AQUA

EXTRA!TERRESTRIAL WATER

The Future of Water: Human and business priority

January 2022

Point-of-View

BDO

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Contents

Water beyond the Earth mainly exists on planets & moons in the form of vapour, ice, liquid, and superionic ice

Key tools for space water search

- Optical telescope
- Space telescope
- NSS[1]
- NIRVSS[2]
- Lander
- Rover

Planets and moons with the highest potential in terms of space water

Key discoveries

MOON	MARS	EUROPA
In 2012, ice was found in the Shackleton Crater on the Moon's south pole.	In 2015, the Curiosity rover identified the presence of liquid brine water.	In 2013, NASA found H_2 and O_2 in plume-like patterns in atmosphere.
In 2019, the LADEE[3] mission discovered hydroxyl or water on the surface.	In 2020, four underground lakes were found near the south pole of Mars.	In 2019, water vapour was discovered above Europa's surface.
In 2020, SOFIA[4] detected water molecules in the Moon's Clavius Crater.	In 2021, a canyon system was found, having water beneath its surface.	There are 3,0 billion km^2 of liquid saltwater under the icy surface.

Other planetary objects carrying water[4]

TITAN

CALLISTO

CERES

JUPITER

GANYMEDE

MIMAS

ENCELADUS

SATURN

URANUS

Ice · Liquid · Vapour · Superionic

Source: NASA – Where is the Water? Two Resource-Hunting Tools for the Moon's Surface – [2019]; Harvard University – Water Beyond Earth: The Search for the Life-sustaining Liquid – [2019]; NASA website; ESA website; Media overview

Notes: (1) Neutron Spectrometer System; (2) Near-Infrared Volatiles Spectrometer System; (3) Lunar Atmosphere Dust and Environment Explorer; (4) Stratospheric Observatory for Infrared Astronomy; (4) Selected

Future missions on the Moon, Mars, and Europa will boost space water exploration and accelerate space development

Key future missions aimed at water in space exploration

2022, Japan
Tera-hertz Explorer lander

2022, ESA / Roscosmos
ExoMars rover and surface platform

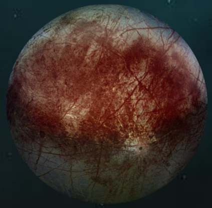
2024, NASA
EscaPADE — dual spacecraft mission

2026, NASA / ESA
Mars Sample Return mission

Water | **Land area** | **Decent sunlight**

2024, NASA
Europa Clipper mission

Liquid salty ocean | **Atomic particles[1]** | **Energy**



2022, South Korea
Korea Pathfinder Lunar Orbiter

2025, NASA
Artemis mission

2023-2027, China
Chang'e 6, Chang'e 7, Chang'e 8 missions

2025, NASA
Lunar Trailblazer mission

Water & Oxygen | **Precious metals** | **Helium-3**

Space water as a boost for long-distance missions & space tourism

- Lowering costs of rocket propellant production
- Decreasing costs of life support systems in space
- Fostering space agriculture development
- Decreasing a radiation effect during space travel

Source: Nature — NASA's Europa Clipper: A Mission to a Potentially Habitable Ocean World — [2020]; NASA website; ESA website; Space website; SpaceX website; Media overview

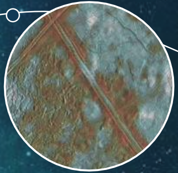
Notes: (1) Carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorus, etc.

EXPLORATION OF WATER IN SPACE

With scientific progress, scientists have learned to find evidence of water existence far beyond the Solar system

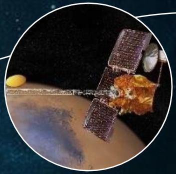
Selected milestones of water in space exploration

1976
Viking 2 (NASA) detected that the north polar cap of Mars is made of ice, rather than frozen CO_2



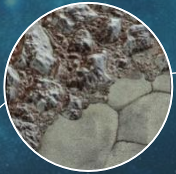
1999
Detailed photos from the Galileo spacecraft (NASA) showed an ice surface on Jupiter's moon Europa

2001
SWAS[1] (NASA) found water around a distant star, IRC+10216 (CW Leonis), located 500 lightyears from the Earth



2002
The Odyssey mission (NASA) found a significant amount of hydrogen near the Martian equator

2008
Ice on the surface of the Moon near the poles was confirmed via Mini-SAR[2] (NASA) and M3[3] (ISRO[4])



2015
The New Horizons probe (NASA) discovered that Pluto is mostly formed of ice and rock

2019
NASA identified the presence of water vapour directly above Europa's surface

2020
SOFIA[5] (NASA) detected water molecules in the Clavius Crater of the Moon's southern hemisphere

2021
NASA observed a cloud of floating water 140 trillion times the amount of water on the Earth[6]

Source: NASA – Viking Mission to Mars – [1988]; NASA website; Media overview
Notes: (1) Submillimeter Wave Astronomy Satellite (NASA); (2) Miniature Synthetic Aperture Radar; (3) Moon Mineralogical Mapper; (4) Indian Space Research Organisation, Chandrayaan-1 mission; (5) Stratospheric Observatory for Infrared Astronomy; (6) Located 30 billion trillion miles away

Telescopes, landers, rovers, and spectrometer systems are the key tools that are used for water search in space

Optical telescope

An optical telescope collects visible light and produces **visual images of distant bodies**. It indicates the brightness and structures, as well as mountains and valleys on the other planets.

Space telescope

A space telescope **operates in outer space** and provides extremely **high-resolution images** with a substantially lower background light of the planet's geological features.

NSS[1,2]

An **NSS** helps to understand the behaviour of hydrogen in space. **It is able to identify hydrogen** up to 0,9 metres below the surface and measures changes in the number and energy of neutrons to detect it.

NIRVSS[2,3]

The tool **distinguishes the nature of the absorbed materials** and **identifies their composition**. Its role in Moon exploration is to detect different types of minerals and ices present in the soil, including water.

Rover

A rover lands and drives on the planet's surface to determine the **size, shape, and material of rocks**. It also provides high-resolution images of the surface due to its built camera and collects samples for further analysis.

Lander

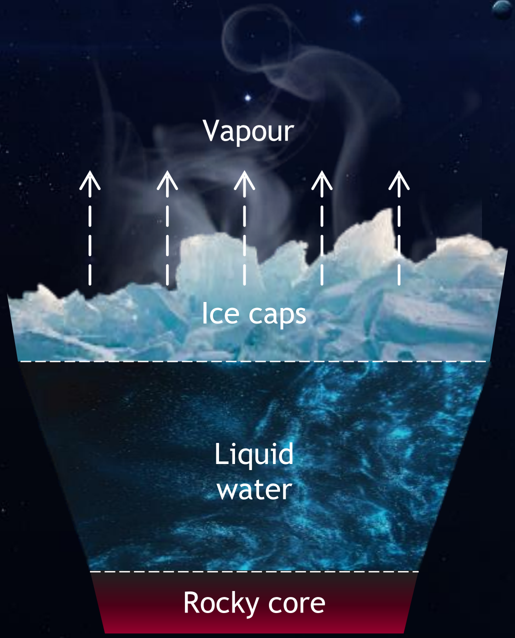
A lander picks samples from the surface and places them within the analytical chamber. Further, **chemical composition and types of minerals are determined.** For instance, a lander might identify clay minerals that are indicators of water.

