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ARTEMIS BEGINS

As Artemis I takes the first step in NASA's plan to return humans to the Moon, **Shaoni Bhattacharya** talks to the people behind the wider series of missions

This year heralds the first crucial stage in NASA's ambitious plans to put 'boots back on the Moon', as Artemis I gets ready for launch.

Artemis I is an uncrewed flight test of two new space systems: the world's most powerful rocket – the Space Launch System – and the Orion crew spacecraft. It will travel to the Moon, skimming 100km above its surface before entering a retrograde orbit that takes it 70,000km beyond the lunar far side and returns to Earth 4–6 weeks later. Though it will have no human crew this time around, it will deploy multiple CubeSats to perform a range of science experiments.

Should all go well, Artemis II will take a four-person crew to lunar orbit and back no earlier than 2024. Finally, Artemis III aims to send astronauts to the lunar surface in 2025, with NASA vowing to put the first woman on the Moon and the first person of colour. Beyond this are plans for building the Lunar Gateway, a staging post in lunar orbit that will enable humans to stay at the Moon for months at a time. To learn more about the programme, we spoke to key figures across the Artemis project.

Primed for flight, Artemis I's Space Launch System rocket and Orion crew module... with their lunar target in sight

A prototype Orion module in splashdown testing. The new generation of spacecraft can carry up to six astronauts

Orion's first flight

The Orion module will house future crews bound for the Moon and for deep space beyond. Its manager **Debbie Korth** reveals how Artemis I will put the new spacecraft through its paces

How will Artemis I test the Orion crew and service module before it carries humans in Artemis II?
There are several big systems that we want to check out. The Orion capsule has a 4.9m diameter heat shield – we need to see how that performs. Orion will come back from the Moon at about 40,000km/h and the heat shield will get to about 2,750°C.

Another objective is our entry, descent and landing back on Earth. At around 480km/h, the 11 parachutes start deploying. When the capsule hits the water, it's got to be at 32km/h or less. That whole sequence is a very orchestrated set of events we'll be testing.

Finally, there's the Crew Module Uprighting System, which deploys a series of bags and balloons [to keep Orion floating] until the recovery crew picks it up.

What are the major challenges with building Orion compared with past vehicles?
One of the biggest ones is the overall mass. We're trying to build a spacecraft that's robust and can support four people for 21 days. But it's also got to be light enough that you can actually fly it. ▸

A series of parachutes will slow the module to 32km/h before it hits the Pacific

NASA/CORY HUSTON, NASA X 2

Orion's first test flight will last longer and travel further than any Moon mission that has gone before

1. SLS and Orion launch from Kennedy Space Center; boosters and core stage jettisoned.

2. Orion and the Interim Cryogenic Propulsion Stage (ICPS) reach Earth orbit.

3. A 20-minute trans-lunar injection burn propels Orion towards the Moon.

4. Orion separates from ICPS. ICPS takes dotted grey line to a disposal orbit around the Sun.

5. First lunar fly-by, 100km from the surface.

6. Orion enters a distant retrograde orbit (DRO) around the Moon.

7. At its furthest point, Orion is 64,000km from the Moon's surface.

8. Orion leaves DRO and begins return to Earth.

9. Second fly-by of the lunar surface; thrusters fire to begin Orion's return coast to Earth.

10. Orion's crew module separates from the service module.

11. Atmospheric entry at 39,500km/h.

12. Orion's splashdown in the Pacific Ocean, with recovery by the US Navy.

A. B. C. ICPS deploys its 10 CubeSats at the points shown.

MISSION DURATIONS
Total: 26–42 days. Outbound transit: 8–14 days. DRO stay: 6–19 days. Return transit: 9–19 days.

NASA, NASA/TONY GRAY AND KEVIN O'CONNELL, NASA/RAD SINYAK, NASA/BILL INGALLS X 17, NASA, NASA/JOEL KOWSKY)

▲ Above left: the Launch Abort System, designed to carry the crew to safety in the event of an emergency during launch or ascent

Above right: the assembled crew and service module stack being readied for testing in 2019

► The other is distance. The Space Shuttle and the International Space Station went to low-Earth orbit a couple of hundred kilometres up – we're going 385,000km to the Moon. If you have a problem, coming home can take up to three days, so Orion has many redundant [back-up] systems. Our Launch Abort System on top of the Orion capsule is also quite unique. If there's a problem during the launch, it can pull the spacecraft off immediately. There's a lot more safety-critical redundancy built into this vehicle than in the past.

