New Scientist

WEEKLY 17 September 2022

WHY HUMANS ARE THE ONLY TALKING APES

THE WONDERFUL BENEFITS OF OUTDOOR SWIMMING

HOW PROBIOTICS COULD BE USED TO TREAT RHEUMATOID ARTHRITIS

SPECIAL ISSUE

RETURN TO THE MOON

The new push to create a permanent lunar outpost, and what it means for humanity

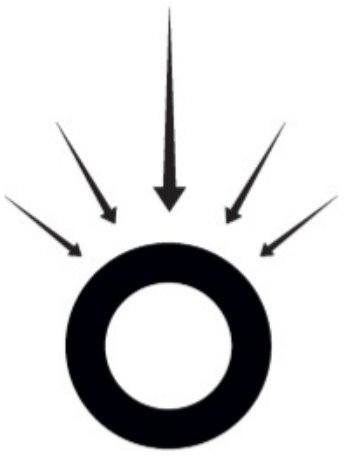
No3404 £6.95 CAN$9.99

RETURN TO THE MOON

PEOPLE ARE ABOUT TO GO BACK TO THE MOON FOR THE FIRST TIME IN 50 YEARS. It is no longer just a race to get there, but the start of a whole new era of lunar exploration and exploitation. Within a few years, we may see people taking steps on the moon again, mining precious resources and setting up long-term bases on Earth's constant companion. Over the next nine pages, we explore the reasons we are so keen to go back, the new technology that will take us there and what lunar settlement could mean for humanity

A DIFFERENT KIND OF SPACE RACE

This next phase of lunar exploration is a departure from what has come before in terms of ambition, the rationale for going – and the sheer amount of missions being planned



NASA

"As I take man's last step from the surface, back home for some time to come – but we believe not too long into the future – I'd like to just say what I believe history will record: that America's challenge of today has forged man's destiny of tomorrow." These were some of the last words spoken on the moon as NASA astronaut Eugene (Gene) Cernan climbed the ladder back into his lunar module in 1972.

Contrary to Cernan's hopes, no one has since set foot on the lonely, cratered world that orbits our own. But that is about to change, because the US is planning to send people back to the moon by 2025 and set up a permanent base there. Add to that the plans of China and other nations, not to mention the deluge of robotic missions, and it is clear that we are entering a new era of lunar exploration. The question is, after so many years, why now?

The decision to end the Apollo programme was made well before Cernan left his footprints on the moon. "Apollo didn't end because it was too expensive or because it was unsustainable – the sunk costs were already sunk," says Mary Lynne Dittmar, an influential figure in space policy at the firm Axiom Space. The adventures ended because Apollo was set up to win a politically motivated race, in which the US wanted to beat the Soviet Union to the moon. With that goal achieved, the moon was no longer a priority.

The forces shaping our return to the moon today are dramatically different. In the 1970s, every mission was an epic, do-or-die affair led by the US or the Soviet Union at incredible expense. Each project was defined in advance and then the machinery of the state would strain every sinew to make it happen. Today, the cost of going to space is lower, so many other nations and private companies can afford to get involved (see "Runners and riders", page 40). Reduced costs also mean they can try missions out and see what works. In the past few years, China has ramped up activity, sending a probe to the far side of the moon, among other impressive feats. It has committed to a joint China-Russia robotic research station, and it says crewed missions are possible by 2030, though it hasn't released firm plans for now.

One thing that hasn't changed is that the US is still at the forefront of space exploration. NASA's Artemis programme is taking centre stage. Its first mission, Artemis I, will be an uncrewed journey far beyond the moon using the purpose-built Space Launch System (SLS), the most powerful rocket ever built. It was due to launch earlier this month, but two attempts have been called off due to problems with fuelling. (As *New Scientist* went to press, the earliest planned launch date was 19 September.)

Still, if all goes well, the project is set to reach a momentous milestone in 2025 when another two people will follow in Cernan's footsteps, including the first woman on the moon. "One of my deepest hopes, and obviously his, was that Gene Cernan would live to see us back there," says Dittmar. Cernan passed away in 2017. "He almost made it."

It would be easy to be sceptical about NASA's ability to pull off these plans so quickly. After all, the agency has been here before. In 2005, it began a programme called Constellation, with goals that included sending humans to the moon by no later than 2020 and eventually on to Mars. It was binned in 2010. But there is a consensus in the space science community that Artemis is different. "Something that has doomed some other projects in the past has been that they've been US-only, but Artemis has momentum," says Laura Forczyk at space consulting firm Astralytical. "I don't think it would have gotten that momentum if it wasn't for international partnerships."

Artemis is one giant collaboration. Various components of the missions are being contributed by the European Space Agency, the Canadian Space Agency, the Japan Aerospace Exploration Agency and others. "That's very different from Apollo," says engineer Erika Alvarez, who is part of NASA's Artemis team. The design and build of critical pieces of technology, such as moon landers and the planned moon-orbiting space station, will be contracted out to private companies. While the first flights will be powered by the government-owned SLS rocket, NASA's plan is that some subsequent trips carrying cargo to the moon will be aboard Starship, a similarly huge rocket designed and built by Elon Musk's company SpaceX. (It is vastly cheaper to run than SLS and some observers think it could and should end up replacing SLS entirely.)

