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SPACE EXPLORATION

SOLAR SYSTEM IN SIGHT

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INSIDE

PARTNERS

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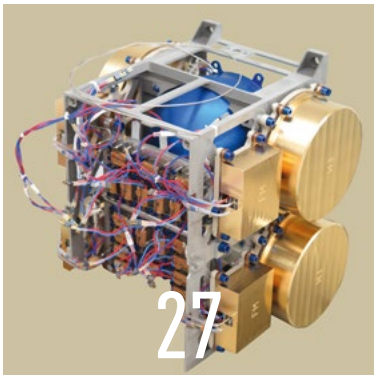
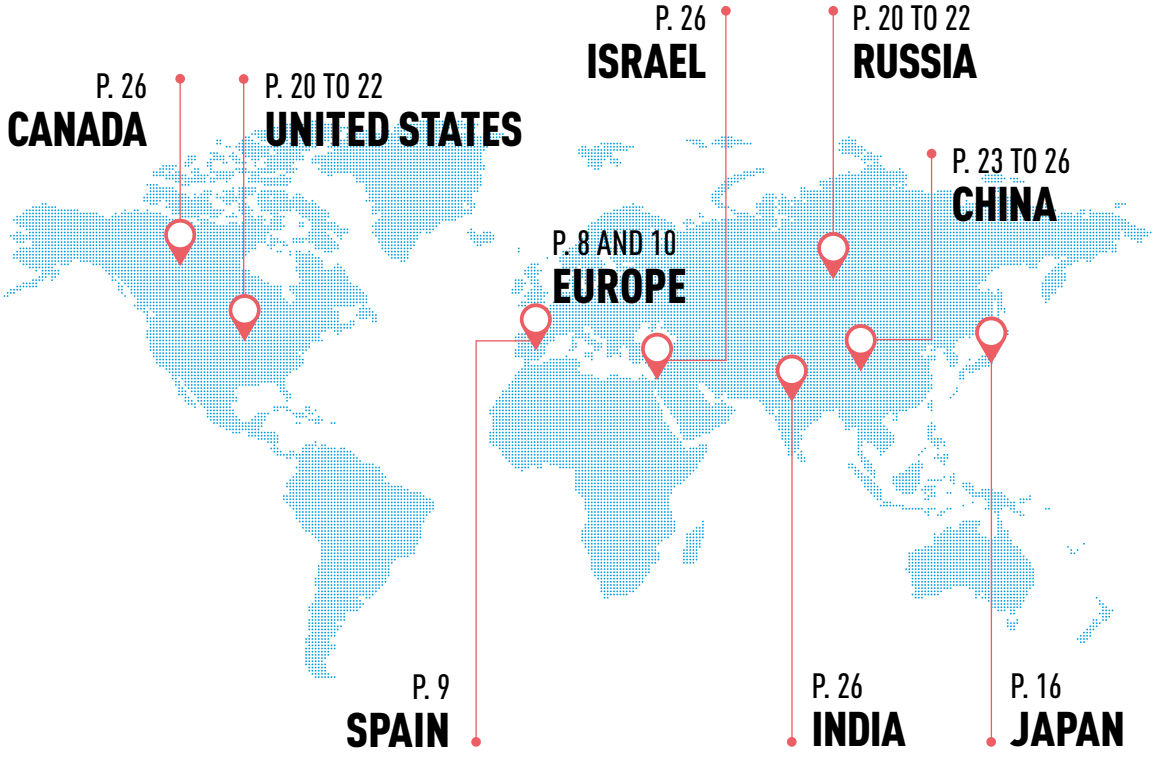


SOLAR SYSTEM
AN INTERNATIONAL QUEST



CONTRIBUTORS

FRANCIS ROCARD

Astrophysicist Francis Rocard is also CNES's expert in the field of solar system exploration. From initial go-ahead to analysis of results, he's a key cog in the works of every French planetology mission. In constant contact with science and engineering teams, he explained how studying other planets is helping us to better understand our own.

JEAN BLOUVAC

At CNES's Directorate of Innovation, Applications and Science (DIA), Jean Blouvac coordinates all work on the agency's Exploration and Human Spaceflight programme. He's also the French delegate at various European and international bodies in the field of Universe sciences. He spelled out the geopolitical stakes of the new race to the Moon for us.

OLIVIER PASCAUD

Olivier Pascaud is an altruist who empathizes easily. For him, photography is a way to meet interesting people. He excels in capturing a look, expression or attitude to reveal the innermost nature of his subject. After Pacôme Revillon, he caught the essence of François Forget's subtle smile on film.

TINO

The cover of this magazine is the creative work of Tino. This illustrator with a style all his own works for the press, public institutions and corporate clients alike. For this issue, he agreed to change his usual graphic signature to reflect the round shapes and stellar motions of the solar system.

CNESMAG

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EDITORIAL

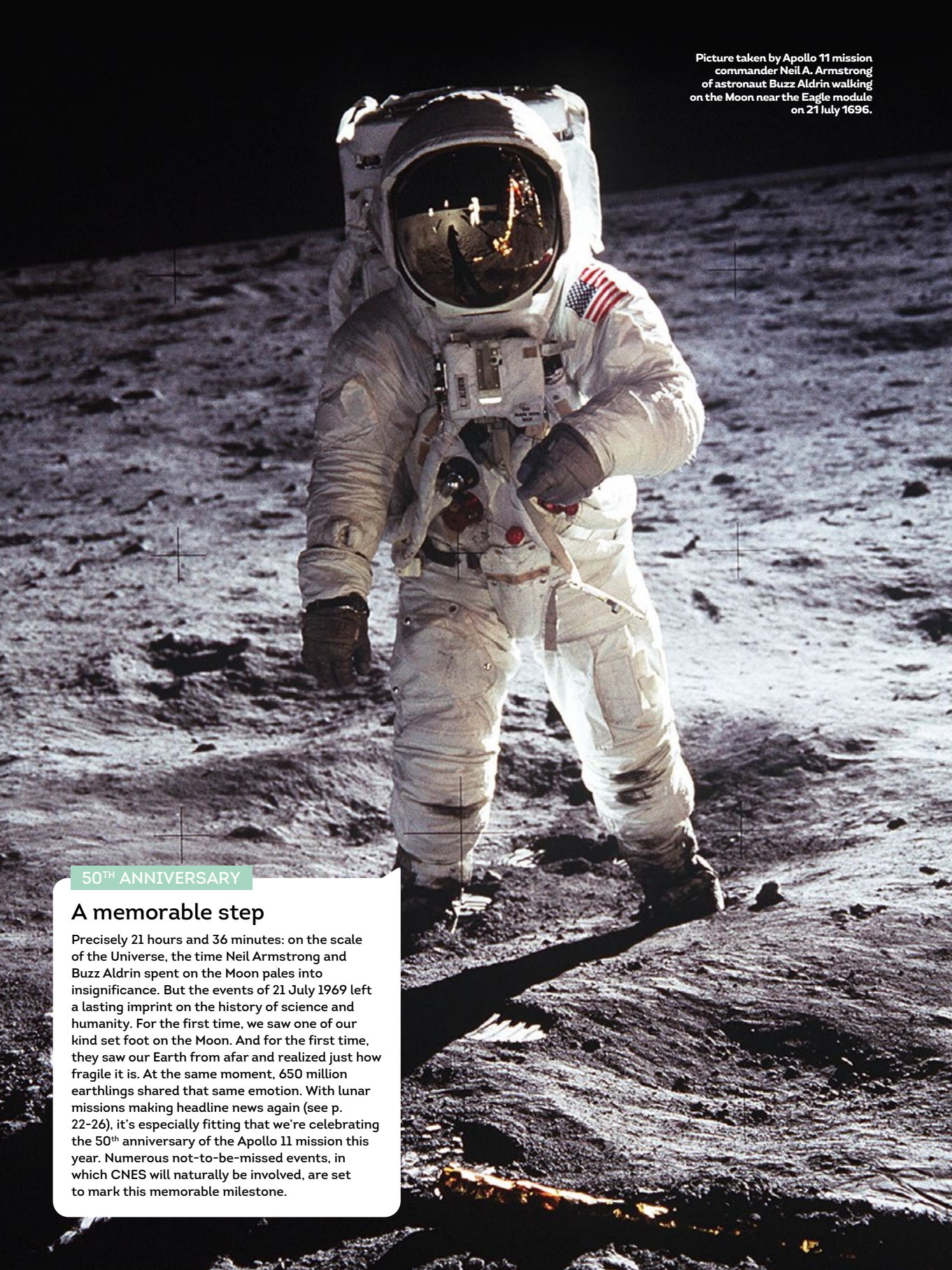
On 21 July, we will be marking the 50th anniversary of man's first steps on the Moon, on what remains to this day the most extraordinary space mission ever undertaken.

These celebrations will be taking place at a time when solar system exploration projects are springing up all over the world, with robotic spacecraft set to deliver new insights into the Moon, Mercury, Mars, asteroids, Jupiter, Saturn and their moons. Other projects are also planning human spaceflight missions to teach us how to survive for longer in space and to return to the Moon as a stepping stone to the ultimate goal of a crewed mission to Mars in the 2030s.

This new-found enthusiasm for space exploration is the result of advances in technology enabling missions that would have been impossible not so very long ago. It's also a chance for space powers to affirm their sovereignty through increasingly spectacular firsts. And it's a way to engage a public grown tired of the mere 'utility' of space, inspired rather by the idea that we should be striving to make the dreams brought to life by Hollywood blockbuster movies come true.

In the final analysis, it's this surprising combination of technology, sovereignty and cinema that today is charting the road ahead for space exploration—in some ways just like 50 years ago, when for the first time in our history we walked on the Moon!

JEAN-YVES LE GALL
CNES PRESIDENT



Picture taken by Apollo 11 mission commander Neil A. Armstrong of astronaut Buzz Aldrin walking on the Moon near the Eagle module on 21 July 1696.

50TH ANNIVERSARY

A memorable step

Precisely 21 hours and 36 minutes: on the scale of the Universe, the time Neil Armstrong and Buzz Aldrin spent on the Moon pales into insignificance. But the events of 21 July 1969 left a lasting imprint on the history of science and humanity. For the first time, we saw one of our kind set foot on the Moon. And for the first time, they saw our Earth from afar and realized just how fragile it is. At the same moment, 650 million earthlings shared that same emotion. With lunar missions making headline news again (see p. 22-26), it's especially fitting that we're celebrating the 50th anniversary of the Apollo 11 mission this year. Numerous not-to-be-missed events, in which CNES will naturally be involved, are set to mark this memorable milestone.

ADVISORY PANEL

SCIENCE PROGRAMMES COMMITTEE

CNES's scientific programme is driven by the pursuit of excellence, and for that it relies on its Science Programmes Committee (CPS) to support the project selection process. The 12 advisors sitting on this committee—six men and six women to ensure strict parity—are all eminent experts in their chosen field. Appointed for a five-year term by the agency's overseeing ministries (Higher Education and Armed Forces) on the proposal of CNES's President, they provide their informed opinion on research projects, their science value and implications. Indeed, getting the green light from the CPS is a prerequisite to a project going ahead. The latest meeting of the CPS in February highlighted the long list of successes achieved in 2018, such as SEIS on InSight, Gaia and its catalogue of celestial objects, Hayabusa2/MASCOT, BepiColombo and SuperCam on Mars 2020. These remarkable results confirm the utility of its recommendations.