Source: NASA — Where is the Water? Two Resource-Hunting Tools for the Moon's Surface — [2019]; Harvard University — Water Beyond Earth: The search for the life-sustaining liquid — [2019]; NASA website

Notes: (1) Neutron Spectrometer System; (2) Created by NASA's Ames Research Center and used for exploration of the Moon; (3) Near-Infrared Volatiles Spectrometer System

Ice is the most spread water form found on Solar system bodies, besides other forms — vapour and liquid water

Forms of water in space



Vapour mostly exists on the planets that have an atmosphere.

Ice caps are made of frozen water and form underground ice deposits.

Liquid water exists beneath the surface of planetary bodies, similar to groundwater on the Earth.

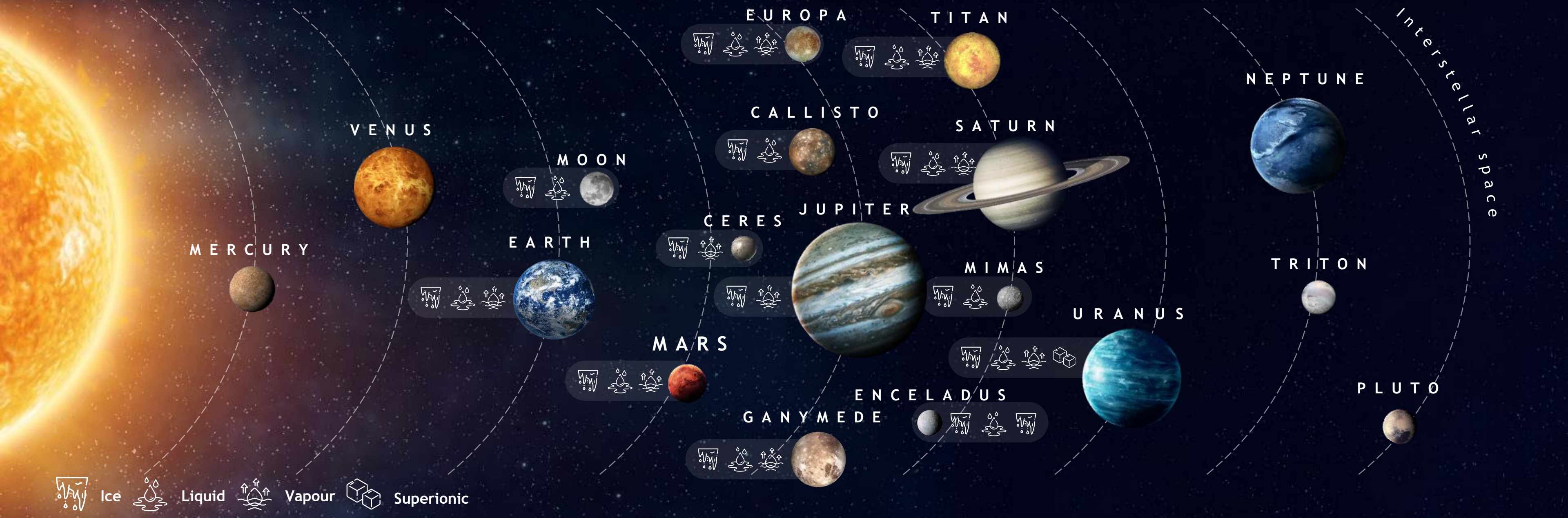
Selected Solar system bodies with different forms of water

Source: NASA website; USGS website

WATER BEYOND THE EARTH

Evidence of water existence in various forms has been found both in the Solar system and beyond its boundaries

Selected planets, moons, and dwarf planets carrying different forms of water



 Source: NASA website; ESA website

WATER BEYOND THE EARTH: PLANETS

A large amount of water that could be reachable in the near future was found on Mars under the equator surface

MARS

Ice   Liquid   Vapour

CO_2 and vapour on Mars

In 1947, **carbon dioxide** was detected as one of the components of the Martian atmosphere. In 1963, **water vapour was discovered.**

More lake discoveries

In 2020, **four underground lakes** were found near the south pole. They are assumed to be extremely salty, so microbial **life there is impossible.**

Ancient freshwater lakes

In 2013, the chemical analysis of the Martian rock taken by NASA's Curiosity rover revealed evidence that Mars could have sustained **microbial life.**

Water reserves in Valles Mariner[1]

In 2021, the ESA-Roscosmos orbiter discovered a **canyon system** on Mars that has **water** beneath the surface and a significant amount of **hydrogen.**

Liquid brine water

In 2015, **liquid brine water** was identified by the Curiosity rover (NASA) in the upper five centimetres of the Martian subsurface at night.

Unstable water distribution

The planet's distinct peculiarity is **vapour migration and dryness,** resulting from dust storms during the southern summer.

Source: NASA website; ESA website; BBC website; Media overview

Notes: (1) The system stretches about 4.000 kilometres in length and up to 7 kilometres in depth

NASA estimates that Jupiter's water reserves in Great Red Spot might even be larger compared to the Earth's ones

JUPITER

Ice Vapour

No possibility of life on Jupiter

Scientists believe that **Jupiter's environment is unsuitable for life.** The planet's conditions are **too extreme for the adaptation of organisms.**

Composition of Jupiter

Jupiter is composed mostly of hydrogen and helium. Thus, Jupiter has the largest ocean in the Solar system, **which is made of hydrogen instead of water.**

First evidence of water

In the 1970s, **Voyager[1] detected some lightning storms on Jupiter,** which could be a sign of **water presence** on the planet, as well as the **dynamic weather system.**

Underestimation of water reserves

Juno's mission[1] (NASA) discovered that **water amounts to 0,25% of the molecules in Jupiter's atmosphere.** It was much greater than what the **Galileo[2] probe measured.**

Ice and vapour in the cloud layers

Jupiter has three distinct cloud layers, which together span ~71 kilometres. The inner layer is possibly made of **ice and vapour, while the top — of ammonia ice.**

More water than on the Earth

In 2018, scientists found a lot of water in Jupiter's **Great Red Spot[3].** In total, it might contain more water than the **amount of water on the Earth.**

Source: Forbes — Is Jupiter A Water World? — [2020]; NASA website; Media overview
Notes: (1) NASA's space probe orbiting Jupiter; (2) NASA's space probe that studied Jupiter in the 1990s; (3) Persistent high-pressure region in the atmosphere of Jupiter

Scientists consider Saturn's rings and more than 60 of its moons to be mostly made of Earth-like water

SATURN

Water in the atmosphere of Saturn

There is water in the atmosphere of Saturn with concentrations **greater than one part per billion**. Around 75% of Saturn's atmosphere is hydrogen and 25% – helium.