You might ask why it has taken so long to get to this point. One reason is that humanity's great space project for the past 20 years has been the International Space Station, a collaboration between the space agencies of the US, Russia, Japan, Canada and Europe. This taught us how to have people in space for extended periods. But equally, the time spent ignoring the moon has meant that many of ›

RUNNERS AND RIDERS

The key players lining up moon missions and what they are aiming to do

US
The US has the most ambitious goals, with NASA's Artemis programme aiming to return people to the moon by 2025. The agency also plans a sequence of increasingly complex missions throughout the 2020s, with rovers, surface bases, power grids and an orbiting space station all featuring.

RUSSIA
Among Russian plans for the coming years are a rover project and a mission to return rock samples to Earth. The country's space agency, Roscosmos, has said the first mission, named Luna 25, will launch in 2023 and do research on lunar ice and dust.

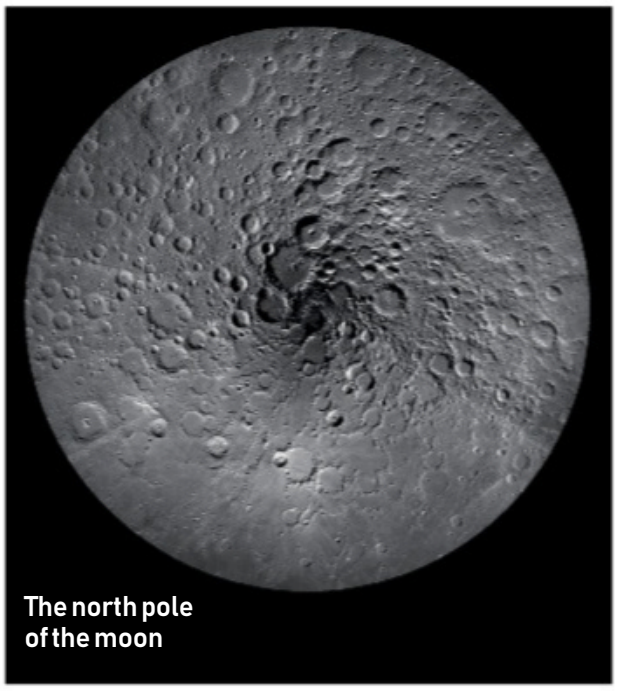
CHINA
Recently, China has carried out a series of impressive lunar missions, including sending the first probe to the far side of the moon (see timeline below). It also says it wants to put people on the moon, perhaps by 2030. And in 2021, China and Russia agreed to build the International Lunar Research Station, a facility on the moon staffed by robots. The aim is for it to be operational by 2036, and humans could go there eventually.

INDIA
India has sent several robotic missions to the moon, but has no plans for crewed missions as yet.

JAPAN
Japan's Lunar Exploration Program sent a rover to the moon in 2007, and several other robotic missions are in the works. The long-term goal is to have Japanese astronauts participate in a future international moon base.

EUROPE
Both through the European Space Agency and its many private space companies, Europe is working with the US on Artemis. Canada's space agency is doing likewise.

PRIVATE FIRMS
Companies will also play a crucial role in the Artemis missions. SpaceX is a linchpin in the plans, as its Starship rocket should carry equipment to the surface. Amazon founder Jeff Bezos's company Blue Origin is developing a vehicle called Blue Moon to land cargo or people. Many other companies plan to go to the moon too.



NASA/GSFC/ARIZONA STATE UNIVERSITY

The north pole of the moon

the engineers who worked on the Apollo missions have retired or died, and some of that expertise has to be rebuilt through extensive testing of the new hardware and processes. "There are some things that were learned the hard way that you don't want to learn again the same way," says Dittmar.

It isn't just the rocket that has to be tested – a massive amount of new technology will be required too (see "Home, home on the moon", right). "We're doing everything from food technology, to modifying our toilets so that they're built to last, to the environmental control systems," says Alvarez.

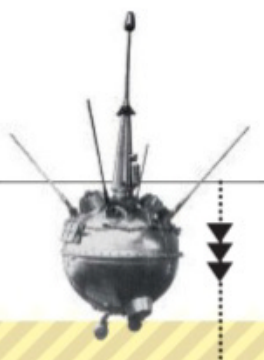
To say it is a tricky task would be an understatement, which might make some people wonder: why bother going back at all? There is the chance to cash in on lunar

70 years on the moon

The space age began as a race between two state powers. These days, many nations and private companies are involved and the pace of exploration has ramped up. These are some of the most important missions, past, present and future

1959

Luna 2
Soviet Union
After several failed attempts, this probe was the first object to reach the surface of the moon, crashing into it



1964

Ranger 7
US
The first US mission to land on the moon. The probe sent back close-up images of the surface

1966

Surveyor 1
US
An uncrewed lander that gathered data about the lunar surface needed for the Apollo missions

1968

Zond 5
Soviet Union
A probe carrying two live tortoises, flies and plants. It circled the moon twice before returning its payload – still alive – back to Earth

JULY 1969

Apollo 11
US
Neil Armstrong becomes the first person to walk on the moon

resources (see "Cosmic capitalism", page 46). But if you ask NASA, it says its principle rationale is that returning to the moon is a vital precursor for a trip to Mars, where it wants to send a cadre of astronauts by the late 2030s.

The first people to visit Mars will face a nine-month trip to get there and they will have to stay for months before making the return journey. With that in mind, learning to set up an independent settlement on the moon will be essential before we can seriously contemplate a sojourn on the Red Planet. "The moon is a perfect platform to test all these technologies, the equipment, the maintenance and repairs – because from the moon, we can get back home," says Alvarez.

Some argue that sending people off world isn't worth the trouble. If the point is to explore and do science, send robots: they are much hardier and more adaptable than humans. They may not be able to interpret the landscape around them or do science quickly, but they can send pictures and data home.

