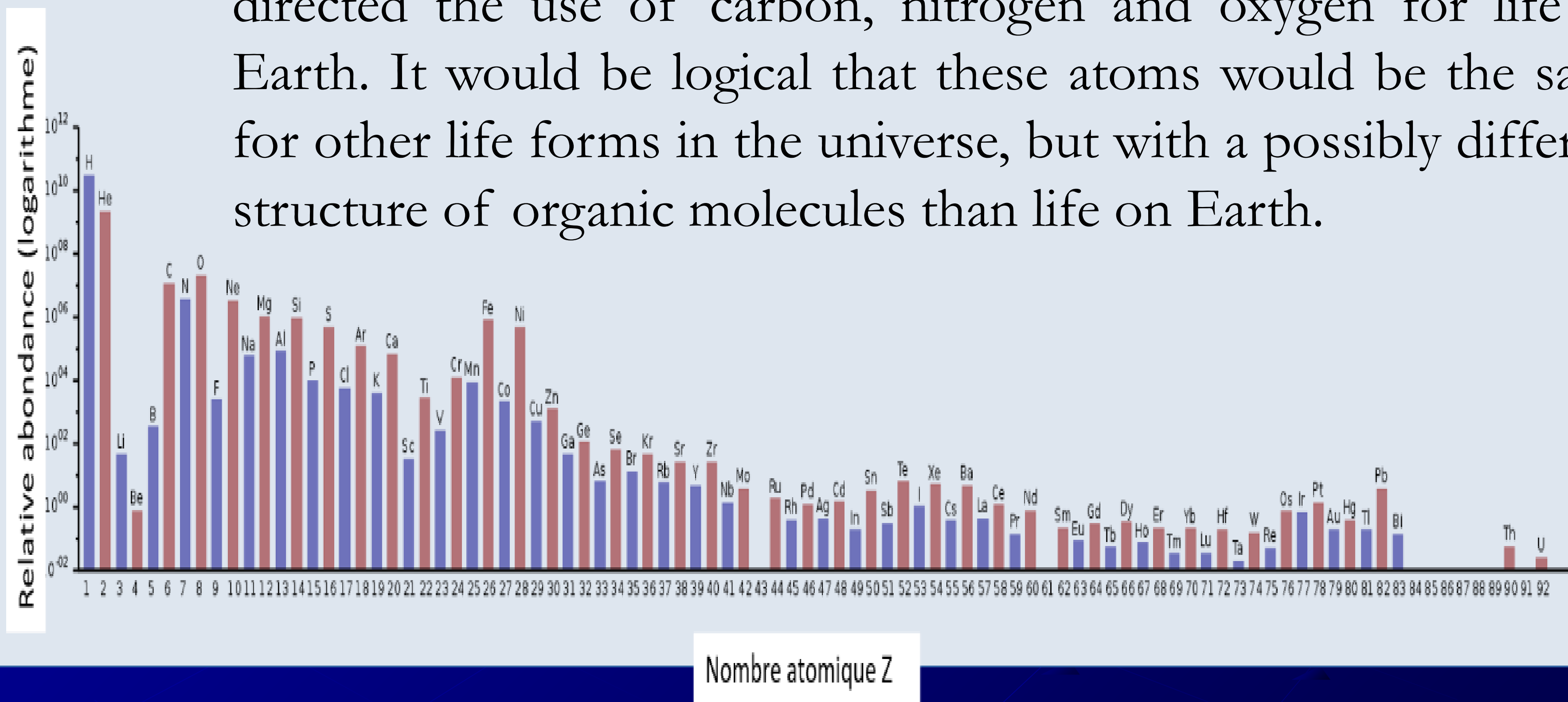


There would not be a strict separation between an abiotic and a biotic system, but rather a continuity, passing through said prebiotic chemistry.

How and where life arose on Earth remains the most complex exobiological question and the possible chemical pathways are so numerous that it is not obvious that the answer will one day be found.

