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Getting Artemis right

NASA must balance safety and science as it assesses 13 potential landing sites for its historic return to the moon. PAGE 30

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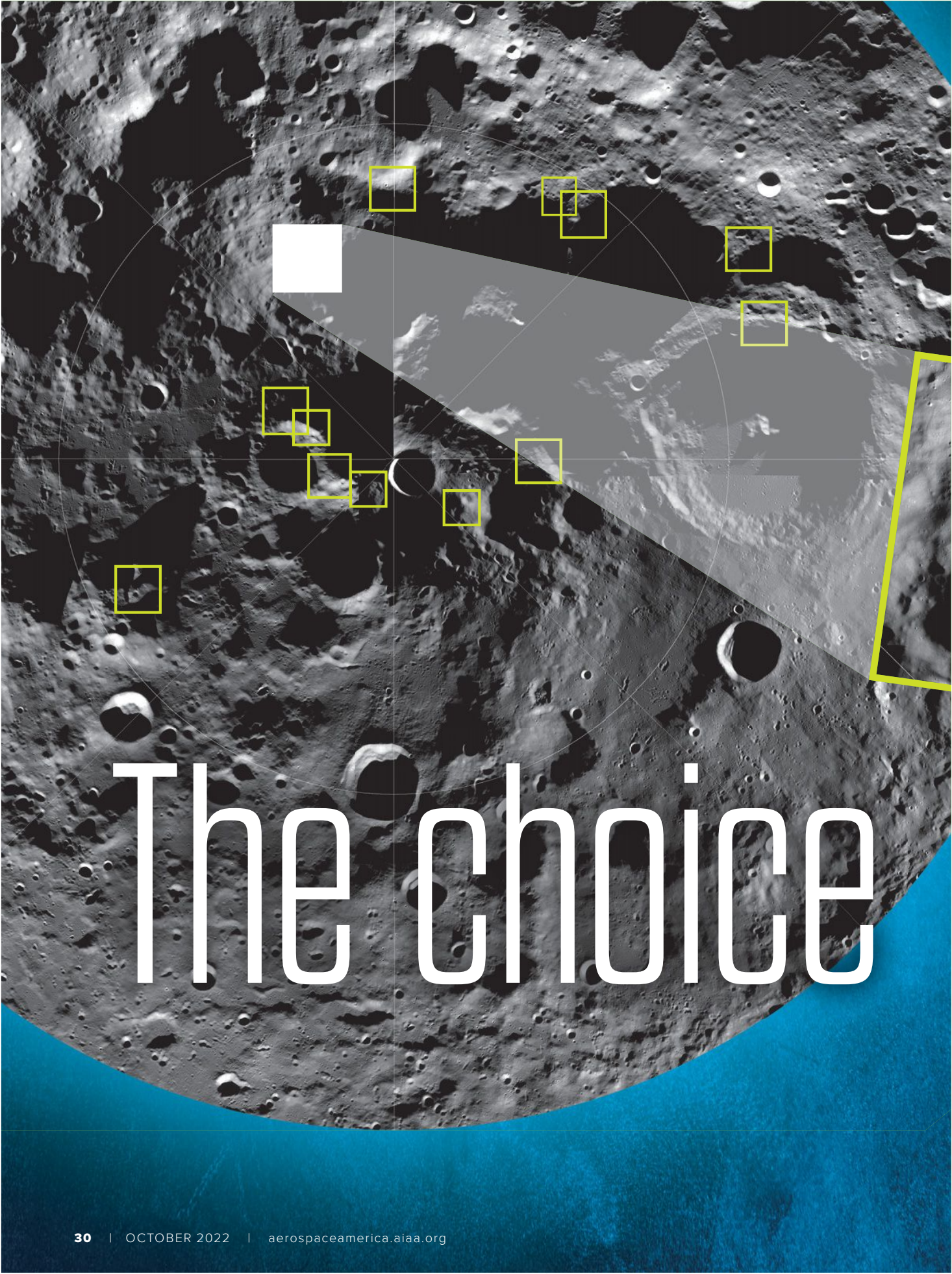
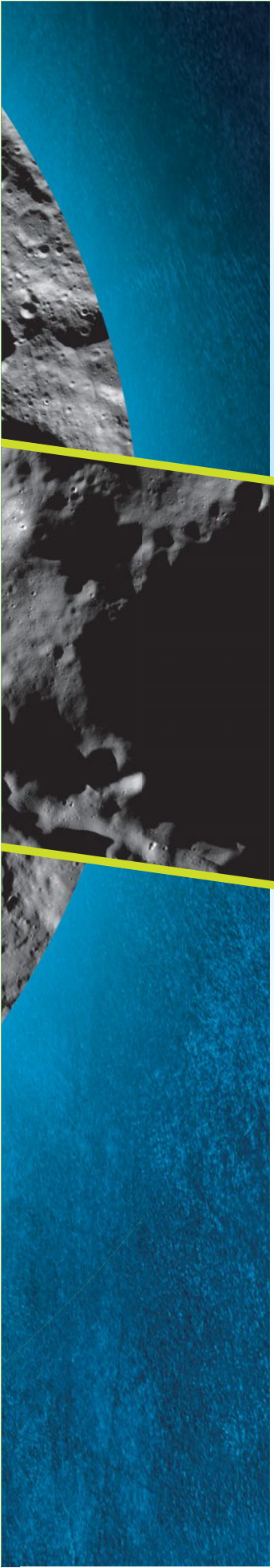