However, as Dittmar says, perhaps the renewed thrust to send people back to moon is just human nature: our species loves to explore. "Why in the world would you get into something called a boat and go over water when you can't swim through it?," she says. "Why would you go through a mountain pass or over an ice bridge? There's something in our make-up; it makes sense to us biologically. All that's happened now is that our technology has evolved the same way it did to take us out of Africa and across oceans, and now it's evolved to take us off the planet. I don't see it as any different from the rest of human history." **Leah Crane**

HOME, HOME ON THE MOON

NASA's plans to return people to the moon and build a long-term base there will require a plethora of new technology.

THE most powerful rocket ever built sits on a launchpad in Florida. Over an intercom, crowds of onlookers listen to the countdown – "4, 3, 2..." – and then the bottom of the rocket begins to rumble. The vibrations first travel through the soles of the watchers' feet and then hit their bodies like an ocean wave. Jets of steam and fire ricochet off the concrete, and suddenly the rocket is blasting skyward. The astronauts within watch the countryside shrink below them as they begin their journey to the moon.

This scene could be from six decades ago – or it could be from just a few years in the future. The launches of the Artemis missions that the US hopes will soon return people to the moon will look very similar to the Apollo launches of the 1960s. But that is where the similarities end. "Apollo was awesome, but a lot of it was to just prove that we could do it," says NASA's Steve Creech. "I'm not saying it wasn't important, but this time we want to do it in a way that's sustainable and that leads to next steps." In other words, this isn't just about going back to the moon. It is the first glimmerings of what many hope will be a sustained campaign of human space exploration.

NASA's plans could hardly be bigger. They feature astronauts on moon buggies and long-term bases with power grids and mining operations. And with the first steps already being taken, this is set to happen by roughly the end of the decade. All of which seems wildly ambitious – and begs the question, what fresh technologies will such adventurous feats require?

To begin with, the Artemis missions will largely be repeating feats managed during the space race. Artemis I will pass 100 kilometres above the moon's surface and orbit for several days, allowing the Orion craft – the capsule intended to carry astronauts – to be tested in space. Artemis II, planned for 2024, will involve a crewed fly-by of the moon. Then, in 2025, the third mission in the programme is set to see people land and walk on the moon again, including the first woman to do so. "I think that seeing women, people of colour, the next generation, walking on the moon can ›

NOVEMBER 1969

Apollo 12
US
Astronauts Charles Conrad and Alan Bean land on the moon

1970

Luna 17
Soviet Union
The first robotic rover on the moon

FEBRUARY 1971

Apollo 14
US
A crewed mission to a more mountainous area. The astronauts collected almost 43 kilograms of rock

JULY 1971

Apollo 15
US
The first mission to use a lunar rover vehicle to explore the surface

APRIL 1972

Apollo 16
US
Astronauts spent almost three days on the surface doing science and exploring

DECEMBER 1972

Apollo 17
US
Gene Cernan walks on the surface – the last person to do so

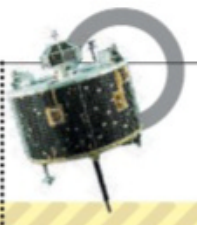
AUGUST 1976

Luna 24
Soviet Union
A lander that returned samples of moon rocks to Earth

CCCP

1980s

No moon missions were launched in this decade



1990

Hiten
Japan
Japan's first space probe orbited the Earth and moon for three years before being crashed into the lunar surface

What will life be like on the moon?

The moon's south pole, 2037. NASA and its contractors have built a habitation staffed by a rotating crew of astronauts, much like the International Space Station was until it was shuttered in the 2020s. There is a power grid of solar panels and several rovers parked outside. When the crew look out of the windows, they can just make out the water ice mining station in permanent shadow at the bottom of the nearby crater.

Life here is no cakewalk. Because of the moon's slow rate of rotation, astronauts will face periods of two weeks of complete darkness and temperatures dipping below -173°C (279°F), followed by two weeks of around-the-clock sunshine and temperatures above 100°C (212°F). It means sleep can be a challenge and going outside to make repairs and do science is dangerous.

The crew handle this by planning their outdoor adventures to coincide with the lunar dawn, when temperatures are more reasonable. Their suits are also specially designed to reflect sunlight and resist heat, plus they have cooling systems inside. One of the best things, they all agree, is that the suits are tailor-made, rather than coming in standard sizes like in the Apollo era.

The time delay for communications to Earth is just over a second, so they can place a video call home whenever they like and see their families' faces. Occasionally, rich space tourists pay them a visit and the astronauts have to smile for a selfie.

"THE PLAN IS TO LAND NEAR THE MOON'S SOUTH POLE, WHERE THERE IS ABUNDANT WATER ICE"

do a lot of the things that it did in the 1960s, can inspire people to go into science and drive the technical state of the art," says Lori Garver, a former deputy administrator of NASA.

From here, the plan is for things to change radically. For starters, NASA aims to put a space station known as Gateway in lunar orbit. The idea is that this will allow a reusable lander to shuttle between orbit and the surface, making trips to the moon's surface cheaper and easier. The agency has already contracted the aerospace company Northrop Grumman to build two founding components of Gateway: a place for astronauts to live, known as the Habitation and Logistics Outpost, and a segment to provide power and propulsion. Artemis IV, which may launch in the second half of the 2020s, will carry these components into lunar orbit. Artemis V, the last mission NASA officially has planned (with no set date as yet), will be the first to see humans drive a rover on the moon. It will also deliver a new refuelling module to Gateway, built by the European Space Agency and partner companies.

