A TWENTY-FIRST-CENTURY MOON RACE IS KICKING OFF A NEW ERA OF LUNAR EXPLORATION

Japan, South Korea, Russia, India and the United Arab Emirates are among the nations aiming to send missions to the Moon in the next year. But will they all make it? **By John Pickrell**

The Moon will be one of the most popular destinations in the Solar System in the next year. No fewer than seven missions are headed there from India, Japan, Russia, South Korea, the United Arab Emirates and the United States, along with several companies.

NASA's US$93-billion Artemis programme might be stealing most of the limelight with its maiden launch this year because it's the first step towards sending astronauts to the Moon. But the United States is just one of many nations and private companies that soon plan to launch missions, heralding what scientists say could be a new golden age of lunar exploration.

Science isn't the only driving force. The flurry of missions also signals the growing ambition of several nations and commercial players to show off their technological prowess and make their mark, particularly now that getting to the Moon is easier and cheaper than ever before.

South Korea's Korean Pathfinder Lunar Orbiter (KPLO), for example, "is the first step to secure and verify Korea's space exploration capability and obtain new scientific measurements of the Moon", says Chae Kyung Sim, a planetary scientist at the Korea Astronomy and Space Science Institute in Daejeon, South Korea, who is a member of the science team designing one of the mission's instruments. "We are enjoying joining this new wave of lunar missions."

Four other nations are also aiming to reach the Moon in 2022. Japan's SLIM (Smart Lander for Investigating the Moon), which is likely to launch sometime later this year, will attempt a pinpoint landing, with a level of accuracy no other country has ever achieved. That mission or one by the Tokyo-based company ispace, also set to launch this year, will be the country's first foray to the Moon.

India's Chandrayaan-3, currently officially slated for an August launch that might get delayed, will be the nation's second attempt to get a lander and rover onto the lunar surface, after the failure of India's previous lunar lander mission.

Russia's Luna-25 lander, scheduled for a July launch to the south polar region, will be the nation's first trip to the surface of the Moon since the Soviet Union's previous lunar lander mission in 1976. And the United Arab Emirates is embarking on its first lunar mission with a rover called Rashid, scheduled to launch later this year. That flight will potentially mark another first — as the pioneering trip to the Moon by a commercial mission. Rashid will be

NASA'S SCIENTIFIC VISUALIZATION STUDIO

An unprecedented number of nations are trying to get to the Moon in the next year.

carried to the surface on a lander developed by ispace that will be riding into lunar orbit on a rocket designed by SpaceX in Hawthorne, California. Other companies are also heading to the Moon as part of a NASA programme, marking the beginning of commercial trips to other worlds.

Some of the national space agencies running these expeditions are providing only scant details about the missions and when they will launch, with schedules changing frequently. Scientists also say that the war in Ukraine is very likely to delay Russia's mission — and could have unexpected effects on other ones, too.

Whenever they launch, the missions aim to provide streams of data about the Moon — only a tiny fraction of which has been explored so far. Scientists also say this flurry of activity is likely to spur more-frequent and cheaper access to the Moon and increase international interest in lunar research. It could also lay the foundation for crewed lunar outposts, which could provide a launching post for travel to Mars.

> "THE MOON IS THE GATEWAY TO THE SOLAR SYSTEM, ESPECIALLY FOR HUMAN EXPLORATION."

It is very exciting and "hugely important to have so many nations involved in this armada of spacecraft going to the Moon", says James Head, a planetary geologist at Brown University in Providence, Rhode Island, who was involved in training NASA's Apollo astronauts in the 1970s. "There are so many unresolved questions that can be addressed with a host of different robotic and human capabilities."

A bonanza for researchers

Scientists can barely contain their delight over the implications of all this activity. "If the missions scheduled for 2022 succeed, it represents more-frequent access to the lunar surface, more data and eventually more samples through robotic sample return," says Clive Neal, a lunar geoscientist at the University of Notre Dame in Indiana. For scientists such as Neal, who lived through a relative drought of lunar missions after the demise of NASA's Apollo programme four decades ago, all of

this "represents a renaissance in lunar science and exploration". The expeditions will enable much more than research on the Moon alone, says Neal, "because the Moon is the gateway to the Solar System, especially for human exploration".

