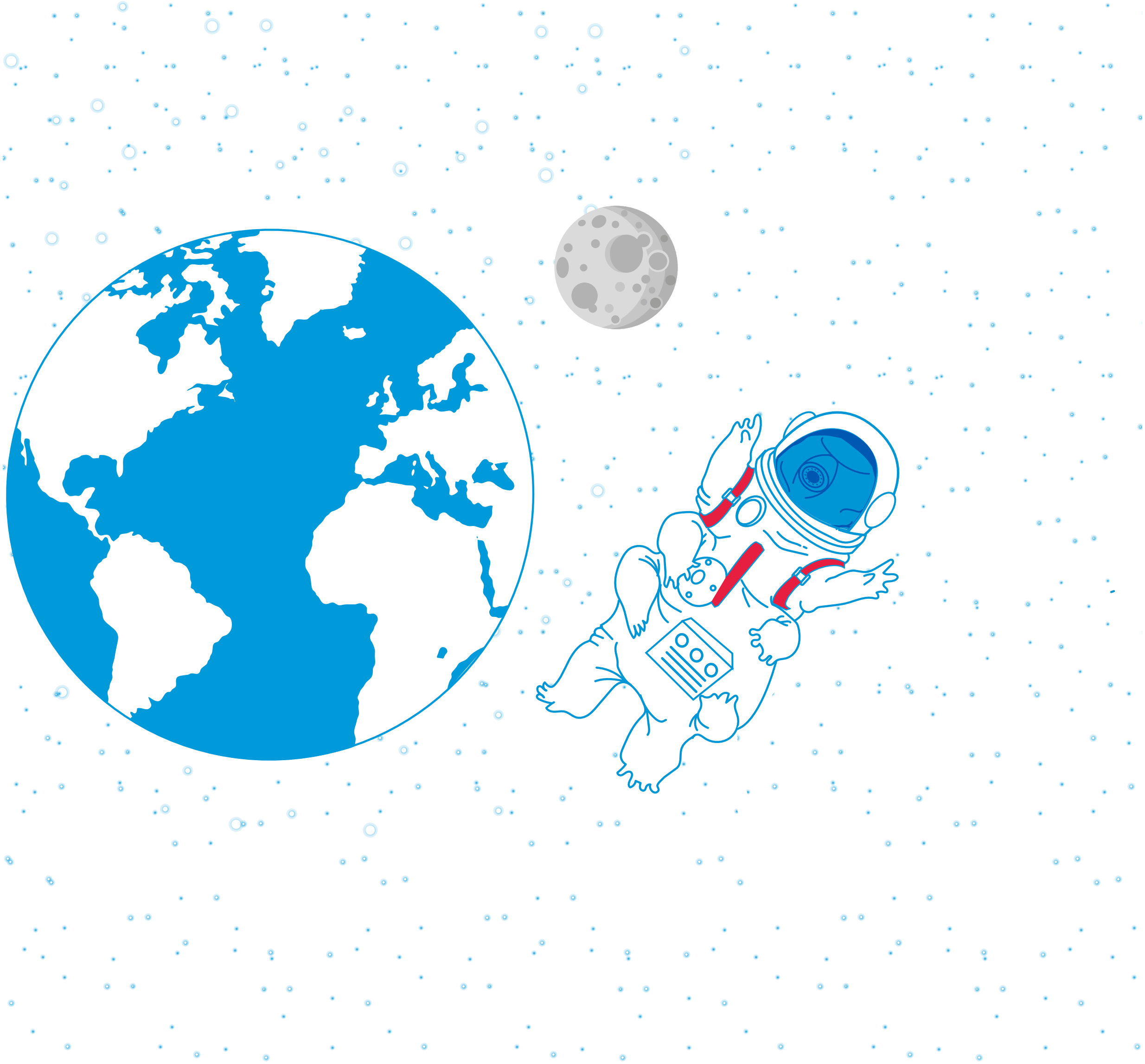
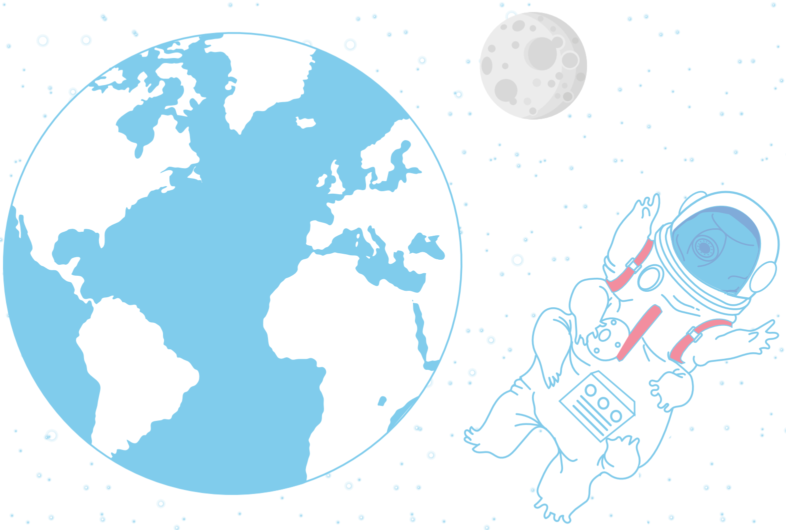
teach with space

→ COULD LIFE SURVIVE IN ALIEN ENVIRONMENTS?

