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50 years of lunar exploration visualised

SPACE EXPLORATION: THE NEXT 50 YEARS

SINCE APOLLO 11, WE'VE LANDED ROBOTS ON MARS, BUILT A BASE IN ORBIT AROUND THE EARTH, AND SENT PROBES BEYOND OUR SOLAR SYSTEM. HERE, SCI-FI AUTHOR **STEPHEN BAXTER** SPECULATES ABOUT WHAT MIGHT BE ACHIEVED IN THE NEXT FIVE DECADES, WITH ILLUSTRATIONS BY SCI-FI ARTIST **MITCHELL STUART**

The previous decade is when it begins.

In March 2019, US Vice President Mike Pence publicly challenges NASA to mount a crewed return to the Moon before the end of 2024. This would be the last year of a second term for President Trump, and so an echo of President Kennedy's call for a Moon landing before the end of the 1960s, which led to the Apollo programme.

The NASA of the 2020s is not the young and nimble organisation of 1960. However, the challenge is accepted.

In fact, NASA, with its overseas partners, has already begun the development of a new lunar architecture. This depends on a heavy-lift launcher called the Space Launch System, which is a rival to the Saturn V; an Apollo-like spacecraft being developed with the Europeans; and the Lunar Gateway, a space station in lunar orbit, from which astronauts could descend to the surface. All that is missing is a lander, a new Lunar Module. But the private company

Blue Origin steps up to the plate, with a design it has been developing since 2016.

And so the first lunar mission since Apollo launches in late 2024.

By now, however, the decade of the Moon is in full swing, with previous visits from automated landers and rovers launched by a variety of countries, including the Europeans, Japan, India, and – most ambitiously – China, which attempts sample-return flights. Still, it is believed that the majority of humankind watch or listen on 13 November 2024 – just inside Pence's deadline – as NASA astronauts Jeff Krauss and Kaui Pukui begin their cautious descent towards the Mare Imbrium, the first lunar crew since Apollo 17…

In the year 2029, 60 years after Apollo 11, a Chinese crew lands on the surface, respectfully close to the site of the 2024 US landing attempt. The 'Pence mission' had always been premature. Krauss and Pukui were not the first to land on the Moon, but, six years after their disastrous descent, they are the first to be buried there.

THE SPACEPLANES

In the early days of space exploration, expensive launchers like the Saturn V were thrown away after one use. A true spaceplane would take off unassisted from a runway, reach orbit, then return to land. (This is called 'SSTO' – single stage to orbit.) The major issue is that such a craft can't carry all its own fuel, and the oxidiser to burn that fuel. A jet engine must collect oxygen from the air, but if the craft itself is travelling faster than sound, the intake of air creates drag. In 2025 that the first true SSTO flies. Skylon's engine works like a conventional jet up to five times the speed of sound, at which point the engine switches to an internal liquid oxygen supply. Other competitors aren't far behind. True space tourism briefly blossoms, before becoming deeply unfashionable in a new age of climate management.

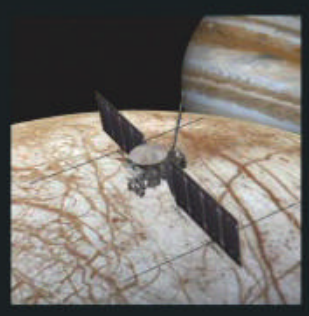
THE MOON BASES

Back in the 1970s, the apparent lack of water in Apollo Moon rock samples had been a grave disappointment. Water could have been cracked into hydrogen and oxygen to supply breathable air and rocket fuel. Without water, the Moon was much less interesting a destination.

But by 2020 extensive water deposits had already been discovered in wide areas of the Moon, in the form of hydroxyl compounds. And in 2028 a dramatic Chinese discovery of easily accessible water-ice in the shadows of the lunar north pole suddenly revived old optimism, and old colonisation studies are dusted off.

By now astronauts from many nations have reached the Moon: the US, China, Europe, Japan, Russia, India. And from the first landing sites colonies have quickly developed, extracting metals and other materials for various purposes, including the manufacture of heavy components of habitats and Mars ships. The endless, unshielded sunlight is an obvious energy resource.

But the detachment from Earth grows. The principles of outer space law are still upheld: you can exploit lunar resources, but there is no sovereignty. No nation owns the Moon. The colonists are happy about that. And through the decade, the colonists increasingly look to the future, rather than the past: to the Moon, rather than ties to Earth.



