RENDEZ-VOUS AVEC LA LUNE

50 YEARS AFTER APOLLO 11,

The Moon remains to be fully explored.

What else is our satellite hiding?

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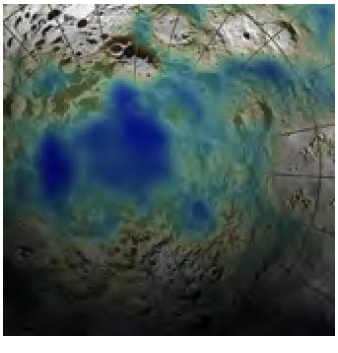
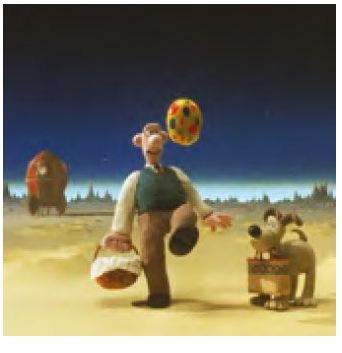
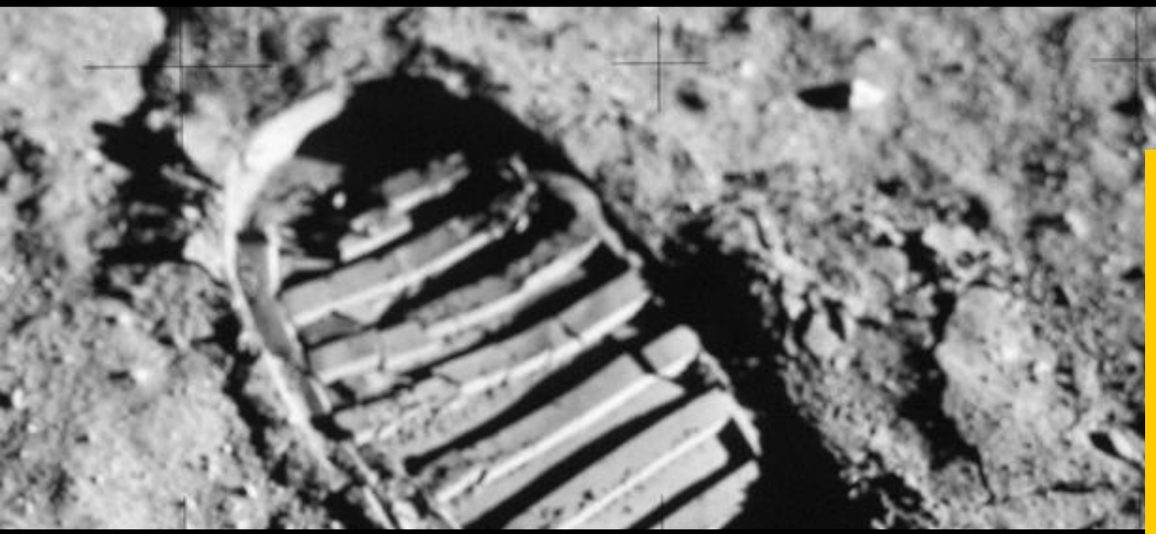




// This iconic photo is the footprint that Buzz Aldrin made and then photographed to give scientists a detailed picture of the mechanical behaviour of lunar regolith.



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Apollo 11

Man walks on the Moon

~~On 21 July 1969, at 3.56 am, French time: Neil Armstrong's left foot stepped on to the~~ lunar surface. This event was a first, the fulfilment of a universal dream and a symbol of the human and technological feats we are capable of to push back the frontiers of knowledge.

When two American astronauts, Neil Armstrong and Buzz Aldrin, landed on the Moon on 20 July 1969, they were the first human beings to set foot on a celestial body other than Earth, marking a decisive step in space exploration.

The Apollo 11 mission was the fifth crewed spaceflight of the Apollo programme and the third human trip to the Moon. The goal was a first: to land men on the Moon and return them safely to Earth.

Mission commander Neil Armstrong, Buzz Aldrin and Michael Collins boarded the Saturn V rocket at 9.32 am, local time, on the morning of 16 July 1969 at the Kennedy Space Center in Florida. After a journey of nearly three days, they reached the lunar orbit. There, after thirteen revolutions around the Moon, the lunar module (LM) undocked from the command and service module (CSM). The LM then began its descent towards the lunar surface, carrying Neil Armstrong and Buzz Aldrin on board.

156 heartbeats per minute

COMPARED TO 77 A FEW SECONDS EARLIER, THIS WAS ARMSTRONG'S HEARTBEAT, RECORDED JUST BEFORE HE TOOK CONTROL OF THE MODULE TO LAND IT ON THE MOON.

> "This is one small step for man, but one giant leap for mankind."
>
> ***Neil Armstrong,*** *21 July 1969, upon setting foot on the Moon*

© NASA

// Neil Amstrong, whose image is reflected here in Buzz Aldrin's helmet, appears in hardly any of the photos taken on the Moon. He was holding the camera, and the schedule was too tight for a selfie session.

MANUAL LANDING

During the descent, the automatic pilot steered the LM down towards a site strewn with rocks. With only a few seconds of fuel to spare, Amstrong saw the danger through the window and took control of the craft, guided by Aldrin's indications of speed and altitude, and landed the module manually.

MAGNIFICENT DESOLATION

Neil Armstrong was the first to set foot on the Moon, followed by Buzz Aldrin 19 minutes later. They then discovered the lunar surface and landscape. A landscape of "magnificent desolation", according to Aldrin's description, which was pitted with boulders and covered in fine dust – regolith – that stuck to their boots and spacesuits.

A UNIVERSAL FEAT

To bear witness to the universal nature of this space adventure, the crew placed a disc on the Moon with messages from the leaders of 73 countries and two medals in honour of the Russian cosmonauts Yuri Gagarin and Vladimir Komarov. American President Richard Nixon reminded the two astronauts of this in a live statement: *"For one priceless moment in the whole history of man, all the people on this Earth are truly one, one in their pride in what you have done."*

GOOD TO KNOW

Saved by a pen

When they were ready to leave the Moon, the switch used to ignite the engine was broken. Aldrin used his pen instead, which fitted perfectly into the empty hole. Without it, the two Apollo 11 astronauts would have been stranded on the Moon.

A PROGRAMME OF MULTIPLE **ACHIEVEMENTS**

Landing on the Moon to conduct experiments required technicians and scientists to achieve multiple technological and human feats. Astronauts underwent extraordinary training and braved the unknown.