Defining environments suitable for life





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teach with space – could life survive in alien environments? | B09
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→ COULD LIFE SURVIVE IN ALIEN ENVIRONMENTS?

Could life survive in alien environments?

Fast facts

Subject: Biology

Age range: 13-16 years old

Type: student activity

Complexity: medium

Cost: Low (0 - 10 euros)

Lesson time required: 1 hour

Location: Classroom

Includes the use of: Internet, books, library

Keywords: Biology, Solar System, Planets, Moons, Extremophiles, Abiotic factors, Search for life

Brief description

In this activity students will consider whether life found in extreme environments on Earth could survive elsewhere in the Solar System. Students will examine the characteristics of different places in the Solar System and then use fact cards of some example extremophiles to hypothesize which they think might be able to survive in the different extra-terrestrial environments.

Learning objectives

- Learn what extremophiles are.
- Consider ecological tolerance.
- Consider the abiotic factors that affect adaptation and survival of lifeforms.
- Learn about the environmental conditions of various Solar System objects.
- Understand that changes in environmental conditions have an impact on the evolution of living organisms.

→ Introduction

The more scientists look on Earth, the more life they find. Earthly life has adapted to an extraordinary variety of conditions, even those that humans had considered inhospitable. Life can exist in the most surprising of places. It has been found in porous rocks in Antarctica, in volcanic springs and even in hot-water geysers on the ocean floor.

Figure 1

↑ From left to right: Porus rocks, Antarctica; Volcanic spring in Yellowstone National Park, USA; Hydrothermal vent, Mariana Trench.

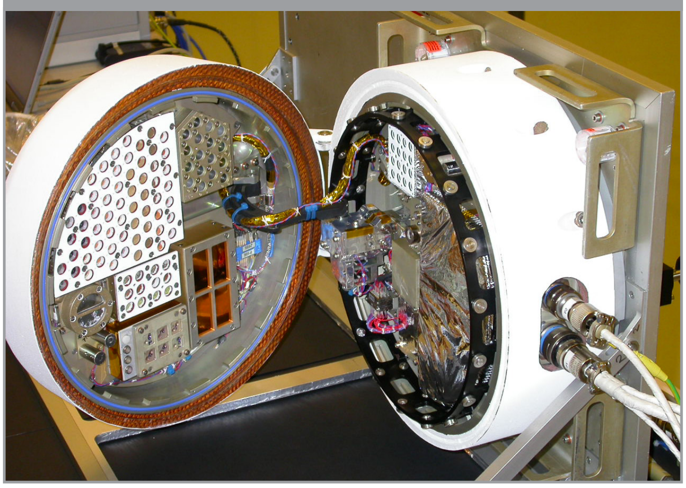
The organisms that live in these and other extreme environments are collectively known as **extremophiles**. They are single-cell or multicellular microorganisms and often derive their energy from a variety of sources found in their environment to catalyse chemical reactions.

Different species adapt, through evolutionary changes to the environment in which they live (or they are forced to migrate to). The Earth is characterised by distinguishable climate zones, areas of land and sea, and differences in altitude. These differences result in specific distribution of organism groups around the Earth. For now, Earth is the only place in the Universe that is known to be inhabited. No evidence for life elsewhere in the Solar System has been found as yet. The current search for life investigates possible environments in which life might be, or was, able to develop and survive.

The activity in this resource will stimulate the students to think about what life might look like beyond Earth, should it be discovered. By using the extremophiles found on Earth as examples, the students will hypothesize what environments elsewhere in the Solar System might potentially be suitable for life. In addition, the students will consider the implications of searching for, and perhaps discovering, alien life.

To get closer to understanding the limits that govern living organisms several experiments are being conducted. This research includes the exposure of organisms to the harsh conditions of space. For example, Tardigrades (organisms that are also known as water bears) have been subjected to the vacuum and extreme temperature fluctuations of space as part of ESA's Biopan 6 mission in order to test their durability to such conditions. Other research studies how the orbiting environment of the International Space Station affects living organisms (without exposing them to the vacuum). For example, research into how plant roots grow without a dominant vector of gravitational acceleration can aid understanding about the behaviour of plants on Earth.