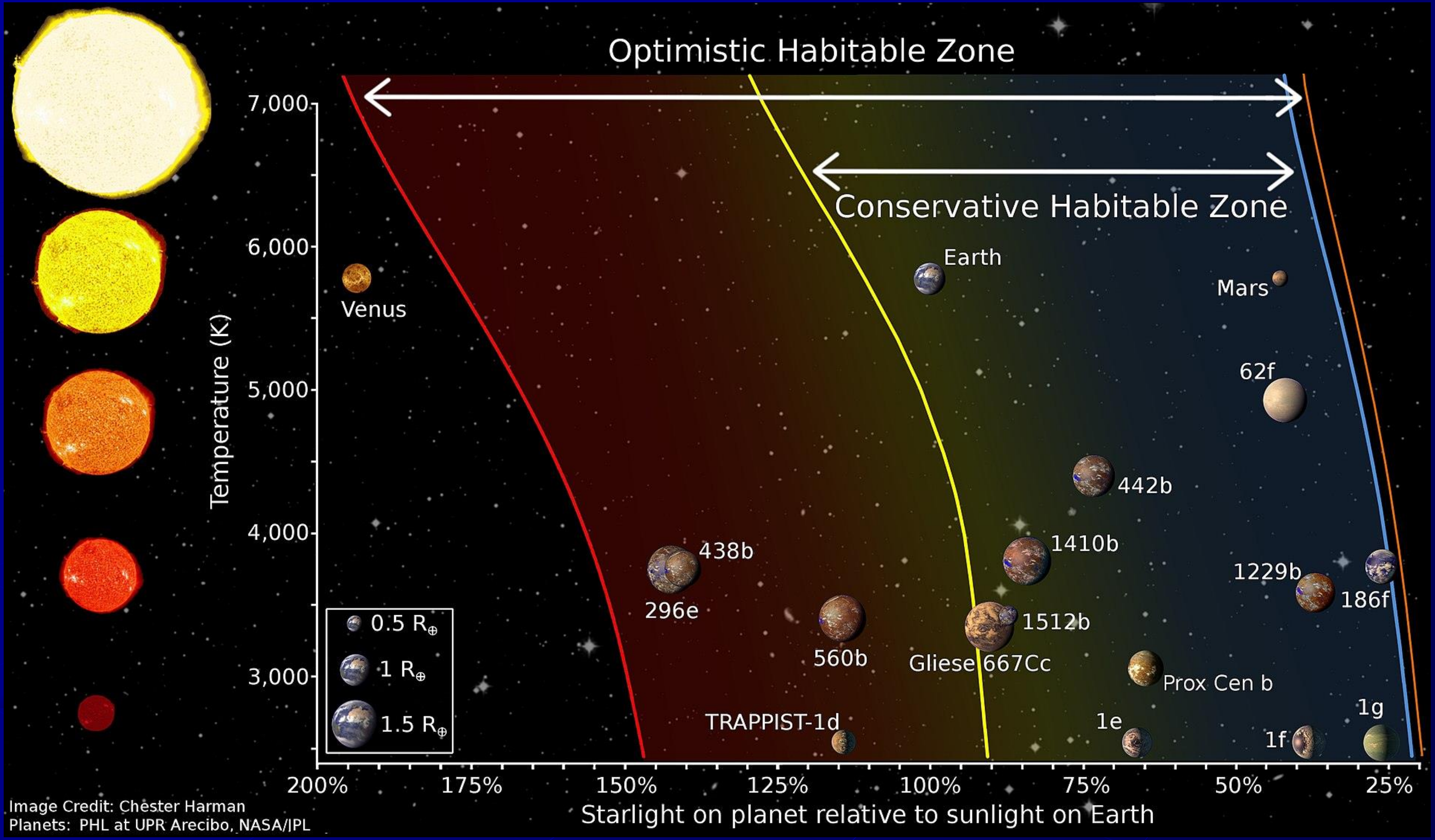
Search for life everywhere

The chemical arrangement of atoms in the Universe has directed the use of carbon, nitrogen and oxygen for life on Earth. It would be logical that these atoms would be the same for other life forms in the universe, but with a possibly different structure of organic molecules than life on Earth.



To look for life in other places you have to know what to look for and one of the bases of Astrobiology, but also its weakness, is the search for life biologically similar to ours.