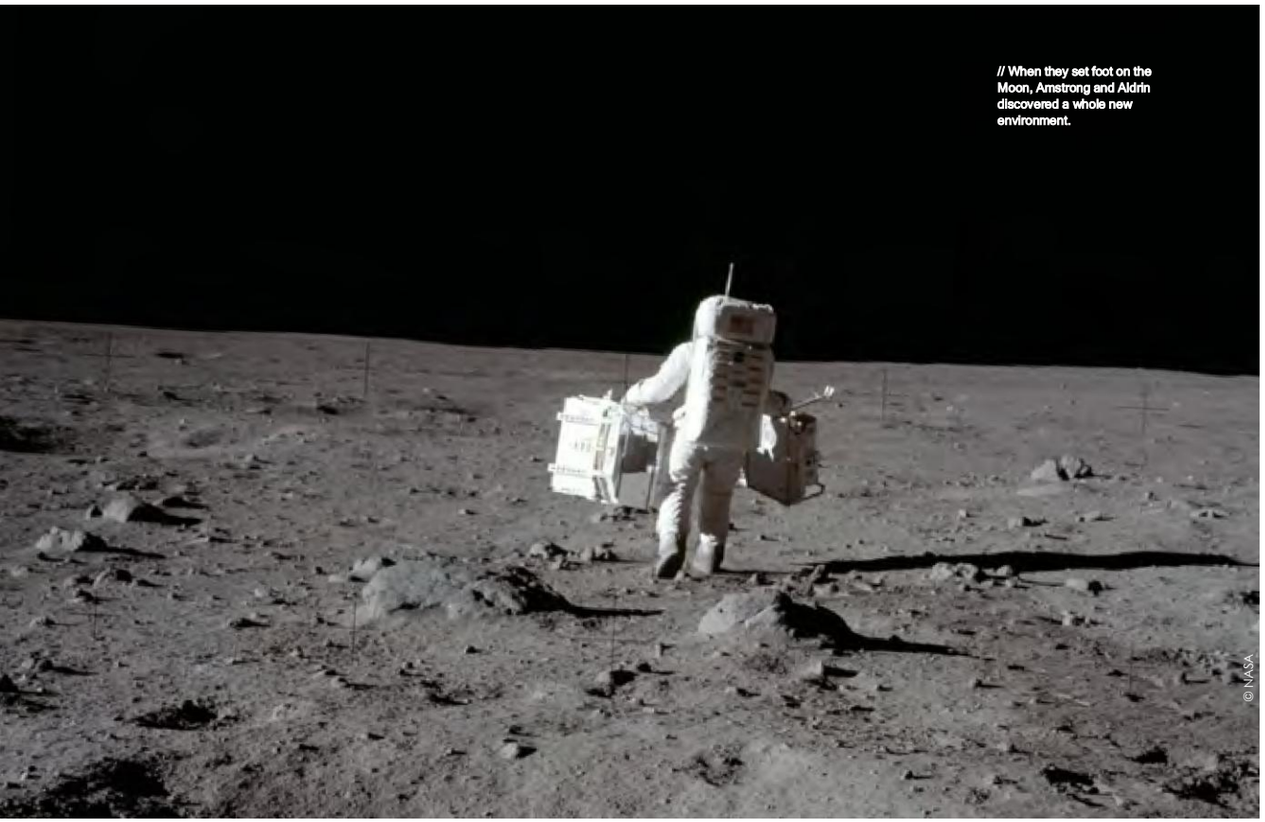
The first lunar missions entailed endless hours of work, astronomical budgets and huge risk.

World War II had seen the emergence of rocket-based weapons, such as missiles. This led to the idea that it was finally possible to send satellites into space, and even men to the Moon. To do this, rockets with enough power had to be built, possible trajectories had to be calculated, and the survival of the future astronauts in a hostile and unfamiliar environment had to be ensured.

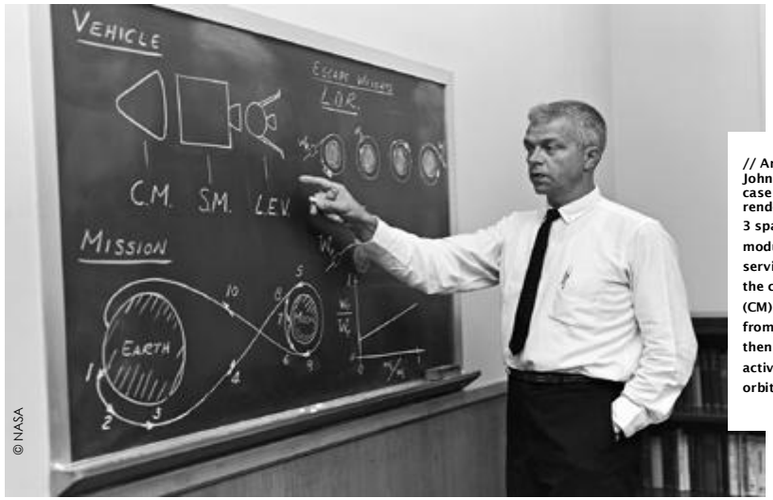
45 TONNES TO THE MOON

The launch vehicles were the first hurdle to overcome. In the middle of the 1950s, no rockets had gone beyond the Earth's atmosphere or carried any satellites. The Russians achieved this feat in 1957 when they placed Sputnik on Earth orbit.

But landing on the Moon required enough power to break free from the Earth's gravitational pull, carrying an extremely heavy load. The Americans finally developed a liquid oxygen and hydrogen fuel that was able to power the Saturn V launch vehicle and its 45-tonne payload, consisting of the three Apollo spacecraft - the lunar, service and command modules.



// When they set foot on the Moon, Amstrong and Aldrin discovered a whole new environment.



// American engineer John Houbolt made the case for a lunar orbit rendezvous: 3 spacecraft, the lunar module (LM or LEV), the service module (SM) and the command module (CM) were to be launched from a single rocket and then independently activated from the lunar orbit.

LUNAR ORBIT RENDEZVOUS

For months, American scientists battled over which route to take: a direct Earth–Moon trajectory, which was highly risky? Or should they plan a first step in Earth orbit, followed by an injection to the Moon and lunar orbit insertion? The solution of a lunar orbit rendezvous was quickly adopted as it was more energy efficient. Stationed in lunar orbit, the LM would separate from the CSM to reach the lunar surface, then return to dock with the CM before it returned to Earth.

// Apollo flight crew patches for crewed Apollo programme missions (Apollo 7 to 17).

A THOUSAND THINGS COULD HAVE GONE WRONG

Most astronauts are fighter pilots, able to take command if necessary, respond calmly in critical situations and learn fast. They have to be trained in spacecraft piloting, astronomy, geology and photography, and become familiar with all the equipment and tools. They also got involved in designing crewed spacecraft.