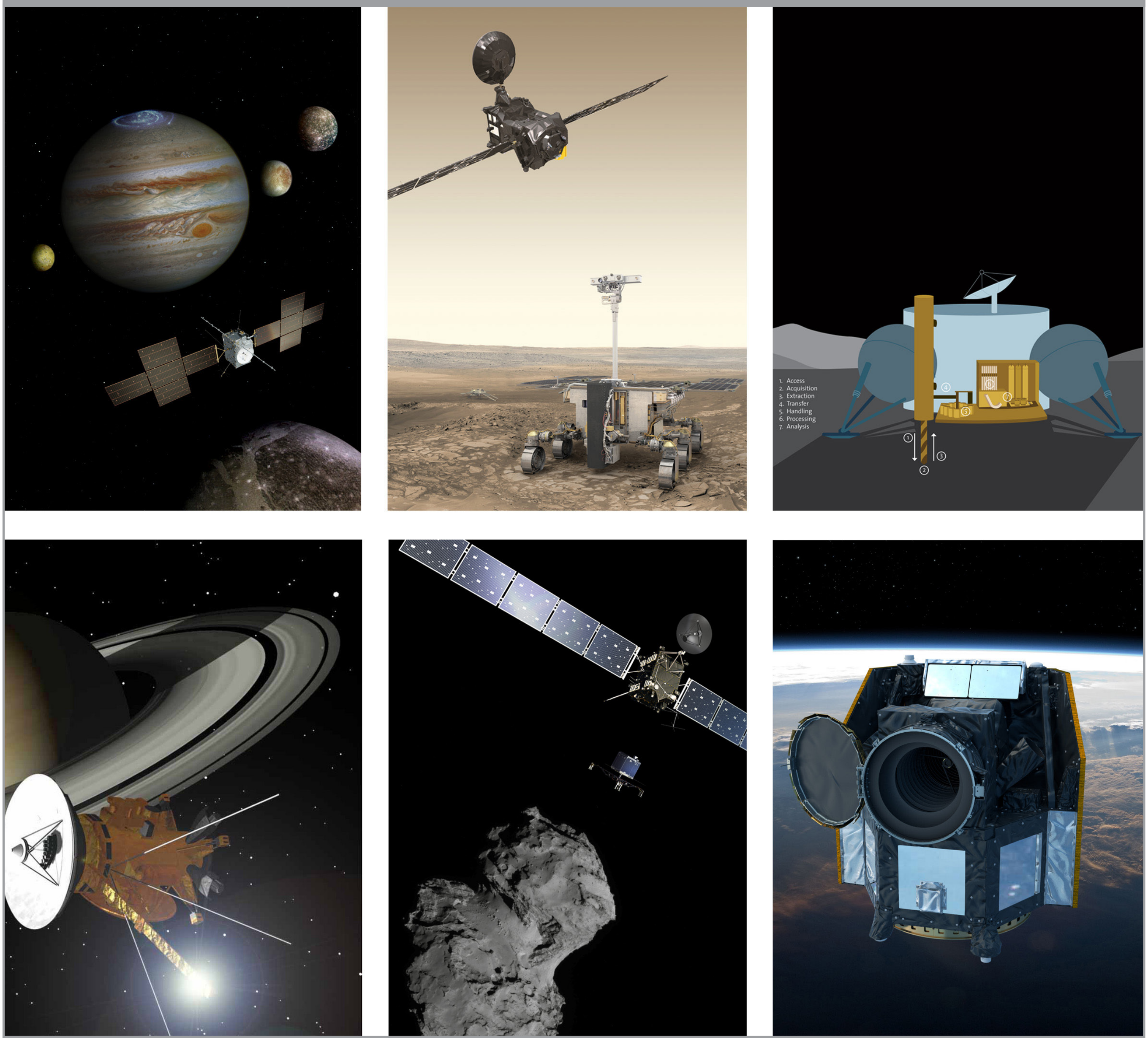
Figure 2



↑ Biopan instrument on outside of Foton capsule.

Several European Space Agency missions have studied and will study extra-terrestrial environments that may have the potential to harbour life. Among them are the Cassini-Huygens mission to the Saturn system; the Rosetta mission to comet 67/P; ExoMars, a two part mission consisting of an orbiter and a rover to the red planet; JUICE that will study Jupiter and three of its largest moons; and future missions to the Moon, such as Luna-27 will search for clues to understand the origins of life. In addition, the CHEOPS and PLATO missions, will look beyond our Solar System to star-systems with orbiting planets (exoplanets).