ROBOTIC EXPLORATION

Two large, expensive and elderly probes finally reach Jupiter in this decade: NASA's Europa Clipper, set in orbit around Jupiter to make multiple flybys of the potentially life-bearing moon Europa; and ESA's JUICE, the JUpiter ICy moons Explorer, sent to study the moons Callisto and Ganymede, along with Europa. The probes are magnificent and return good science. But, having been designed and largely built before 2020, they now seem too big, too heavy, and frustratingly dumb – in contrast to a new generation of small, smart, highly capable probes already being sent out to explore the asteroid belt and beyond.

"THE LANDING SITE ON MARS IS IN THE ARES VALLIS"

The 2030s is the decade in which humans finally land on Mars – using a technology strategy already decades old. Back in 1990 a team of engineers led by Robert Zubrin presented NASA with a new plan to get people to Mars, called 'Mars Direct'. The core of it was a scheme to manufacture rocket fuel on Mars, by using the Red Planet's carbon dioxide air to make methane. Removing the need to carry the propellant for a return journey all the way to Mars reduces the mission size and cuts costs. The mission unfolds across several launch windows. First, an uncrewed Earth Return Vehicle (ERV) is sent to Mars, along with an automated factory for manufacturing the methane propellant. The stratagem is designed for safety. The human crew do not launch until their return ship is safely on Mars and fuelled up.

At last, on 4 April 2038, a crew drawn from four nations – the US, Russia, China, and the European Federation – travelling in a ship assembled at Lagrange Station in Earth orbit, lands on Mars. (Turn the page for more information on Lagrange Station.) And Zubrin lives to see his vision fulfilled. The landing site is in the Ares Vallis, close to the remains of NASA's Pathfinder probe. This echoes the achievement of Apollo 12 on the Moon in 1969, which had tested navigation techniques by landing within walking distance of an inert Surveyor probe. It is necessary for ERV and lander to touch down close to each other – and Pathfinder is as good a marker to aim for as any. There are other scientific objectives, such as in examining the behaviour of materials on Mars.

Just as reaching the Surveyor was a mission highlight for the Apollo astronauts, it is a cultural feat to visit the monument. A shot of mission commander Martha Ono cradling Pathfinder's tiny Sojourner rover in her arms is the most forwarded post in social media history. Space archaeologists, however, howl with anguish.

GETTY IMAGES, NASA

The largest single colony off planet Earth is in orbit. Lagrange Station is situated at L4 – the fourth Lagrange point – a gravitationally stable location in the Moon's orbit around Earth.

The central habitat, a squat, tuna-can-like cylinder, is all but lost in a wider infrastructure of support facilities: a solar sail for station-keeping, an extensive radiator farm, and ring-shaped mirrors that provide the habitat with sunlight. The interior of Lagrange is spectacular, with a farmed landscape curving up over the visitor's head. But this is a place of work, for 10,000 people. It was from here that the first crewed Mars missions were launched.

Now, though, Lagrange's main customer is not Mars but Earth. Led by such prestigious bodies as the Cambridge University Centre for Climate Management, founded in 2025, large-scale geoengineering initiatives are underway in an attempt to salvage Earth's climate. Among them is 'albedo manipulation' – cooling the planet by reflecting or deflecting away some of the sunlight. By now, the tremendous orbital mirrors and lenses tended by Lagrange crews are themselves planetary in scale.

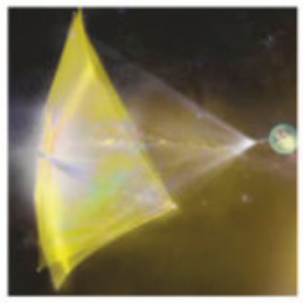
All this is controversial on Earth, because such solutions inevitably favour some nations over others. Amid rising sea levels, the desiccating tropics, and gathering migrant flows, there is a feeling of a slide to war.

However the citizens of Lagrange are more concerned about their own politics, rather than Earth's. Here, on the Moon, and even on Mars, debates are underway on the future of human rights. A confined colony in space will always be an intrinsically tyrannous environment, because

all human life will depend on centrally controlled systems. Bluntly, a tyrant in control of the air supply would have the power of life and death. A new constitution, called the Cockell Protocol, named after the astrobiologist Charles Cockell, is being drafted to ensure freedom and safety. It will be a new way of living, unimagined on the Earth – and yet, as many point out, with lessons for the inhabitants of that small world.

And on the Moon, at least, with the first children born there already in their teens, the right to freedom and self-governance is high on the agenda. This comes to a head in 2045, a century after the first use of atomic weapons in war. When the US attempts to set up a nuclear weapons site at its own Moon base, the lunar colonies – including the American ones – declare unilateral independence. A new nation is born, the first in space.