SURVEY SEMINAR

CHARTING THE FUTURE OF SCIENCE

In science, you have to think long term and plan ahead. Every four to five years, CNES invites the French scientific community to come together and outline space programme strategies. From 8 to 10 October in Le Havre, the agency's science survey seminar will be studying proposals for 2025-2035 from across the spectrum of research disciplines. Based on the latest discoveries about Mars, the Moon and asteroids, these proposals will fuel future projects seeking to delve deeper into the origins of the Universe or hunt for traces of life and habitability on extraterrestrial worlds. The conclusions of the survey's thematic working groups will ultimately be examined by the agency's Science Programmes Committee (CPS, see opposite), which will then advise on the final selection.

45 TONNES

Before the Apollo programme, no rocket had ever been developed powerful enough to escape Earth's atmosphere. So to get to the Moon, the United States developed a liquid oxygen-hydrogen engine capable of powering its Saturn V launcher. At 45 tonnes, the Apollo 11 mission's payload comprised a lunar module, service module and command module.

SUMMIT MEETING

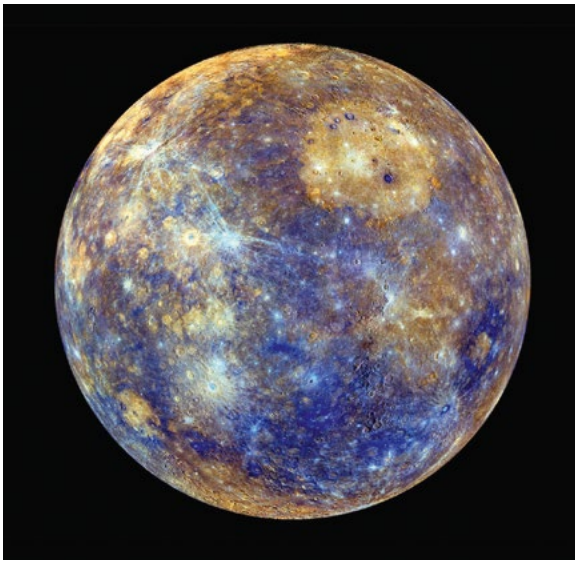
SPACE19+ IN ANDALUSIA

The Space19+ meeting of Europe's ministers with responsibility for space will take place this November in Seville, where they will be aiming to conduct a comprehensive survey of all areas covered by space. But the ministers are also expected to commit to making Europe a leading player in new international space exploration endeavours to the Moon and Mars, working with current partners like the United States and new ones like China. This commitment makes sense in light of the exponential growth in the number of planned lunar missions in a fast-changing international arena. It also reflects the rationale promoted by scientific bodies and European working groups liaising with CNES's Science Programmes Committee (CPS).

BEPICOLOMBO

GETTING TO KNOW MERCURY

Due to its proximity to the Sun, the smallest planet in the solar system remains largely unknown. What little we do know is that it experiences wild temperature swings from +430°C at its equator on the day side to –180°C on the night side, making it hard to design instruments able to withstand such harsh conditions. But the European-Japanese BepiColombo mission launched on 19 October 2018 is setting out to do just that with the two probes it is carrying. After a seven-year cruise phase during which it will circle the Sun 18 times, fly by Earth once, Venus twice and Mercury six times, it will arrive at its destination late in 2025 and spend a year exploring its target planet.
It aims is to get to know Mercury better, mapping its surface, studying its composition and interior structure, and analysing its magnetic field and how it interacts with the solar wind. These data will give scientists new insights into the formation and evolution of planets like Mercury and Earth that orbit close to their star.



VENUS
EYE ON THE SHEPHERD'S STAR

The uncanny resemblance between Earth and Venus has long sparked scientists' curiosity. In 2006, the European Venus Express mission collected data on the planet's structure and chemistry, finding sulphur dioxide in its upper atmosphere and confirming the existence of a double storm system over its south pole. Extended four times, Venus Express came to an end in 2014. With EnVision, ESA is now seeking to pursue exploration of Venus to find out if its geology is still active, retrace its history, understand its erosion processes and probe how its interior, surface and atmosphere are connected. Eight French research laboratories will be working on this mission with support from CNES. The French contribution is being led by the LATMOS[1] atmospheres, environments and space observations laboratory. In the running to be the fifth Medium-class mission (M5) of ESA's Cosmic Vision programme, EnVision will have to wait until 2021 to see if it is selected, and if so will fly in 2032.

1. Laboratoire atmosphères, milieux, observations spatiales.

827,000
NAMES

When NASA invited earthlings to 'send their name to Mars', 827,000 people answered the call. Their names are engraved on two microchips flying on InSight—a great way for them to join the adventure.

217,594

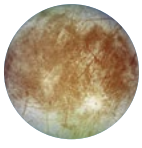
The number of pictures from the Opportunity rover made available to the public on line. The rover covered a total of 45.16 kilometres on Mars, beating the previous record of 35 kilometres by the lunar rover on the Apollo 17 mission.

48 SPACECRAFT

By 2016, 48 spacecraft, probes, orbiters and landers had been sent to Mars since the early 1960s. Almost all launch window opportunities were used.

JOURNEYS TO THE MOONS OF THE SOLAR SYSTEM

EUROPA

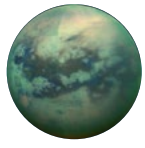


Jupiter's fourth largest moon conceals a liquid ocean beneath its icy crust. The Europa Clipper mission plans to fly by Europa in 2023 to scout sites where the ice is thinnest.

GANYMEDE

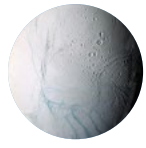
The seventh moon from Jupiter has already been probed by Pioneer 10, Galileo and Voyager. In 2022, the JUICE icy moons mission will study it in closer detail.

TITAN



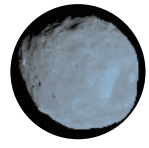
This Saturnian moon is in various ways an analogue for Earth. After Cassini-Huygens (2004-2017), the new Titan Saturn System Mission (TSSM) will explore it around 2030 after a 10-year journey.

ENCELADUS



This moon of Saturn was viewed by Voyager 1 and 2. The Dragonfly mission will study Titan and Enceladus around 2025 for a private exploration project.

PHOBOS



The larger of Mars' two natural satellites is the focus of two missions: PADME (Phobos And Deimos & Mars Environment) in 2020 and MMX (Mars Moons Explorer) around 2031 (see p. 26-27).

TRITON

Neptune's largest moon, like the planet itself, remains largely unknown. Voyager 2 performed a flyby in 1989. A mission could be sent there in 2028-2030.

JUICE

INVESTIGATING JUPITER'S ICY MOONS

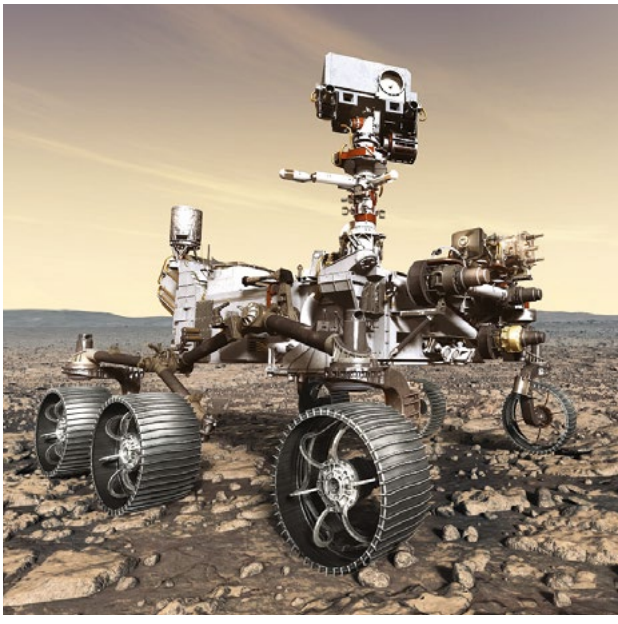
The planets of the solar system still hold plenty of secrets. Europe's JUICE[1] mission plans to decipher the inner workings of one of them: Jupiter. The Jovian system is truly a miniature solar system, with its moons Callisto, Europa and Ganymede thought to harbour subsurface oceans. But are these oceans deep under the ice habitable? To find out, JUICE will be performing a three-year tour culminating with detailed investigations from orbit around Ganymede, the only one of Jupiter's moons protected from radiation by a magnetic field. Scientists suspect it harbours an ocean between two layers of ice, a metal core and rocky mantle, all unique features in the Jovian system. Decided in 2004, JUICE is scheduled to launch in 2022 and arrive in 2029. It is the result of exemplary international cooperation, with 80 European firms working under the leadership of Airbus Defence & Space (ADS). JUICE will be carrying 10 instruments designed by scientists from 15 European countries, as well as from Japan, the United States, Canada, Russia and Israel. CNES is overseeing the French contribution to the mission.

1. JUpiter ICy moons Explorer.

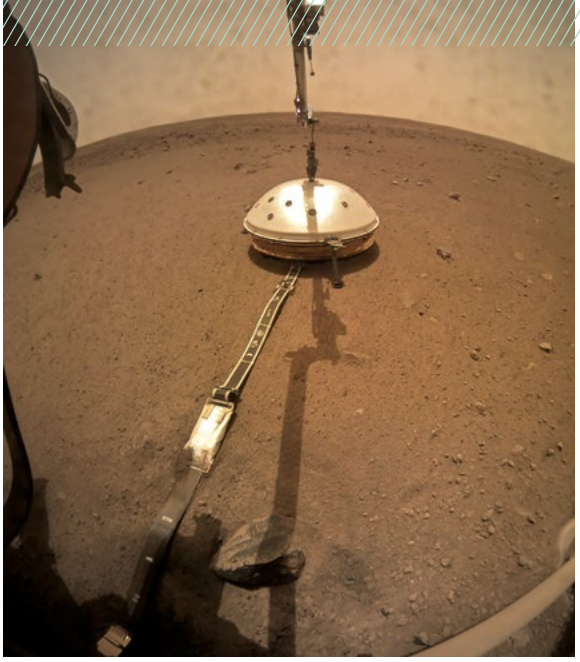
MARS

MAKING ROCKS TALK

For seven years now, the tiny Curiosity rover has been zapping rocks on the surface of Mars with its ChemCam laser camera. After visiting Gale Crater, it has been driving since February in the foothills of Mount Sharp en route to Glen Torridon, where it will look for organic molecules that could reveal if Mars once supported conditions suitable for life. It recently detected a source of surface methane and uncovered organic molecules containing sulphur. Mars 2020 will pursue this task, departing in July 2020 and landing on the red planet in February 2021. The rover will explore Jezero Crater and lay the groundwork for a future sample return mission. Its number one asset is SuperCam, an enhanced version of ChemCam capable of selecting samples and caching them for later return to Earth.



Artist's impression of the Mars 2020 rover.



The InSight lander's robotic arm carefully lowered the SEIS seismometer's protective wind and thermal shield into place on the surface of Mars on 2 February 2019.