Figure 3



↑ Artist impressions from left to right: (Top) JUICE mission to Jupiter, ExoMars rover on Mars, PROSPECT instrument package of Luna-27 mission on the Moon. (Bottom) Cassini-Huygens approaching Saturn, Rosetta and Philae at Comet 67/P, CHEOPS in orbit above Earth.

→ Background

Extremophiles

An extremophile is an organism that thrives in physically or geochemically extreme conditions that are detrimental to most life on Earth. Extremophiles include acid-loving and salt-loving organisms, and those that can exist at extremely high and extremely low temperatures. Some extremophiles can withstand high pressures, greater than 350 times atmospheric pressure at sea level.

Organisms that can live in scalding water are known as hyperthermophiles. They make up a particularly important branch of the extremophiles, because they appear to be among the most ancient species that live on Earth. Some scientists believe that this means life itself began in high-temperature environments, perhaps in the hot-water geysers on the ocean floor, known as black smokers. An outline of some different types of extremophiles are outlined in Table 1.

Outline of different types of extremophiles — Table 1

Extremophile	Characteristic
Acidophile	Thrive in highly acidic environments with pH lower than 3
Alkaliphile	Thrive in highly alkaline environments with pH higher than 9
Anaerobe	Need little or no oxygen for growth
Halophile	Require high salt concentrations for growth
Hyperthermophile	Thrive at temperatures above 100°C up to around 130°C
Hypolith	Live underneath rocks in cold deserts
Metallotolerant	Survive in environments with high levels of dissolved heavy metals
Oligotroph	Grow in environments with low levels of nutrients
Osmophile	Able to grow in environments with high sugar concentration
Piezophile (barophile)	Live in high pressure environments
Psychrophile	Thrive in low temperature environments, below -15°C
Radioresistant	Resistant to high doses of radiation
Thermophile	Thrive in high temperature environments above 40°C but below 100°C
Xerophile	Able to grow in very dry conditions

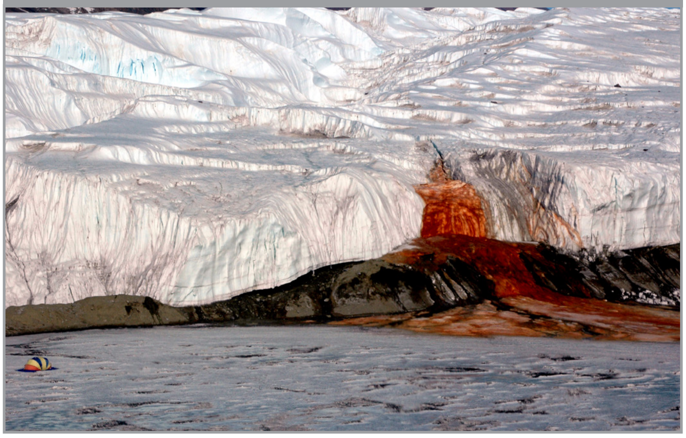
Life in the Solar System

The study of Solar System environments that may have the potential for life rely on data obtained through imagery and spectroscopy of atmospheres, or surfaces of the objects of interest (planets, moons, comets, asteroids).

During the search for life beyond Earth, scientists have to follow some assumptions about what exactly would be treated as a success of finding life (or signature hints of it). The first of these assumptions is that we look for microorganisms or traces of their past existence. Chances of finding primitive organisms are much bigger than looking for advanced species. Just imagine that, although Earth is 4.5 billion years old, species that are called non-primitive appeared no earlier than 0.5 billion years ago! Earlier Earth was inhabited only by microorganisms. The next assumption is to (mostly) look for water-based life. This condition narrows down the list of possible places that might harbour life to so called “Habitable Zone” around a star, in which water can be present in liquid state (where it is not too hot and not too cold for life to exist as we know it, and atmospheric pressure is sufficient).

Analogue environments

Figure 4



↑ Blood falls present at Antarctic dry valleys - iron rich subglacial outflows.

Analysing environments in terms of ability to harbour life is among the interest of a field called astrobiology. Scientists study areas of celestial bodies to look for clues to whether or not life potentially could have begun elsewhere in the Solar System.

This can be done by studying so called analogue environments. They are essentially environments that exhibit a set of conditions that are similar to the extra-terrestrial area of interest.

The dry valleys of Antarctica (Figure 4) are considered to be the most ‘Mars-like’ environment on Earth and contain a range of features found on Mars in the past and today. They can therefore serve as an approximation of Mars’s extra-glacial environment.

Another analogue for the Martian environment, but totally different to Antarctica, is the Rio Tinto river in Spain (Figure 4). It is a highly acidic blood red river system lined with banks of iron-rich rocks. This environment is thought to resemble what an ancient river channel on Mars might have been like when it had an atmosphere. It is therefore thought to imitate the conditions needed to precipitate specific minerals (i.e. jarosite) that have been detected on Mars, which need an acidic and iron-rich system to form.