Water vapour from geysers

Water from the geysers[1] of the subglacial ocean of **Enceladus**[2] may be the source of **water ice in Saturn's rings**, which gives them shine and brightness.

Different concentrations of water

The **highest** water concentration is at the **equator**, and the **lowest** – at the **poles of Saturn's gaseous shell,** which confirms that water on Saturn **could not have appeared from the comet.**

Water on Phoebe[3]

Water in Saturn's rings and satellites does not differ from the Earth. **Phoebe** also has **water**, yet **with a specific formula** not found anywhere in the Solar system.

Possibility of rain on Saturn

The first suggestion about **rain on Saturn** was made when **Voyager 1** noticed several dark belts. In **2011,** rainy areas were found via the telescopes of the Hawaiian Keck Observatory.

Invisible clouds

Water from the **upper atmosphere** of Saturn **moves to lower levels**. It **condenses**, but the formed clouds are invisible since **the amount of water is small.**

Ice Liquid Vapour

Source: NASA website; ESA website; USGS website; CNN website; Media overview

Notes: (1) Discovered by the Cassini probe; (2) Satellite of Saturn; (3) Irregular satellite of Saturn

Being one of the ice giants, Uranus has very deep ice layers under its atmosphere, unlike the terrestrial planets

URANUS

Ice | Liquid[1] | Vapour | Superionic[1]

Ice giant

Uranus is classified as one of the **ice giants** and is assumed to have **large layers of ice** or **possibly liquid water** under its atmosphere.

Closest glimpse

Being the 7th planet from the Sun, Uranus has **limited research opportunities.** The only spacecraft flying by was Voyager 2 in 1986.

Severe atmosphere

Uranus is one of the coldest planets. Its atmosphere mostly consists of **hydrogen, helium, methane**, as well as **traces of water and ammonia.**

Superionic water on Uranus

Scientists assume that **superionic water** might compose a **large part of Uranus's inner layers** and has higher **electrical conductivity**[2].

Uranus's composition

Around 80% of Uranus's mass is **water, methane, and ammonia that form** a hot dense fluid of **icy materials** located **above the rocky core.**

Uranus's moons

Uranus's inner moons are comprised of **approximately half water ice and half rock**, while the structure of **outer moons still remains unknown.**

Source: NASA website; EarthSky website; Media overview

Notes: (1) These types of water are only assumed to be presented on Uranus; (2) Compared to water on the Earth

WATER BEYOND THE EARTH: MOONS & DWARF PLANETS

Scientists focus on the exploration of the Moon to look for potential water sources in the closest distance to the Earth

MOON

Ice[1] Liquid

Existence of ice on the Moon

In 1961, **the existence of ice** in the floors of polar lunar craters was supposed, while most of the lunar surface was presumed to be completely dry.

First evidence of water

In 2008, the exploration of lunar rock samples from the Apollo missions provided **evidence of the existence of water molecules** in volcanic glasses.

Ice in the Shackleton Crater

In 2012, ice was found in the Shackleton Crater on the Moon's south pole. The crater is more than 19 kilometres wide and 3 kilometres deep, similar to the Earth's oceans.

Discovery of molecular water

In 2019, the LADEE[2] mission (NASA) revealed that hydroxyl or water **existed on the sun-shining surface of the Moon**, and might be found throughout all lunar surfaces.

Water in the Clavius Crater

In 2020, SOFIA[3] (NASA) detected water molecules in the Moon's **Clavius Crater** on the southern hemisphere using **an infrared telescope.**

Limited water concentration

The amount of liquid water detected by SOFIA in the lunar regolith is 100 times less than in the Sahara Desert. Its concentration is 100 to 412 parts per million.

Source: Space – Huge Moon Crater's Water Ice Supply Revealed – [2012]; NASA website; Planetary website; Media overview
Notes: (1) The expected amount of water ice on the Moon is 20% of the surface and the lunar poles have over 600 billion kilogrammes of water ice; (2) Lunar Atmosphere Dust and Environment Explorer; (3) Stratospheric Observatory for Infrared Astronomy

Ceres is the largest dwarf planet, which has 20-30% of water ice under a thin outer layer of dust and rock

CERES

Ice Vapour

Potential life on Ceres

Scientists focus on **discovering life signs on Ceres.** Since water presence is a crucial aspect of life, **it has a perspective for further research.**

Icy dwarf planet[2]

The Dawn mission discovered that **Ceres's density is ~2,2 grammes per cubic centimetre.** Thus, scientists suggest that **~25% of its mass is water ice.**

Ancient salty water

In the 1800s, **salts bearing water that quickly dehydrated** were noticed on Ceres. **The Dawn mission** concluded that **salt compounds concentrate within the Occator Crater and still have water.**

Ceres's composition

In 2015, **the Dawn mission (NASA)** discovered that Ceres contains **20-30% of water ice,** and its bowels are divided into a **rocky core and a thin outer ice mantle.**

Discovery of water vapour

In 2014, the ESAHSO[1] detected **water vapour around Ceres,** which created a transient atmosphere, **known as an exosphere.**

Probable presence of oceans

In 2020, **scientists found** that a liquid ocean comes from **an underground reservoir of water, located** 40 kilometres below the surface.

Source: NASA website; ESA website; Media overview

Notes: (1) ESA's Herschel Space Observatory; (2) Classified as a dwarf planet in 2006

Jupiter's second-largest moon might have a salty ocean under the surface and the potential for supporting life

CALLISTO

Ice Liquid[1]

Jupiter's huge moon

Callisto is **Jupiter's second-largest moon**, which is also the **third-biggest moon** in the whole Solar system, with an **icy surface** densely **covered with craters.**

Callisto's salty ocean

Callisto was **believed** to be composed of **only rock and ice** for a long time. However, in **the 1990s NASA's Galileo spacecraft** discovered that it has an **underground salty ocean.**

Structure of Callisto

The composition of Callisto is assumed to have **almost equal parts of water ice and rocks.** The **share of ice,** which **contains ammonia, constitutes up to 55%** of Callisto's structure.