When Artemis I launches, what are the key moments when you'll be holding your breath?
For me, I think the first 'Ahhh' moment will be when the Launch Abort System separates from the spacecraft. That means we've achieved a safe orbit, we no longer need to have the ability to pull the crew module off.

Getting into orbit around the Moon will be another, 'Wow, we made it!' moment. This spacecraft is going further than any human-rated spacecraft ever. We're going not just to the Moon 385,000km away, but another 64,000km beyond that. In pictures from the spacecraft you'll be able to see the Moon and Earth – I think it's going to be beautiful.

The third thing will be the landing back on Earth. That's when we are really going to prove our systems.

If all goes to plan with Artemis I, what are your dreams for the programme?
To me, Artemis I and II are proving out flights. What I'm most looking ahead to is Artemis III, when we have boots on the Moon again. That to me is really exciting. I have three kids; two are daughters and one's in high school. When I talk to her about putting a woman on the Moon she says, "What! A woman never went?". That's what I'm really looking forward to.

How to train an astronaut

A lunar mission is a mammoth undertaking, demanding a lot from its crew. **Jacki Mahaffey**, lead chief training officer for Artemis II, tells us how the astronauts will prepare

▲ The Artemis astronauts, clockwise from top left: Joseph Acaba, Kayla Barron, Raja Chari, Matthew Dominick, Victor Glover, Warren Hoburg, Jonny Kim, Christina H Koch, Kjell Lindgren, Stephanie Wilson, Jessica Watkins, Scott Tingle, Frank Rubio, Kate Rubins, Jasmin Moghbeli, Jessica Meir, Anne McClain and Nicole A Mann. The mission plans to put the first woman and person of colour on the Moon

Eighteen astronauts have been selected for NASA's 'Artemis Team' to support missions to the Moon. Following Artemis I, four NASA astronauts will be selected by the end of this year to fly to lunar orbit with Artemis II.

Since the training for this mission is brand new, Jacki Mahaffey from Johnson Space Center in Houston is leading a team of instructors not only to conduct astronaut training, but also to draw up the Artemis training programme.

"We start with training for the Orion capsule and launching on the Space Launch System (SLS) because the Artemis II mission will be a figure-8 around the Moon," she said. "Then we'll continue to grow as we add the [Lunar] Lander and Gateway and learn how to use suits to do moonwalks and all sorts of things."