Aside from all that new infrastructure, the science carried out on these missions will be different too. The plan is for the Artemis landings to be near the moon's south pole, which is of particular interest because of its abundant water ice (see "Going off piste", right). Astronauts staying on the moon will need a local supply of drinking water, as it is too heavy to transport from Earth. What's more, water can be split into oxygen and hydrogen, the first being vital for breathing and the second for fuel to power the rockets that could potentially launch from our lunar staging post to Mars and elsewhere.

The moon's water ice is far colder than the ice cubes in your freezer and it is distributed through the lunar rock. Understanding how the ice behaves and how we can best make use of it is going to be crucial, and it will require a host of new technologies. Investigations are due to begin later this year, when a robotic lander called Nova-C – a partnership between NASA and US aerospace firm Intuitive Machines – will try drilling almost a metre into the lunar "soil" to extract and analyse the ice.

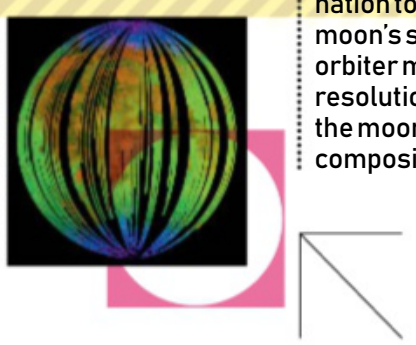
The next step will come when humans return to the moon as part of Artemis III. A key element of their mission will be to retrieve ice samples and bring them back to Earth, where they can be more thoroughly analysed. That might sound simple – we have freezers, after

1994
Clementine
US
A probe that tested how communications equipment and sensors responded to long-term exposure to deep space. It also observed an asteroid called 1620 Geographos

2003
SMART-1
Europe
This probe orbited the moon for three years. Among other things, it discovered deposits of calcium and high points on the moon that are in constant sunlight

2007
SELENE
Japan
Japan's second lunar probe, which, among other things, performed sensitive measurements of the moon's gravitational field

2007
Chang'e 1
China
A lunar orbiter that conducted the first microwave imaging of the moon



2008
Chandrayaan-1
India
This mission included an orbiter and impactor, making India the fifth nation to reach the moon's surface. The orbiter made high-resolution maps of the moon's mineral composition

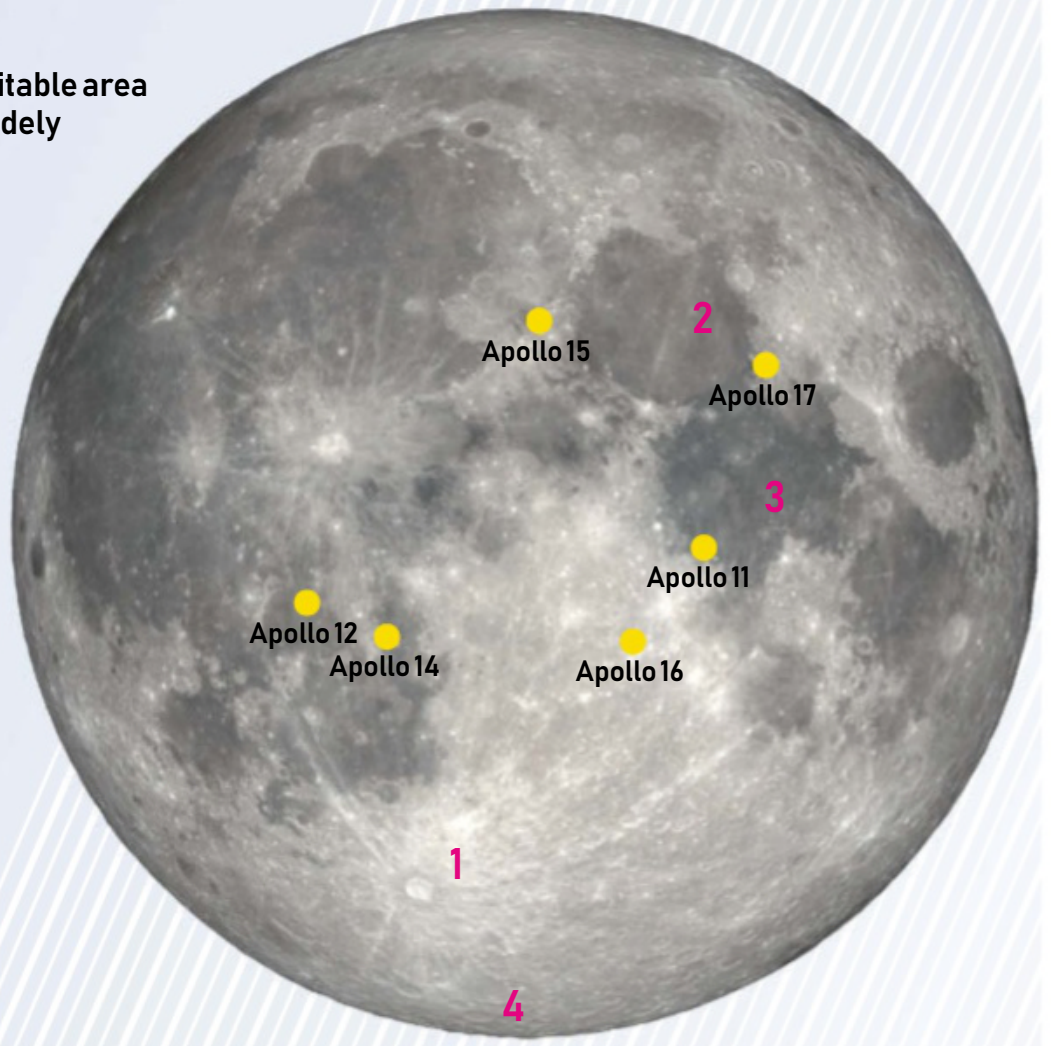
2009
Lunar Reconnaissance Orbiter
US
Created high-resolution maps of the surface to aid future missions, for instance by assessing landing sites