Figure 4

phys.org

↑ "Red River" - Rio Tinto in Spain.

→ Activity: Life in space?

In this activity students will first consider what abiotic factors to investigate when searching for extra-terrestrial life and then examine the characteristics of different Solar System environments. Students will next be introduced to extremophiles and hypothesize which could possibly survive on the different Solar System bodies they investigated.

Equipment

- Fact cards available in Annex 1 and Annex 2, one set for each group.

Exercise

Introduce the students to the idea that different lifeforms can adapt to and survive in a range of different environmental conditions and that there are a number of non-living (abiotic) factors that affect this.

So, what about alien life? No evidence for extra-terrestrial life has been found yet, but scientists are looking. The question is what are they looking for and where should they look?

Discuss with the students what they think the most exciting abiotic factors would be to find out about on Solar System moons or other planets, if they were investigating them from the perspective of searching for life.

The students might give suggestions such as, oxygen, water, temperature, radiation, atmosphere. Working in pairs (or small groups), ask the students to look at the set of Solar System facts cards (Annex 1) and discuss what they know about the places in the images.
The students should then examine the environmental conditions of each place. The parameters specified are given in Table 2.

Characteristics of Solar System objects for students to investigate — Table 2

Object	Surface temperature (°C)	Atmospheric pressure (Pa)	Atmospheric gases	Radiation exposure	Magnetic field?	Acceleration of gravity (ms^{-2})
Mercury	-180 to +430	10^{-7}	Tenuous atmosphere including: hydrogen, helium, oxygen, water vapour	High	Yes	3.7
Venus	470	9.3×10^{6}	carbon dioxide, nitrogen	Low	No	8.87
Earth	-88 to +58	101.3×10^{3}	nitrogen, oxygen	Low	Yes	9.81
Moon	-233 to +123	10^{-7}	Tenuous atmosphere including: helium, argon, sodium, hydrogen	High	No	1.6
Outside of the International Space Station	-157 to +120	0	-	High	-	Microgravity
Mars	-153 to +20	600	carbon dioxide, nitrogen, argon	High	No	3.71
Titan	-179	146.7×10^{3}	nitrogen, methane	Low	No	1.35
Enceladus	-201	-	-	High	No	0.113

Some of these Solar System environments seem to be very hostile compared to most of the environments that host life on Earth. Ask the students if they know of any environments/locations on Earth that have similar environments. Suggestions might include: deserts, Arctic/Antarctica, hot acidic springs, volcanoes, depths of the ocean.

Some life on Earth has been found living in extreme environments on our planet that were previously considered to be uninhabitable. These life forms have adapted to tolerate these harsh conditions. But what type of organisms are they?

Introduce extremophiles. Give each pair (or small group) a set of extremophile fact cards (Annex 2). The students should list which extremophile(s) they think might be able to survive in each of the Solar System environments described on the Solar System fact cards. The students could also research other types of extremophiles to add to their hypothesis.

Discuss with the students their ideas for which life might be able to survive in each Solar System location. The students should give a sound justification for their choices based on the information they have been provided with or have researched.

Discussion

It must be made clear to the students that no evidence of extra-terrestrial life (including extremophiles) has been discovered yet. But discovering life in extreme environments on Earth and understanding the conditions they can survive in can help the search for life elsewhere in the Solar System and beyond. Scientists can also study environments on Earth that have some similarities to environments on other Solar System places, such as Mars.

Whilst life beyond Earth has not been discovered yet, what do the students think we should do if life is found? What do the students think is more likely to be found - intelligent life or just tiny microorganisms? And where (which planets or moons), do they think scientists should focus on looking for life?

Although extremophiles derive their energy from a wide array of chemical processes, they all rely on water and contain DNA. Perhaps exotic alien life forms use another liquid other than water, or another information-carrying molecule other than DNA. Only space missions can find this out.
Discuss with the students the implications of humans sending spacecraft to land in these environments. Every mission to other planets, for example, Mars, has very strict rules about contamination – discuss why.

Other questions to discuss with the students could be:

- Is liquid water necessary for the development of life?
- Do you think that alien life exists that doesn't use DNA as its information-carrying molecule?
- If extra-terrestial life is found would it make any difference?

This discussion could be extended to ask students to think about and list what parameters are met for something to be considered alive (made of cells, obtain and use energy, grow and develop, reproduce, respond to their environment, adapt to their environment).