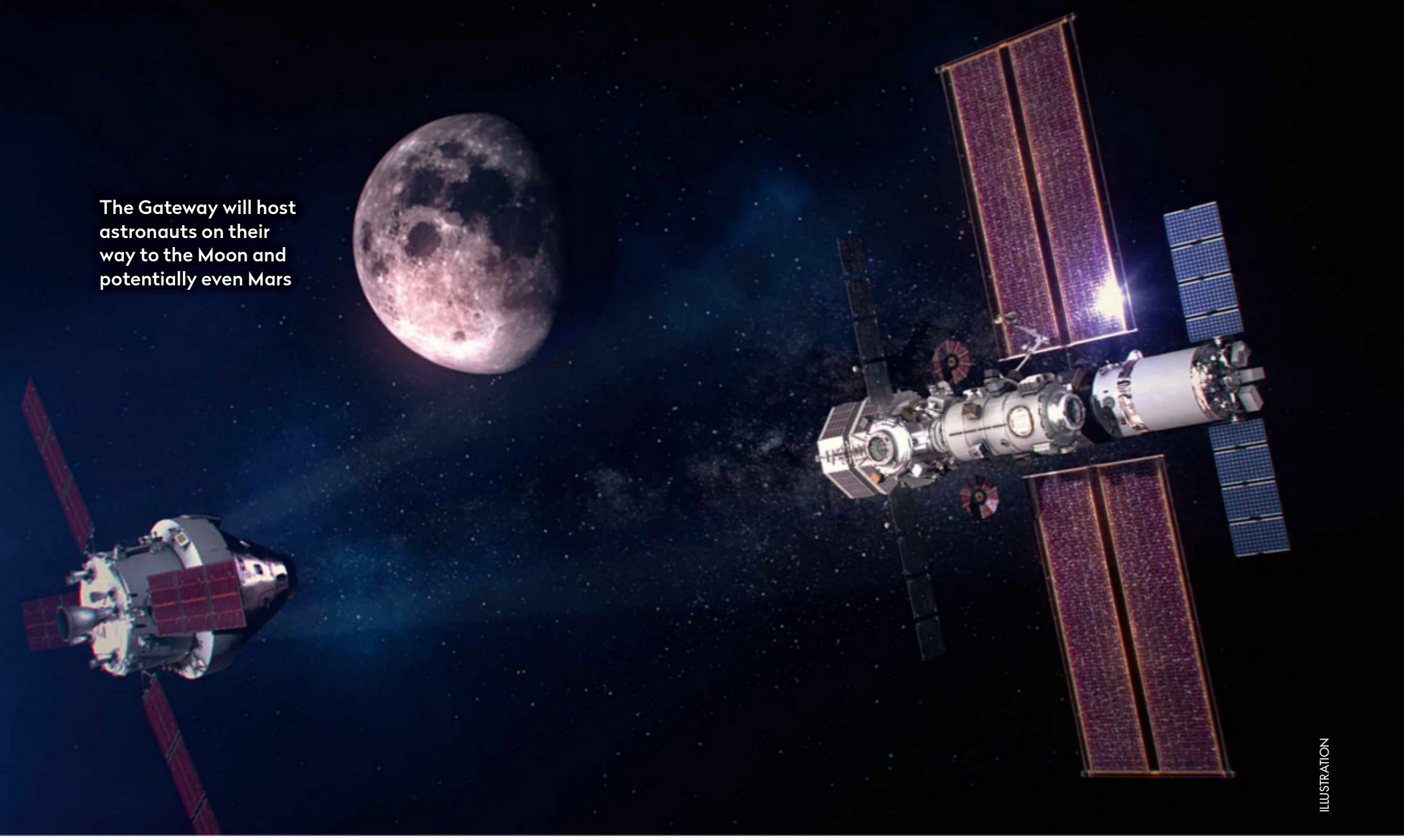
During Apollo crew training in the 1960s, one of the main tasks was learning to navigate the dizzying array of switches and systems in the spacecraft, but a lot has changed in the last 50 years.

"One of the big differences between the earlier missions and what we have now is much more computer power and automation capability," says Mahaffey. "There's a lot fewer switches and circuit breakers in the Orion capsule than you would have seen on the Shuttle or in an Apollo capsule.

▼ What the next moonwalker will wear. Spacesuit engineer Kristine Davis in the new 'extravehicular mobility unit'

"But it leaves an interesting puzzle. The reason that we're flying humans is because we have this unique capability to synthesise the unexpected. But maybe we didn't anticipate something when we built the computer. Can the crew understand what the computer has been trying to do, and then insert themselves into that process to achieve mission success? A big part of our training is to give them enough background on what the vehicle is doing."

Looking forward to the Moon landing of Artemis III, the lunar environment hasn't changed at all since Apollo – it's still dusty with one-sixth the gravity of Earth. The landing will happen near the southern pole and the low Sun will cast many more shadows than the more equatorial Apollo landings. One area that has improved, however, is the space suits, which are much better fitting, with more mobility, meaning astronauts should be able to bounce-walk across the surface with ease. ▸



The Gateway will host astronauts on their way to the Moon and potentially even Mars