Astronauts and ground teams were prepared and trained to deal with a thousand problems that could arise during the mission. To minimize risk, safety procedures were established to secure the ignition process, and double and even triple specific computer control systems, among other things. But the status of knowledge and technology at the time meant that taking risks was unavoidable and that considerable technological innovation needed to be achieved fast.

A technological monster

The LM measured over 7 metres high and 9.4 m wide and weighed 15 tonnes. Being both a laboratory and a temporary living space, it had to include all the equipment needed for exploration and survival. Conducting a precision landing with such a monster was a real feat.

Although an international treaty laid down the principle that outer space should not be subject to national appropriation, flags were everywhere.

The race to the Moon

The final sprint

Apollo 11 was the culmination of a race to space between the Soviet Union and the United States, which began at the end of World War II. The two opposing blocs believed that whoever would conquer space first would dominate the world.

After World War II, the United States and the USSR (Union of Soviet Socialist Republics) were engaged in a "cold war". Each country tried to assert its influence, politically, economically and technologically.

The race to space began officially in 1955. The Soviet and American Governments both announced their intention to launch a satellite to contribute to science and peace. Political pressure provided the final push for scientists and engineers, who were already working hard on their respective programmes. For fear of being beaten to it by the Americans, Korolev, the man in charge of Soviet cosmonautics, launched the Sputnik programme in 1956, without waiting for the government's green light.

SOVIET DOMINANCE

The Soviets won the first round. After the launch of Sputnik, the first satellite to be placed in orbit in October 1957, they sent the first living being into space – a dog called Laïka – in November, accomplished the first flyby of the Moon with Luna 1 in January 1959, the first impact of the Moon with Luna 2, the first photographs of the far side of the Moon (Luna 3) in autumn 1959, and finally, the first human flight in orbit with Yuri Gagarin, on 12 April 1961.

> "The first country to achieve significant progress with spaceflight would effectively be considered the military and scientific leader."
>
> ***James Lipp,*** *head of a US satellite development company, in 1946*

AMERICAN CATCH-UP

This latest event fuelled American ambitions. President Kennedy, elected in November 1960, announced his intention to launch a programme that would see "an American on the Moon before the end of the decade".
A few months earlier, Kennedy had refused to grant NASA, the US space agency, a major increase in funding. But in 1961, in addition to the Soviet successes in space, the Americans suffered a major political and military defeat at the hands of the Russians, who succeeded in botching the landing of American-backed Cuban exiles in Cuba's Bay of Pigs.
Kennedy saw space as a way of reasserting American dominance and declared the Apollo programme a top national priority. From then on, the support of the American industrial sector was enlisted, and the US programme accelerated.

GOOD TO KNOW

Apollo was a key accelerator of American success

Mercury, with 6 crewed flights from 1959 to 1963, and Gemini, with 10 crewed flights from 1964 to 1966, fine-tuned the manoeuvres required for an orbit rendezvous.
Apollo's first technical flights (2 to 6) were followed by crewed flights: Apollo 7 was placed on Earth orbit in October 1968; Apollo 8 flew over the Moon in December 1968; Apollo 9 rehearsed separation manoeuvres around Earth in March 1969; and Apollo 10 tested the descent in lunar orbit one last time in May 1969.

// September 1959: The Soviet leader Nikita Khrushchev (right) taunts the American president Dwight Eisenhower (centre) by offering him a replica of the Luna 2 space probe, which had just deposited the Soviet emblems on to the Moon's surface.

MOVEMENTS OF THE **1960s**

The 1960s were a decade of huge change. Against the backdrop of the cold war between the USA and the USSR, global exchanges accelerated, including in terms of technology and culture. Apollo 11 was one of the first events to be shared worldwide.

// Astronauts were celebrated like national heroes. Returning from their mission, the astronauts were congratulated by American President Richard Nixon while in quarantine inside a confinement module.

/ /Several hundred people camped near the Kennedy Space Center in Florida to see the mission launch. Apollo 11.

The first steps on the Moon were an event followed by all sorts of people. Everywhere on the planet, it left its mark on people's minds and contributed to propelling the world into a new era.

The end of the 1950s brought a new boom to the Western world. The scars of World War II were fading, the economy was recovering, and the wind of freedom was blowing across countries. At the same time, tensions were mounting in South America and Asia, two continents where Americans and Europeans maintained a military presence against opponents backed by the URSS, whose influence was growing.

POSITIVE IMAGES

In this context of increasing tension , television proved to be an effective propaganda tool. Images of successful astronauts helped people forget those of American soldiers mired in an unending war in Vietnam or racist violence in suburban America.

A LONGING FOR PEACE AND PROGRESS

Part of the American public was sceptical about the amount of money spent on space exploration at a time when the country was struggling with difficult issues internally. The 1960s were also a time when people who had gone through World War II wanted peace, international cooperation and progress, and space fulfilled that aspiration.

The American and Soviet Governments managed to gain the support of industry and public opinion for their spatial programmes, and of the whole world. The Apollo 11 landing was broadcast live on television around the world.

600 million

VIEWERS WATCHED ON LIVE TELEVISION AS NEIL ARMSTRONG AND BUZZ ALDRIN LANDED AND WALKED ON THE MOON.

The first steps of man on the Moon were one of the very first events to be broadcast all over the world. The first was a TV transmission of a Beatles concert in June 1967, which was watched by 400 to 700 million viewers.

// The Moon ceased to be geologically active a long time ago, shortly after its formation. This is why we are interested in its components; by studying them, we are also improving our understanding of the Earth's history.

The Moon

A concentrate of Earth

We have always been fascinated by the Moon because it is close enough for us to be able to see it. Its continuous presence in the Earth's sky makes it familiar. In fact, the Moon is a close relative of the Earth and is partly made from the same components as our planet.

//This image taken during the Apollo 17 in 1972 reveals the lunar relief.

The Moon was formed from a piece of Earth, when, 4.35 billion years ago, a giant impact occurred between the Earth and a little planet called Theia. The collision was so great that molten material collected in an orbit around Earth and coalesced to form the Moon.

Our satellite still bears the scars of its dramatic formation. The dark patches and lighter areas visible to the naked eye suggest a craggy surface, studded with craters formed when it was bombarded with asteroids and meteorites.
Most of its surface, which appears light, is made up of plateaux. The darker patches, which astronomers have dubbed "seas", are the result of a giant impact. This shock punctuated the solid crust and caused liquid magma to well up to the surface as the heat from the impact melted the underlying mantle.

The Moon loses its compass

The Apollo magnetometers like the one here, which was installed by Apollo 16, detected a very weak magnetic field that varied depending on the location.
While the Earth's magnetic field is strong and spreads evenly outwards from a north–south axis, the Moon has multiple weak magnetic sources, as if several small magnets were scattered all over its surface. A compass would be useless on the Moon!