Possibility of life

Scientists assume that the **ocean under Callisto's surface** might reach **up to 250 kilometres below the surface,** therefore, creating a **possibility of life on Callisto.**

Icy surface

Spectroscopy discovered the **presence of water ice, carbon dioxide, silicates, and organics** on Callisto. The **mass share of ice** on Callisto's surface is assumed to **compose up to 25-50%.**

Callisto's further exploration

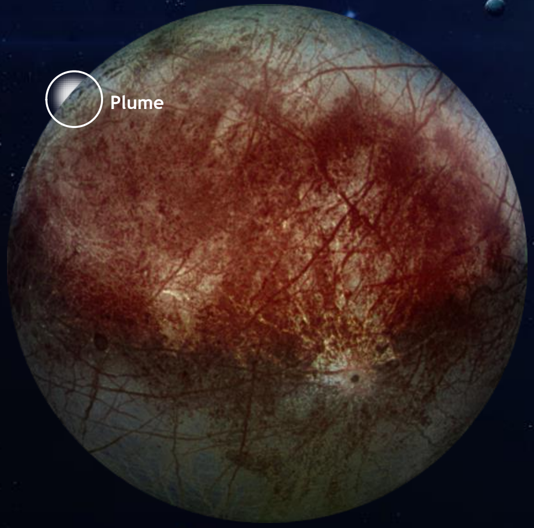
ESA aims to send the **Jupiter Icy Moons Explorer spacecraft** to Jupiter, which is projected to **arrive by 2029,** and **fly by Callisto to get more data about its water and potential life.**

Source: NASA website; Universe Today website; European Central Commission website; Media overview

Notes: (1) Liquid water is only assumed to be presented on Callisto

Under the miles-thick ice cover, Europa has a liquid water ocean that could be twice as large as the one on the Earth

EUROPA



Ice Liquid Vapour

Potential presence of water

In 1979, two American Voyager spacecraft (NASA) explored the Jupiter system, providing **the first evidence that Europa might have liquid water.**

Existence of global ocean

Based on the findings from the Galileo mission in 1989 (NASA), scientists built a hypothesis that there is **a global ocean of salty water under the icy surface of Europa.**

Amount of water on Europa

According to NASA estimations, there are ~**3,0 billion cubic kilometres of liquid saltwater** under the icy surface, which is about twice as much as on the Earth.

Possible water plumes

In 2013, NASA found **the chemical elements hydrogen and oxygen** in plume-like patterns in Europa's atmosphere, confirming the earlier atomic species detections.

Detection of water vapour

In 2019, **NASA discovered vapour directly above Europa's surface.** Via one of the world's largest telescopes in Hawaii, scientists managed to measure the vapour.

Further exploration

In 2024, NASA plans to launch the Europa Clipper that will study Europa's interior to **confirm the presence of the ocean and assess the possibility of life on Europa.**

 Source: NASA website; Media overview

Ganymede, Jupiter's satellite, is thought to hold significantly more water than all of the Earth's oceans

GANYMEDE

Ice Liquid Vapour

Ganymede's composition

Jupiter's moon is made of equal amounts of **silicate rock** and **water ice.** A **liquid core** of Ganymede is rich in **iron.**

Subterranean ocean

In 2015, Hubble Space Telescope found evidence of a **salty ocean** – 100 kilometres thick and buried under a 150 kilometres thick ice crust.

Magnetosphere[1]

In 1996, NASA's Galileo spacecraft captured **sounds of whistling and static** sounds generated by Ganymede's magnetosphere.

Water vapour

In 2021, NASA obtained the presence of **water vapour in the atmosphere.** This water vapour is formed when ice from the surface sublimates.

Beneath the ice

In **2004**, NASA discovered irregular lumps beneath the icy surface. The irregular masses might be **rock formations**, supported by an icy shell.

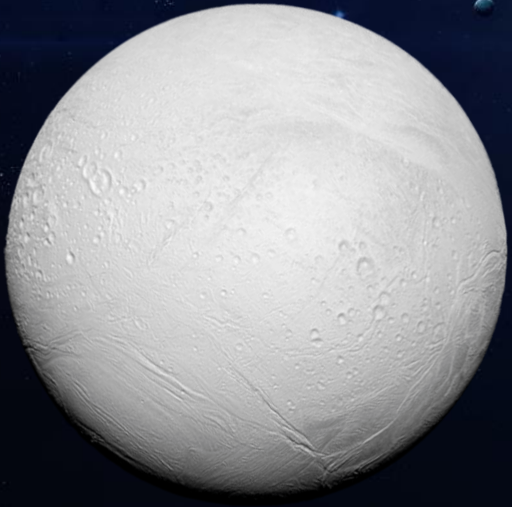
Further explorations

The future mission focused on the Ganymede research is **JUICE** (ESA, 2022). It will explore the **icy Galilean moons** with a focus on Ganymede.

 Source: NASA website; Media overview

There is evidence of a water subsurface ocean with a 10 kilometres thickness on Saturn's satellite Enceladus

ENCELADUS



Ice Liquid Vapour

Enceladus's composition

In the 1980s, it was revealed that the **icy surface of Enceladus** is smooth and bright white, making it one of **the most reflective bodies** in the Solar system and the brightest of all satellites.

Hidden ocean within the moon

In 2005, **vapour, ice particles, and organic compounds pouring from the south polar area** were discovered, which resulted in the assumption that the moon has a liquid water ocean.

First detailed images of Enceladus

In 2008, Cassini (NASA) examined the plume and identified the presence of **volatile gases, water vapour, carbon dioxide, and carbon monoxide, as well as organic compounds.**

Ocean on Enceladus

In 2010, Cassini discovered signs of **a massive subsurface ocean on the south polar consisting** of liquid water with a thickness of 10 kilometres behind a **30-40 kilometres ice crust.**

Organic macromolecules

In June 2018, Southwest Research Institute scientists announced the discovery of complex **organic macromolecules** in samples collected by NASA's Cassini.

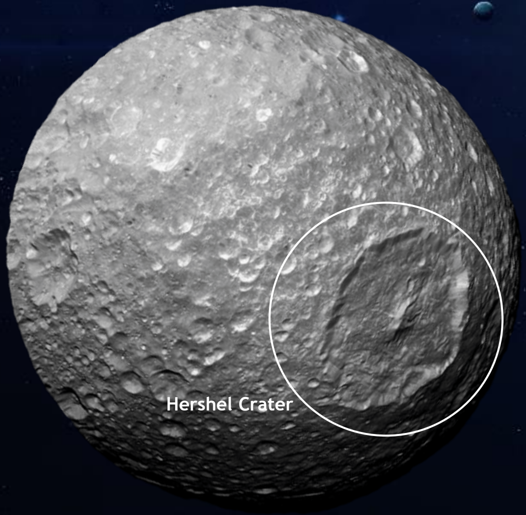
Further explorations

Despite the fact that the Cassini mission ended in 2017, researchers are still analysing **the plume data to gain a deeper understanding of Enceladus's ocean.**

 Source: NASA website; Media overview

Mimas is Saturn’s smallest moon and is known for its massive ice deposits and enormous Herschel Crater

MIMAS



Ice

Liquid

Mimas’s composition

Mimas’s low density proves that **it consists almost entirely of water ice**, which is the only substance detected on Mimas. Rock is assumed to form around 1% of Mimas.

Closest glimpse

Mimas was captured several times by the Cassini orbiter, which entered Saturn’s orbit in 2004. On 13 February 2010, **Cassini passed by Mimas** at a distance of 9.500 kilometres.