Given the continuing conflict in Ukraine, it's not clear how many of these missions will go ahead this year. It is possible that the war could cause delays beyond Russia because some of the spacecraft from other nations will require transport on massive cargo planes to the launch sites, and Russia's attacks on Ukraine have damaged the largest cargo plane in the world — the Antonov An-225. Scientists say that its destruction could have ripple effects on the planes available to provide such services.

Even if missions depart from Earth as scheduled, there is no guarantee of their success. India's last lunar mission, Chandrayaan-2, succeeded in getting a spacecraft into orbit in 2019, but its lander and rover crashed when they tried to land. Israel's privately developed Beresheet lander also smashed into the surface earlier that year.

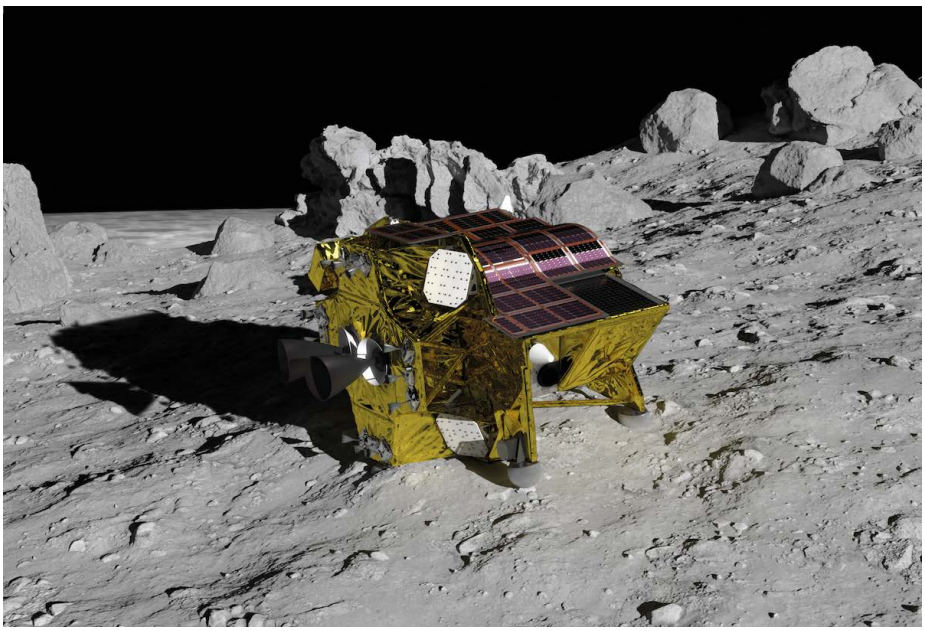
Much more successful were China's Chang'e-4 and Chang'e-5 missions, which have collected reams of data from the surface with a lander and rover since 2019, and returned samples of lunar regolith, or soil, to Earth in 2020. China is planning its next sample-return mission, Chang'e-6, for launch in 2024.

It's unlikely that all of the missions will make it to the Moon this year, given the mixture of past successes and failures, says Mahesh Anand, a planetary scientist at the Open University in Milton Keynes, UK. "Until all the players really demonstrate that they can actually land at the Moon safely, and conduct scientific investigations of significant value, I think we have to watch this space."

South Korea's view from orbit

Of all the missions scheduled for 2022, researchers are especially enthused about the science that could come from the KPLO, South Korea's first attempt to reach another celestial body. Expected to launch in August, this craft will orbit 100 kilometres above the lunar surface and operate for at least one year. It will feature five instruments built and operated by South-Korean-led teams, as well as the 'ShadowCam' — a highly sensitive visible-light camera provided by NASA.

As the name suggests, this instrument will peer into the Moon's deeply shaded areas, providing "the first ever high-resolution look into lunar permanently shadowed regions", says Mark Robinson at Arizona State University in Tempe, who is principal investigator for that instrument and NASA's Lunar Reconnaissance Orbiter Camera, which has been circling the Moon since 2009. ShadowCam will help in the search for water ice in polar craters, and will hunt for unusual geological features related to extremely low temperatures.



JAXA

Japan's SLIM mission will test strategies aimed at making highly accurate landings on the Moon.

Scientists are also looking forward to data from the South Korean mission's PolCam instrument, which Sim says will provide the first map of the entire Moon using polarized light, something that hasn't been done for any moons or planets. Those data will provide details about the structure and size of surface materials based on the way they scatter the light.