2010
Chang'e 2
China
A similar mission to Chang'e 1, laying the groundwork for future missions

CCP

Going off piste

Apollo-era missions stuck mostly to a small, relatively hospitable area of the moon's surface. Now, we are set to explore far more widely



1. VIPER rover landing site
NASA has selected Nobile crater to be the landing site for its robotic VIPER rover in 2024. This will hunt for water ice and other resources. Nobile is in almost permanent shadow, making it one of the coldest places in the solar system. The crewed Artemis missions will probably land near here too.

2. Beresheet crash site
In 2019, this craft from private firm SpaceIL crash-landed on the moon while carrying a cargo of microscopic animals called tardigrades. Notoriously hardy, there was speculation that they could have survived – though subsequent experiments suggest the impact would have smooshed them.

3. Titanium deposits
In 2011, NASA's Lunar Reconnaissance Orbiter produced a map of the moon that revealed the elements on its surface. Among other useful deposits, it found that rocks in the Sea of Tranquillity contain large amounts of titanium, with some areas holding 10 times more than typical Earth rocks.

4. Water ice
Successive studies have shown that shadowed, cold areas of the lunar surface – an area totalling about 40,000 square kilometres – should contain water ice. Astronauts could harvest this to produce oxygen to breathe and hydrogen fuel.

Apollo landing sites

all. But we will need to invent a special kind of freezer. "The samples will have to be kept extremely cold at all times, so those freezers need to be able to be transported between all of our vehicles and stay cold," says Erika Alvarez, part of NASA's Artemis team.

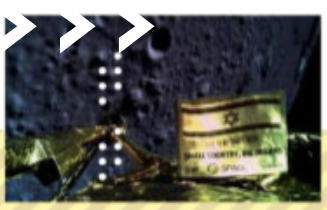
Eventually, the plan is to construct a surface habitat called Artemis Base Camp so that astronauts can remain on the moon's surface for days or perhaps even weeks, collecting samples and data. And though it might seem like a small step from spending a few hours on the surface to staying for a few days, it requires a huge leap in technology.

Before they can even begin to build a base, the explorers will need a power grid. Solar power will be possible, but the base will have to stay operational through periods of darkness lasting about two weeks. Temperatures during these periods can dip below -173°C (279°F). "You've got to have a grid that can sustain itself in that environment, that can generate enough power to do everything from life support to literally keeping the lights on to operational support," says Mary Lynne Dittmar at private firm Axiom Space. NASA is working with the US departments of energy and defence to develop a small nuclear power plant for the base.

Once power is established, there is the problem of actually constructing the base. ›

2013
Chang'e 3
China
A robotic lander accompanied by a rover called Yutu

JANUARY 2019
Chang'e 4
China
The first-ever craft to land on the side of the moon that is always facing away from Earth. It included a "moon garden" in which cotton seeds briefly sprouted

APRIL 2019


Beresheet
Private
This craft from firm SpaceIL crash-landed on the moon. It was carrying notoriously hardy creatures called tardigrades. Experiments have since suggested that they would probably have been mushed on impact

2020
Chang'e 5
China
A lander that collected samples of moon rock before returning them to Earth. A little water was found in the rock. The first sample-return mission to the moon since the Apollo era

AUGUST 2022
Danuri
South Korea
A mission that plans to image the moon using polarised light

AUGUST 2022
CAPSTONE
US
This recently launched lunar orbiter will test the stability of the planned orbit for the Gateway space station around the moon

US

SEPTEMBER 2022
Artemis I
US
First test flight around the moon in this programme

When it comes to space flight, mass is everything – it isn't feasible to send all the materials to build an entire base camp, along with tools, supplies and astronauts, to the moon. Instead, several teams of researchers are evaluating how we might make building materials from the resources that will be readily available on the moon. This might mean mining stone, making bricks from lunar dust or even 3D printing with materials made from dust.

The trouble is that handling moon dust is tricky in the extreme. Because there is no wind or rain to smooth the particles, they are spiky and electrostatically charged, meaning they stick to everything, including spacesuits and tools. We know from the Apollo missions that it is tough to keep moon dust out of airlocks – and once it is inside, it can be breathed in, causing "space hay fever". NASA is already working on dust mitigation strategies, from nanocoatings for equipment to special filtration systems for habitations. All of which is a reminder that everyday life for astronauts on the moon will be far from straightforward (see "What will life be like on the moon?", page 42).

So how hard will it be to build a home on the moon? Very, is the short answer. As well as designing all this new technology, we will have to make sure it can withstand radiation from space. With no magnetic field to protect it, the moon is constantly exposed. One consolation, perhaps, is that at least the people who go the establish a base on the moon will have the option of coming home at speed if they need to. After another short countdown, they can fire their thrusters and be back within the embrace of Earth's atmosphere in three short days. **LC**

GUNS ON THE MOON

There are already signs that the moon is becoming a strategic military priority. Do we want soldiers anywhere near it?