→ Links

ESA resources

ESA classroom resources esa.int/Education/Classroom_resources

ESA space projects

The International Space Station
esa.int/Our_Activities/Human_Spaceflight/International_Space_Station

Cassini-Huygens esa.int/Our_Activities/Space_Science/Cassini-Huygens

Rosetta esa.int/Our_Activities/Space_Science/Rosetta

ExoMars sci.esa.int/mars

CHEOPS sci.esa.int/cheops

PLATO sci.esa.int/plato

JUICE sci.esa.int/juice

PROSPECT instrument package on Luna-27
exploration.esa.int/moon/59102-about-prospect

Extra information

Research about exobiology on the International Space Station (including a video)
www.esa.int/Our_Activities/Human_Spaceflight/Research/Exobiology

Exobiology and space missions (video)
esa.int/spaceinvideos/Videos/2013/01/Exobiology_and_Space_Missions

Planetary Protection
exploration.esa.int/mars/57581-planetary-protection

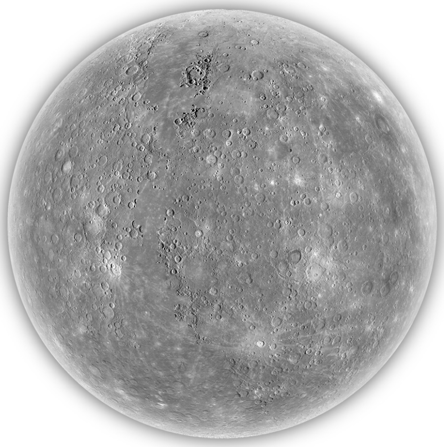
Planetary analogues
esamultimedia.esa.int/docs/gsp/The_Catalogue_of_Planetary_Analogues.pdf

Life in extreme conditions sci.esa.int/home/30550-life-in-extreme-conditions

Understanding the origins of life lunarexploration.esa.int/#/library?a=284

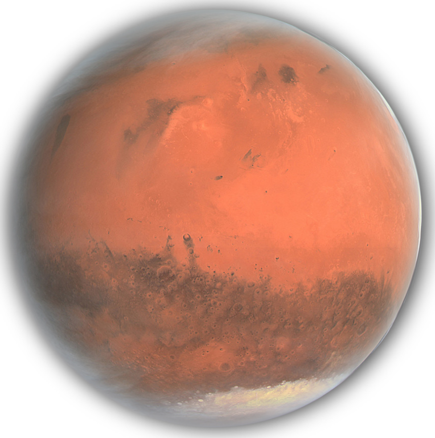
→ Annex 1: Solar System fact cards

Mercury



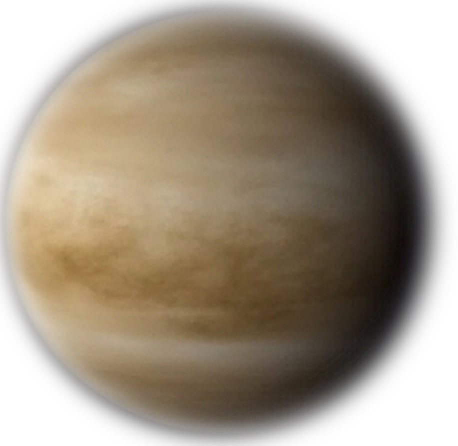
Surface temperature: -180°C to 430°C
Atmospheric pressure: 10^{-7} Pa
Atmosphere composition: Tenuous atmosphere including: hydrogen, helium, oxygen, water vapour
Radiation: High
Magnetic field?: Yes
Acceleration of gravity: 3.7 ms^{-2}
Extra information: Despite the high temperatures the planet endures during the daytime, it might be cold enough deep inside craters at its poles for water ice to be present.

Mars



Surface temperature: -153°C to 20°C
Atmospheric pressure: 600 Pa
Atmosphere composition: Carbon dioxide, nitrogen, argon
Radiation: High
Magnetic field?: No
Acceleration of gravity: 3.7 ms^{-2}
Extra information: Has water ice at the poles and at the south polar region a pond of liquid water has been detected under layers of ice and dust.

Venus



Surface temperature: 470°C
Atmospheric pressure: 9.3 MPa
Atmosphere composition: Carbon dioxide, nitrogen
Radiation: Low
Magnetic field?: No
Acceleration of gravity: 8.87 ms^{-2}
Extra information: Has a toxic and heavy atmosphere almost entirely made up of carbon dioxide. A thick layer of cloud surrounds the planet, of which the upper part consists mostly of tiny sulphuric acid droplets. At the surface, the atmospheric pressure of Venus is more than 90 times greater than the Earth's.