"The soil is fine and powdery. It does adhere in thin layers like powdered charcoal to the soles and sides of my boots.
I only go in a small fraction of an inch, maybe an eighth of an inch."

Neil Armstrong, *on the Moon, 21 July 1969*

ABSENCE OF WATER

The Moon surface is covered with regolith, a layer of very fine dust made of fragments of rocks that were pulverised by meteorite bombardments, and have accumulated over 4 billion years. The Moon rock samples brought back by the Apollo missions were analysed to identify their composition. As on Earth, oxygen is the main component. However, no water has been detected on the Moon - it all evaporated during the giant impact - and lunar rocks are much less varied than their terrestrial cousins.

A HOSTILE COMPANION

The Moon is far less welcoming than Earth! Because there is no atmosphere, which diffuses light on Earth and gives the sky its blue colour, the sky seen from the Moon is always black. Not a great setting.
Because of this lack of a protective atmosphere, temperatures can exceed +120°C in the areas most exposed to the Sun, and drop to -230°C in the coldest patches, such as in the dark depths of craters.

Its surface, and anybody on it, is hit directly by radiation from high-energy particles emitted by galactic cosmic rays and solar flares. It would be impossible for humans to survive in such conditions.

EARTH-MOON, A HAPPY UNION

The Moon revolves around the Earth, which pulls it along in its orbit around the Sun. Their movements are connected and influence each other to a great extent. Moon-Earth interactions are vital for our planet.

// The Moon is the Earth's natural satellite. It is smaller in size and has a smaller mass than Earth, and revolves around it. When humans are in orbit around the Moon, they can see "Earth rises".

// With a diameter of 3,476 km, the Moon is four times smaller than Earth.

Seen from Earth, the Moon frequently changes its appearance, position and size in the sky. Because its orbit around Earth is elliptical, its distance from Earth varies during its orbit. These interactions between our two stars also change in intensity during this journey.

The Moon is held in a gravitational pull from the Earth: when it was formed, it acquired speed that "propelled" it away from Earth. But our planet's gravitational force is always pulling it back as it keeps moving away. The Moon is therefore maintained in an orbit around Earth, at an average distance of 384,400 km.

HIDE AND SEEK

The Moon takes around 28 days to orbit the Earth (27.32 Earth days) and almost the same amount of time to spin on its own axis (29.53 Earth days) in relation to the stars. This is why we always see the same side of the Moon.

The gravitational force on Earth from the Sun and especially the Moon, lifts the Earth's waters towards the Moon. This gravitational force also has an effect on the Earth's crust, which rises and falls twice a day, with a maximum bulge of 40 centimetres. Ocean tides cause friction between the oceans and the seabed, which slows down the Earth's rotation but also pushes the Moon further away.

ESSENTIAL TO LIFE

If the Moon were to move so far away from Earth that it no longer had any effect on it, our environment would be dangerously altered. Without the Moon's gravitational pull, the Earth's axis of rotation, which is tilted by 25.5 degrees, would oscillate by several degrees more. Because the Earth's tilt has given us seasons, if it were to increase significantly, the seasons would be much more pronounced, with climatic variations of such magnitude that life could be threatened!

3.8 cm

EVERY YEAR, THE MOON MOVES 3.8 CM AWAY FROM EARTH. WHEN IT WAS FORMED, IT WAS ESTIMATED TO BE TWICE AS CLOSE TO EARTH AS IT IS TODAY.

// When the Moon passes between Earth and the Sun, it blocks it out from our view as we stand on Earth, resulting in a solar eclipse. If we were on the Moon and the Earth blocked out the Sun from view, that would be a lunar eclipse.

GOOD TO KNOW

On the Moon, which is surrounded by vacuum, there is neither wind nor rain to erase the tracks and debris left by the astronauts. They could remain visible for millions of years. Eugene Cernan, the last astronaut to walk on the Moon, drew his daughter's initials, TDC, in the lunar dust. This tribute will remain there for eternity.

//Data and samples returned by Apollo missions are still being studied in various laboratories around the world.

Apollo, accelerating science

Scientists on the Moon

The American and Soviet programmes of the 1960s have brought back 382 kilograms of lunar rocks and taken thousands of measurements and photographs of the Moon. The study of these samples and data helped scientists to make great leaps in space research.

During the Apollo missions, 31 experiments were conducted in six different lunar regions. Seismic and gravity measurements, chemical analyses of rock structure, among other experiments, aimed to improve our understanding of the Moon's formation and its relationship to Earth.

These have been highly successful. The study of lunar samples has confirmed the theory that the Moon formed from the debris of a violent collision between Earth and a small planet (see p. 13). This was a major discovery because before Apollo, this hypothesis was considered the least likely.

Its confirmation heightened our interest in the Moon, and lunar research will help us better understand the Moon's close relationship to Earth.

The numerous craters found on the Moon suggested volcanic activity. However, *in situ* observations and examination of the rocks from these craters proved otherwise. The craters on the Moon are almost all the result of meteorite and asteroid impacts. The moon has not had any internal activity for a long time. This has been confirmed by the dating of lunar samples: the oldest rocks are 4.4 billion years old while the youngest are 2 billion years old.

10% of the samples collected by Apollo missions were destroyed during analysis. The rest are kept in Houston, safe from any contamination. NASA distributes a few milligrams of sample material to laboratories that request it, but the samples are preserved for more detailed analysis when better instruments become available.

> "The far side of the Moon looks like a sandpit after my children have played in it. Everything has been destroyed. There are no words to describe it. It is just full of bumps and holes."
>
> ***William Anders,*** *Apollo 8 astronaut*

THE MYSTERY OF WATER

Several years after Apollo, we realised that water could be present on certain areas of the Moon. This water was brought by comets, since the water contained in the Moon's original materials evaporated when it was formed.

It would be 20 years before lunar missions resumed, looking for water in particular. In 1998, thanks to a neutron spectrometer capable of detecting the presence of hydrogen, the American probe Lunar Prospector found evidence of water ice at both lunar poles, in the bottom of craters, where it is permanently shadowed from sunlight. To confirm the presence of ice, Lunar Prospector was sent to the bottom of a crater. The scientists hoped that the impact would eject water vapour. But this was not the case. Subsequent missions, including the Lunar Reconnaissance Orbiter (USA, 2009) with LCROSS - the part of the mission concerned with detecting water ice at the poles – confirmed that water is trapped in the form of ice at the lunar poles.

BIOLOGICAL EXPERIMENTS

French scientists, supported by the French Space Agency (CNES), took part in the Biostack bioscience experiment led by Apollo 16 and 17. They studied the effect of cosmic rays on living organisms by observing shrimp eggs that were on board the command module. This was an important study for the continuation of crewed spaceflight.