MARS

MASTERING COMPLEX PROCEDURES

To understand the red planet, we also need to take its pulse and listen to its beating heart. That's just what the SEIS seismometer overseen by CNES is doing on the InSight mission. On 19 December 2018, InSight gently set down SEIS on the surface of Mars, and then in early February covered it with a shield to offer protection from the wind and low temperatures, including a chainmail skirt that hugs the ground and settles easily over any rocks. SEIS is ultra-sensitive to vibrations, which it is recording to detect any seismic activity ('marsquakes') and meteorite impacts. And on 6 April, this mission really began in earnest (see In Pictures, p. 17). Schiaparelli, on the other hand, wasn't quite so successful. The ExoMars programme's small rover was meant to validate entry, descent and landing technologies for a future sample return mission, but its crash landing in 2016 was a reminder of just how complex space exploration is. However, Schiaparelli was only the first phase of the programme and a second mission will depart in 2020 with the same goal of searching for signs of life. This time, a Russian instrument platform will set down the European rover on the surface where it will take readings for a whole Martian year. CNES and French laboratories are supplying two of its instruments.

SUN

TAKING THE HEAT

The temperature at the surface of the Sun is around 3,500°C. But in the corona, it can reach one million degrees Celsius. Why such a big difference? The Parker Solar Probe mission launched on 12 August 2018 will be the first to acquire measurements close to the Sun in an attempt to find out. In 2024, it will come within less than six million kilometres of our star, where it will be buffeted by the solar wind, ions and electrons discharged at high speed. That's the price to pay to gain new insights into its atmosphere and better protect ourselves from its effects. Europe's Solar Orbiter mission will depart in February 2020. By observing the Sun's poles and its hidden side from further away, the probe intends to use its unprecedented resolution to reveal the mechanisms driving the formation of the corona and solar wind. Scientists are eagerly awaiting the results of these two complementary missions and looking forward to mining the potential of their combined observations.

COMMUNITY

Every day, CNES engages with you on social networks and you share your thoughts and questions with us. Join the conversation!

@FRANCESPACE96

Engineering undergraduate @ISAE_ENSMA // materials, aerospace, industry // @3AF_asso
✈️🌠🇫🇷

Ariane 5 successfully launched the European-Japanese BepiColombo mission that will reach Mercury in 7 years' time. Another great feat to look forward to for European robotic exploration of the solar system. 🌍–––>🌠––––>🌚

@LCHAINESPATIALE

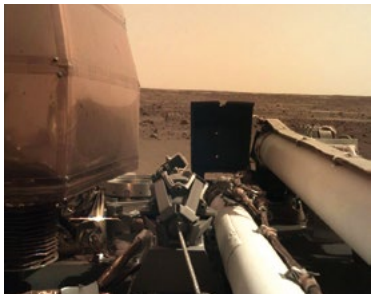
Space and aviation enthusiast

Solar system exploration in a picture.

@NASAINSIGHT

The InSight mission will study the early evolution of terrestrial planets. Launched May 5, 2018. Landed Nov. 26, 2018.

There's a quiet beauty here. Looking forward to exploring my new home. #MarsLanding



@STEPHANIE24120

Paranormal investigations #jordanperrigaud, sport #basicfit, social media #netflix and #LGBT are my daily areas of interest 👌😍

🌎🌌 On a journey to beyond the solar system! NASA's New Horizons probe is on its way to the outer reaches of the Universe. Ultima Thule is almost 7 billion km from Earth #NASANewHorizons @NASA #univers #systemesolaire #UltimaThulé #Terre #exploration

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Q & A

FRANÇOIS FORGET

ASTROPHYSICIST, PLANETOLOGIST AND DEPUTY DIRECTOR OF THE LMD DYNAMIC METEOROLOGY LABORATORY, François Forget gives us an insider's view of the very real stakes of space exploration, explained simply and honestly with a wealth of examples to illustrate.

WHAT MYSTERIES ARE WE SEEKING TO UNTANGLE IN EXPLORING THE SOLAR SYSTEM?

François Forget: Why are we humans looking to advance our understanding of the solar system despite the huge technical and economic obstacles to be overcome? In the same way that we study animals to understand the human body, astrophysicists are probing other planets to gain new insights into Earth and the origins of life. That said, it's true that human space exploration as such may sometimes seem an irrational endeavour given what it costs to achieve results.

WHAT IS SO INTERESTING ABOUT MARS?

F. F.: Mars is one of the ten worlds with an atmosphere—seven planets, two moons and one dwarf planet—being studied at LMD. It's like a smaller analogue of Earth, with its own winds, trade winds and jet stream. For example, testing our numerical climate model on Mars has enabled us to uncover some defects and subsequently model the monsoon in India more precisely. While Mars is inhospitable today, we're looking for fossils because in its ancient past it was covered with lakes and rivers. It's therefore a great place to investigate prebiotic chemistry and decipher the steps leading to life. Indeed, Mars is the only planet hospitable enough for astronauts to survive with the technologies now at our disposal.

FRANÇOIS FORGET

DEPUTY DIRECTOR OF THE LMD DYNAMIC METEOROLOGY LABORATORY

"WE ALSO NEED TO SUPPORT EXPLORATION FOR PURELY SCIENTIFIC PURPOSES."

But there's no philosophical or economic value in seeing it as a 'substitute' for Earth; its value remains purely scientific. Obviously, other planets are fascinating to study and space agencies are also interested in planetary bodies without an atmosphere like Mercury, Europa, Ganymede and Enceladus.

WHAT TANGIBLE BENEFITS CAN WE EXPECT TO SEE FROM SPACE RESEARCH?

F. F.: Besides GPS, the daily utility of which needs no confirmation, space exploration is giving us new insights into Earth and what lies in store for it. Subtle phenomena on Earth that are much easier to see elsewhere in the Universe are helping us to study climate change, volcanology and the environment. For example, we now know that a doubling of the amount of carbon dioxide in Earth's atmosphere would be catastrophic. Another example: when the ozone hole was first detected, nobody understood the underlying mechanisms. It was work on chlorine present on Venus that helped to characterize how chlorine and ozone react chemically, which led to chlorofluorocarbons (CFCs[1]) being banned. Robotic exploration also has tangible benefits, if only because sending a rover to another planet confronts us with new issues. But we also need to support exploration for purely scientific purposes.

WHAT IN YOUR VIEW ARE THE LATEST MAJOR DISCOVERIES ABOUT THE SOLAR SYSTEM?

F. F.: There are so many! Thanks to the Cassini and Juno missions, we now have a better grasp of the complexity of giant planets like Jupiter. With New Horizons, Pluto has proved to be a world of nitrogen glaciers, methane dunes and ice mountains. And Ultima Thule, a very cold object beyond the orbit of Neptune that's neither a planet nor an asteroid, is like nothing we've ever seen before. Another key discovery is that most stars in the sky also have planets. Among them, Proxima B, which is just four light-years away, will be able to be characterized by the Extra Large Telescope (ELT) in Chile. And as for the TRAPPIST-1 system, which comprises seven rocky planets, it's an absolute marvel that the James Webb

Space Telescope (JWST) will survey to peer into their atmospheres when they cross in front of their star.

HOW HAVE SPACE MISSIONS EVOLVED IN THE LAST 50 YEARS?

F. F.: The Apollo programme remains an absolute masterpiece. NASA had massive resources at its disposal and the engineers of the 1960s invented everything. If you think about it, the pictures of Neil Armstrong on the Moon still look like something out of science-fiction today. So, we haven't really seen anything revolutionary in the last 50 years. Thomas Pesquet's spacesuit is pretty much like those the Apollo crews wore, and launchers and engines have evolved little despite our best hopes. The launch vehicle that will send a space station into lunar orbit will probably not be all that more powerful than Saturn V. What has come on in leaps and bounds, however, is computing power.

WHAT OBSTACLES AND LIMITS TO SPACE EXPLORATION DO YOU SEE?

F. F.: The main obstacle is funding, which explains why we've been hearing for 50 years now that we'll be going to Mars in 20 years' time! In the field of robotic exploration, space agencies' calls for ideas are spawning some great ideas, but it's really frustrating that only one in fifteen actually makes it into space. But projects are limited by costs. For example, there are plans to build a permanent outpost on the Moon. The cost of such a project would push missions to Mars back tens of years. There are also technology issues. Conceiving a robot submarine to go beneath Europa's icy crust and into its subsurface ocean is unbelievably complex. The electronics on today's rovers would be unable to withstand the heat on Venus. And driving rovers remotely across the surface of Mars remains a slow process because of the distance from Earth. They would be much more effective if we could control them in real time, for example from a crewed orbiter, until we've figured out how to reliably land and take off again, which is both costly and hard to do.

"HUMAN SPACE EXPLORATION MAY SOMETIMES SEEM AN IRRATIONAL ENDEAVOUR GIVEN WHAT IT COSTS TO ACHIEVE RESULTS."

IS COOPERATION A NECESSITY?

F. F.: In space, cooperation is the rule, as illustrated by the International Space Station. Projects conducted by a single nation in isolation are the exception: India began by studying Mars alone, but now it's looking for partners to explore Venus. Even China is exploring the far side of the Moon with Belgium, the Netherlands and Sweden. Crewed missions to Mars are also likely to be pursued by an international consortium led by NASA. And we're seeing cooperation between the public and private sectors with the emergence of New Space[2]. Space X, in particular, has delivered technical solutions for NASA and driven down the cost of launchers. The United States' future heavy-lift Space Launch System (SLS) may cost more than Space X's Big Falcon Rocket (BFR)! More recently, 14-kilogram cubesats accompanied the InSight mission and its SEIS seismometer co-developed by CNES to Mars, beaming back the first pictures from the red planet in real time—a technology demonstration that will no doubt pave the way for cheaper, miniaturized exploration missions.

1. Chlorofluorocarbons (CFCs) are gases containing only carbon, chorine and fluorine, and are derived from saturated hydrocarbons.

2. New Space or entrepreneurial space encompasses a range of private initiatives driving a paradigm shift in the space industry.