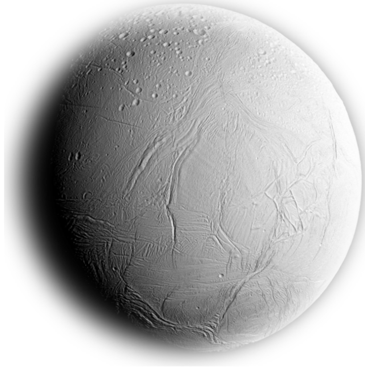
Moon

Surface temperature: -233°C to 123°C
Atmospheric pressure: 10^{-7} Pa
Atmosphere composition: Tenuous atmosphere including: helium, argon, sodium, hydrogen
Radiation: High
Magnetic field?: No
Acceleration of gravity: 1.6 ms^{-2}
Extra information: Liquid water cannot exist on the Moon. But it is thought that water ice could be found in permanently shadowed craters at the Moon's poles, and could be trapped beneath its surface.

Titan

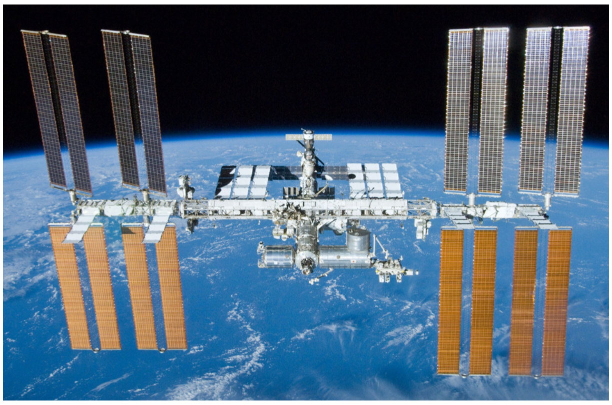
Surface temperature: -179°C
Atmospheric pressure: 146.7 Pa
Atmosphere composition: Nitrogen, methane
Radiation: Low
Magnetic field?: No
Acceleration of gravity: 1.35 ms^{-2}
Extra information: Has clouds, rain, rivers, lakes and seas of liquid hydrocarbons, such as methane and ethane. Below a thick crust of water ice there is thought to be a liquid water ocean.

Enceladus



Surface temperature: -201°C
Atmospheric pressure: -
Atmosphere composition: -
Radiation: High
Magnetic field?: No
Acceleration of gravity: 0.113 ms^{-2}
Extra information: Thought to have hydrothermal vents that sprew out mineral-rich water into an ocean that lies beneath its icy surface.

International Space Station



Surface temperature: -157°C to 120°C
Atmospheric pressure: -
Atmosphere composition: -
Radiation: High
Magnetic field?: -
Acceleration of gravity: Microgravity
Extra information: The European Space Agency has conducted a number of experiments on the International Space Station and other missions to see if organisms can survive being exposed to the harsh conditions of space.

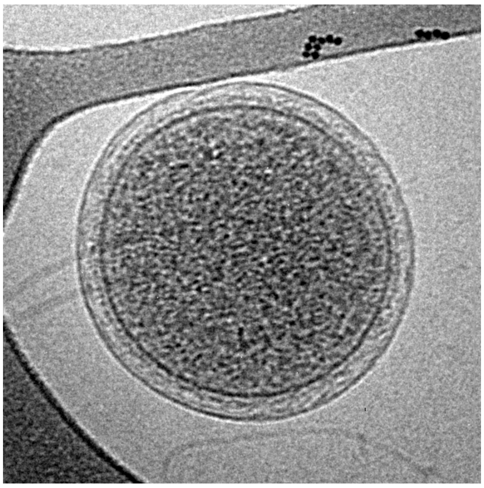
Earth

Surface temperature: -88°C to 58°C
Atmospheric pressure: 101.3 kPa
Atmospheric gases: Nitrogen, oxygen
Radiation exposure: Low
Magnetic field: Yes
Acceleration of gravity: 9.81 ms^{-2}
Extra information: The only planet in the Solar System known to host life and to have liquid water on the surface. Most of the Earth is covered in water.

→ Annex 2: Extremophile fact cards

Archaeal Richmond Mine acidophilic nanoorganism (ARMAN)

Extremophile type: acidophile



- Thrives in acidic environments between pH 2 and pH 6.
- Have been found in areas ranging in temperature from 10 - 50°C.
- Found on Earth in acid mine drains formed by weathering of sulphide-rich minerals, for example, Richmond Mine in the USA and Rio Tinto in Spain.

Xanthoria elegans

Extremophile type: psychrophile

- Found in many locations on Earth but prefers cold environments, such as boreal forests of Antarctic regions.
- Flew on outside of International Space Station for an experiment and proved to be durable to vacuum of space, high doses of radiation, extreme temperature changes and low pressure.
- Can grow up to 5 cm wide.

Artemia franciscana

Extremophile type: psychrophile

- A primitive crustacean also known as Brine Shrimp.
- Tolerates high and low levels of salt.
- Its eggs (known as cysts) can survive for 2 years in dry, oxygen-free conditions.
- Found in inland salt water lakes such as the Great Salt Lake in the USA.
- Cysts were flown on ESA's Biopan 2 mission and were found to be able to endure the low pressure environment of a vacuum and temperatures below freezing.
- Can grow up to 11 mm in length.