The choice



We've all heard of the Sea of Tranquility where the Eagle touched down in the historic Apollo 11 mission. In a few years, if things go as NASA plans, another region could become world famous as the place where the United States made its human return to the moon. Jon Kelvey spoke to scientists who aim to help NASA choose a safe but scientifically exciting area to land.

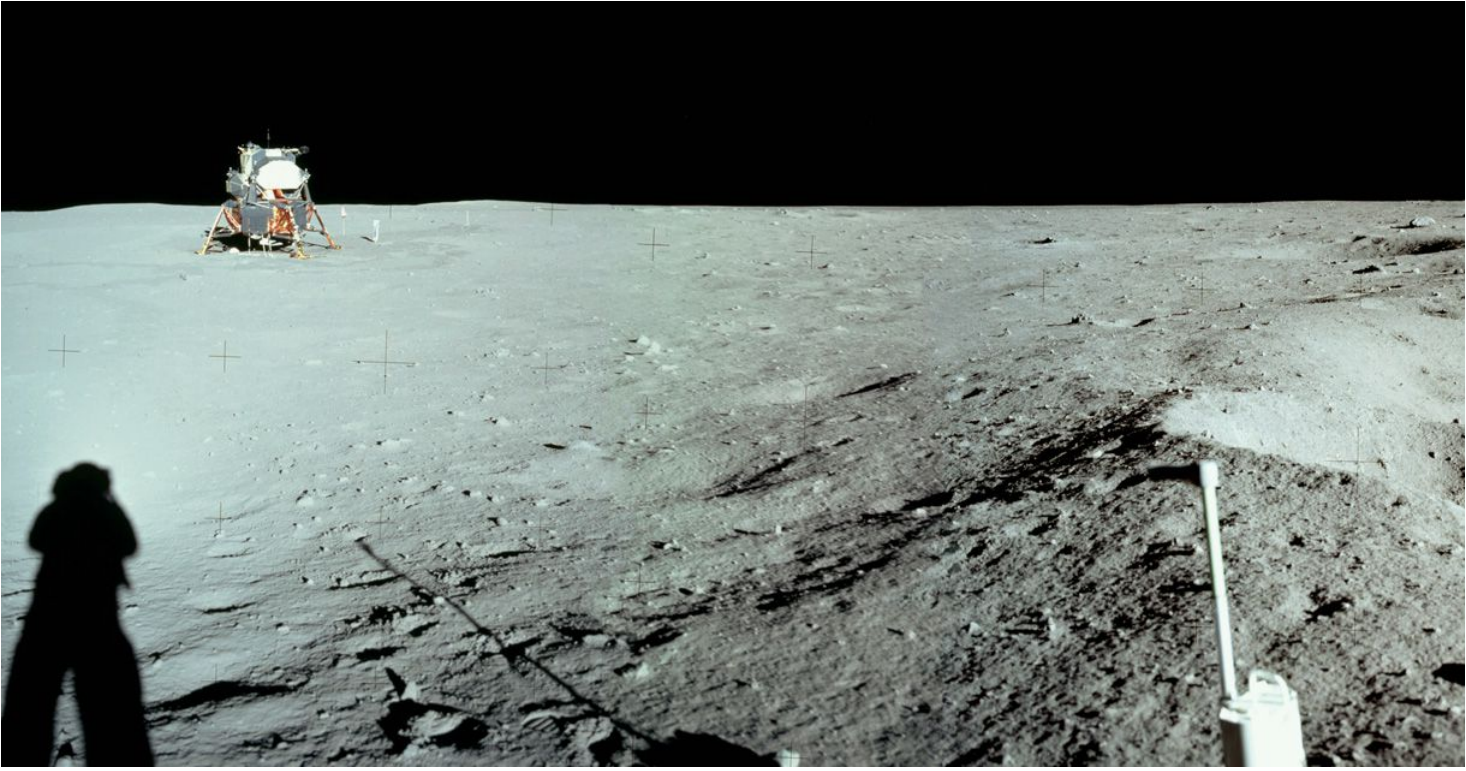
BY JON KELVEY | jonkelvey@gmail.com

When NASA astronauts step out of a modified version of SpaceX's Starship spacecraft and onto the surface of the moon in 2025, they'll be presented with terrain far different than the relatively flat and sunny equatorial sites of the Apollo missions. Artemis III, if all goes according to plan, will take them within about six degrees latitude of the lunar south pole, an area of towering mountains and deep impact craters meeting or exceeding the most tortured topography on Earth. And being near the pole, sunlight comes in at a shallow angle and is highly variable: There are peaks of eternal light and pits of endless darkness, with a chiaroscuro landscape of long shadows and streaks of light in between them.

It's a landscape Lunar and Planetary Institute principal scientist David Kring can only describe as magnificent. "If this type of topography was anywhere on Earth, it would be a national park," he says. Measuring from the depths of some craters to the nearby peaks "is an elevation change that is higher than Mount Everest on Earth."

The terrain will present multiple challenges for safely landing astronauts and giving them adequate mobility. But that same landscape may also bring incredible discoveries, such as ancient water ice preserved in the permanent shadows inside impact craters and impact ejecta from deep within the moon's primordial crust. Beyond the thrill of the science, this is an environment where NASA would like to learn to live off the land, creating rocket fuel and other necessities in situ out of lunar ice and regolith as a practice run for going to Mars.