BREAKTHROUGH STARSHOT, NASA

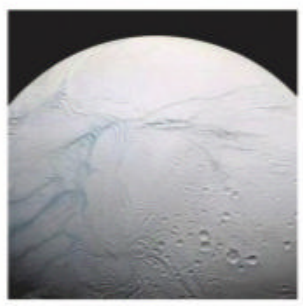


THE SOLAR FOCUS

After decades of development, the Breakthrough Starshot programme achieves its first significant triumph.

The ultimate goal of Starshot is to send tiny 'light sail' craft to the stars. Such craft carry no propulsion system. Instead they are pushed by light from a tremendous laser on Earth.

The stars are still out of reach for Starshot – but in 2047, after a journey of 20 days, a trial craft reaches a significant interim goal: the 'solar focus', a point more than 500 times as far from the Sun as Earth, where the Sun's gravitational field, acting as a lens, focuses the light of distant stars and planets. And as it dashes through the focus, moving at a seventh the speed of light, Starshot picks up imagery from the star Fomalhaut, located 25 light-years away, with its known planet Dagon – and now, it is revealed, Dagon has a large moon, invisible without the lensing. A moon that shows traces of life.



THE AI ASTRONAUT

Up to now, humans have been better than the machines at science in space. By the 2040s, though, AI is advancing rapidly. Now the designers believe they are close to achieving an AI that is capable of exhibiting such human qualities as common sense, creativity and judgment.

This is demonstrated by ROBBIE, the ROBot Ice-moon Explorer, an advanced-AI mission to Enceladus, a moon of Jupiter. Far from following instructions from Earth, the probe devises its own research objectives, carries out its own explorations, and even designs and builds custom subprobes on the spot. An explosion of new science results follows – and all far more cheaply than a human mission. But some fear for the future of humans in space.

The year 2051 marks the 250th anniversary of the discovery of dwarf planet Ceres, now known to be the largest object in the main asteroid belt between Mars and Jupiter. Some asteroids, known as near-Earth objects (NEOs), wander within the orbit of Mars, and even approach Earth. And the Trojan asteroids, beyond the main belt in Jupiter's orbit, are believed to have a mass several times more than those of the main belt itself.

And in the 2050s a new wave of super-smart automated probes push out through the Solar System, hunting the asteroids. One goal is science: the asteroids are thought to be relics of the Solar System's formation. Earth's safety is another factor. For decades we have been tracking NEOs; soon the probes will be able to push away any threats.

But what primarily draws the probes is the asteroids' promise.

Some asteroids are flying mountains of natural steel and precious metals. Others, known as C-type asteroids, are full of organic compounds and water. You can use asteroid dirt to make glass, fibreglass, ceramics, concrete, rocket fuel, and – with suitable engineering – all the requirements of life support.

But the probes' single most crucial task is to use asteroid resources to manufacture copies of themselves: to self-replicate. The plan is that a steadily growing swarm of probes will sweep out through the asteroids, at no additional cost to Earth. And the flow of materials to the inner Solar System will double in volume, then double again, and again…

Until one such probe, hunting down an anomalous heat source in the main belt, discovers something strange. An artefact, but not of human origin. It is a 'lurker', in the jargon. Alien, very ancient, it has been monitoring our Solar System for millions of years, and waiting for contact.

After much consideration and debate the miner cautiously approaches the stranger.

It is first contact: not between human and alien, but between robot emissaries.

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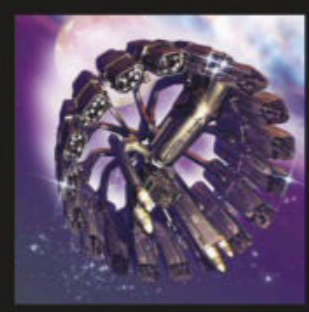
LURKERS

The idea of using smart space probes as a means to make contact with extraterrestrial civilisations dates back to astronomer and physicist Ronald Bracewell, who proposed the idea in 1960. This was at the beginning of the SETI enterprise, which searched for signals from extraterrestrial intelligence using radio telescopes. Rather than transmitting brief radio signals, Bracewell imagined sending out many cheap, long-lived probes equipped with artificial intelligence. A probe could sit in a target system and wait for a culture to develop, and then initiate contact. The advantages of this approach lie in the possibility of rapid dialogue with a nearby probe, compared to an interstellar exchange of radio signals which might last decades, as well as the probe's ability to wait for long periods for a contact opportunity.