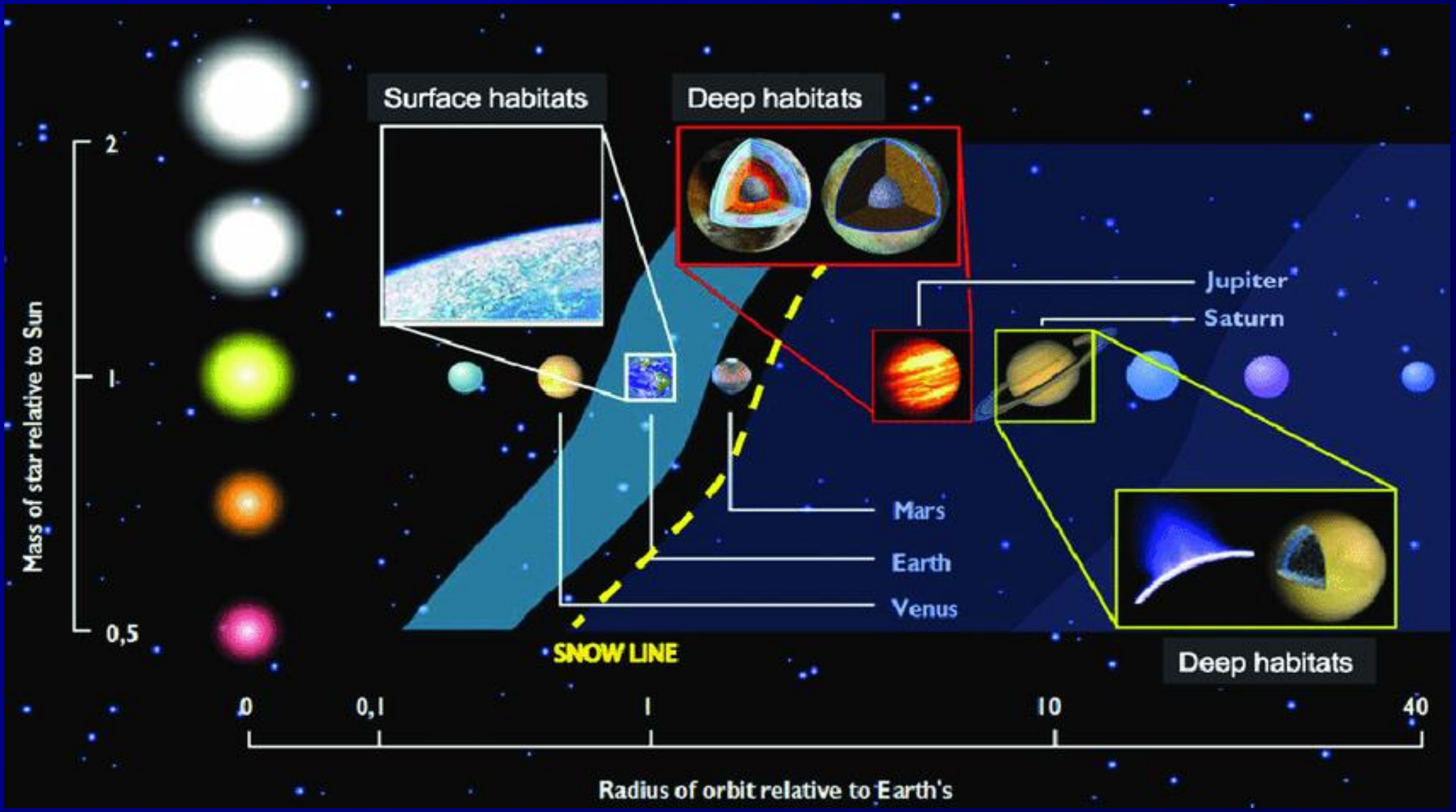
Search for life everywhere



The notion of habitability is a debated topic , its definition is linked to the conditions that allowed the emergence and evolution of the only (terrestrial) life we know.

Search for life everywhere

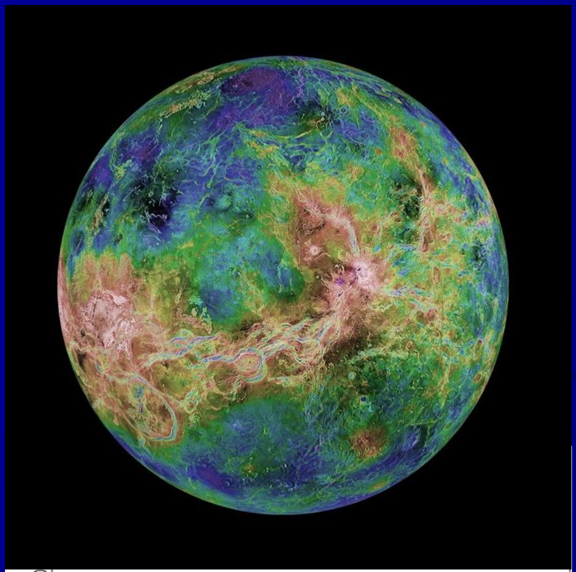
The extension of the habitable zone to underground environments is an example of research into the possibility of life in these environments of the solar system.