Profile

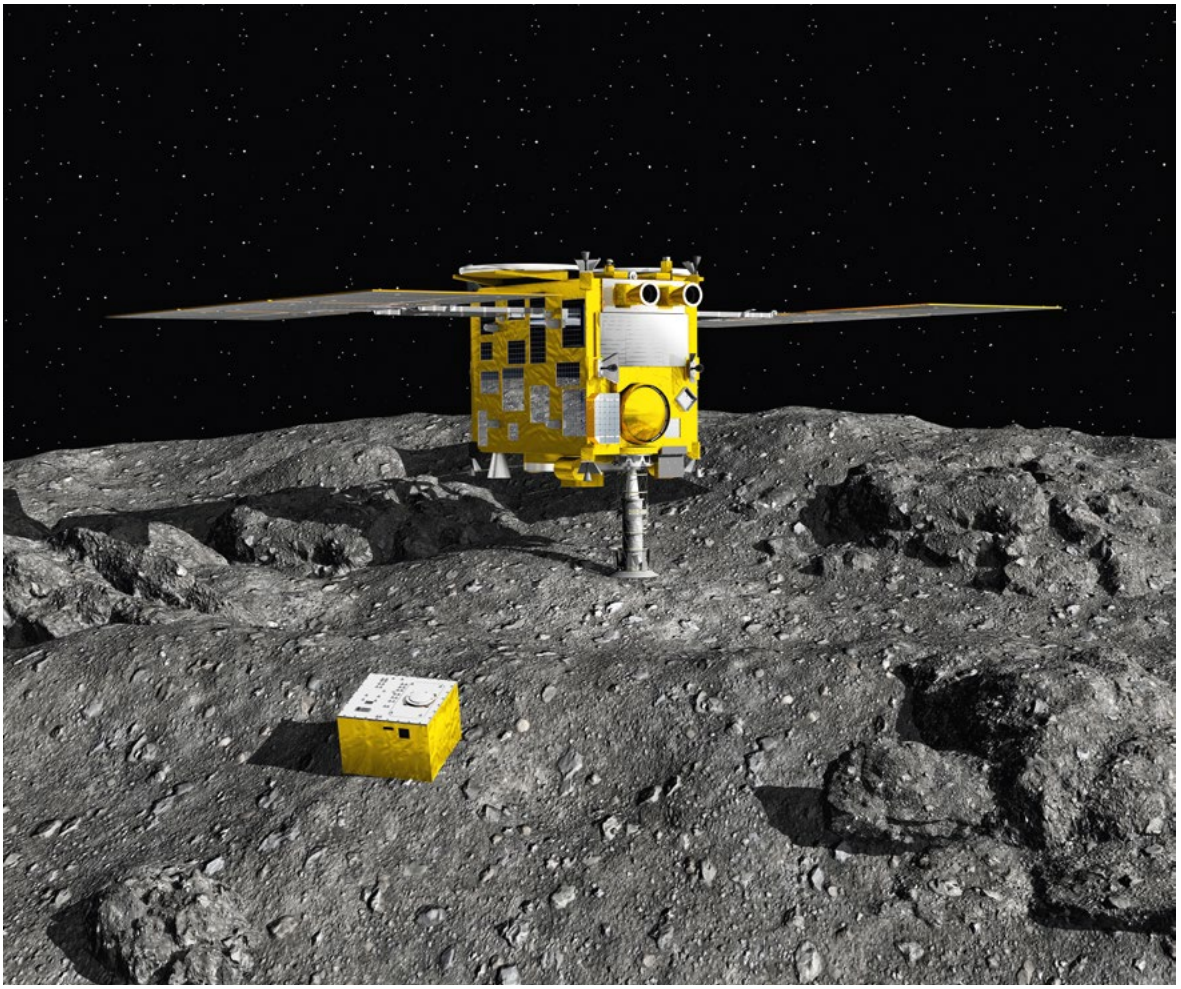
1998-2010
Research scientist at CNRS

2004-2005
Research scientist at NASA

Since 2010
Research Director at CNRS

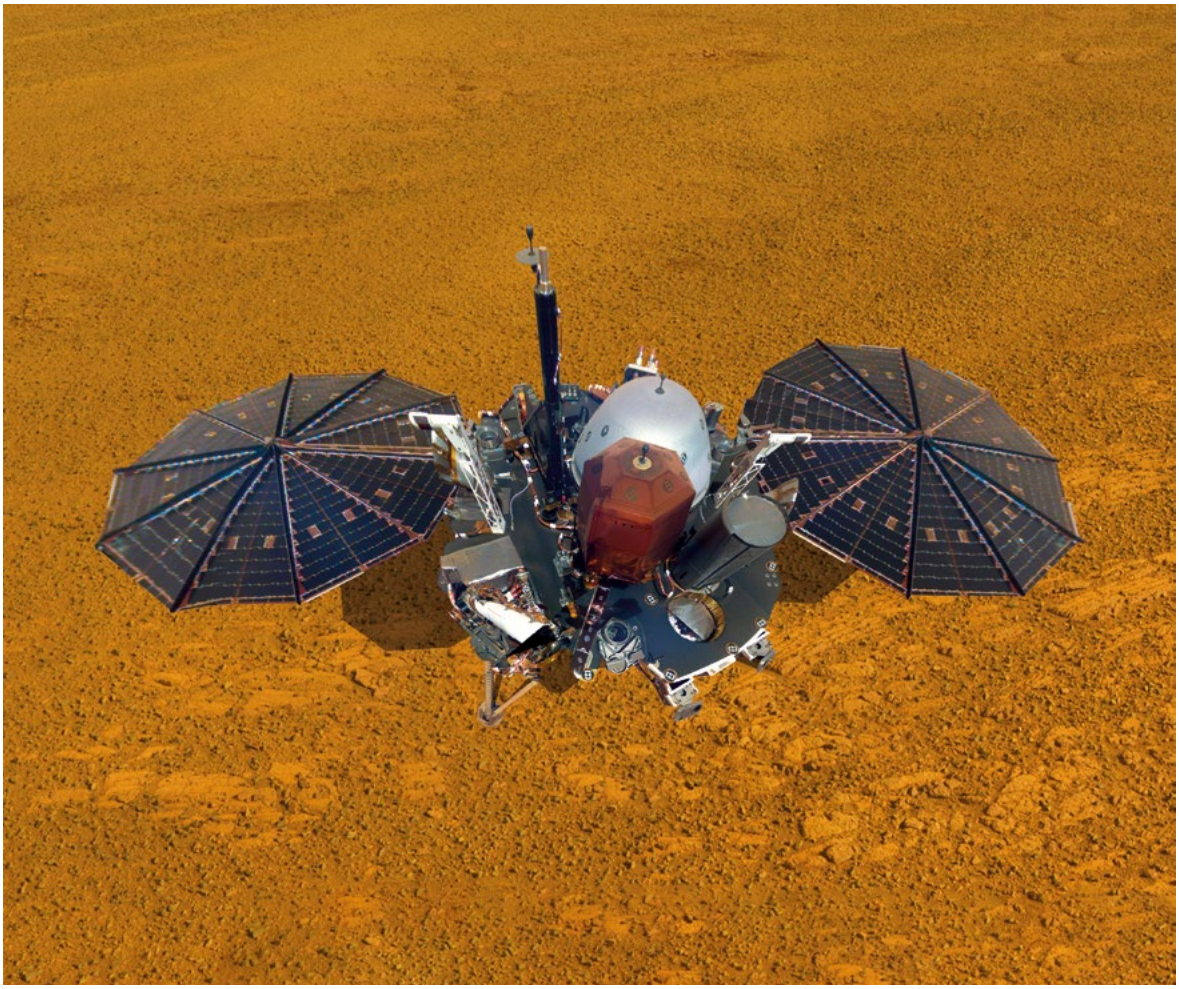
Since 2016
Deputy Director of LMD

2017
Inducted into the French Academy of Sciences



MASCOT'S DESCENT

3 October 2018 at 03:57 and 25 seconds, the Hayabusa2 probe released MASCOT and the tiny rover began its descent to asteroid Ryugu. At 04:04, after a four-year journey, the 10-kilogram module anchored itself to the surface despite the rocks and craters. Scouting ahead for Hayabusa2, it helped mission teams to rejig the sample-collection procedure and guide the probe more precisely, delaying its landing on Ryugu by a few months. On 21 February, Hayabusa2 successfully collected its first samples from the asteroid.



INSIGHT TAKES CARE OF SEIS

The U.S. InSight mission carrying the French SEIS seismometer landed on the surface of Mars on 26 November 2018. On 2 February 2019, the lander carefully placed a protective dome-shaped shield over the seismometer. Since then, SEIS has been sounding the planet's interior. It detected a first faint seismic signal on 6 April. Meanwhile, InSight's camera is taking advantage of the sunlight to record pictures for posterity of the tiny seismometer at work.

SECOND STAY

His photos have been viewed with wonder around the globe and his regular tweets kept us entertained for the 200 days he spent on the International Space Station. But Thomas Pesquet was there above all to conduct scientific experiments for the Proxima programme. This committed ambassador for human space exploration was chosen in January by ESA for a second sojourn in space.

5,250

DAYS
The Opportunity rover operated for 14 years, 4 months and 16 days on the surface of Mars. It arrived on 25 January 2004 and stopped transmitting on 10 June 2018.

9 minutes from Mars

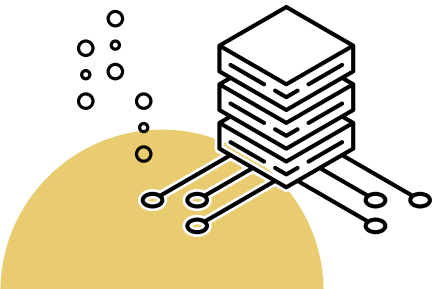
CAN NANOSATS AND CUBESATS support space exploration missions? To find out, NASA sent two cubesats last year to Mars. The radio signals beamed back to Earth by MarCo A and MarCo B enabled the U.S. space agency to confirm InSight's successful landing just nine minutes after its arrival.

GAIA

The Gaia mission launched in 2013 has already surveyed 1.7 billion stars with its 500 million daily measurements. A first data release was published in 2016 and a second in April 2018. Through its repeated sky scans, Gaia has been able to record increasingly precise details like the position, motion and composition of stars. But it has its eyes on all celestial objects, including those still to be discovered. The third data release planned for 2020 will be the most comprehensive yet.

7 million files

Science data constitute a priceless record. In 1999, the INSU universe sciences institute and CNES set up the CDPP plasma physics data centre. Twenty years on, this repository employs robot technologies and its data are finding applications in numerous fields of research spanning Earth's magnetosphere and planetology to heliophysics and space weather. With its seven million files, the CDPP today offers value-added services covering a broad spectrum of scientific needs. In 2018 alone, it supplied data to more than 300 users.



DESTINATION MOON

ON 21 JULY 1969, THE CREW OF APOLLO 11 MADE IT TO THE MOON. FIFTY YEARS LATER, LUNAR MISSIONS ARE HEADLINE NEWS AGAIN. AS A KEY PARTNER ON HUMAN SPACEFLIGHTS, AN EXPERT IN SPACEFLIGHT DYNAMICS AND A PRIME MOVER BEHIND EUROPE'S SPACE PROGRAMME, CNES WILL BE CENTRAL TO ALL EXPLORATION ENDEAVOURS—TODAY TO THE MOON AND TOMORROW TO MARS, ON BOTH ROBOTIC AND CREWED MISSIONS.

The Moon seen by the Pleiades 1A satellite. Free from the perturbing effects of Earth's atmosphere, the Moon's seas and craters are perfect 'targets' for finely calibrating Pleiades' optical instrument.