Herschel Crater

The **Herschel Crater, named after** the discoverer of Mimas, is its key defining feature and stretches **139 kilometres wide.** Its diameter is ~60% of the diameter of Mimas.

‘Mimas Test’ paradox

Tidal heating is much stronger on Mimas than on Saturn’s moon Enceladus, yet water geysers were noticed on Enceladus instead. This paradox was called the **‘Mimas Test’**.

Mimas’ motion

In 2014, NASA noted that the **librational motion** of Mimas might be caused by the **hydrostatic equilibrium or by an interior ocean.**

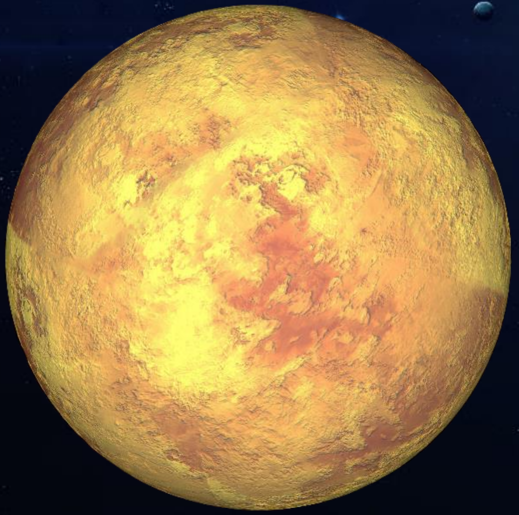
Possible ocean on Mimas

In 2022, Cassini mission showed that Mimas might be **warm enough to harbour a liquid ocean** beneath a 24-31 kilometres thick ice shell.

 Source: NASA website; Forbes website; Media overview

Titan has liquid bodies on the surface, such as rivers, lakes, and seas, as well as the liquids circulation cycle

TITAN



Ice Liquid[1] Vapour

Moon with liquid bodies

Titan is **Saturn's largest moon** and **the second-biggest moon in the Solar system**, which has **liquid bodies on the surface**, including **rivers, lakes, and seas.**

Titan's structure

Titan is supposed to have **a multi-layer composition: the rocky core** covered with **ice**, a **layer of salty liquid water**, the **outer crust of ice**, and an **organic-rich atmosphere**.

Liquids circulation

Titan is the **only moon in the Solar system**, which has a **circulation cycle of liquids**, analogous to the one on the **Earth.** Liquids **rain from clouds, fill lakes and seas,** and then **evaporate**.

Prevention of ice melting

Cold temperature and **high pressures prevent the melting of ice**, therefore, there is almost **no liquid water in the atmosphere**, and **ice plays the role of rock.**

Water vapour

In December **1997**, the European Space Agency's **Infrared Space Observatory** revealed **the presence of water vapour** in **Titan's atmosphere**.

Underground ocean

The Cassini spacecraft and the **Huygens probe** discovered an **ocean of liquid water** possibly mixed with **salts and ammonia** that might reach **55-80 kilometres under the surface**.

Source: NASA website; ESA website; Media overview
Notes: (1) Liquid water is only assumed to be presented on Titan

WATER BEYOND THE EARTH: OTHER OBJECTS IN SPACE

Comets and asteroids might have carried a large part of ocean water at the early stage of the Earth's development

What is a comet?

A comet is composed of the **rock-ice nucleus**, the **atmosphere** that appears as the **part of ice begins to melt** and **boil off** together with particles of dust, and the **tail**.

Possible source of water

Scientists assume that comets **might have played a key role in delivering water** to the Earth, as water on comets might **have the same origin** as in **the Earth's oceans.**

What is an asteroid?

An asteroid is **composed of rock, metals, other elements**, and sometimes **water**. It is assumed that water on asteroids might be **in the form of ice or hydrated minerals.**

Potential answer for water origin

Scientists guess that almost half **of the Earth's ocean water could have been brought with asteroids** due to the similarity of **isotopes distribution.**

Halley's Comet

This **comet approaches the Earth every 75 years**. It was revealed that **gases ejected from the nucleus** composed **~80% of vapour**, yet, of a **different kind than on the Earth.**

46P / Wirtanen comet

In 2018, **SOFIA**[1] discovered that comet **46P / Wirtanen** contains **Earth-like water**. It is the **third known comet** to have the same **D/H ratio**[2] **as terrestrial water.**

Proved presence of water

The first evidence of water on asteroids was in 2010 when Scientists **found water ice** on **asteroid 24 Themis**. In 2018, **hydrated minerals** were discovered on **Bennu.**

Itokawa asteroid

In 2019, Arizona State University researchers detected **water and organic contents** in dust particles of **25143 Itokawa**, brought by **Japan's Hayabusa spacecraft** in 2010.

Source: NASA website; ESA website; Space website; Media overview

Notes: (1) Stratospheric Observatory for Infrared Astronomy (NASA); (2) Ratio between heavy hydrogen and hydrogen in natural waters and other fluids that indicates the origin and geologic history of the fluid, as well as shows data on fluid and rock interactions

The Kuiper Belt contains millions of various-size icy objects, the Orion Nebula generates a huge amount of water vapour

Faraway belt

The Kuiper Belt is one of the largest structures in the Solar system **located beyond Neptune's orbit**. It has a doughnut-shaped ring and **consists of icy bodies**.

Structure of Kuiper Belt

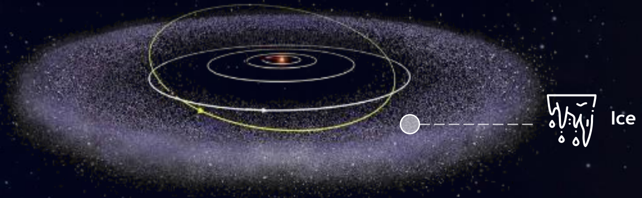
The Kuiper Belt might **comprise millions of icy objects** that were created as **leftovers from the Solar system formation**. It has hundreds of thousands of icy bodies >100 kilometres.

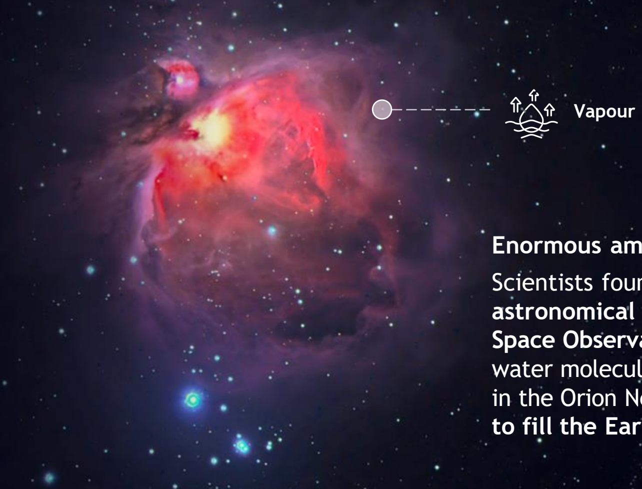
Orion Nebula

The **Orion Nebula** is the **closest region of star formation** to the Earth. It includes **thousands of stars**, as well as **planet-mass objects** surrounded by **hydrogen and other elements.**

Discovery of life elements

Scientists discovered the **presence of elements** needed for supporting life, such as **water, methanol, sulphur dioxide, and hydrogen sulphide,** using the **Herschel Telescope**.