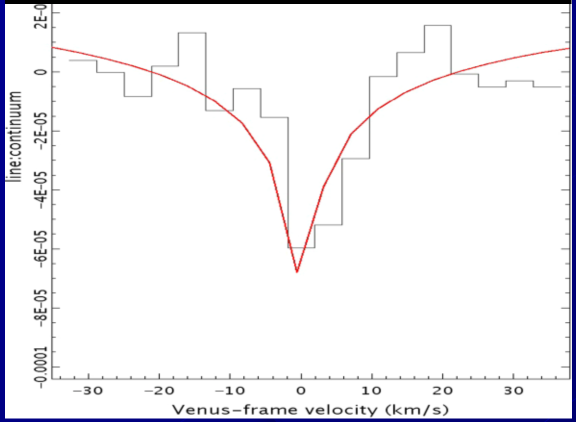


Bodies in the Solar System and their astrobiological interest

Astrobiology studies are then interested in the possible emergence of life in these environments, beyond Earth, which have been defined as habitable

Planets in the Solar System and their astrobiological interest: VENUS





Our "sister planet" has relatively complex organic chemistry, with sulfur and phosphorus molecules in an extremely dense atmosphere composed of more than 96% CO_2.

It is not found in the habitable zone of the solar system and it lacks an essential component: water on its surface.

Deuterated water (HDO) detection on Venus in ALMA data (Greaves, J.S., Richards, A.M., Bains, W. et al. Phosphine gas in the cloud decks of Venus. Nat Astron 5, 655–664 (2021).

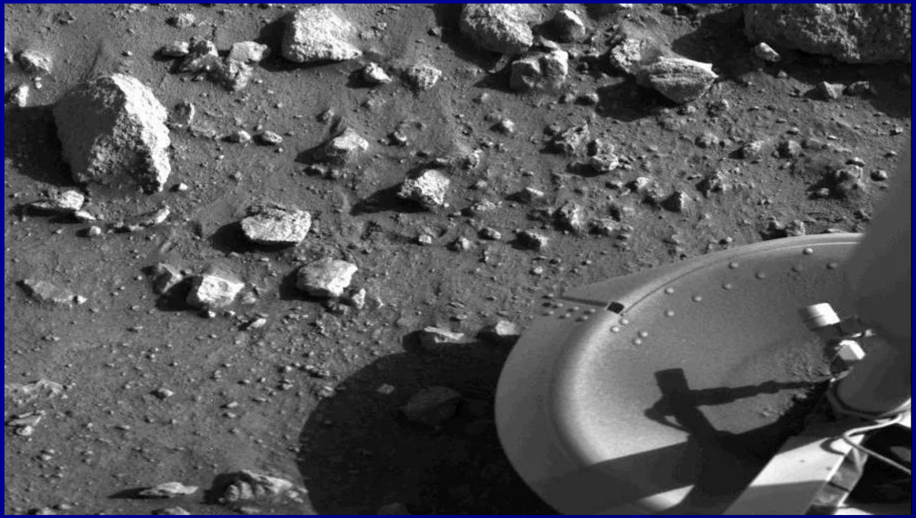
Planets in the Solar System and their astrobiological interest: VENUS

Venus benefited from exogenous inputs like Earth after its formation, it may have had liquid water on its surface and a water-rich atmosphere 4.5 billion years ago and for some time.

Currently its surface is only active volcanism with temperatures of around 460°C.

If life developed at the most favorable time, it is proposed that it survived in the form of microorganisms in the clouds of its atmosphere, with a temperature of ~75°C

Planets in the Solar System and their astrobiological interest: MARS



This planet has often been proposed as the best place in the solar system to have had, or still have, conditions for life.

The existence of microbial life was already considered in the 70s during the preparation of the Viking mission: the landers were equipped with instruments capable of carrying out experiments aimed at highlighting Martian life, detecting photosynthetic biological activity or providing nutrients to Martian bacteria, with negative responses.