ILLUSTRATION

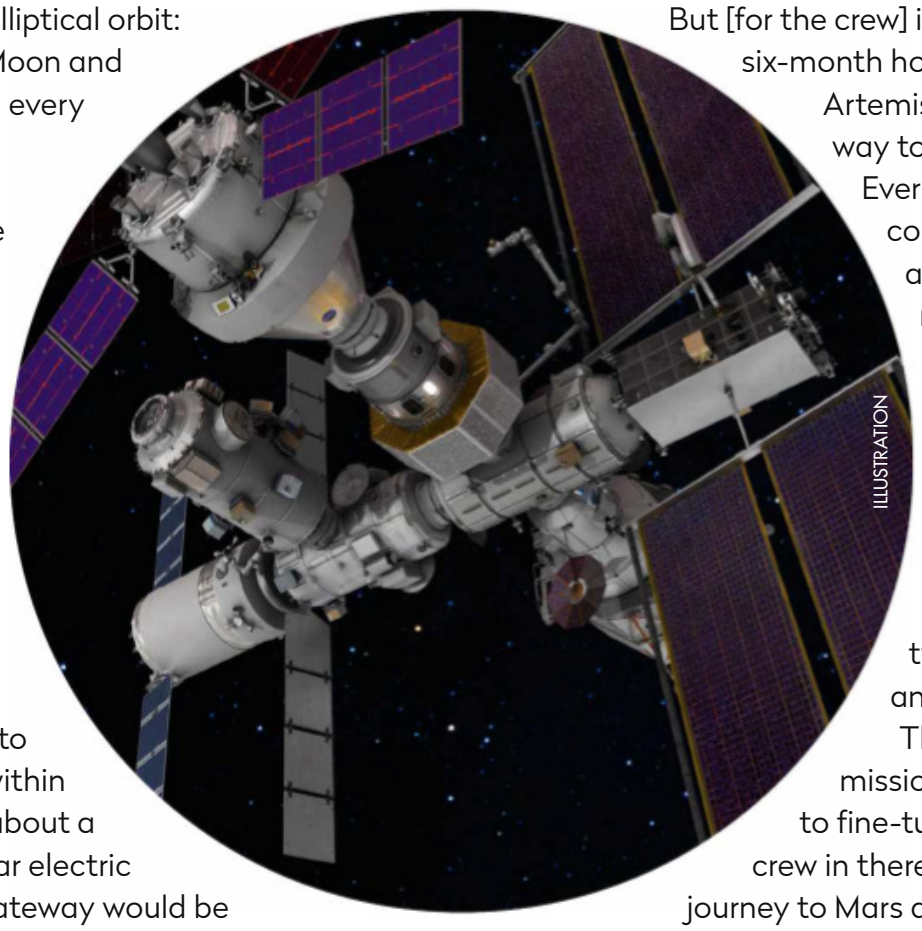
Gateway to the Moon

Dan Hartman, programme manager for NASA's Lunar Gateway, tells us about the ambitious project to construct a permanent space station in orbit around the Moon

The Lunar Gateway will sit in an elliptical orbit: we'll get within 10,000km of the Moon and then out to about 70,000km. And every six-and-a-half days we'll make a complete revolution.

It'll be maybe one-eighth of the size of the ISS and is going to be human-tended, nominally for 30 days but we can go to 60 or 90 days. Even though it's not permanently crewed, we are going to run research on the Lunar Gateway 24/7, 365 days a year. The first two elements of the Gateway – the PPE (Power Propulsion Element) and HALO (Habitation and Logistics Outpost) – are planned to fly up on a Falcon Heavy rocket within the next few years, and will take about a year to get to the Moon using solar electric power propulsion. So the initial Gateway would be in place and ready to accommodate the first crew of Artemis IV in late 2026.

It will have a lot of similarities with the International Space Station: a cupola, so the crew can see out; exercise devices and sleep stations.



ILLUSTRATION

▲ **Like the ISS, the Gateway will be habitable, but it won't have permanent crew**

But [for the crew] it's more of a camping trip than a six-month hotel stay like the ISS.

Artemis III is our fastest, least complex way to get a crew to the surface. Every mission after that is going to come to the Gateway. It will be an aggregation point. Ahead of a mission we'll launch the supplies, research tools, EVA suits, all those kinds of things, as well as the human landing system.

Finally, the four crew will come on an Orion. [Once on board] two crew get in a lander and go to the surface of the Moon, while two crew stay on the Gateway and do research or maintenance.