Among the first orders of business will be deciding just where to touch down on the polar landscape, and to make that choice, NASA must balance astronaut safety, exploration and scientific objectives. So far, NASA has settled on 13 potential landing regions, and the agency plans to work at whittling those options down right up until the launch of the Artemis II lunar flyby, the first crewed mission by a Space Launch System rocket scheduled for 2024. NASA officials say they will select a final destination for Artemis III by the time that mission's SLS rocket is launched in 2025, but it's complicated. Exactly where the crew touches down could depend on the specific timing of the launch.



▲ Apollo 11 astronaut Neil Armstrong took this panorama of the Tranquility Base landing site while standing near the rim of the Little West Crater. Similarly, NASA wants to choose a landing site for Artemis III that would put the astronauts and their Starship lander within close range of shadowed craters or other features of interest in the south pole.

NASA

A lunar menu

On Aug. 19, NASA issued a press release and held an audio teleconference to announce these 13 candidate regions. The term "region" is deliberate, as these are 15-by-15-kilometer areas, each containing multiple potential landing sites about 100 meters across — parking spots within parking lots. Most of the contenders are named for the large features they're near, such as Nobile rim 1 and Nobile rim 2. These regions are on the rim of the large Nobile impact crater, itself named for Umberto Nobile, an Italian arctic explorer and developer of airships in the interwar years. The large Shackleton Crater is named after Antarctic explorer Ernest Shackleton.

All together, the regions offer a wide variety of terrains across hundreds of square kilometers around the south pole. Kevin Cannon, an assistant professor of geology and space resources at the Colorado School of Mines, was pleasantly surprised by the number of candidate regions identified by NASA and their diversity.

"There are some perched on giant mountains that are very highly illuminated for large portions of the time. There are others next to gigantic impact craters that could host deep reservoirs of ice, and then there's everything in between that," he says. "In the past, there's been a more narrow focus just on Shackleton and the immediate surroundings. It's good in that it gives the science and space resources communities a lot to talk about leading up to the landing."