Planets in the Solar System and their astrobiological interest: MARS

Evidence of ancient presence of water on Mars. (Curiosity, NASA/JPL)

The Vikings confirmed the presence of liquid water in the past of Mars, observing channels, dry rivers and dendritic valleys.

The water could have remained on its surface for at least a billion years and is still present in the minerals that currently cover the surface .

At the poles there is water ice in the polar caps and it is suspected that water is present in greater quantities in the Martian crust

Planets in the Solar System and their astrobiological interest: MARS

Life could have developed on Mars at the same time as on Earth and perhaps persisted underground.

Finding life on Mars would provide many answers about the emergence of life on our planet.

If life existed on Mars, even in the form of microorganisms, and since the planet is no longer geologically active, it should be possible to discover it in the form of trace fossils on the surface or even hope that it exists and has survived underground.

Bodies in the Solar System and their astrobiological interest: SATELLITES

In recent decades, other habitable bodies of astrobiological interest have been discovered beyond the asteroid barrier: the satellites of giant gaseous planets.

Giant planets are of limited interest to astrobiology because they have no surfaces and therefore no rocks.

Their satellites are also important for understanding the origin and evolution of the Solar System.

Satellites in the Solar System and their astrobiological interest

Around Jupiter: Ganymede, Callisto and Europa.

Around Saturn: Enceladus and Titan.

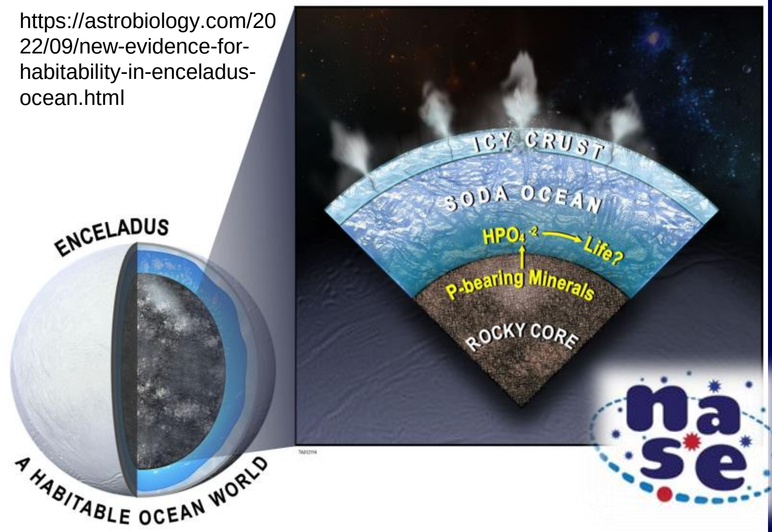
Revealed thanks to the Cassini-Huygens probe (1997-2017), which visited these worlds for 15 years, the icy satellites of Saturn surprise with their diversity and the abundance of liquid water they contain.

Satellites in the Solar System and their astrobiological interest

Europa would contain an ocean ten times larger than Earth's, while being three times smaller than our planet.

Enceladus In 2014 water geysers on its surface, which extend up to 100 km above its surface, were discovered.
This observation has revealed the presence of an ocean under the ice sheet.

Kelvinsong – Own job, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=23640295



https://astrobiology.com/2022/09/new-evidence-for-habitability-in-enceladus-ocean.html

Satellites in the Solar System and their astrobiological interest: TITAN

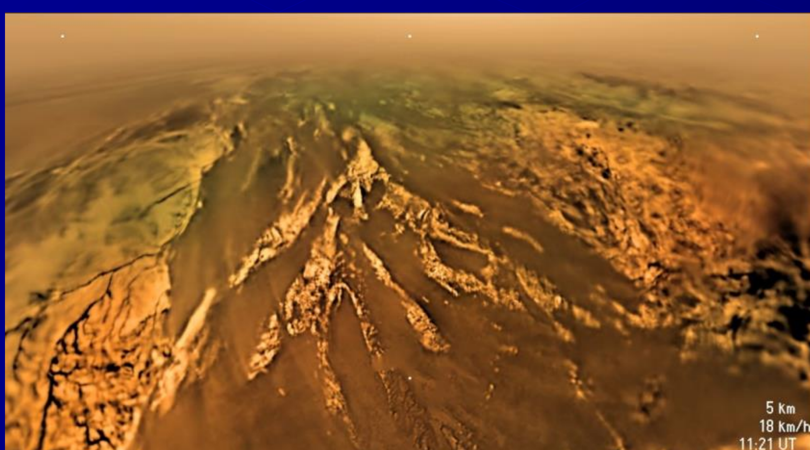
Saturn's largest satellite, Titan, presents a large amount of organic matter that forms in its atmosphere.