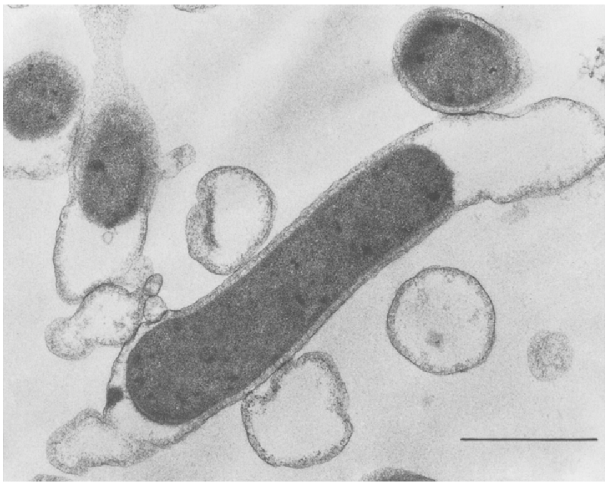
Polypedilum vanderplanki

Extremophile type: xerophile

- The larvae of this insect can tolerate being dehydrated to about 3% body weight of water (humans have 33%). Found in small rock pools in arid parts of Africa.
- Larvae were exposed to the space environment during an experiment on the International Space Station. They proved to be able to withstand extreme temperatures, high doses of radiation and the vacuum of space.
- Larvae can be up to 7 mm in length.

Thermotoga maritima

Extremophile type: hyperthermophile



- Anaerobic bacteria that thrives in water with a temperature range of 50 – 90°C.
- Prefers a neutral pH.
- Typically can grow where salt levels are low.
- Can live and grow without oxygen.
- Found in hot springs and hydrothermal vents.

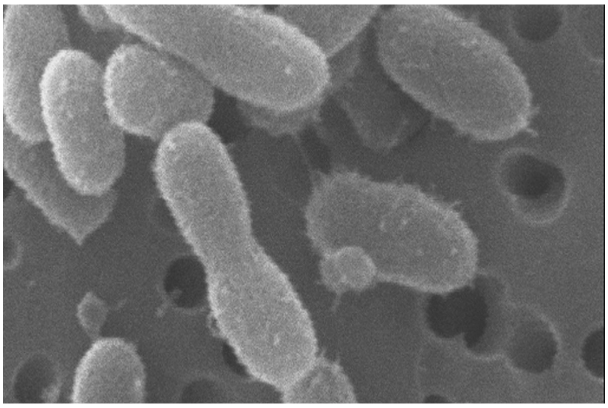
Xenophyophore

Extremophile type: piezophile

- Largest single-celled organism on Earth.
- A multinucleate (has more than one nucleus) single-celled organism.
- Can survive extreme pressure environments (1000 times atmospheric pressure).
- Found on the ocean floor around the world.

Chryseobacterium greenlandensis

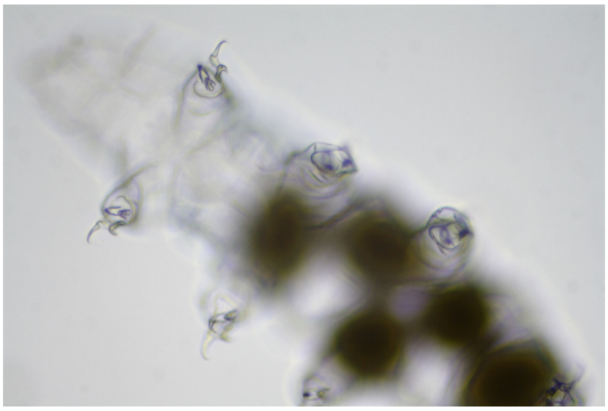
Extremophile type: psychrophile



- Ultra small bacteria.
- Thrives in temperatures between 1°C and 37°C but can survive in temperatures well below freezing.
- Resistant to low temperatures, high pressure and reduced oxygen.
- Found in a 120 000 year old ice core taken from about 3 km below the surface of a Greenland glacier.

Tardigrade

Extremophile type: not considered an extremophile



- Minute animals commonly known as water bears.
- Able to survive in but not to adapt to extreme conditions.
- Can survive a number of extreme environments: very low temperatures down to -200°C; very high temperatures up to 150°C; high doses of radiation; very high pressures; and long periods of very dry conditions.
- Can live just about anywhere on Earth but prefer wet environments such as moss.
- Were flown on ESA's Biopan 6 mission and were able to survive the harsh environment of space; extreme temperature changes, high radiation, and low pressure of a vacuum.