For instance, take Malapert Massif, named after 17th century Belgian astronomer Charles Malapert. "It's the biggest, tallest mountain at the south pole, which means it gets some of the most light," says Sarah Noble, NASA's Artemis lunar science lead. Malapert is a great landing region for visibility and solar power, but it may lack access to shadowed regions containing water ice.

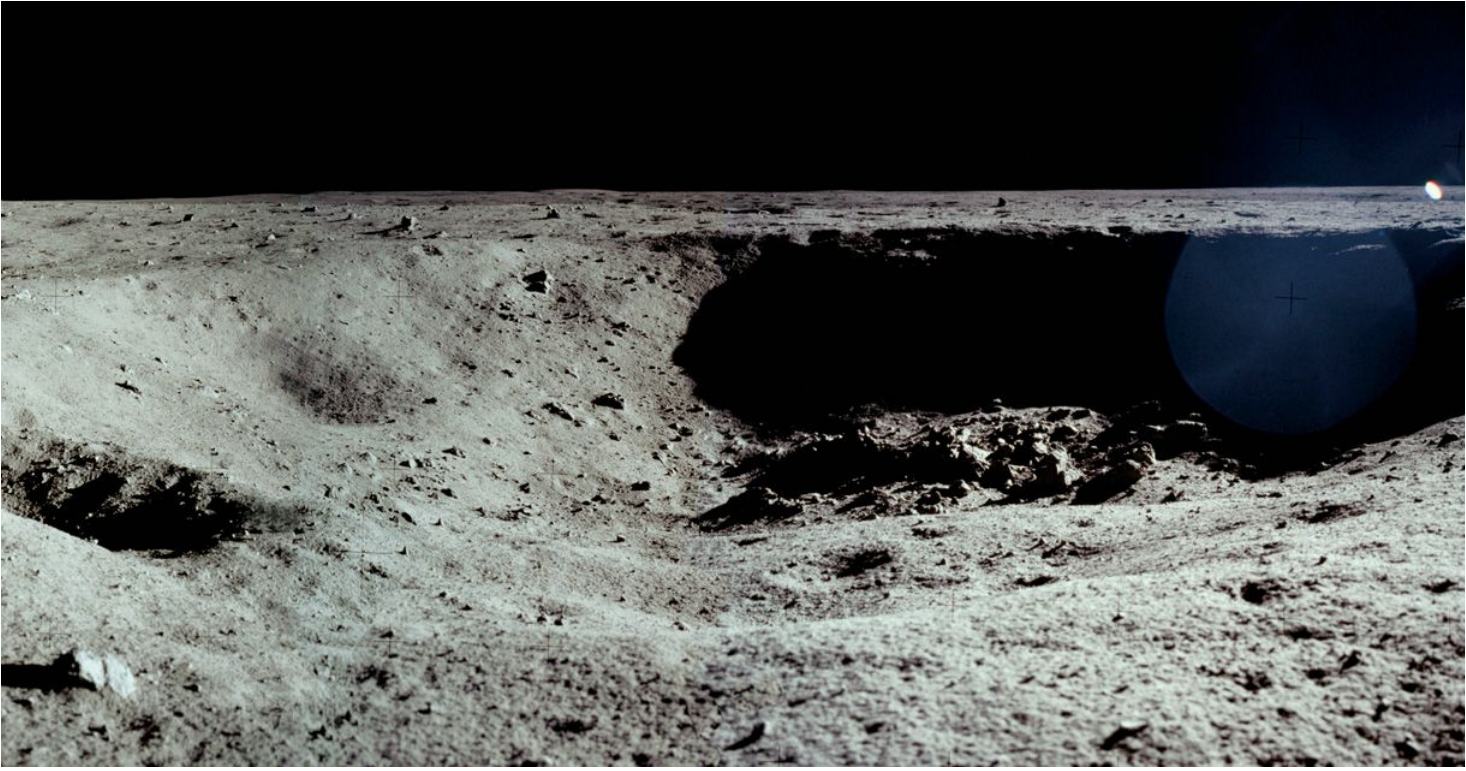
The rims of Amundsen or Nobile, 50- to 80-kilometer-wide craters, meanwhile, "are some of the regions that people are most excited about as potentially having a lot of water ice," Cannon says, but that comes with less guaranteed sunlight.