91

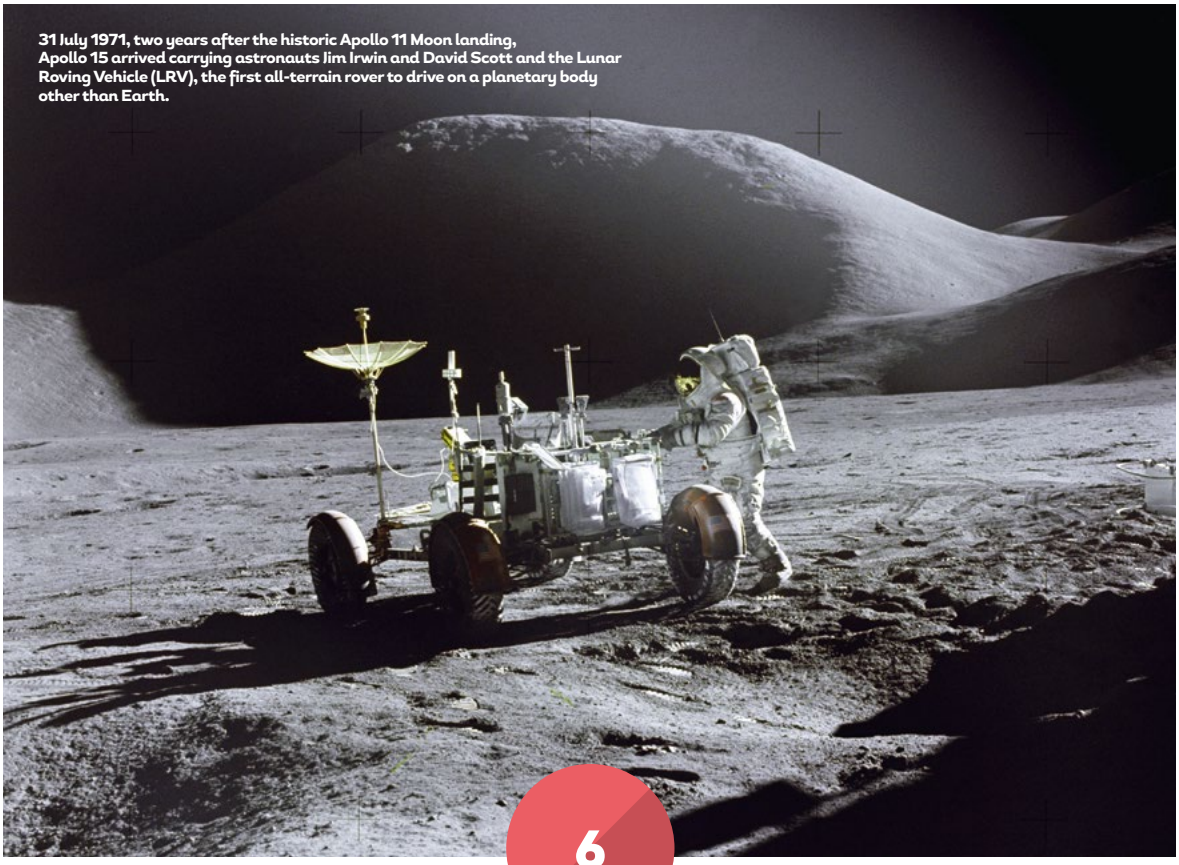
On 23 September 1958, the Soviet Union launched a first unmanned mission to the Moon. Between then and the start of January 2019, there have been 91 lunar missions. Ten are thought to be in development or under study to depart by 2025.

The iconic 'Earthrise' picture taken from the Moon on the Apollo 8 mission.

On 21 July 1969, 650 million earthlings watched with bated breath as two astronauts from the Apollo 11 mission crew achieved the improbable feat of setting foot on the surface of the Moon. In January 1961, newly elected U.S. President John Fitzgerald Kennedy had set the goal of reaching the Moon within the decade; in the end, it took just eight years. Such unfaltering motivation had little to do with science and everything to do with politics, as the United States sought to counter the Soviet Union in mid-Cold War. It must be said that the Soviets had gained the edge in space. After sending Sputnik and the dog Laika into space in 1957, they flew around the Moon and took the first pictures of its far side in 1959 on the Luna 3 mission. Two years later, in 1961, Yuri Gagarin became the first man in space.

COLLATERAL BENEFITS

The Apollo 11 mission will not only go down in history as the United States' spectacularly successful response; it also greatly advanced science, "*one of the programme's collateral benefits*," in the words of Francis Rocard, head of solar system exploration programmes at CNES. Lunar science has seen two distinct eras, one before and one after Apollo 11. The mission settled the debate on a number of previously unverifiable hypotheses, confirming that our Moon was indeed formed after a collision between Earth and another planet the size of Mars. While water is absent on most of its surface, traces from cometary impacts probably persist at the poles. The age of the rocks in its mountainous regions has been estimated at 4.4 billion years, and that of certain 'seas'—the lunar maria (singular 'mare')—at 2 billion years. And the Moon's mantle is made up of variable amounts of silicates (olivine and pyroxene). More surprising yet and inconceivable before Apollo 11, an ocean of magma was even uncovered.
The 1960s and 70s saw a succession of both



31 July 1971, two years after the historic Apollo 11 Moon landing, Apollo 15 arrived carrying astronauts Jim Irwin and David Scott and the Lunar Roving Vehicle (LRV), the first all-terrain rover to drive on a planetary body other than Earth.

6

Crewed exploration missions

to the Moon were undertaken by NASA. The last men to set foot on its surface were scientist Harrison Schmitt and astronaut Eugene Cernan on the Apollo 17 mission, in December 1972.

robotic and crewed lunar missions. In all, 12 astronauts would set foot on the Moon in the space of three years, 380 kilograms of rock and regolith were brought back and a suite of instruments was installed on the surface by five consecutive missions to collect new data. Some samples have been analysed by thousands of scientists all over the world, providing new insights into the Moon's geology shaped by its mare basalts, magnesium-rich and alkali-rich rocks, and regolith. Many French scientists among those performing mineralogical analyses thus acquired world renown. These first missions also provided the chance to validate technologies for Moon landings and extravehicular activities, and to establish a first diagnosis of the effects of spaceflight on humans. On 15 July 1975, an orbital rendezvous was orchestrated between the Apollo and Soyuz vessels as a sign of detente between the United States and the Soviet Union. Crewed spaceflights now became a symbol of brotherhood and international space cooperation moved into the fast lane.

INTEREST IN THE MOON WANES

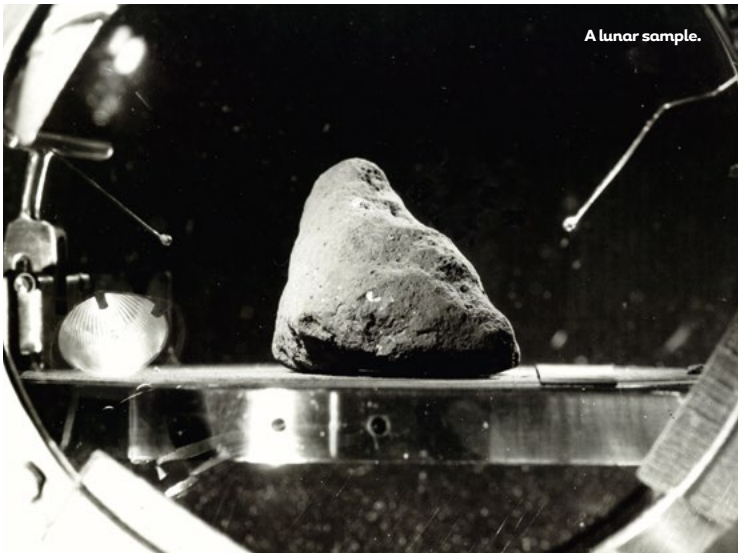
After reaching its zenith in the 1970s, lunar exploration gradually waned for more down-to-earth reasons: missions to the Moon were costly, and so was the Vietnam War. Budget realities kicked in, prompting the United

States to adopt a more pragmatic approach. And scientific realities, too: "*Given the state of scientific knowledge at the time, there was no great value in spending billions of dollars to send crews back to the Moon*," notes Francis Rocard. This was all the more so as new challenges and adventures—to Mars, Venus, Mercury, Titan, asteroids and comets—beckoned for humankind and the scientific community.
Through CNES, France has always shown a strong willingness to be a part of the space exploration adventure, working with both the U.S. and Russian space agencies. Today, within the framework of ESA or bilateral and multilateral agreements, CNES remains a key partner on world-class science missions like Rosetta (to comet Chury) and Hayabusa2 (to asteroid Ryugu). It is also closely involved in Mars exploration through ever-bolder programmes like Curiosity, InSight, Mars 2020, ExoMars and MMX.

FRANCE

A LONG RELATIONSHIP WITH THE MOON

In the domain of planetary exploration, the first French instrument delivered by CNES was a laser retroreflector for the Soviet Lunokhod rovers in the 1970s.
This instrument served to develop a budding laser technology used to measure the Earth-Moon distance and the rate at which it is gradually spiralling away from Earth with centimetre precision. The Apollo missions opened up new avenues of investigation such as geochemical analysis of lunar samples. Unique expertise in this field has been developed in France with CNES's support. Advances in methodology have enabled French scientists, among them those at the IPGP Earth physics institute in Paris, to determine that the Moon's interior—like Earth's—is not uniform but rather consists of a thin crust, a thick mantle and a dense core.
In 1994, CNES contributed to the U.S. Clementine mission, for which it developed an image compressor that greatly boosted the probe's image transmission capability. Today, CNES remains a watchful and motivated partner. With an eye on its science survey seminar in November (see. p. 7), the agency invited the lunar science community to Paris on 1 March to consider the current outlook for studying our natural satellite. This gathering pointed up the grey areas that will shape the future goals of the many missions that numerous nations are planning between now and 2030.


A lunar sample.

Artist's impression of the proposed LOP-G space station in lunar orbit.

TURNAROUND
BACK IN FAVOUR

That lunar missions are undeniably attracting renewed interest in these early years of the 21st century may surprise. Why is this? And what value can we expect them to deliver? Almost in spite of itself, the Moon embodies many stakes and challenges.

While the Apollo programme made the first inroads, the Moon is today more than ever the subject of strong scientific interest. "*Analytical methods and models of how the Moon formed have changed over the last 20 years. So we're reconsidering the value of studying lunar geology to better retrace its history and understand how the Moon-Earth system evolved*," explains Jean Blouvac, head of CNES's exploration and human spaceflight programme. From another perspective, its far side is shielded from Earth's electromagnetic pollution, making it an excellent vantage point for radio-astronomy.

WHY WE SHOULD GO TO THE MOON

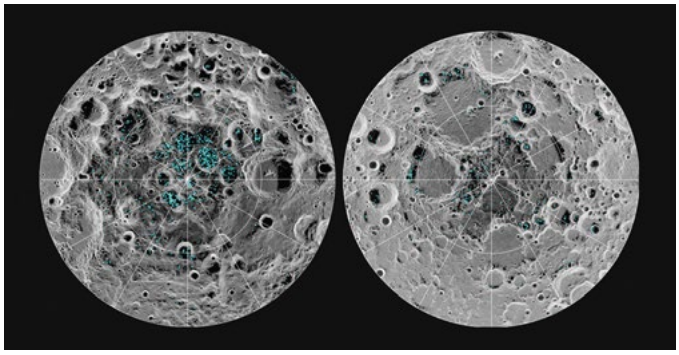
But as is often the case in space exploration, science is not the only motivation. Today, the Moon is attracting attention for its resources. Quite logically, after the International Space Station (ISS) in low Earth orbit the Moon is seen as the next stepping stone to Mars. For setting foot on Mars one day is no longer a pipe dream: "*Technically speaking, we're almost there*," says Jean Blouvac. And the even more distant prospect of Earth-crossing asteroids is already in sight. But first, we need to characterize lunar resources to determine if we can extract and use them. If so, the Moon can serve as a

laboratory and proving ground. It could even fuel economic activities and influences beyond Earth and low Earth orbit.