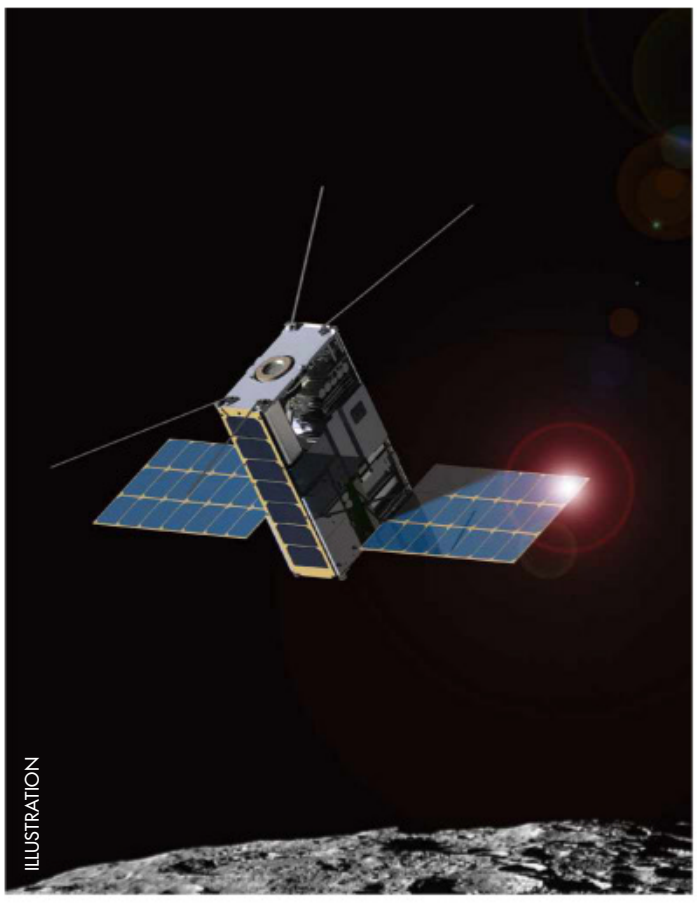
Thinking forward to potential Mars missions, the Gateway offers a place to fine-tune modules before you put the crew in there to head off on an 18-month journey to Mars and back.

We're building the Gateway to last 15 years. Just like the ISS, which extended its life based on how well it's performing, I fully envision us doing the same on Gateway. It wouldn't surprise me if we're good for 20 or 25 years."

NASA/ALBERTO BERTOLIN, NASA X 3

Small spacecraft, big science

Ten shoebox-sized CubeSats are hitching a ride on top of the Artemis I mission. We meet **Andres Martinez**, programme executive for NASA's Small Spacecrafts, to find out more