CROUCHED in an area of permanent shadow, the soldier looks out over a landscape of craters and dust in a thousand shades of grey. A few kilometres away, the enemy's transportation buggy is parked in what they must have thought was a discrete location. But as they should have learned in training, tracking enemies is easier on the moon because tyre marks aren't eroded by the elements. Now all it will take is a squeeze of the trigger.

For now, scenes like this are, of course, distant science fiction. But it is fair to say military organisations are keeping an increasingly watchful eye on the moon. The US, Russia and China – competing powers on Earth – have ambitions to send missions back to the moon in the next decade or so. They will all be heading for roughly the same place: the moon's south polar region, with its precious resources, such as water ice. Even before that, these nations have been sending up a steady stream of satellites.

With this renewed push for the moon, and the lucrative returns that might result, military interest is inevitably following. "The United States is certainly aware the moon could have tremendous long-term economic potential," says Peter Garretson, a defence expert at the American Foreign Policy Council, a US think tank. "The military doesn't want an outpost to be threatened due to the lack of a sheriff." Yet even in these tentative early stages, there are concerns that military activity could snowball. If we are to return to the moon, how much of a role, if any, are we comfortable with the armed forces playing?

US military interest in lunar space dates back to the dawn of the space age. In 1959, the US Army proposed a crewed military outpost on the moon called Project Horizon. Notions of such bases, as well as nuclear testing on the moon, had supporters during the cold war too.

Those proposals never gained traction, but recently there has been more concrete interest and action. The US and Chinese militaries have spoken about conducting surveillance beyond Earth orbit for years, says space policy expert Bleddyn Bowen at the University of Leicester, UK. This would include things like using satellites to track debris from rockets in order to prevent collisions between spacecraft in lunar orbit. "If the moon is going to be a busier

2022

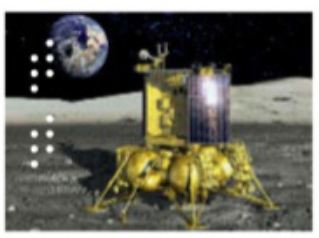
MAPP rover
Private
The company Lunar Outpost plans to collect lunar dust and transfer ownership of it to NASA, in the first-ever sale of space resources

2022

Asagumo
Private
UK-based company Spacebit plans to launch a small, four-legged robot to explore tunnels left by ancient lava flows

2022

Luna 25
Russia
A robotic lander designed to explore the moon's natural resources. Part of the Luna-Glob programme, which aims to build a robotic base on the moon



2023

Garatéa-L
Private
This probe from Brazilian company Airvantis is intended to measure the effects of cosmic rays on bacterial cells and human tissue samples, and image the far side of the moon

2023

Luna Zebro
The Netherlands
Lander to make measurements at south pole

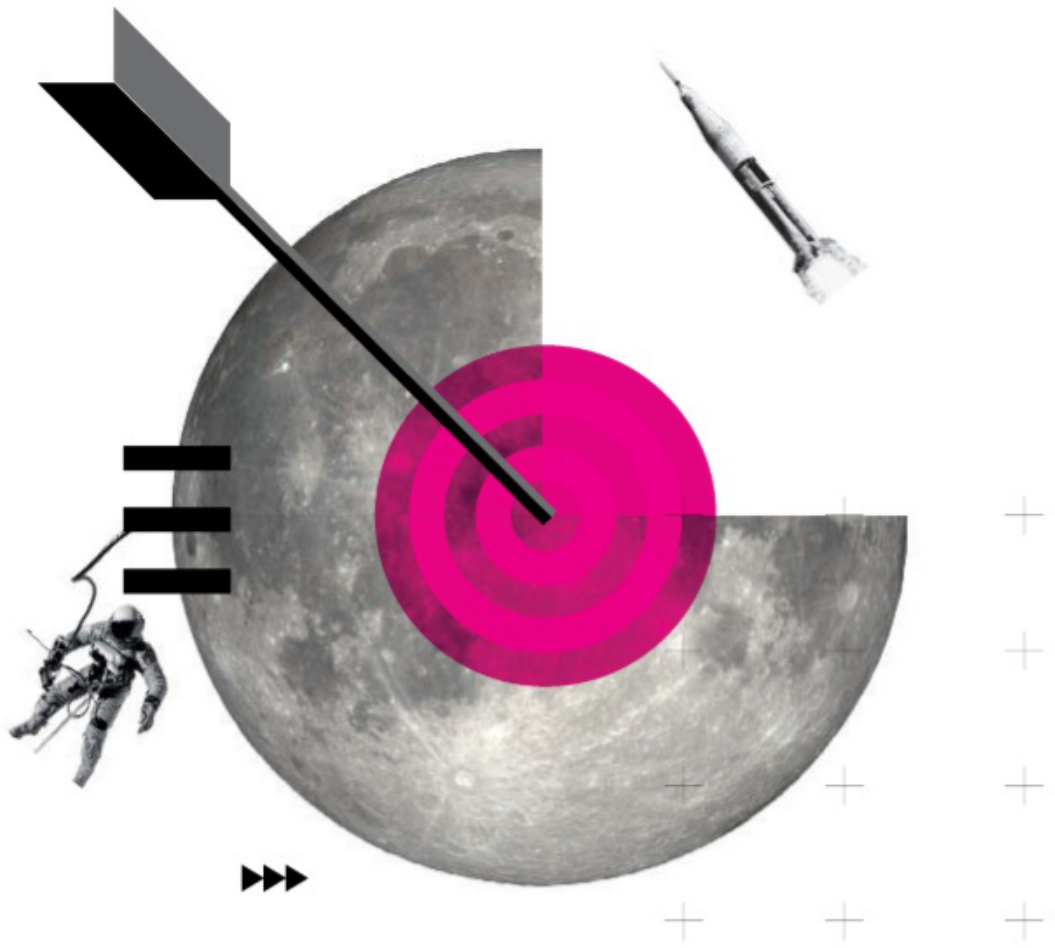
ESA

2024

Beresheet 2
Private
A planned follow-up to the 2019 mission from SpaceIL, with as-yet unclear objectives

2024

VIPER
US
A NASA rover aiming to visit the south pole and study the composition of its water ice in detail



NASA / RYAN WILLS

place, you're going to need more infrastructure to support it," he says.