Polarization "has not been employed very much to study solid planetary surfaces, so it will be interesting to find out what the data can tell us about the texture, composition and, thus, the geology of various locations on the Moon", says David Blewett, a lunar scientist at Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland, who is the principal investigator of the NASA-funded Lunar Vertex rover slated to launch in 2024.

Sim, who is part of the team behind the instrument, says that a map of lunar regolith grain size — one of the goals of the mission — "will facilitate selecting landing sites for future lunar landers, including a Korean one". The same method could help scientists to study asteroids and other planets, such as Mercury, she says. A γ-ray spectrometer on the orbiter will map the concentration of a dozen or so elements, which "will be essential to identify the distribution of lunar resources" for potential future extraction, she adds.

Ian Garrick-Bethell, a planetary scientist at the University of California, Santa Cruz, says the map of regolith texture and grain size could help scientists to understand a "big mystery in lunar science" — that of the nature of Moon dust, which smothers nearly the entire surface. By mapping how the dust varies by latitude and studying other aspects of it, researchers hope to get a better sense of how the Moon has evolved over its history, he says.

Garrick-Bethell is part of a team helping to interpret data on the Moon's magnetic field from the KPLO magnetometer called KMAG, which is being built and led by Ho Jin, a space scientist at Kyung Hee University in Seoul. Garrick-Bethell hopes that KMAG will help to solve another lunar mystery: scientists are baffled as to how the Moon had a strong magnetic field in its early history, billions of years ago, given that it never had a core of liquid iron sloshing around, which is what generates Earth's magnetic field.

The Moon's tiny iron core "is so small that no existing theory can explain how it once generated a strong magnetic field", he says. Yet observations from space of ancient rocks in the Moon's crust today reveal that they are highly magnetic and were formed in the presence of a magnetic field. "So there is a huge disconnect between theory and the observations."

Sim says the KPLO will hopefully be the start of a series of planned South Korean forays to the Moon, including a sample-return mission by 2030.

Japan's landing plans

Japan's SLIM mission, launching from Tanegashima Space Center at some point before March 2023, would mark that country's first time reaching the lunar surface. The roughly cube-shaped probe, which is 2.4 metres tall, aims to use highly precise lunar landing technologies to allow future missions to set down in specific locations with a high degree of accuracy — particularly those expeditions hoping to find water ice in shaded craters at the Moon's poles.

"Pinpoint landing is mandatory technology for the next generation of lunar exploration," says Shin-ichiro Sakai, SLIM project manager

at the Japan Aerospace Exploration Agency (JAXA) in Tokyo.

SLIM is intended to set down within 100 metres of a proposed target, rather than simply in an area that has favourable landing conditions.

One of the several instruments on the lander is a multi-band camera, which will carry out spectroscopic observations for the mineral olivine. Originally formed deep inside the Moon, olivine can be exposed by meteorite impacts.

No missions so far have collected these minerals, and scientists say they could shed light on the composition, structure and evolution of the Moon's interior. "Olivine has been identified at a few specific points on the Moon's surface, and SLIM's pinpoint landing capability will allow such observations to be carried out," says Sakai.

Russia to the Moon

Russia's Luna-25 mission will be the first probe it has sent to the surface since the Soviet Union's Luna-24 sample-return mission in 1976. In January, the Russian space agency Roscosmos in Moscow announced that it would launch the mission on a Soyuz-2 Fregat rocket from Vostochny spaceport in far-eastern Russia in late July. Roscosmos told *Nature* that the mission will launch in the third quarter of this year. But the war against Ukraine has upset some of Russia's space plans, with the European Space Agency announcing on 13 April that it would pull out of the Luna-25 mission.

If the probe does arrive as planned – north of the Boguslawsky crater near the Moon's south pole – it will be the first to reach the lunar poles, which are thought to be a possible source of water for future crewed bases or settlements.

Luna-25 will have eight instruments, including a robotic arm. This will excavate polar regolith in various spots to a depth of 20–30 centimetres and deliver the samples to the craft's spectrometer to analyse the rocks' elemental and isotopic compositions. The mission also aims to detect water.

Luna-25 is the first of a series of Luna missions scheduled for the coming years, and is intended to operate and collect data for one year.

However, researchers say they wouldn't be surprised if the mission is delayed. "This war certainly will have some major consequences on these things," says Anand.