WATER'S THE LIMIT

Although unable to quantify it, in 2009 the U.S Lunar Reconnaissance Orbiter (LRO) detected ice at the bottom of frozen craters at the Moon's poles. Water, as well as oxygen, is also present in significant amounts in the regolith covering the lunar surface. And in terms of lunar resources, water and oxygen are the priorities, because having to ferry such vital resources for exploration into space would be expensive. Being able to resupply a future cislunar space station from the Moon rather than from Earth would most likely reduce costs. Electrolysis could also be employed to extract oxygen and hydrogen from water to produce fuel for propulsion. A sort of 'resupply depot' could thus be stationed in lunar orbit for spacecraft, again a more profitable solution than resupplying them from Earth.

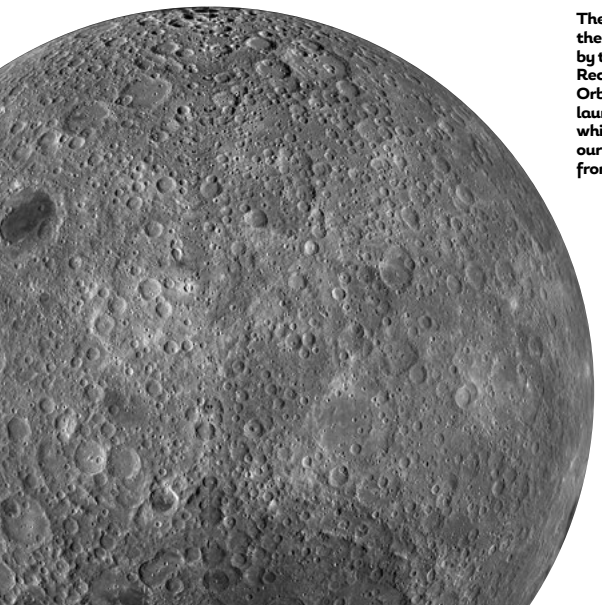
The Moon also harbours resources that could be mined to serve as building materials. In a sophisticated scenario, regolith—fragmental and unconsolidated rock material—could be used to build habitable structures by 3D printing. Once the realm of make-believe, this concept is now being looked at seriously.



Distribution of surface ice at the Moon's south pole (left) and north pole (right) detected by the U.S. Moon Mineralogy Mapper instrument.

ALL-OUT PROSPECTION

The prospection phase has already begun. It now remains to venture further into relatively unknown regions of the Moon like its poles and far side, where China set down its Chang'e 4 rover in January. Bringing back samples from these new sites would provide new clues to unlock the secrets of the 400 kilograms of lunar material collected from a fairly small area by the Apollo missions. The United States is rolling out several lunar prospection programmes. For example, the Lunar Orbital Platform-Gateway (LOP-G) project plans to put robots and humans back on the Moon. New crewed missions will enable us to learn to live and build in deep space. LOP-G is designed as a staging point, for example to build spacecraft destined for Mars. It will also serve as a checkpoint for utilization of extracted resources, a laboratory for analysing the effects of radiation on humans, and possibly even a back-up base for lunar surface missions. Lying days from Earth rather than hours in the case of the ISS, it will give these new pioneers greater autonomy, making them less and less dependent on commands from the ground. Here, there really is no alternative, since ultimately to go to Mars on missions lasting several years, humans will have to learn to decide and act alone. Obviously, many very complex steps still need to be completed along the way, calling for a 'test-and-learn' approach.

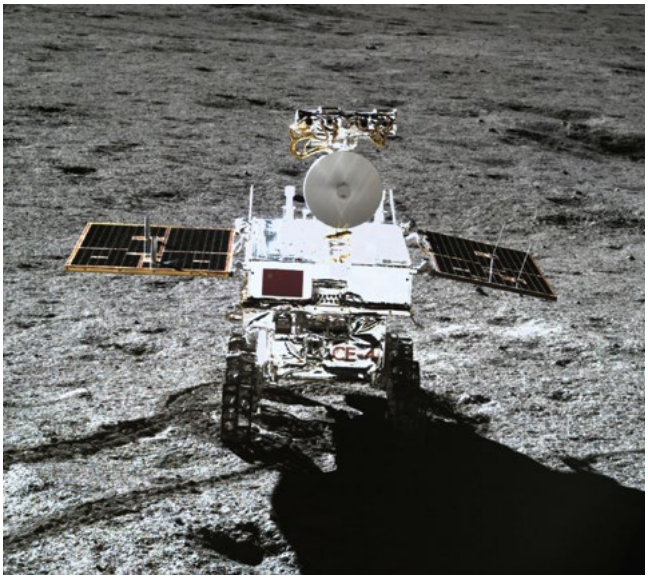


The far side of the Moon viewed by the U.S. Lunar Reconnaissance Orbiter (LRO), launched in 2009, which is studying our natural satellite from lunar orbit.

PANORAMA
SHOOTING **FOR THE MOON**

Several large-scale lunar missions are planned in the years ahead. While there is consensus on the need to explore the Moon, the protagonists' motivations vary. Despite this, synergies are emerging to develop cheaper and more-robust missions.

Chang'e 1 and 2 circled the Moon, and Chang'e 3 put a rover on its surface. On 3 January 2019, in landing Chang'e 4 on its far side, China took the world by surprise. With its Chang'e programme, the China National Space Administration (CNSA) is seeking to overcome one of the obstacles to deep space exploration, that is, the complexity of the technologies required—like autonomous landing—and the constraints of long-distance communication, as well as the particularly harsh thermal environment.



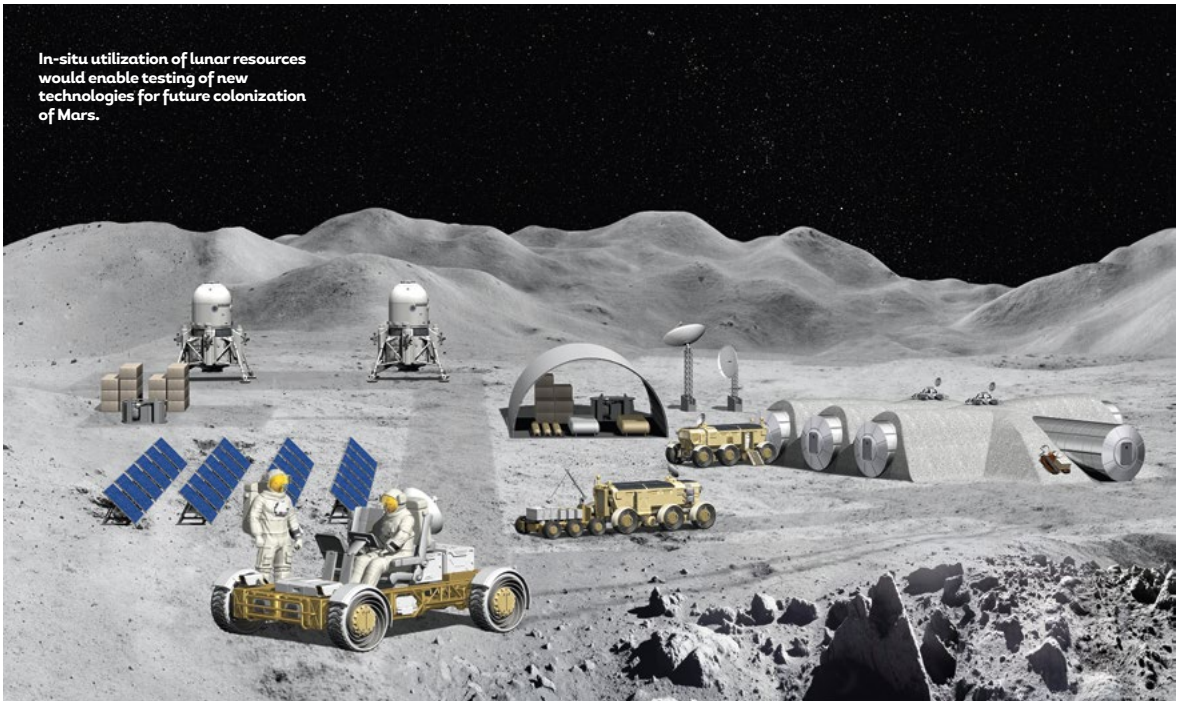
The Chinese Yutu-2 rover exploring the far side of the Moon, pictured by the Chang'e 4 spacecraft on 11 January 2019.

TECHNOLOGY CHALLENGE

With Chang'e 5, planned for the end of this year, CNSA will test its ability to return a capsule of lunar samples to Earth. Chang'e 6 will also bring back samples, only this time from the Moon's south pole. On 25 March, CNES President Jean-Yves Le Gall signed a cooperation agreement with his Chinese counterpart to fly 15 kilograms of French experiments on this mission—a first. The next and last step of the programme has already been announced, as Chang'e 8 will test key technologies for the construction of an unmanned lunar base. China also intends to put a taikonaut on the Moon in under 20 years. Besides this plethora of lunar missions, CNSA also wants to extend its investigations to Mars, Venus and Jupiter.

In India, ten years after Chandrayaan 1, the Indian Space Research Organisation (ISRO) is envisioning a return to lunar orbit with Chandrayaan 2, carrying a lander and rover. Like China's, ISRO's programme is driven more by technology than science. Its launch has already been pushed back three times, but is expected to go ahead this year.

On 22 February, it was Israel's turn to enter the fray as it sent the Beresheet lander on its way to the Moon. Built by a private firm, SpaceIL, the small craft was designed to operate for two days on the lunar surface but unfortunately crashed on landing on 11 April. Beresheet was above all a prestige mission for Israel, but that hasn't stopped it