The site selection process is all about such trade-offs and providing balanced options, according to NASA's Tamra George, surface mission planning lead for Artemis campaign development, a role within NASA's Cross-Artemis Site Selection Analysis group. When George joined the group in July 2021, it had identified a larger number of potential landing regions based on Lunar Reconnaissance Orbiter data.

"When I stepped in," she says, the task was to take "over 20 regions and start narrowing it down to where we can [eventually] get to three to five specific candidate sites" within multiple regions.

CASSA began filtering regions by assessing them by basic constraints. For instance, out of a concern for astronaut safety, NASA requires that the Starship Human Landing System land at no more than 8 degrees from vertical, which can be met by touching down on a slope of 8 degrees or less. The Starship could also land on a steeper slope and adjust after that initial descent. CASSA's assessment assumes landing sites would have a slope of 10 degrees or less.

Any landing site should also be relatively close to places astronauts will want to explore, particularly permanently shadowed regions. While later Artemis missions will use rovers, Artemis III astronauts will



"We're not going to go down into Shackleton [Crater]. That would be the equivalent of walking to the bottom of the Grand Canyon, in darkness, with no path to follow."

— Sarah Noble, NASA

have to hoof it in surface "extravehicular activity" spacesuits built by Axiom Space of Texas that will limit their range to about 2 kilometers, according to Kring.

The most interesting shadowed regions will be inaccessible, at least to Artemis III astronauts, as NASA is not yet confident they can land safely in the darkness of a big crater, or that astronauts could climb into one.

"We're not going to go down into Shackleton [Crater]," Noble says. "That would be the equivalent of walking to the bottom of the Grand Canyon, in darkness, with no path to follow."

But don't rule out the crater's vicinity completely for Artemis III: Still among the contenders is a region imaginatively named "Peak near Shackleton," a high point overlooking the deep crater.

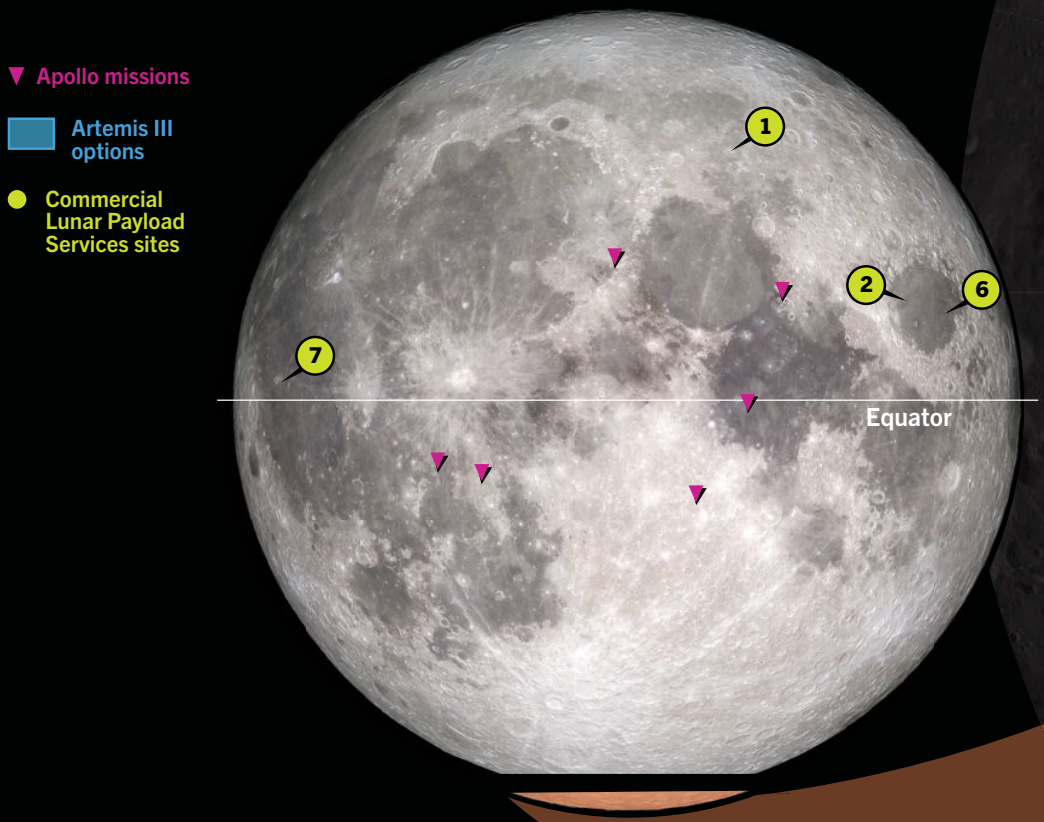
Instead of hiking into deep and dangerous craters, NASA wants astronauts to land within walking distance of smaller craters with permanently shadowed regions where they may still find ice and volatiles while maintaining critically important access to sunlight for what would essentially be a solar- and battery-powered operation. Whereas Apollo astronauts could count on 14 Earth days of continuous sunshine across landing sites at or near the lunar equator, the 13 Artemis III candidate regions experience wildly varying amounts of sunshine. There's almost no single region that can guarantee the six to seven days of sunlight needed for Artemis III for every possible launch date — so depending on when the mission launches, certain regions will be ruled out.