Kuiper Belt Objects (KBOs)

KBOs include **both small and large bodies** that might reach **1.000 kilometres in diameter,** which are composed of **rock, water ice**, and various **frozen compounds, namely ammonia and methane.**

Ultima Thule

In 2019, during the **New Horizons spacecraft** flyby, **NASA** discovered a **combination of methanol, water ice, and organic molecules** on the surface of **Ultima Thule** – the **farthest object explored by mankind.**

Enormous amount of vapour

Scientists found **vapour** using **an astronomical satellite Infrared Space Observatory**. The amount of water molecules generated in a day in the Orion Nebula might be **enough to fill the Earth's oceans 60 times.**

 Source: NASA website; ESA website; Space website; Media overview

NASA's Hubble Space Telescope found signs of water and vapour in the atmospheres of several exoplanets

Selected exoplanets[1] containing signs of water[2,3]

Gliese 581c, Gliese 581d, and Gliese 581g in the Gliese 581 system might **have liquid water**. In 2019, it was discovered that **Gliese 581d might have a dense atmosphere, water oceans, and even traces of life. Gliese 581c** is also in the **habitable zone.**

Liquid

Gliese 581c, Gliese 581d, and Gliese 581g

Kepler-22b

Liquid

Discovered in **2011**, **Kepler-22b** potentially could be **an ocean planet.** It likely has a volatile composition with a **liquid or gaseous shell**, and **life might exist in this ocean.**

In 2016, it was assumed that **Kepler-62f** might be an **ocean-covered planet** with **water** on its **surface**. It also could have **climate changes similar to those happening on the Earth.**

Kelper-62f

Liquid

Kepler-452b

Liquid

Kepler-452b is assumed to **have lakes, pools, and rivers.** Probably there could be **oceans**, yet all of them **have dried up.** The majority of the **surface** is blue, **indicating water** with patches of land.

K2-18b is the **only exoplanet** with **both liquid water and acceptable temperatures** for the emergence of **life**. Its **atmosphere** also contains **vapour, hydrogen, and helium.**

K2-18b

Liquid Vapour

Source: Nature Astronomy website; NASA website; Media overview

Notes: (1) Planets outside the Solar system; (2) All pictures are an artist's conception; (3) All types of water are only assumed to be presented on exoplanets

FUTURE MISSIONS AIMED AT WATER IN SPACE EXPLORATION

The James Webb Space Telescope will study phases of cosmic history, including the birth of stars and life's origins

James Webb Space Telescope is a **space-based observatory** with large primary **mirror** and **infrared instruments** that **orbits the Sun** at **1,5 million kilometres from the Earth.**

Key facts

Launch date: 25 December 2021

Cost: 8,8 Bn Euro[1]

Lifetime: 10 years

Partners: NASA, ESA, CSA[2]

Mirror size: 6,5 metres

Mass: 6.200 kg

Operating temperature: -230°C

Travel distance: 1,5 million kilometres from the Earth

Key goals of James Webb Space Telescope

Studying Universe

Using the powerful **infrared vision, the James Webb Telescope will** search for the **first galaxies and luminous objects** that developed **after the Big Bang.**

Galaxies development survey

Considering remarkable **infrared sensitivity**, the James Webb Telescope will **examine** the **galaxies' evolution process** starting **from their formation until the present time.**

Star lifecycle observation

Another Telescope's **key goal** is the **observation of the full star formation process**, starting from the **first stages** to the **establishment of planetary systems.**

Discovering other worlds

The James Webb Telescope will **examine atmospheres** and measure **chemical & physical characteristics of planetary systems** to discover **potential life.**

Source: NASA website; Space website; Media overview

Notes: (1) Numbers are converted from USD to Euro due to the average annual exchange rate by ECB; (2) Canadian Space Agency

Future missions will focus on the exploration of the lunar environment for conducting further activities on the Moon

Key reasons to explore the Moon

Water and oxygen to produce rocket fuel and establish a human base

Precious metals, rocks, and rare earths to create building & raw materials

Helium-3 to create fuel suitable for fusion energy generation

2022
South Korea, KPLO
Korea Pathfinder Lunar Orbiter will start a technology demonstration mission to establish basic facilities for lunar exploration for South Korea.

2023
SpaceX, #dearMoon project
Japanese billionaire Yusaku Maezawa and up to eight other passengers will start the lunar tourism at the Starship spaceship.

2023-2024[1]
China, Chang'e 6
The mission will bring rock samples from the Moon's south pole and carry science payloads developed in France, Italy, Russia, and Sweden.

2024[1]
China, Chang'e 7
A relay satellite, a lander, a rover, and a mini flying craft will explore the lunar environment, including geological composition and location of water ice.

2025
NASA's Lunar Trailblazer
The mission within NASA's SIMPLEx[2] programme will study the lunar water cycle and detect traces of water ice and water trapped in rock.

2027[1]
China, Chang'e 8
The mission will start the reconstruction of the joint project between Russia and China — International Lunar Research Station.

Source: Space website; New York Times website; NASA website; Media overview
Notes: (1) Preliminary year of launch; (2) Small Innovative Missions for Planetary Exploration

Artemis's mission aims to establish a long-term presence on the Moon with further exploration of water and resources

Key objectives of Artemis's mission

Technology: develop technologies to provide future deep-space missions

Long-term presence: establish a base to extend the space trips to months

Knowledge: get samples more strategically with the help of new advanced technologies

Resources: further discover water on and rare minerals deposits to provide scientific and economic exploration

Estimated budget: **~82 Bn Euro[1]**

2021 → 2024

First CPLS[2] mission delivered 16 instruments to the Moon

VIPER will explore the environment of the Moon in search of water ice and other resources

CAPSTONE CubeSat will test navigation techniques to reduce uncertainties

Artemis I[3] will verify spacecraft performance

PPE & HALO[4] launch will conduct research of the deep space environment

Artemis II[5] will validate space communication and navigation systems

Artemis III will bring the first woman and next man to the Moon

Source: NASA – Human Exploration and Operations Mission Directorate – [2019]; NASA – Lunar Exploration Programme Overview – [2020]; Media overview
Notes: (1) Numbers are converted from Euro to USD due to the average annual exchange rate by ECB; (2) Commercial Lunar Payload Services; (3) Uncrewed mission; (4) Power and Propulsion Element & Habitation and Logistics Outpost; (5) 10-day crewed test flight

Further exploration of Mars is crucial for studying a possible life existence and water presence on the planet

Key reasons to explore Mars

Water is locked into the Mars icy polar caps

Mars's **land area** is almost equal to the surface area of the Earth's continents

Mars still has **decent sunlight** as it is about half as far from the Sun as the Earth

2022

Japan, TEREX[1]

Japanese Aerospace Exploration Agency will send a TEREX lander to study water and oxygen molecules, as well as search for water sources on Mars.