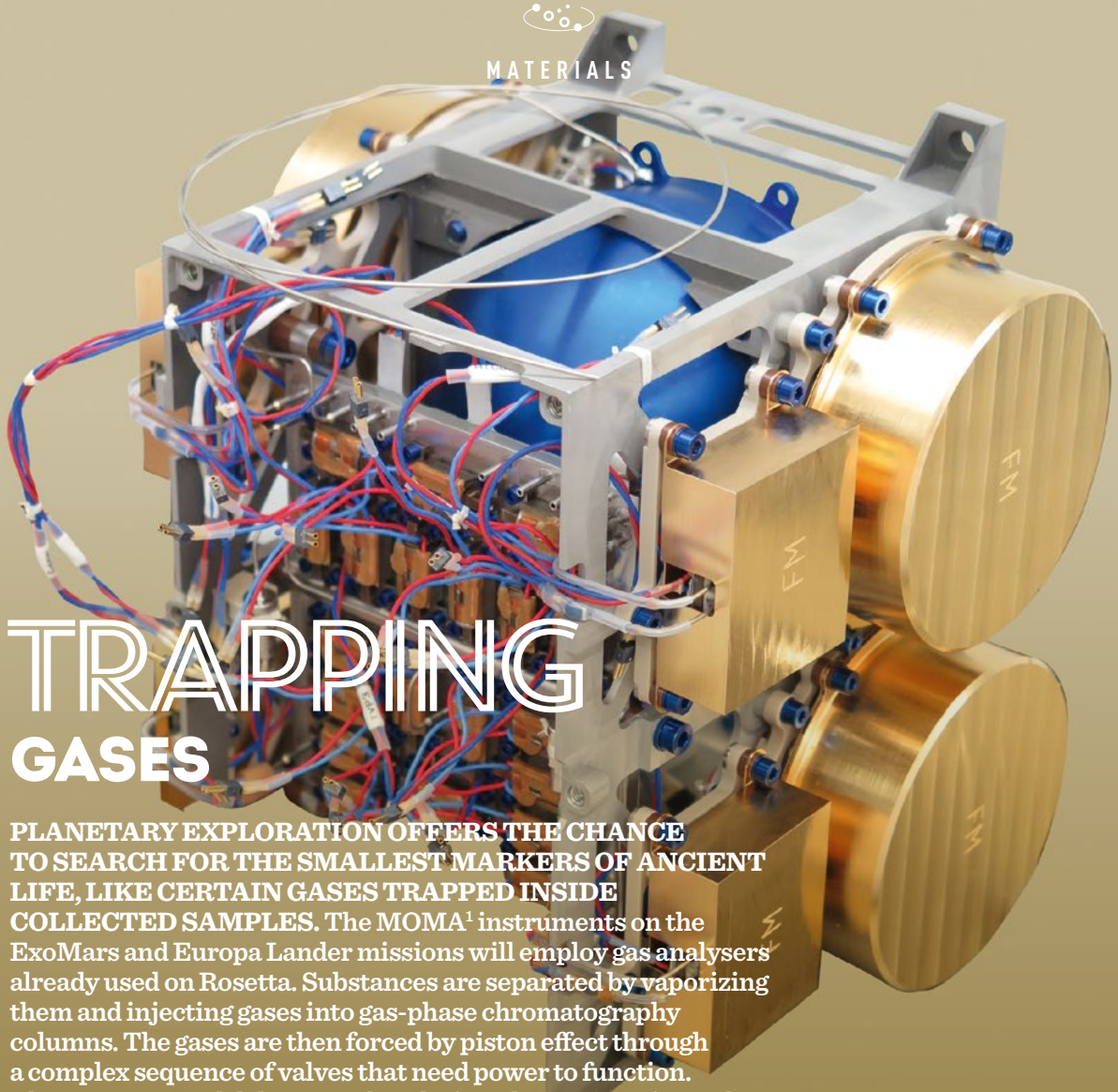


In-situ utilization of lunar resources would enable testing of new technologies for future colonization of Mars.

sealing an agreement with NASA to work together on a commercial service to ferry payloads to the Moon.

LONG-TERM PRESENCE

Unsurprisingly, the most ambitious projects are coming from across the Atlantic. In 2017, NASA committed to putting a space station in lunar orbit called the Lunar Orbital Platform-Gateway (LOP-G, see p. 24). To serve it, the U.S. space agency is developing a heavy-lift Space Launch System (SLS) and the Orion crew capsule. This orbital infrastructure could be a staging post for missions to Mars and beyond, and would also have service modules. Functionally, it is drawing heavily on the heritage of the ISS, and likewise will be built with international partners. Japan is expected to be actively involved in the project and the Russian federal space agency has already signed a first commitment in 2017. In March, the Canadian Space Agency (CSA) also announced it would develop the station's robotic arm and contribute to technology developments. Europe will of course be on board, too. Leveraging the experience acquired from its five ATV resupply vehicles that flew to the ISS and were controlled from CNES's facility in Toulouse, the agency is investing in development of Orion service modules. In November 2018, it delivered the first European Service Module, ESM 1, which will provide power, propulsion, thermal control, air and water for Orion. ESA has also awarded study contracts for two pressurized modules, I-HAB and ESPRIT, which will be submitted to the Space19+ ministerial conference (see p. 9). If they get the go-ahead, construction could begin around 2020 and the Gateway could be completed in 2027. But whatever decisions are taken and whoever the partners are, CNES will be part of the lunar adventure.



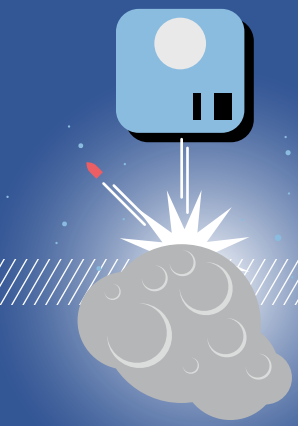
TRAPPING GASES

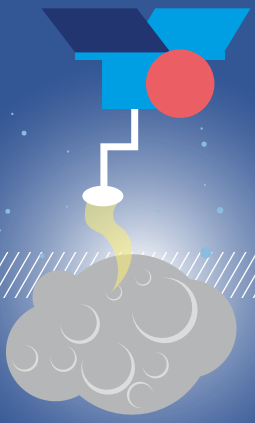
PLANETARY EXPLORATION OFFERS THE CHANCE TO SEARCH FOR THE SMALLEST MARKERS OF ANCIENT LIFE, LIKE CERTAIN GASES TRAPPED INSIDE COLLECTED SAMPLES. The MOMA[1] instruments on the ExoMars and Europa Lander missions will employ gas analysers already used on Rosetta. Substances are separated by vaporizing them and injecting gases into gas-phase chromatography columns. The gases are then forced by piston effect through a complex sequence of valves that need power to function. The LISA research laboratory has designed 10-gram microvalves that save power, weight and space. Working with CNES and research laboratories, Air Liquide Advanced Technologies built a prototype and specification models. Today qualified to operate in science instruments in space, these microvalves are set to find applications in industry and in all sectors using control valves.

1. Mars Organic Molecule Analyser, developed by the LISA inter-university laboratory for the study of atmospheric systems and the LATMOS atmospheres, environments and space observations laboratory.

MOMA-GC – Analytical part of the instrument with its 20 valves.

RETURN





END 2020

DUST FROM **RYUGU**

In October 2018, the Japanese Hayabusa2 probe released three small rovers and the French-German MASCOT lander onto the surface of asteroid Ryugu. This February, the probe successfully collected its first samples: it had just seconds to fire a small impactor and kick up surface material for collection. The goal of the 18-strong science team is to bring back 100 milligrams of material. A second attempt to collect material could be made if conditions are right. Hayabusa2 will then leave the asteroid in December and begin its return to Earth, with arrival planned for end 2020.

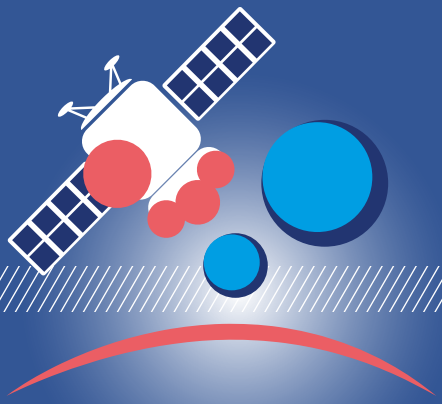
SEPTEMBER 2023

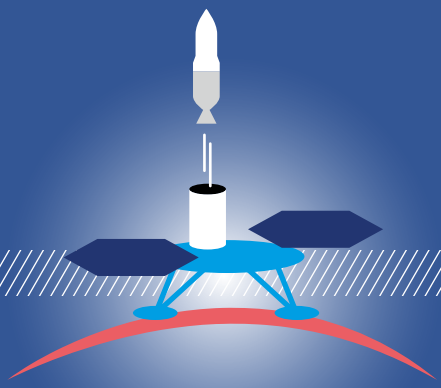
PARTICLES FROM **BENNU**

On 3 December 2018, the U.S. OSIRIS-REx probe approached Bennu, an asteroid under close surveillance because its orbit could cross Earth's towards the end of the 22nd century. But Bennu is also of interest for its hydrated minerals. As a primitive carbonaceous asteroid, it could yield vital clues about the origins of life. The mission's goal is to bring back between 60 grams and 2 kilograms of material, for which the probe will employ an innovative method: a cylinder on the end of a robotic arm will release a burst of nitrogen gas to stir loose rock and soil into a sample collector. Return to Earth is scheduled for September 2023.

TIMELINE

ONCE COLLECTED FROM CELESTIAL BODIES, SAMPLES BEGIN A LONG RETURN JOURNEY TO EARTH FOR ANALYSIS IN THE LABORATORY. SEVERAL MISSIONS ARE SET TO BRING BACK THEIR BOUNTY IN THE YEARS AHEAD.





2029

FRAGMENTS FROM **MARS' MOONS**

Confirming the excellent collaboration between France and Japan, the MMX mission (Martian Moons eXploration) will explore Mars' moons Deimos and above all Phobos, which could harbour fossil materials marking the formation of the solar system. Dust and loose rock from Phobos could also yield new insights into the red planet. France is closely involved in a series of Martian missions—Mars 2020, ExoMars and Mars Sample Return—and will be supplying the mineralogy instrument for MMX. The mission is scheduled to depart in 2024 and plans to return its samples by 2029.

2031

SAMPLES FROM **MARS**

The NASA-ESA Mars Sample Return mission (MSR) plans to set down its Mars 2020 rover (see p. 10) in 2021. It will cache samples previously selected by SuperCam into 31 pen-sized canisters. Another rover will fetch the samples and put them on a small ascent vehicle to be placed in Martian orbit. An orbiter will then capture the samples and return them to Earth, where a capsule will re-enter the atmosphere and land somewhere in Utah, in around 2030. The first phase of the mission is underway, with the Mars 2020 rover in construction since 2017.

ATHENA COUSTENIS

CNRS research director at the Paris Observatory's LESIA space and astrophysics instrumentation research laboratory

"The Moon is a staging point for human exploration of Mars..."

Dr Athena Coustenis must take after one of the 12 Olympians of her native Greece, such is her boundless energy. "*I'd love to go to Titan, where one day lasts 18 Earth days!*" jokes the astrophysicist. **Involved on a daily basis in several space exploration missions, she chairs four major committees working in this area** for the European Science Foundation, ESA, CNES and the Committee on Space Research (COSPAR). In a consultative role, they bring together the best scientific experts to help decide which missions to adopt and fund at national and European level. "*The sudden emergence of the private sector is taking us beyond science, so space agencies need to adapt,*" she says. "*At the CERES space research and exploration committee, we're looking at 230 proposals from the science community so that CNES can announce France's new strategy at the end of the year.*"

Indeed, space exploration is entering an incredible new era. "*Before, habitability stopped at Mars, but we now realize the concept could be extended much further,*" she explains. After the Cassini-Huygens probe and its revelations about Saturn's moon Titan, she's now working on the Jupiter Icy Moons Explorer mission, or JUICE. This ESA spacecraft will enter orbit around Ganymede, while NASA is sending an orbiter to study Jupiter's natural moon Europa. "*Collaboration is vital.* ***It's great we're not duplicating efforts but pursuing complementary missions, which is exactly the kind of balance the committees are keen to ensure.*"**

Against this backdrop, the renewed interest in the Moon is a logical next step—in which Europe has a role to play. "*We'll be back there one day to set up a base, learn more about how Earth formed and, thanks to its quiet radio wave environment, explore the early Universe,*" she concludes. "*The Moon is a staging point for human exploration of Mars and beyond!*"

Dr PHILIPPE ACHILLEAS

Director of the Institute of Space and Telecommunications Law (IDEST)
at Paris-Sud University

"The way forward will be found in international law..."