In 1980 and 1981, the Voyager 1 and 2 probes revealed an extremely dense atmosphere composed primarily of nitrogen and methane.

The chemistry in Titan's atmosphere has proven to be extremely complex, resulting in the formation of organic aerosols that settle on the surface.

The Cassini-Huygens mission (1997-2017) confirmed complex organic chemistry in the atmosphere of Titan.

Cassini/Huygens Mission, NASA,



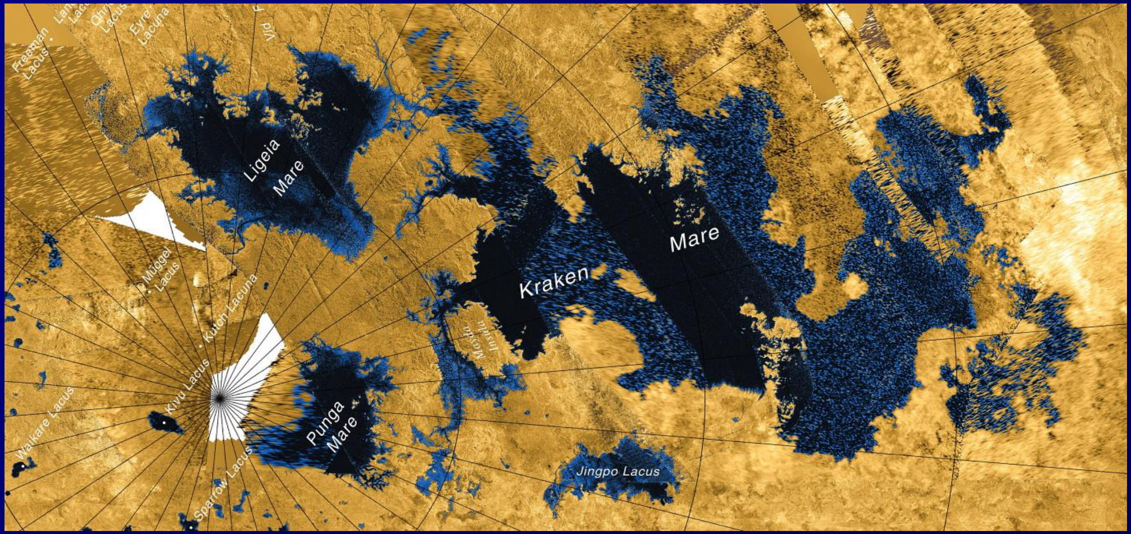
Surface of Titan.(Cassini/Huygens, NASA)

Impressive images were obtained of the surface covered with organic grains, dunes and hydrocarbon lakes.

Astrophysical models have proposed that Titan may harbor an ocean of liquid water beneath its surface and presents all the necessary ingredients for the emergence of rich prebiotic chemistry and a possible form of life.

Evolutionary geochemical models suggest that from the first million years after the formation of Titan, this underground ocean was in contact with the atmosphere, in which the first complex molecules would have been produced.

By analogy with Earth, the presence of hydrothermal vents is expected in this Titan ocean, which constitute a source of energy for organic molecules and a potential environment for prebiotic systems.



Beyond the Solar System

5500 exoplanets (up to now 2024) have being discovered and confirmed in our galaxy. It helps us to understand the formation of our Solar System and that islikely unique.

With the current state of knowledge and advances in the field of Astrobiology, it is very difficult to hypothesize an inhabited planet and the proven presence of life in our galaxy or beyond.

There seem to be more and more potential sites for the development of life, but what about the actual development of life?

Conclusions

Astrobiology attempts to determine whether life could exist in other parts of the universe and, if so, in what form, to try to answer an existential question: are we alone in the universe?

For several decades, understanding the appearance of life on Earth has been crucial to determine whether it is a coincidence or a reproducible phenomenon under specific conditions and environments.

Conclusions

This understanding is necessary to draw conclusions about the possibility of life elsewhere in the universe.

Despite active efforts, no such conclusions have yet been reached.

¡Thank you for
your attention!