2024[2]

NASA, EscaPADE

The dual spacecraft mission will study the processes in Mars's magnetosphere, as well as its interaction with the Solar wind.

2024

Japan, Martian Moons eXploration

The mission will study the surface of Mars's moons and bring the sample of Phobos to the Earth to survey the traces of water and organic materials.

2026

NASA / ASI[3] / CSA / JAXA[4], Mars Ice Mapper

The collaborative mission is directed at discovering location, depth, and abundance as well as mapping deposits of near-surface ice.

2022

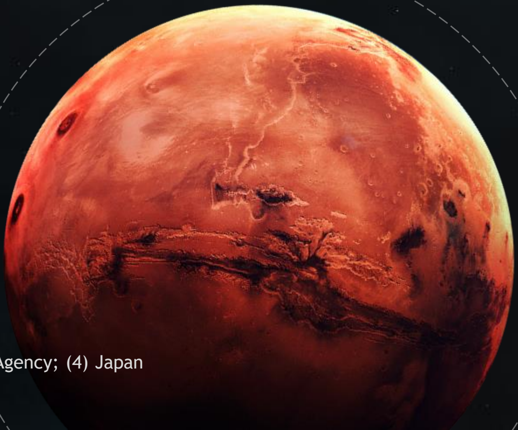
ESA / Roscosmos, ExoMars 2022

An ExoMars rover and a surface platform will search for organic materials, as well as drill and analyse samples from the surface to study the possible life existence on Mars.

2026[2]

NASA / ESA, Mars Sample Return

The international Mars Sample Return mission will be aimed at gathering and delivering the samples of Mars's surface to the Earth.



Source: NASA website; ESA website; SpaceX website; Media overview

Notes: (1) Tera-hertz Explorer; (2) Preliminary year of launch; (3) Italian Space Agency; (4) Japan Aerospace Exploration Agency

The Clipper mission aims to define if Europa has conditions suitable for life, especially a hidden saltwater ocean

Key reasons to explore Europa

A liquid salty ocean is predicted to lie beneath Europa's surface

Atomic particles[1] produce compounds that could be used for living

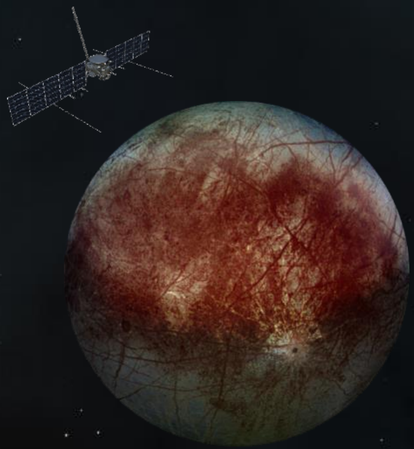
Jupiter's gravity creates tides on Europa that produce **heat and energy** to sustain life

Europa Clipper mission

Date: October 2024

Launch: Falcon Heavy rocket[2]

Weight: 6.000 kilogrammes at launch[3]



The key objective of the Europa Clipper mission is to understand:

- **Ice shell and subsurface water** — ocean properties and the nature of the surface-ice-ocean exchange
- **Habitability of Europa's ocean** through **composition and chemistry**
- Formation of **surface features**, including sites of **recent geological activity** and high science interest

Key groups of instruments:

- **Cameras and spectrometers** for high-resolution images of the surface and atmosphere
- **Thermal camera** to pinpoint warmer ice and reveal eruptions of water
- **Ice-penetrating radar, magnetometer, and plasma sensors** to investigate the ocean
- **Dust analyser and mass spectrometer** to study the chemistry of particles in space

Source: Nature — NASA's Europa Clipper: A Mission to a Potentially Habitable Ocean World — [2020]; NASA website

Notes: (1) Carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorus, etc.; (2) Launch services amount to ~158 Mn Euro; (3) Around 65% of mass is fuel

SPACE WATER AS A BOOST FOR LONG-DISTANCE MISSIONS

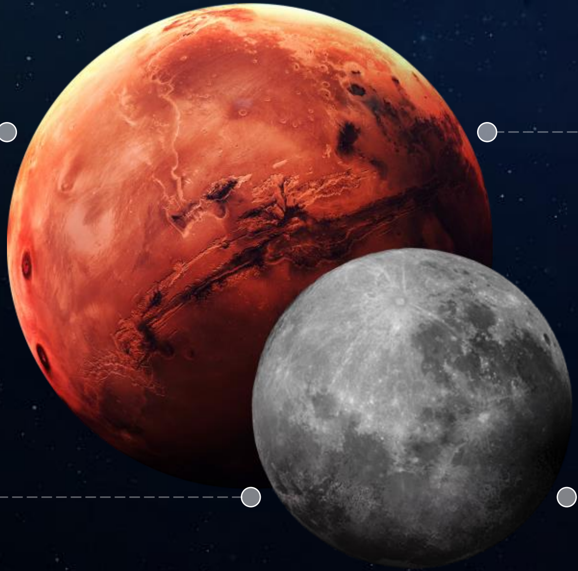
Space water will boost space development and tourism, as it might be used for fuel production and for life support

Lowering costs of rocket propellant production

The outer space refuelling with LH_2 produced from the water in space will substantially reduce the rocket launch costs and increase the distance of the space missions.

Fostering space agriculture development

Extracting water from Mars and the Moon might be more cost-efficient than delivering it from the Earth, which will also be crucial for the colonisation of other planets. It will boost the development of space agriculture and farming.



Decreasing a radiation effect during space travel

Current countermeasures against space radiation are expensive and not fully secure. Usage of hydrogen-rich plastic for spacecraft and liquid hydrogen & water might minimise the effects of space radiation.

Lowering costs of life support systems in space

Usage of space water will be beneficial for life support during space missions, providing astronauts with the necessary amount of water for drinking and hygiene. It will also boost space tourism development and colonisation.