After graduating in international law, Philippe Achilleas was working on his PhD thesis on satellite television when he was *"swept up"* by space. Supported by CNES, which was keen to see a French centre emerge for training and research in space law, he founded IDEST in 2000. ***"We've trained students from over 68 countries,"*** he says. **The baseline for his work is the UN Outer Space Treaty, ratified in 1967.** Article IV calls for the peaceful use of space, while Article II states that space and celestial bodies shall not be subject to national appropriation. **Recently, however, the United States and Luxembourg have passed national laws allowing private companies to extract resources such as water and rare metals from celestial bodies.** For now, the idea is to simply use these resources to fuel further deep space missions, but other plans are afoot. No other countries are protesting, since we all have common interests and need private sector support. *"We're moving toward exploitation of resources, that's a fact. But it's unfortunate that some countries are adopting unilateral policies, whereas the way forward will be found in international law."* Indeed, the whole point of the Outer Space Treaty, signed during the Cold War, was to avoid making the same mistakes in space that we've made on Earth, especially another profit-driven arms race. *"We need to recover this ideal and find a balance between profit, environmental protection and quality of life for all,"* says Achilleas.

Today, the only institution with the legitimacy to develop space law is the UN, which already has several of Dr Achilleas's students in its ranks. A veteran traveller, he takes his students to the ends of the world to *"expose them to other cultures, break them out of their comfort zones and help them realize the importance and vastness of space"*.

MICHEL VISO

Head of exobiology and planetary protection at CNES

"If there's any doubt about the integrity of a sample, we'll simply redirect it into the Sun..."

"None of the interesting stuff happens with well-behaved kids!" Meet Michel Viso, who confesses he was *"unruly and rebellious"* as a youngster. He first worked as a vet, then later became a research engineer before being selected as an astronaut for the Rhesus mission. His role was to prepare for taking monkeys into orbit. As it happened, neither man nor monkeys got to fly, but **Michel Viso found his vocation: exobiology. He now searches for extraterrestrial lifeforms and seeks to understand the role of interstellar chemistry in the emergence of life on Earth.** Rule number 1: look for liquid water, which is everywhere in the solar system. *"On Jupiter's moon Europa, the thick water-ice crust conceals a deep ocean,"* he says. *"Internal planetary dynamics cause undersea volcanoes, possibly forming a whole range of chemical compounds and reactions eventually leading to metabolism. Further out, Saturn's moon Enceladus shoots out jets of water vapour and ice crystals containing organic matter, making it a priority target for exobiology."* **With its remnants of ancient rivers, lakes and seas, Mars is a focus of intense interest for scientists and has been extensively studied. Bringing back samples is the next vital step.** To protect Earth from the risk of a harmful Martian microorganism spreading, Europe and the United States will implement 'planetary protection' measures, including a hermetically sealed sample return system. *"If there's any doubt about the integrity of a sample container, we'll simply redirect it into the Sun,"* he concludes. *"To protect their original characteristics as well as the terrestrial biosphere, samples are stored and studied at laboratories with high biological security.* ***We're curious but also conscientious, so until we know exactly what we're dealing with, we'll be taking all the necessary precautions!"***

Jacques Arnould,
science historian
and theologian,
CNES ethics officer.

ETHICS CORNER

JACQUES **ARNOULD**

THE MOON **TOLD ME...**

The Ancients saw the Moon as a kind of border post between Earth—our "little dungeon", as author Blaise Pascal put it—and the cosmos, with its unbearable and inaccessible perfection. Then 50 years ago, humans put boots there. An act of total sacrilege, or a feat of no particular consequence?

What a strange relationship we have with our nocturnal neighbour! For millennia, the Moon has fascinated us, drawn our gaze after sundown and scared us with its ghostly pale face. But now we've "been there, done that", with Armstrong and Aldrin's footprints on the surface as proof, it's like we've diverted our gaze. The next giant leap prophesied by the "first man" hasn't taken us beyond the Sea of Tranquillity, as if our curiosity and interests have led us down different paths. Were we let down by what Aldrin described as the Moon's "*magnificent desolation*"? Isn't it more likely we were simply wrong about what we were reaching for and expecting to find? Maybe French pop-rock band Indochine were right: the Moon isn't used to dealing with cases like ours.

"I asked the Moon
Whether you [the Sun] wanted
me anymore.
She told me: I'm not used
To dealing with cases like yours."

(Indochine, *J'ai demandé à la Lune,* 2002 – translated)

LUNAR INDIFFERENCE

Just months after Apollo 11, French biochemist Jacques Monod had already drawn lessons from the Moon and Universe's apparent indifference. It's up to us humans, he said, to "*choose between the kingdom and the darkness*". In other words, we can no longer offload our responsibilities onto the shoulders of others, to consciences other than our own. By accomplishing one of humanity's most ancient dreams, pushing far beyond the boundaries of our knowledge and technical wherewithal, we've gained a whole new perspective on our planet. And having realized it's in danger, we feel more responsible for its future—our future! Over half a century of space endeavours have ultimately brought us a kind of humanist wisdom: however far we venture—to the Moon and maybe one day beyond it, since we're born explorers—our human odyssey will always have its roots in our human and terrestrial condition. No doubt humanity will forever seek to go where "*no one has gone before*", but without ever losing its grounding or reason.

Further reading
Jacques Arnould is the author of *La Lune m'a dit. Cinquante ans après le premier homme sur la Lune*, Paris, published by Cerf, 2019, 175 pages.

EXHIBITIONS

‘CIEL SUR CORDES’ EVENT

The village of Cordes-sur-Ciel in southwest France is closer to space than most (ciel means ‘sky’ or ‘heavens’, reflecting its location on a rocky peak). Organized in partnership with the local authorities, ‘Ciel sur Cordes’ in mid-July is a great opportunity for CNES to engage with the public. The programme includes an exhibition about the lunar adventure, from Apollo 11 to today and beyond. On 19 July, there’ll be a series of talks from 8:30 to 10:30 pm. And throughout the festivities, younger visitors will be treated to fun educational workshops.

PARIS

After our 2007 exhibition to mark 50 years in space, CNES is back this autumn with a set of 80 photographs mounted on the railings of the Luxembourg Garden in Paris to celebrate 50 years since humans first set foot on the Moon. A fantastic voyage to the heart of the solar system, from low Earth orbit to the most mysterious celestial bodies.
22 September 2019 to 15 January 2020.

PARIS AIR SHOW

At every Paris Air Show, CNES proudly presents French space activities to the public, combining high-quality content with an original and attractive take. This year, our resolutely retrofuturistic pavilion will showcase the latest innovations in launchers, satellites and applications. CNES experts will be in the meeting area each day to chat with the public on a whole host of topics. There’ll also be giant LED screens, a holographic installation and all-new scale models of space hardware, plus a mystery room where you can have your photo taken in weightlessness!

EYES ON THE SKY

MERCURY IN TRANSIT

If you missed it on 7 May 2003 and 9 May 2016, here’s your next chance: Mercury will pass directly (transit) between the Earth and Sun on 11 November 2019. A near-perfect alignment is a rare occurrence: the next time the Sun, Mercury and Earth all line up will be in November 2032, then in May 2049. Mercury will appear as a tiny pinhead on the Sun’s disk. The phenomenon will be visible in Europe, Africa and North and South America. And of course, never look at the Sun without proper eye protection!

BOOKS

The spirit of space

From the most extraordinary feats to everyday applications, learn more about the epic era of space exploration in a book based on CNES President Jean-Yves Le Gall’s daily slot on Europe 1 radio over the summer of 2018.

L’espace en Tête – Published by Michel Lafon

EUCLID

INSPIRATIONS


Artist Mathilde Jallot.

The Euclid[1] symposium last November probed the dark side of the Universe. Art student Mathilde Jallot presented a remarkable interpretation of the effervescent aspect of space, convulsive movements and the atmosphere's brightness. Designed as a performance in the Laque workshop, her Theatre of Dark Matter took the form of three beaten panels of aesthetic and infinitely duplicated curves. Here, dark energy took on beautiful warm shades across the entire spectrum. Produced under a partnership between CNES and the Ensaama[2] art school, the installation was on display at the school's biennial Révélation show at the Grand Palais in Paris, 23 to 26 May 2019. Artist in residence at the LAM astrophysics laboratory in Marseille, Caroline Corbasson also offered a take on Euclid's universe. Encompassing technical and human aspects, she drew on a rich array of sources–from collected materials, data and documents to video footage, photographs, audio clips and ways of capturing the meticulousness of the people involved–to produce a short film called *Le Voyage avant le Voyage*. Critically acclaimed, it will be shown along with a special installation at the FRAC Provence-Alpes-Côte d'Azur gallery in Marseille, 28 June to 22 September 2019.

1. Space telescope, scheduled to launch in 2022.
2. École Nationale Supérieure des Arts Appliqués et des Métiers d'Art.

DIARY

APRIL TO NOVEMBER
2019: Moon year
Cité de l'espace space theme park, Toulouse

17–23 JUNE
53rd Paris Air Show
Paris-Le Bourget Airport

15–19 JULY
'Le Ciel sur Cordes' event
Cordes-sur-Ciel, France

8–10 OCTOBER
CNES Science Survey Seminar
Le Havre, France

NOVEMBER
Space19+
Seville, Spain

WEBSITE

Comet Chury as you've never seen it before

Don your 3D headset for an incredible voyage. CNES's new rosetta-3dcomet.cnes.fr website features 1,500 stereoscopic photographs or 'anaglyphs' of the surface of comet 67P/Churyumov–Gerasimenko, visited by the Rosetta spacecraft from 2014 to 2016. Cliffs, plains, sinkholes and more—discover its richly varied landscape, shaped by 4.5 billion years of roaming the solar system.

PROCESS
THE POWER OF RECYCLING

Is it right that we use drinking water to flush our toilets? Private company Firmus doesn't think so and has conceived an alternative. Designed for spaceflights, its FGWRS grey water recycling process could be used in our homes.

More than half of the water consumed in every home—for showers, washing machines, swimming pools and so on—is only slightly polluted after use. The FGWRS[1] system gives this so-called 'grey water' a second lease of life, employing a sequence of membrane-filter stages between doubled grey-water and black-water collection systems and drinking water and recycled water supply systems. Developed for CNES and ESA, the system is in use since 2005 at the French-Italian Concordia research station where 15 scientists—equivalent to the crew of a long-duration spaceflight—spend the polar winter cut off from the outside world.

MEETING TOMORROW'S CHALLENGES

Firmus offers the capability to scale its system to varying degrees of use and is now looking to take it into people's homes, initially for multi-residential housing. With this aim in mind, the company has brought on board the complementary expertise of Sherpa Engineering (modelling), MRI (upstream and downstream water treatment) and Dalkia Smart Building (energy efficiency). "*Investing today in grey water recycling technologies will allow us in the future to combat water stress and the effects of climate change to conserve drinking water resources*," says Firmus CEO Pierre Magnes. "*These recycling technologies aren't authorized in France but we've tested our process for a hotel in Monaco. Combined with the very good results from Concordia, we'll be able to demonstrate that re-using grey water poses no risk.*"

1. Full/Firmus Grey Water Recycling System