In comments to reporters in late August, Deputy Associate Administrator for the Artemis campaign Mark Kirasich said NASA is working with SpaceX to assess specific landing sites within the 13 regions, with the aim of creating a shortlist of sites that would be illuminated at different times based on the various launch windows. The list could include sites from different regions.

"There will be more than one," he said at the time. "Exactly how many we don't know yet."

Back to the moon

For its human landing under the Artemis program, NASA is not limiting itself to the equatorial region explored during the six Apollo landings. Ahead of the Artemis III crewed landing scheduled to touch down in the south pole in 2025, plans call for launching later this year the first in a series of robotic missions consisting of NASA instruments and rovers aboard commercial landers.



ROBOTIC MISSIONS*

1 Peregrine Mission One

Astrobotic's Peregrine lander will deliver 11 payloads from NASA, the German Aerospace Center and companies to the basaltic lava-filled crater Lacus Mortis. Among them: The shoebox-sized IRIS rover built by Carnegie Mellon University will roll off the lander and take pictures of the lunar dust during its 72-hour lifespan, a test of future autonomous robots that could prep a lunar base before crew arrives.

Launch details:
Late 2022 by a United Launch Alliance Vulcan Centaur

2 Intuitive Machines 1

An Intuitive Machines Nova C lander will deliver 11 payloads from NASA and companies on Mare Crisium, a flat plane of basalt. A NASA-built camera will record and photograph how the lander stirs up regolith upon descent, a technique that future crews could employ to ensure safe landings.

Launch details:
2023 by a SpaceX Falcon 9

3 PRIME-1

The Polar Resources Ice Mining Experiment-1 experiment aboard an Intuitive Machines Nova C lander will land near the connecting ridge between Shackleton, de Gerlache and Sverdrup craters. A 1-meter-long drill built by Honeybee Robotics will collect regolith below the surface, and a NASA-built mass spectrometer will analyze it for evidence of water ice that future explorers could harvest.