Even if the mission is technically able to go ahead, the collapse of the Russian economy in the face of sanctions could affect it, says Neal. "The Russian rouble has tanked. That's why I say they won't launch. If everything had been prepaid there could be a chance, but I am sceptical."

The commercial Moon race

Nations aren't the only ones aiming for the Moon. NASA is supporting a number of companies to carry out relatively small-scale missions through its Commercial Lunar Payload Services – which aim to get private landers and rovers to the Moon on commercial rockets. The first of these commercial missions, which will scout for resources and collect data together with NASA's Artemis programme, is scheduled to launch in late 2022 (see page 212).

It'll be a race to see which company reaches the lunar surface first. Japan's ispace plans to launch the M1 mission of its HAKUTO-R programme in the final quarter of 2022 and could beat the SLIM mission to the Moon. The ispace lander includes cameras, a flight computer that uses artificial intelligence and a solid-state battery, all of which will be tested under the extreme lunar conditions.

Hideki Shimomura, ispace's chief technology officer, says that successfully delivering a commercial lander would be a "significant scientific achievement" and a step towards public–private missions that will reduce the cost of reaching the Moon and could deliver many scientific instruments.

> "COMMERCIAL LUNAR EXPLORATION IS GAINING SIGNIFICANT MOMENTUM."

"As the Moon becomes more accessible through lower-cost transportation, private commercial missions will support frequent experiments and more scientific activities," he says. "Commercial lunar exploration is gaining significant momentum around the world."

The ispace craft will also carry small lunar rovers built by the United Arab Emirates' Mohammed Bin Rashid Space Centre and JAXA. The Rashid rover is little bigger than a radio-controlled toy car – it weighs 10 kilograms and is 50 centimetres long, and is planned to operate for about a month.

It carries an array of instruments, including a microscopic imager to capture high-resolution shots of the lunar regolith. A Langmuir probe on the rover will measure the density and temperature of ions and electrons in the lunar exosphere to reveal whether the solar wind is moving dust on the surface of the Moon. There's also a thermal imaging camera to study the lunar surface, and an experiment to assess how different materials interact with the lunar regolith, which could improve the design of future vehicles.

JAXA says its rover is a small, two-wheeled 'transformable robot' that will operate for several hours. It will unfold and deploy from the ispace lander, collecting images and data about the lunar regolith and providing information about the driving conditions that could help the agency to plan a future mission with a pressurized rover for astronauts.

India's bid for a successful landing

Many scientists say that the Chandrayaan-3 mission, run by the Indian Space Research Organization (ISRO) in Bengaluru, is mainly about a second stab at getting a lander and rover onto the Moon's surface. And like other missions this year, it is also heading for the highlands near the south pole.

The lander and rover will be similar to those of the Chandrayaan-2 lander, but will be modified to help ensure a successful landing. The mission will have a seismometer, an experiment to measure heat flow from the Moon, and spectrometers.

In February, ISRO announced that the mission will launch in August, but it has provided few details since then about the mission or its status. "I wouldn't be surprised if that gets pushed back by a few months," Anand says, but he's very hopeful India will succeed. "Every time we fail, we learn something new."

ISRO has not responded to *Nature*'s questions, but its chairman S. Somanath told *The Times of India* newspaper last month that the launch could be delayed to 2023, adding: "The list of tests is long and we do not want to compromise on anything."

India can take some credit for the surge of interest in the Moon. The discovery of the signature of water – in part by a NASA instrument on India's Chandrayaan-1 mission in 2008 – and the possibility of water ice at the lunar poles has been a big factor, says Anand, who helped to analyse lunar regolith samples brought to Earth by China's Chang'e-5 mission to explore the history of water on the Moon. "The water story has been a bit of a game changer."

Blewett says that there is an element of national prestige and geopolitics, too, given China's lunar successes and the fact that the United States plans to return people to the Moon in 2025.

"Other countries want to show their colours at the Moon," he says, perhaps by planting a flag on the surface.

Researchers also argue that nations and private players are realizing that they don't need big rockets, massive space programmes or vast coffers to reach the Moon – and they are also seeing it as a potential business opportunity.

"This has been building up for the last 10 years," says Anand. "But I feel that this is just the beginning."

John Pickrell is an editor with Springer Nature in Sydney, Australia.