// Since Apollo 11, astronauts have conducted scientific experiments, like collecting samples of rocks and regolith.

THE FAR SIDE OF THE MOON
A GATEWAY TO DEEP SPACE EXPLORATION

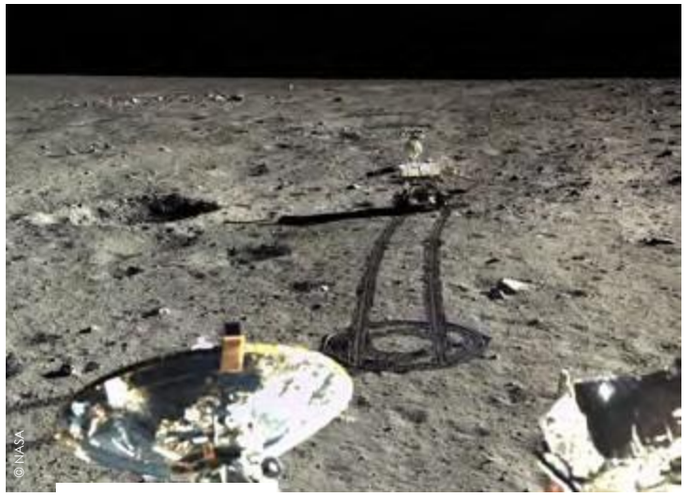
The lunar exploration programmes resumed. They all set their sights on the south pole and the far side of the Moon. This part of our satellite appears to be the ideal location for a lunar science station and establishing a base from which to conduct more distant future missions, towards Mars for example.

Photographed for the first time by the Soviet probe Luna 3 in 1959, the far side of the Moon is now proving to be the destination of choice. It is an ideal base for observing the universe and training to venture further out into space, and it also harbours energy resources.

The side of the Moon that cannot be seen from Earth (see p. 15) is very different from the visible part. There are many more craters on the far side than on the near side. Landings are therefore much more complex. Additionally, direct communication with Earth is impossible from the far side of the Moon. However, since the 2000s, several probes have been exploring that side of the Moon, including American (5), Chinese (3), Japanese (1), Indian (1) and European (1) ones. At the end of 2018, the Chinese rover Chang'e 4 was the first automatic vehicle to land there.

// The European Space Agency (ESA) aims to set up a base at the south pole. Artists are already imagining the future infrastructure and life on our satellite.

© Jorge Mañes RubioSpatial design & visualisation in collaboration with DitiShoe http://ditishoe/

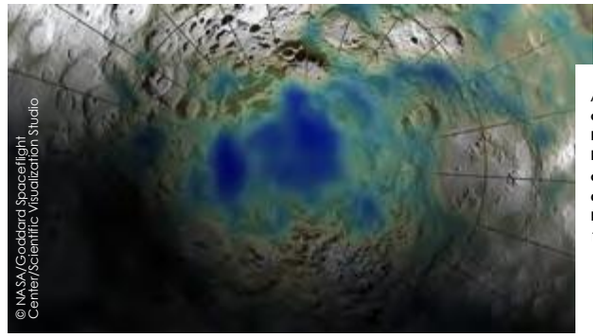


© NASA

// In 2013, the Chinese mission Chang'3 deposited the Jade Rabbit (Yutu) rover on the Moon. The lander and the rover are still sending us information on how their components are ageing in the lunar environment, where there is vacuum with extreme temperatures.

400 metres

THIS IS THE DISTANCE AT WHICH THE ASTRONAUT ALAN SHEPARD SENT ONE OF THE THREE GOLF BALLS HE TOOK TO THE MOON. THOUGH NOT SCIENCE, THIS WAS AN INTERGALACTIC RECORD!



© NASA/Goddard Spaceflight Center/Scientific Visualization Studio

// Water ice has been confirmed at the poles. It is shown here as hydrogen concentrations detected by the Lunar Prospector probe in 1998.

SETTLEMENTS ON THE MOON

The end goal is to settle on the Moon and/or build a lunar orbit station. China, NASA, the Russian agency Roscosmos and the European Space Agency (ESA) are now cooperating to reach this shared goal. The Chinese agency is aiming directly for the far side. ESA is planning to establish a "Moon Village", an international base at the south pole, while NASA is preparing a lunar orbit station - Lunar Orbital Platform Gateway - as an outpost for exploring Mars. Europe and Russia will be involved.

EXPLORING AND MINING LUNAR RESOURCES

The main motive behind these ventures is to prepare for future crewed missions to Mars and explore and mine lunar resources. The south pole bears hydrogen and oxygen, which are essential elements for sustaining human beings on the Moon and for manufacturing the rocket propellants needed to power spacecraft. The Moon also hosts helium 3 reserves, which could be used in the future as fuel for nuclear fusion.

OBSERVATION OUTPOST

A scientific base on the Moon or in lunar orbit would be useful for exploring our satellite. ESA is building a drill to sample the deep subsurface at the south pole. Scientists are also keen to install a radio telescope there to listen to space through hitherto unexplored radio wavelengths without interference from radio waves emitted from Earth.

GOOD TO KNOW

To communicate with Earth, in 2018, the Chinese placed the satellite Quequiao on one of the Lagrange points (point L2), which is close to the Moon and at the opposite side of Earth.

At these points, the gravitational forces of the Earth and Moon balance each other, ensuring a stable position for objects at these points.

In a specific orbit known as a halo orbit, the satellite is able to communicate alternately with the rover and with Earth.

// Establishing a base on the Moon will require assistance from robots. These will be useful for building living quarters or for exploring the subsurface.

© ESA

The robot workshop

Probes for exploring and learning

Before the crewed landings on the Moon, probes observed and analysed the Moon and the lunar environment and tested the equipment. These autonomous devices were the first space robots, followed by stationary landers and mobile rovers.

The space programmes of the 1960s were developed at a time when computer technology was making great progress. Thanks to these advances, guiding and navigation technology has made great strides forward, as well as the programming, control and transmission of remote-controlled and then automated tasks.

The first Soviet Luna probes helped confirm that flights beyond the Earth's gravitational pull and then to the Moon were possible (Luna 1 and 2, and in particular, Luna 3 which took the first photograph of the far side of the Moon), and finally landing on it (Luna 9, 1966). The goal at that time was to demonstrate the technical capabilities for such missions.

Following these flights, the Americans launched a dozen probes and landers from 1961 to 1968. Thanks to the images from the Lunar Orbiter probes, they were able to select the landing sites, and the Lunar Surveyor landers could check that the astronauts would not sink into the surface.