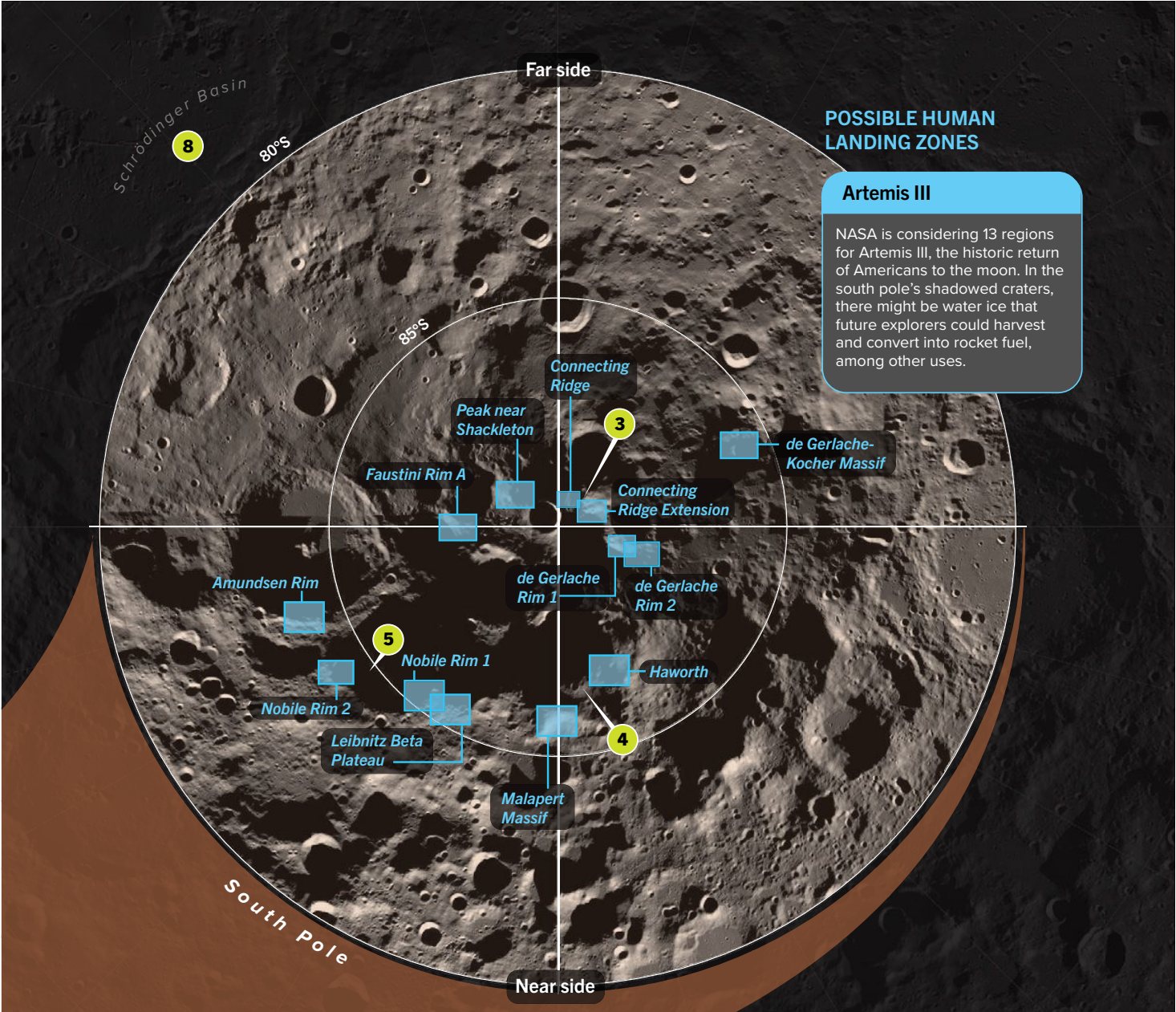
Launch details:
2023 by a SpaceX Falcon 9

4 Masten Mission One

A Masten Space Systems XL-1 lander had been tasked with delivering nine instruments to the rim of Haworth Crater, but the company declared bankruptcy in July and was purchased by Astrobotic in September. NASA has not said how the mission might be affected.

Launch details:
2023 by a SpaceX Falcon 9

Graphic by David Evans, reporting by Jacqueline Havelka and Cat Hofacker
Sources: NASA/GSFC/Arizona State University



POSSIBLE HUMAN LANDING ZONES

Artemis III

NASA is considering 13 regions for Artemis III, the historic return of Americans to the moon. In the south pole's shadowed craters, there might be water ice that future explorers could harvest and convert into rocket fuel, among other uses.

5 VIPER

The Volatiles Polar Exploration Rover built by NASA's Johnson Space Center will roll off an Astrobotic Griffin lander to explore various sites around the ridge of the permanently shadowed Nobile Crater gathering water ice, frozen carbon dioxide and other substances that vaporize easily and could be of use to explorers.

Launch details:
November 2024 by a SpaceX Falcon Heavy

6 Blue Ghost Mission 1

Ten NASA payloads and an unspecified number of commercial payloads will operate for a full lunar day (14 Earth days) in the Mare Crisium basin after landing aboard a Blue Ghost lander from Firefly Aerospace. NASA's Lunar GNSS Receiver Experiment will attempt to transmit and receive navigation signals, the first step toward establishing lunar GPS.