Source: NASA website; ESA website; Media overview

Using water in outer space as a resource for LH_2 might unlock opportunities for long-distance missions

Water from Earth

Limitations of rocket propellant usage and production

High cost of the launch due to transportation requirements of LH_2

Short distance for the space travel due to specific characteristics[1] of LH_2

Requirement of increased safety measures due to high flammability of LH_2

Higher atmospheric pollution during non-renewable LH_2 production

Water from space

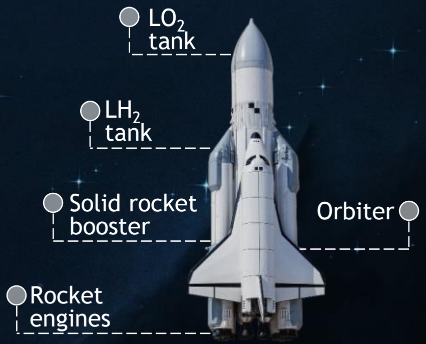
Advantages of space water usage

Longer distance missions as LH_2 will be refilled in outer space

Lower pollutions as part of hydrogen will be produced in outer space

After landing, spacecraft will be refuelled using local resources – water and CO_2

LH_2 as a space rocket fuel



BLUE ORIGIN
SPACEX
SKYRE
OxEon energy

In 2019, NASA awarded 15,5 Mn Euro to four companies to study and produce technologies to create fuel on the Moon and Mars

- **High rocket propellant consumption** during the rocket take-off is caused by the **high gravity** of the Earth. The outer space refuelling with LH_2 produced from the water in space will substantially **reduce the rocket launch costs** and **increase the distance** of the missions
- Usage of **space water** might **increase LH_2 competitiveness** in the aerospace industry, as it will be impossible to use other rocket propellants, such as methane and kerosene, for refuelling in space

Source: NASA website; Media overview

Notes: (1) LH_2 is consumed in minutes during the launch, yet it takes a lot of space in the rocket (~80-90%)

Oxygen generation and water purification of the space water might increase crew size and space travel distance

Limitations of life support systems in space

Water from Earth

Limited oxygen capacity limits space travel with a larger crew

High cost of transportation leads to limited water resources on the spacecraft

Lack of hygiene activities on the spacecraft limits space tourism

High operational costs of life support systems due to limited water resources

Advantages of space water usage

Water from space

Longer distance space missions as O_2 could be produced from the water in space

More realistic plans for colonisation due to larger purified water and O_2 resources

Growth of space tourism due to development of orbital recreational centres

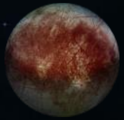
Extra cargo could be carried out from the Earth instead of the water and oxygen supplies

Estimated costs for a private astronaut flight on ISS[1,2]

Per person, per day

- **1.690** Euro — **Food & Beverages**[3]
- **1.270** Euro — **Crew provision**[4]
- **138.670** Euro — **Upmass / disposal**

- **2,3 K** Euro — cost for sending a 1 litre bottle with SpaceX Falcon 9
- **1,5 thousand litres** — is carried by one supply trip to fill reserves of the ISS



- In order to make water potable, the crew has to conduct a multi-level purification process that makes the life support process during **space travel extremely expensive**. Usage of space water might **make space travel on longer distances more cost-effective**
- **Usage of space water** will boost the development of **space tourism**, as water purification will become **more affordable**. Some **companies** plan to start commercial space hotels construction, e.g. Voyager Station[5]

Source: NASA — Commercial and Marketing Pricing Policy — [2021]; NASA website; Media overview
Notes: (1) International Space Station; (2) As of April 2021; (3) Upmass and trash disposal not included; (4) Clothing, hygiene products, office supplies, sleeping bags, and other crew supplies; (5) Orbital Assemble Corporation conceptual project

Using water from space might potentially lower costs for delivering water from the Earth and boost space agriculture

Water from Earth

Limitations of space agriculture & farming

Microgravity is a challenge for growing plants in space due to the problematic water delivery

High Solar radiation might adversely affect plants' growth and reproduction

High costs for water delivery from the Earth limit development space agriculture projects

Limited resources in space require the usage of highly efficient facilities

Water from space

Advantages of space water usage

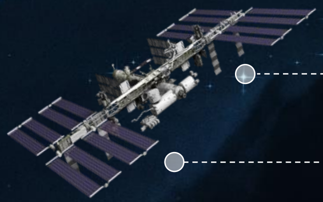
Cost reduction for life support as the supply of food to space stations is long and expensive

Growth of space tourism due to the development of space agriculture & farming

Obtaining water directly from space will **boost the terraforming of Solar system objects**

More realistic plans for colonisation due to the possibility to grow plants on the Moon and Mars

NASA is currently developing space agriculture & farming projects on ISS:



Veggie is a low-power **space garden** that allows to **grow fresh food** on space stations

Advanced Plant Habitat is an automated facility designed to grow different types of plants

Biological Research in Canisters is a unit used to study the space impact on small organisms

- Nowadays, astronauts get regular **shipments of freeze-dried and pre-packaged meals** to fulfil their dietary needs, yet NASA as well as other space organisations and companies plan to provide astronauts with nutrients by **growing fruits and vegetables** on terraformed planets
- Usage of space water will boost space farming that **will lower the costs of space hospitality** and **facilitate long-term missions**, since there will be less need in **food supply** from the Earth

Source: NASA website; ESA website; Media overview

Using space water as the radiation shield might allow to pursue long-haul missions and conduct deeper research

Limitations of space radiation shields

Water from Earth

Very high cost of a water radiation shield due to the relatively high mass of water

Shorter distance of space travel due to the high radiation exposure of the astronauts

Extra expenses on medical & dietary supplements to mitigate radiation exposure

Limited space tourism opportunities due to high radiation exposure[1]

Advantages of space water usage

Water from space

Reduced launch cost, as the radiation shield deployment will be conducted on the orbit

Potential for the development of permanent colonies due to water radiation shield deployment

Space missions for longer distances will become possible due to reduced radiation exposure

Possibility for carrying extra cargo, as the water shield will be deployed on the orbit

Space water as a radiation countermeasure

Annual radiation of the Mars mission 500-1.000 mSv[2,3]

Hydrogen-rich plastic for spacecraft and liquid hydrogen & water minimise the effects of space radiation

A water-filled garment might be used during interplanetary missions

- **Hydrogen-rich materials** are good at **shielding solar flares and space radiation**. Usage of space water will leverage **effective shielding** and **cost-efficient countermeasures**, as the water will be pumped on the Moon or Mars, making the spacecraft launch **cheaper**
- **Space radiation** is considered as one of the **limitation factors** for **long-distance manned space missions.** Current countermeasures are **expensive** and do not fully secure astronauts from space radiation

Source: ESA – The Radiation Showstopper for Mars Exploration – [2019]; National Library of Medicine website; NASA website; Media overview
Notes: (1) Current shields block only 30-35% of radiation; (2) Millisievert; (3) Estimated annual radiation humans receive on the Earth is 2,4 mSv, and in interplanetary mission – 400-900 mSv

Usage of space water will accelerate space exploration and give a start to the active mining of rare space resources

	Short term: 10 years	Medium term: 15-20 years	Long term: >20 years
MOON	Water	Raw regolith, Metals	
ASTEROIDS	Water		Metals, Platinum group metals
MARS	Water	Raw regolith	Metals

Water · Raw regolith · Metals · Platinum group metals

Enabled applications

Rocket fuelling · Life support · Infrastructure · Equipment · Bringing resources back to the Earth

Source: ESA – Space Resources Strategy – [2019]; NASA website; ESA website

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