REMOTE-CONTROLLED ROBOTS

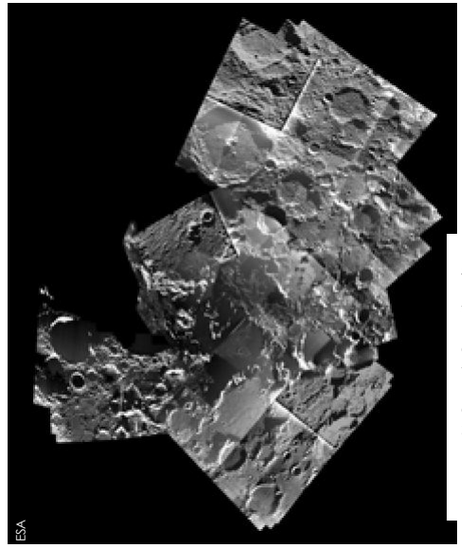
Ahead of the Americans in the crewed spaceflight race, the Soviets were the first to send an automated mission for returning samples (Luna 16, 1970), followed by a robot, the Lunakhod 1 rover (1970), capable of moving on the lunar surface, taking photographs and carrying out experiments. It was operated remotely from Earth.

COSMIC HAZARDS

Since Lunakhod, rovers have become essential for exploring deep space. Robots can withstand long journeys and exposure to cosmic radiation, which would be fatal to humans.

Four rovers - Sojourner (1997), Spirit and Opportunity (2004) and Curiosity (2012) - were sent to Mars. Robots have landed on comets (Rosetta/Philae, ESA/DLR/CNES, 2014) and asteroids (Hayabusa2/Mascot, JAXA/DLR/CNES, 2018).

Today, as interest in the Moon is rekindled, China is aiming to be the first nation to send humans back to our satellite. Its future crewed missions are being prepared by sending the first rovers to the Moon since Lunakhod 1. The robot explorer Jade Rabbit got there in 2013, while the Chang'e 4 probe landed on the far side at the end of 2018.



ESA

// Scientists acquired many new images from the probes, like this image of the north pole, constructed from shots taken by the SMART probe's miniature camera (ESA, 2003-2006).

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Lunakhod was the first mobile robot of space history.

It landed on the Moon in 1970, where it covered about ten kilometres in nearly 11 months. It was operated remotely from Earth and powered by solar collectors under its cover, which was closed during the freezing lunar nights.

GOOD TO KNOW

The Soviet engineers were so certain of the superiority and reliability of machines compared to humans that they said to Yuri Gagarin, the first man in space: *"Whatever you do, don't touch anything!"* However, Neil Armstrong managed to land on the Moon precisely by taking manual control of the LM (see p. 5).

ROBOTS HELPING PEOPLE

Sending humans into space helps to complete tasks more accurately and quickly compared to robots, but robots are essential for helping astronauts and scientists work and survive in extreme environments.

Robots are more resistant to the conditions of the space environment and help reduce the costs of missions. To run, all they need is energy, which is provided by solar panels or a battery, whereas humans need air, water and food. Robots and humans complement each other.

The Apollo missions have shown how machines and tools are valuable for working and moving about on the Moon. Future programmes are planning on sending smart assistants to help astronauts.

Robots have already been tested on board the International Space Station (ISS) to see how they could help or replace astronauts for certain tasks, such as filming experiments and handling certain mundane or dangerous tasks, particularly during spacewalks. A Japanese robot has been tasked with keeping astronauts company by making conversation!

// Humanoid robots could carry out dangerous missions in space, such as extra-vehicular activity. Each agency is working on its own programmes: Justin for ESA (Europe), Fedor for Roscosmos (Russia) or here, Robonaut for NASA (USA).

© NASA

Rovers paired with drones could help astronauts explore and map Mars.

ROBOT WORKERS

Robots are mainly useful for practical reasons. To build future bases on the Moon or on Mars, space agencies plan to use robot workers. These are devices that can build 3D housing, autonomous mechanical shovels, remote-controlled tipper vehicles to move or dispose of materials, etc. They will also be essential for drilling boreholes to extract minerals, oxygen or water.

EXPLORER DRONES

Future plans to explore deep space also involve rover-drone pairs to pave the way for humans. These autonomous roving and flying devices will provide scientists based on Earth or on extraterrestrial bases with the data they need to map the environment on Martian stations for example.

© Chinese Academy of Sciences,

// Selfie by the Chinese lander Yutu (Jade Rabbit), which landed in 2013 on the northern part of the far side of the Moon. Its successor, Chang'e 4 landed near the south pole of the far side in 2018.

8 MHz

THIS WAS THE POWER OF THE CHIPS FITTED TO THE PHILAE LANDER THAT WAS DROPPED ON COMET CHURY IN NOVEMBER 2014. THE POWER OF A SMARTPHONE CHIP IS 1 TO 3 GHz. BUT PHILAE WAS DESIGNED IN THE 1990s AND LAUNCHED IN 2004. RECENT TECHNOLOGICAL ADVANCES PROVIDE AN INDICATION OF THE CAPABILITIES OF FUTURE ROBOTS.

// Made in 1902, the film *A Trip to the Moon* by the French filmmaker Georges Méliès, is a classic of early science fiction. It depicts with humour all the classic lunar imagery, from a cannon shooting to the Moon, to fantasy landscapes and strange lunar creatures.

Moon musings: the Moon in art

Reaching for the Moon

Observing the Moon has always been conducive to imaginative dreaming. Writers, poets and filmmakers took an early interest in trips to this unexplored celestial body and its inhabitants. Their depictions of the Moon have evolved with the findings of astronomy and technological progress, and the authors' imagination.

Well before humans succeeded in landing on the Moon, artists have dreamt of going there. They imagined all sort of interesting and exotic ways that this could be achieved, sometimes leading the way.

At the end of antiquity, the Greek author Lucian of Samosata wrote the first known science fiction story about the Moon. *Vera Historia* was written in second century AD and tells the story of a ship transported by a storm to the Moon, which is inhabited by the "Hippogypi".

In a second story, Lucian of Samosata sends the character Menippus to the Moon in a contraption made from the wings of a vulture and an eagle. Birds, such as eagles, geese and swans were often thought of as a means of getting to the Moon. In the astronomer Johannes Kepler's account of a trip to the Moon in *Somnium* (1634), demons transport humans from Earth to the satellite. The only realistic detail in this story is the distance separating the two stars, estimated at 370,000 km.

> "The Earth is the cradle of humanity, but one cannot live in a cradle forever"
>
> ***Konstantin Tsiolkovsky,***
> *rocket scientist and science fiction writer (1857-1935)*

// For the animated clay characters Wallace and Gromit (1989) created by the English filmmaker Nick Park, the Moon is made of cheese.