Evidence for this came in March, when a discarded rocket booster, believed to be of Chinese origin, hit the moon, having been untracked for years following its launch in 2014. "Eventually there will be astronauts on the moon," says Vishnu Reddy, a space tracking expert at the University of Arizona. "The chance is very small of them getting hit by something. But we've clearly seen that it is a possibility." Part of the military's role in relation to the moon could be preventing such accidental impacts.

The US Space Force, the sixth branch of the country's military that was founded in 2019, is now taking action on this. In March, it announced it was developing the Cislunar Highway Patrol System (CHPS) satellite in collaboration with the Air Force Research Laboratory. The plan is for this craft to test technologies to track objects up to and beyond the orbit of the moon for the first time. Prototype proposals have been submitted, with a contract due to be awarded to a manufacturing company soon.

Experts agree that tracking of this sort will be useful. But it is "not clear why this has to be the military and not a civilian programme", says astronomer Aaron Boley at the University of British Columbia, Canada.

Having the US military involved in our future on the moon could lead to a scenario where the forces of other countries, such as China, feel the need to escalate their activity. There was an incident earlier this year in which US and Chinese satellites in a geostationary orbit about 36,000 kilometres above Earth came into close contact and manoeuvred to get a better look at each other.

"You've got the US and China each casting suspicions about what the other might do," says Brian Weeden at the Secure World Foundation, a US think tank that promotes the peaceful use of space. "That is going to send exactly the wrong signal."

Only the US appears to have made public its lunar military ambitions so far, though. "No one else has expressed a military interest in the moon," says Jonathan McDowell, an astronomer at the at the Harvard-Smithsonian Center for Astrophysics, US. "There's a danger that the rhetoric that the US military is playing with will generate military interest in the moon where there really is no need for it."

While Russia has been relatively lacklustre in terms of moon exploration lately, China is generating concern among some Western observers. China's ongoing lunar programme – which has included sending a rover to the far side of the moon – has already raised some red flags, says Garretson, with the West struggling to figure out what to make of the intentions of a civilian-built but military-run effort.

China's equivalent of NASA is the China National Space Administration, a civilian ›

2024

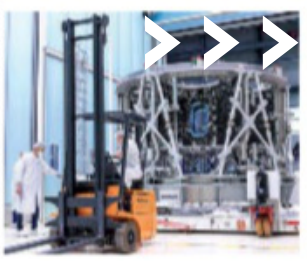
Chang'e 6 & 7
China
Two further robotic missions, one intended to carry out another sample and return, the other to visit the moon's south pole

2025

Lunar Polar Exploration
India and Japan
A mission to send a lander and rover to explore the moon's south pole

2025

Artemis III
US
NASA says it intends to land people on the moon again, for a brief visit at first, as part of its flagship lunar programme



2027

European Large Logistics Lander
Europe, Canada and Japan
A lander designed to deliver a large payload of food, air and water to NASA's burgeoning moon operations

2027

Luna 28
Russia
A sample-return mission destined for the moon's south pole

PRIVATE

2030

Africa 2 Moon
South Africa
A crowd-funded mission masterminded by a non-profit based in Cape Town

2035

International Lunar Research Station
Russia and China
The two countries say they will collaborate to build an extensive moon base for scientific research, staffed by robots. The aim is for it to be operational by the middle of the next decade

NASA/JAXA/ESA/ISRO/NASA/JPL-CALTECH/BROWN UNIV./USGS/CNSA/SPACEIL/SPACEBIT/AIRBUS

organisation. But the body actually in charge of human space flight is the China Manned Space Engineering Office, which is part of the military. Similarly, infrastructure such as launchpads and satellites are mostly run by the People's Liberation Army. China has also recently sent up a communications satellite called Queqiao (see timeline) and Garretson says this could be used for military applications.

Further in the future, the US envisages a more established presence on the moon, including business ventures (see "Cosmic capitalism", right). By that time, a military presence may be unavoidable, says Garretson. "The intent is to make sure we have eyes in that area and ensure freedom of operations, in order to deter anybody from thinking they could get away with some level of coercion, or blockade, or that sort of thing."

Others want to see more open discourse between the US and China. "I am worried that the lack of communication and the inclination to assume the worst is potentially going to create a bad situation," says Weeden.

We are unlikely to see troops on the moon any time soon. But within a decade, it is feasible that US and Chinese astronauts will be simultaneously operating there in close proximity, near to the south pole. Perhaps there will be valuable mining robots from other nations and companies too. "This is a good time to be figuring out how we're going to make this work," says McDowell. "Before it gets too fractious." **Jonathan O'Callaghan**

NASA

COSMIC CAPITALISM

Money-making ventures are going to be an essential part of our return to the moon. Who is to say what constitutes a fair deal in space?