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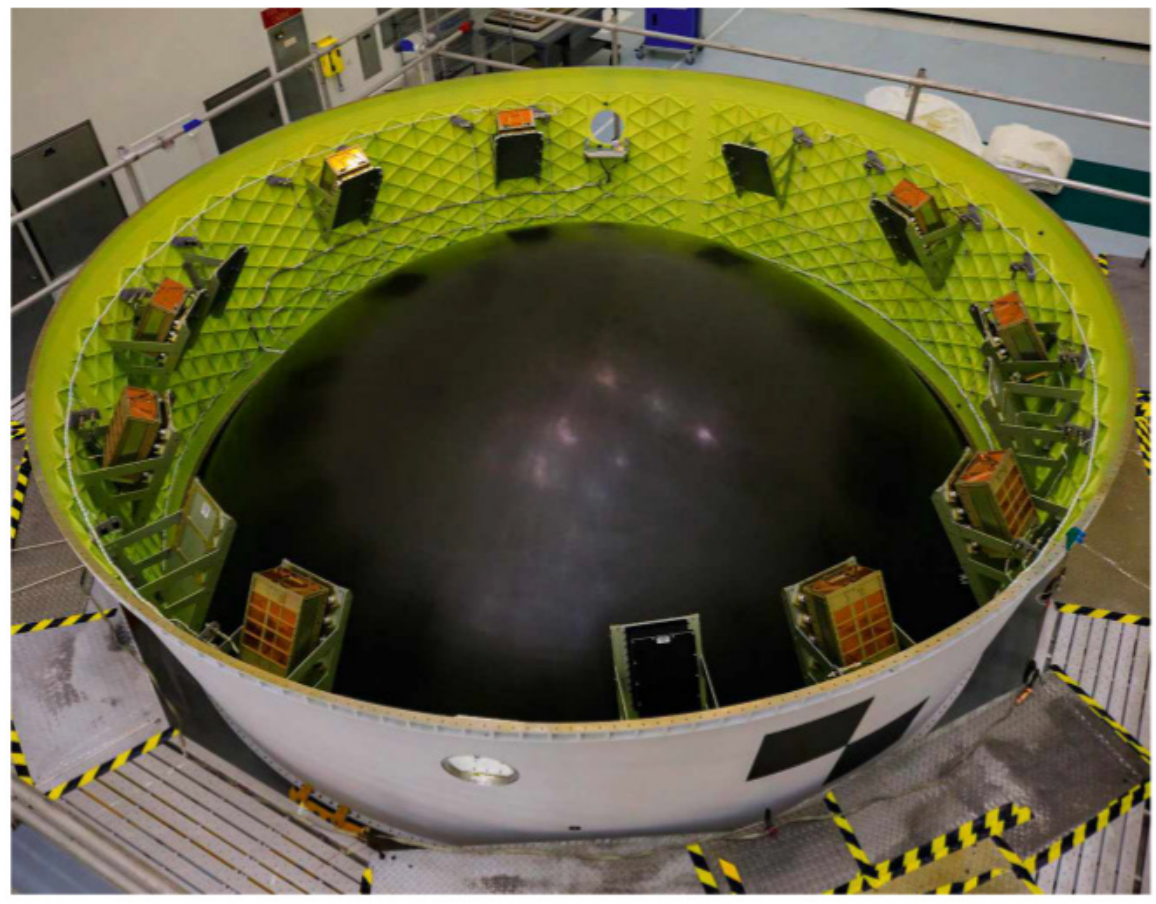

▲ **Above left: a secondary payload to Artemis I, Lunar IceCube will map water on the Moon**

Above right: CubeSats being installed inside the SLS's Orion Stage Adapter in 2021

How many CubeSats are on board Artemis I?
There are 10 CubeSats installed alongside Artemis I. Seven of them are sponsored by NASA; four are under my responsibility. We also have three international CubeSats aboard. When you see the size of these CubeSats, and look into the incredible science that we're going to be conducting, your first reaction is 'no way!', because they're the size of a shoebox.

What sort of science will your four CubeSats be conducting?
The first is called Lunar IceCube and is led by Morehead State University in eastern Kentucky, with 100 university students participating. Lunar IceCube will orbit the Moon for six months and has an incredible infrared spectrometer. It will document where water is on the Moon and its daily movement.

The second one, LunIR, is led by Lockheed Martin. It doesn't have any propulsion, but will travel on a ballistic trajectory straight to the Moon. Over the 72 minutes that it goes by the Moon it's going to take some incredible high-resolution images with a very sophisticated infrared instrument.

Shaoni Bhattacharya is a science writer and editor, as well as a short fiction author

The third is the Near-Earth Asteroid Scout, led by Marshall Space Flight Center. It will rendezvous with an asteroid, take images and send those back to us. It will use a 80m^2 solar sail – the size of a bus – as its main propulsion system. The target asteroid is about the size of a Volkswagen.

The fourth mission is BioSentinel, led by Ames, which will send live biology further into space than ever before, namely yeast. We are going to put BioSentinel in a heliocentric orbit, trailing behind Earth. As we expect solar events to take place, it will go through very harmful radiation and we're going to document the effects on live organisms.

Do you have a favourite CubeSat?
I'm very fond of Lunar IceCube because I saw many kids grow up during the project. A couple were a little cocky, but I could see fear in some of them – especially when I walked into the room in a suit with a NASA pin. The first thing I would tell them was "I'm one of you. NASA is on your team." What makes me super-happy is that a lot of these kids have now graduated and come to work here at NASA.