SELF-REPLICATORS

In 1980 physicist Frank Tipler used self-replication to develop Ronald Bracewell's lurker idea. The costs of an interstellar exploratory programme could be minimised if, rather than sending out lurkers to every star, the makers sent out a single probe capable of self-replicating. On arriving at a star system it would send out copies of itself to further systems – and its descendants would do the same. Even if the colonising wavefront moved at a conservative 1 per cent of light speed, the Galaxy would be covered in 10,000,000 years: an immense period of time, but the Galaxy is perhaps a thousand times older. There has been time for the makers of the asteroid-belt lurker to seed all the stars with their probes.

Deep in the asteroid belt, the AI miners understand this. And they begin to consider the opportunities and hazards of unrestricted growth.

In the 2060s, the 100th anniversary of the Apollo 11 landing approaches. And a grand new project is underway to connect Earth to sky. The Borneo Tower is a space elevator. It began with a satellite orbiting the Earth in 24 hours at an altitude of 36,000km. It was placed in a geosynchronous orbit, which means it hovers over the same spot on the equator, the chosen site being Borneo. Then, a cable of super-strong materials was dropped down to the surface, to be used as the basis of an elevator system, carrying goods and people from Earth to space and back again. The reduction in cost of getting cargo into space is huge, but the engineering details are challenging. The key breakthrough was the successful development of 'super-fullerenes', carbon molecules that offer cables with high tensile strengths. On Mars, building such an elevator would be easier because of the planet's lower gravity. The Olympus Elevator is already on the drawing board.

Resources from space are brought down the space elevator in increasing volumes, safely and cleanly, to help the recovery of Earth's environment – and, eventually, the preservation of Mars's.

Meanwhile, the development of an automated industrial civilisation in deep space continues. With self-replication and AI technologies rapidly advancing, a new generation of probes – themselves built by earlier probes – is pushing further out: to the ice giants, into the Kuiper Belt beyond Pluto, and soon

SCIENCE PHOTO LIBRARY, NASA

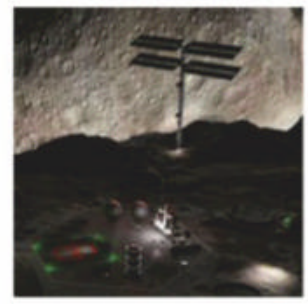
even the Oort Cloud with its enigmatic Planet Nine. The flow of science results and industrial development is spectacular. But this is all happening independently of humanity.

There are now healthy democracies on the Moon and Mars, and in Lagrange and other large orbital habitats. But it has become obvious that humans have no direct role to play in space beyond the orbit of Mars, and none venture there. And indeed humanity has, gracefully, agreed with the AIs what is known as the Milligan Accord, to accept a long-term limit on the industrial development of the Solar System. The quality of judgment in the new generations of AIs is vindicated.

But many eyes look to the sky – a Starshot probe has been sent to Fomalhaut, the origin star of the alien lurker. Soon, perhaps, humanity's relationship with the cosmos will change again.

by **STEPHEN BAXTER**

Stephen is a science fiction author, who has written more than 40 books.



GROWTH LIMITS

While resources pour from the sky to Earth, the AIs in deep space are increasingly aware of the exponential growth in the volumes of resources humanity has had them extract. Already, the main belt miners are returning 2,000,000 tonnes of iron ore per year, matching Earth's own output. But the industry could double in volume in another 20 years – and double again 20 years after that. The main belt contains some billion billion tonnes of ore, but that could be consumed in a mere eight centuries, if the doubling process continues.

The AIs are aware of the damage done to Earth in the past by unrestricted, exponentially growing exploitation. The AIs, their wisdom developing, fear for the long-term integrity of the Solar System, for the impact on life yet to be discovered, as well as the effect on humans when the inevitable crash comes. So they suggest the 'Milligan Accord'. This is a 'one-eighth' rule, meaning exploitation of any resource should stop when one-eighth of it has been consumed, a safe three doubling intervals before exhaustion. This would preserve most of the Solar System as 'wilderness'.

On a slowly recovering Earth, humanity accepts the advice of its junior partners.

FOMALHAUT

Thanks to painstaking analysis, the home star of the alien lurker probe has been identified as Fomalhaut, 25 light-years away, with the apparently life-bearing moon of Dagon probably its origin. Already, a Starshot probe has been sent to the moon – but will not arrive before 150 years have passed.

However, it is soon realised that the light of the Starshot laser launcher itself will have been visible, after just 25 years, as a brilliant star in the skies of the Dagon moon. Perhaps the inhabitants will choose to reply in a similar manner. In which case we may receive our first calls from extraterrestrials by laser beams travelling at the speed of light. And the first reply may come in a mere 50 more years – in the year 2119. **SF**