GRAVITY-DEFYING MAGIC

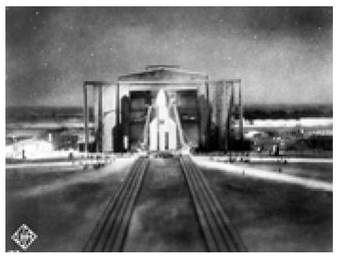
The idea that breaking free from Earth's gravitational pull was necessary to be able to travel in space with ease gave rise to the design of the most implausible "gravity-defying" devices. In a novel by the French writer Savinien de Cyrano de Bergerac, a character wears a belt carrying bottles of dew. This magic dew is drawn to the Sun's rays and lifts Cyrano above Earth *(Comical History of the States and Empires of the Moon*, 1657). A magic metal known as "Lunarium" powers the machine invented by British writer Joseph Atterlay (*A Trip to the Moon*, 1827).

From the 18th century onwards, writers emphasised machines, including catapults mounted on giant springs, balloons, devices with motorised wings, etc.

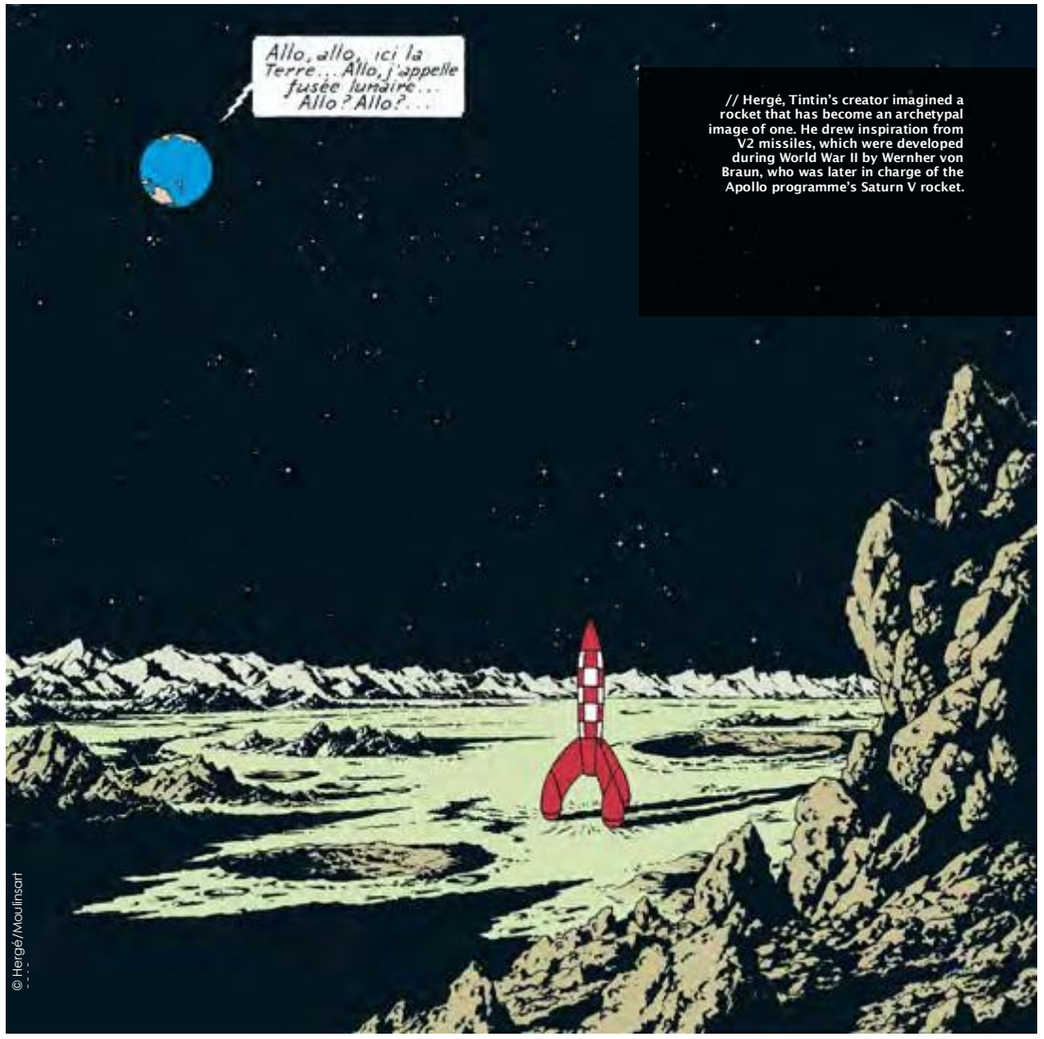
Later, the British writer Murtagh McDermot imagined a cannon (*A Trip to the Moon*, 1728). His idea was often taken up later, in particular by the French novelist Jules Verne, who gave an especially realistic account of it in his novel, *From the Earth to the Moon* (1865).

ANTICIPATION

Comics have made motorised interplanetary travel popular, particularly in the Tintin comic book series, the volumes *Destination Moon* (1953) and *Explorers on the Moon* (1954). Hergé, Tintin's creator, consulted the scientists of his time and credibly anticipated man's trip to the Moon, 16 years before Apollo 11.



Novelists, filmmakers and comics creators of all times have consulted scientists and engineers to give credibility to their creative works.
The German film *Woman in the Moon*, by Fritz Lang (1929), demonstrated Germany's technological expertise.



© Hergé/Moulinsart

// Hergé, Tintin's creator imagined a rocket that has become an archetypal image of one. He drew inspiration from V2 missiles, which were developed during World War II by Wernher von Braun, who was later in charge of the Apollo programme's Saturn V rocket.

DIFFERENT FACES OF THE **MOON**

The Moon's appearance, changing shapes and colours, and rugged relief, have fuelled the imagination. The Moon has inspired many early science fictions works, with eerie settings inhabited by creatures who were not always friendly. The collective imagination has staged the Moon is many different ways and genres.

The first stories of voyages to the Moon were an opportunity to conjure up all sorts of fantasy worlds. The lack of actual knowledge of the Moon meant that imagination had free reign. This uncharted land inspired a host of creative works, including novels, adverts and songs.

With Georges Méliès (A Trip to the Moon, 1902), imagination knew no bounds. According to him, the inside of the Moon was covered with giant mushrooms.

// The Moon is omnipresent in the sky and our daily lives. Even cheese brands use its reassuring and enchanting image to make their products seem more familiar and attractive.

© Collection privée Serge Schéhadé/ www.camembert-museum.com

In the 1950s and 1960s, filmmakers saw in the Moon an ideal setting for science fiction. Its rugged landscapes could host all kinds of adventures and creatures.

© All

Giant plants and mushrooms also inhabited the Moon in several silent films from the 1900s. The Moon was then a fashionable backdrop for a number of unusual adventures (*Excursion to the Moon*, 1908, *Mariage interplanétaire* [*Interplanetary Wedding*], 1910).