BILL NELSON, the administrator of NASA, grinned for the cameras as he handed over a cheque to Justin Cyrus, the boss of a company called Lunar Outpost. The amount? A mere 10 cents. This moment last year was partly a marketing gimmick. But in its own strange way, it was also a legitimately important milestone: it marked the first time that a government agency – or anyone else for that matter – had signed a deal to buy natural resources in space.

If all goes to plan, later this year Lunar Outpost will use a rover to scoop up some lunar dust, snap a photo of it, and officially transfer ownership of the material to NASA. In return, the agency will pay a further fee, this time 90 cents to make a round dollar.

The sums may be small, but this is the start of a new era for humanity, one in which the buying and selling of resources will extend beyond our home planet for the first time. And though Lunar Outpost looks set to be one of the first companies making money on the moon, it will be quickly followed by others. US plans to return people to the lunar surface rely heavily on partnering with companies.

There is just one problem. International space law is hazy about how business should work there and indeed if it is allowed at all. "This is uncharted terrain for sure," says space law expert Tanja Masson-Zwaan at Leiden University in the Netherlands. Outer space commerce is at an inflection point, and the precedents we set today could have far-reaching consequences.

NASA / IMAGE BY EVENING_TAO/ON / DILOKASTUDIO FREEPIK / RYAN WILLS

Space law has long been dominated by the Outer Space Treaty, which was negotiated through the UN and first came into force in 1967. More than 100 nations are now party to it, including all the major space powers. It says the moon and other celestial bodies "shall be free for exploration and use". But what does that mean, exactly?

The US takes the view that "use" means people can mine resources in space, so long as they only profess to own the materials collected from their excavations. A few other nations, such as Luxembourg and the United Arab Emirates, have embraced this view too, in an effort to attract fledgling space companies. Others, notably Russia and China, have historically opposed such notions.

Exactly what kind of cosmic capitalism is permitted remained a moot point until about a decade ago when two companies, Planetary Resources and Deep Space Industries, announced plans to prospect for and mine water and precious metals on asteroids. This sparked debates at the UN's Committee on the Peaceful Uses of Outer Space (COPUOS) over the legality of their business models. The companies have since run out of money and been acquired by other enterprises.

Discussions have now settled in an extraction-friendly direction. "I think a consensus has been emerging in the past few years that owning resources isn't per se appropriation, hence not illegal," says Masson-Zwaan. "However, you need to ave a regulatory framework so that it's not a gold rush."

In May 2020, the US tried to deliver exactly this by unveiling a set of principles for the use of space called the Artemis Accords. These include promises to share data openly, preserve historical areas like the Apollo landing sites and assist astronauts of all stripes in emergencies. Agreeing to the accords allows countries to participate in the US's lunar plans, giving them greater access to scientific expertise and potentially allowing them to reap technological benefits. Signatories to the pact – of which there are now 21, including countries as diverse as Colombia, Singapore, France and Bahrain – must also accept the US interpretation of international space law regarding resource extraction.

NASA's deal with Lunar Outpost was a continuation of these US efforts to set precedents for how businesses can operate in space. But what will Lunar Outpost actually do up there to make money?

The company plans to land its rover, the Mobile Autonomous Prospecting Platform (MAPP), on the moon by late 2022. It will aim for the lunar south pole, which is also a target landing site for the Artemis missions to return people to the moon. The area is known to host plenty of water ice, which will be needed to help keep astronauts hydrated among other uses (see "Home, home on the moon", page 41). MAPP will use its perforated wheels to collect fine lunar regolith, or dust, and store this in its body. Lunar Outpost will then send NASA the rover's coordinates, leaving its bounty in place until the agency can pick it up.

The idea to sell this haul so cheaply came to Cyrus when he and his colleagues heard that NASA was seeking to purchase lunar rocks from private companies that were already headed to the moon. The lowball bid – to sell a scoop for $1 – was about attracting attention and starting a conversation about the long-term future of business in space. Meanwhile, the company is making its real money in the short term by selling slots on its rover for other companies' hardware. One customer is the smartphone company Nokia, which hopes to test high-bandwidth communications on the moon.

There are still many outstanding questions about how business will work up there, and academics are trying to iron them out. Masson-Zwaan was a co-founder of the Hague International Space Resources Governance Working Group, which included members of spacefaring nations, universities, intergovernmental organisations and private businesses. In 2019, it published a set of recommendations on how to achieve equitable and sustainable use of space resources. Some of its proposals, such as establishing safety zones around mines, have already found their way into the Artemis Accords.

"OWNING SPACE RESOURCES ISN'T ILLEGAL. BUT YOU NEED REGULATIONS SO IT ISN'T A GOLD RUSH"

The Hague group has since disbanded. But last August, COPUOS created a subcommittee called the Working Group on Legal Aspects of Space Resource Activities with a formal, five-year mandate to iron out the remaining questions surrounding governance of space resources. While its recommendations won't be legally binding, they could be used as guidelines for laws enacted in different countries regarding resource extraction.

Perhaps the biggest sticking point will be how to ensure the benefits of space mining are equitably shared. The Outer Space Treaty says any use of space resources "should be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development". But it is unclear how this ought to work. One previous suggestion has been that nations using moon resources should somehow compensate lower-income nations for the privilege. At the Hague group, all parties agreed that this compensation didn't have to be monetary, says Masson-Zwaan. It could include things like higher-income nations investing in research and building capacity for others.

Whatever happens, most observers expect that future generations will look back at this point as the time when governance and commerce in space really began to take shape. "It's an exciting time, and it will go down in history," says Masson-Zwaan. "It's important that we get things right." ▮ **Adam Mann**