SCARY SELENITES

British writer H.G. Wells also fed moon mushrooms to the characters in his novel *The First Men in the Moon* (1901). This leads them to meet the local inhabitants, the Selenites who resembled ants on two legs.

In the 1950s, the Moon was the perfect setting for filmmakers, who populated it with all kinds of weird and wonderful beings, such as a bloodthirsty dictator (*Radar Men from the Moon*, 1953), cat women who wanted to conquer Earth (*Cat-Women of the Moon*, 1953), and various monsters hiding in lunar caves (*Missile to the Moon*, 1958).

REALITY MEETS SCIENCE FICTION

Following the Apollo mission, voyages to the Moon became part of reality, and the lunar environment became more and more familiar. The living conditions on the Moon and the dangers of space exploration now became the preferred themes of imaginary adventures. The film *Moon* by Duncan Jones (2009) combined technological and scientific realism (the main character works on a space base, extracting helium 3) with fantasy (the Moon seems to reject him).

The Moon is part of our collective imagination, and was even used in advertising: extraordinary cars were driven on the Moon, astronauts walked on the lunar surface, praising the merits of a drink or mobile phone company. And the Moon also inspired musicians. From classic composers such as Frantz Schubert and Gabriel Fauré, to rock bands Pink Floyd (UK) and R.E.M (USA), and the French songwriter Charles Trenet and band Indochine, moonlight and the feats of explorers continued and will continue to feature in many songs.

GOOD TO KNOW

In antiquity, the Moon was considered and represented as a divinity: Thoth for Egyptians, Nanna for Sumerians, Sin for Akkadians, and the goddess Artemis for the Greeks, also known as Selene or Mene, and then Luna for the Romans.

GLOSSARY

Asteroid
Small rocky body of up to one hundred kilometres in diameter that orbits the solar system. Most asteroids are located between the orbits of Mars and Jupiter.

Atmosphere
Layer of gas surrounding a planet or star.

Lander
Spacecraft that studies a celestial body by landing on it.

Payload
Equipment or cargo transported by spacecraft. On a launch vehicle or launcher: satellites, station equipment, probes and capsules, etc. that are placed on orbit by the launch vehicle; on a satellite: scientific instruments.

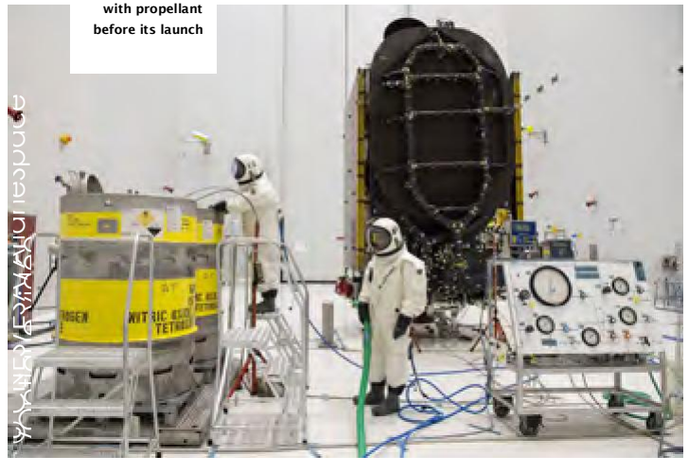
Comet
Celestial body orbiting the Sun, whose composition is dust and frozen gases. These are ejected as a coma or tail as the comet comes close to the Sun and heats up.

Cosmonautics
(synonymous with astronautics) Science of navigation in space. This term was coined in 1927 by the French writer Joseph Henri Rosny.

Crust
The outermost layer of a planet.

Propellant
Fuel used to power a rocket engine.

Gravitational pull or force
Mutual attraction of two massive bodies (whose mass is not zero). This attraction causes a gravitational force that is a function of both bodies and the distance between them.



Filling a satellite with propellant before its launch

Mantle
Layer of a planet located under the crust.

Meteorite
Asteroid or comet that hits a planet.

Microgravity
Condition in which the effect of a celestial body's gravitational force disappears almost entirely.

Orbit
Trajectory of an artificial or natural object spinning around a celestial body.

Propaganda
Action designed to influence public opinion to spread ideas and persuade people to adopt a certain type of behaviour and/or support a decision.

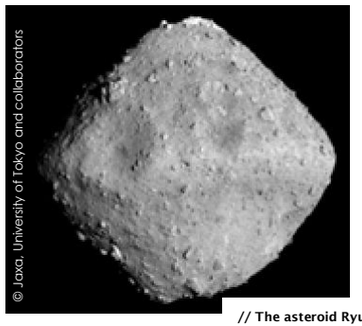
Regolith
Very fine layer of dust made from debris of rocks that were pulverised by constant bombardment from meteorites or asteroids, which covers the surface of the Moon or another celestial body.

Radiation
Energy emitted and propagated in space or matter in the form of electromagnetic waves or particles.

Galactic cosmic rays
Emissions of high-energy particles that travel within our galaxy's interstellar medium.

Revolution
Orbital motion of a celestial body around another, which passes at regular intervals over the same point.

Space probe
Uncrewed spacecraft designed to explore space and/or bodies in space.



// The asteroid Ryugu photographed by the Japanese probe Hayabusa2.

EXHIBITION

MOON EPISODE II

Fifty years after man's first steps on the Moon on 20 July 1969, the rush to the Moon is back in the news. Together, let's rise to the challenge of returning to the Moon.

At the interactive and hands-on exhibition **"MOON – EPISODE II"** at the Cité de l'Espace, you will have the opportunity to relive Apollo's success and prepare for this upcoming challenge by learning about the lunar environment and its constraints.

From April 2019

at the Cité de l'Espace

www.cite-espace.com

Cité de l'espace TOULOUSE
DÉCOUVRIR • S'ÉTONNER • COMPRENDRE

// Parabole Project: CNES lets students experience spaceflying on board Airbus A310 Zero G.

SPACE AS A TOP PRIORITY

CNES (the French Space Agency) is at the crossroads of research and industry. It sets out France's space policies at the national, European and international levels.

With 4 centres and a staff of 2,500, CNES designs, develops and operates space projects, from launch vehicles and satellites to space probes and related ground segments. The work of CNES is organised in five strategic areas: **Ariane, Sciences, Observation, Telecommunications and Defence.**

Since its founding in 1961, CNES has actively pursued a communication and education policy aimed at developing a culture of space and science among young people and teachers. One way we do this is by designing and disseminating information materials, alongside the provision of teacher training, space data, and guidance on offering educational projects in the classroom and as part of extra-curricular activities. The contents of this booklet and the associated activity sheets can be downloaded from the teacher mediator profile section on the CNES website.
Enjoy your reading!

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