Launch details:
2024 by a SpaceX Falcon 9

7 Intuitive Machines 3

An Intuitive Machines Nova C lander will deliver four NASA experiments to the Reiner Gamma swirl. Among them is CADRE, Cooperative Autonomous Distributed Robotic Exploration, a swarm of tiny robots that will explore the area.

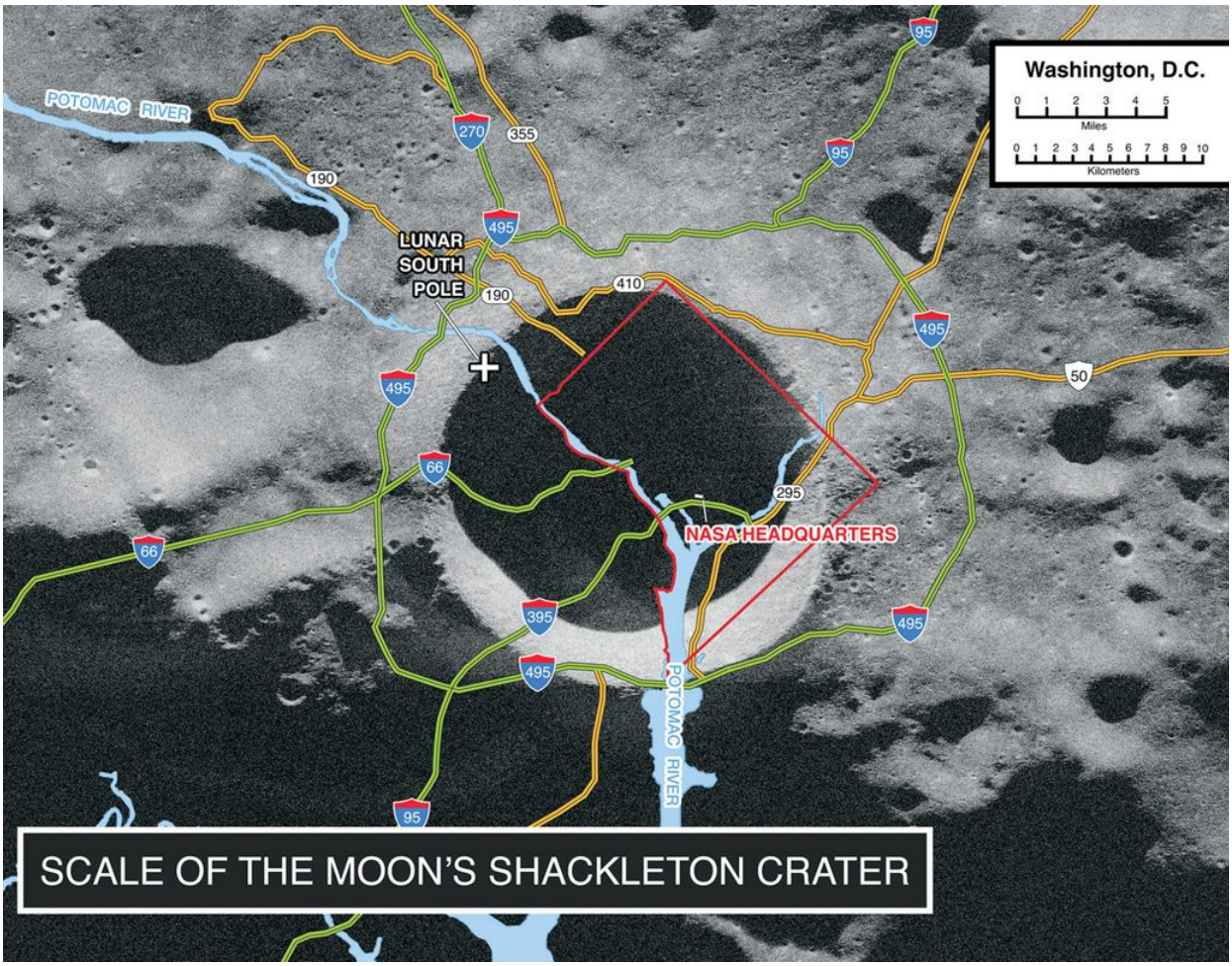
Launch details:
2024 by a SpaceX Falcon 9

8 CP-12

Draper's SERIES-2 lander will deliver three suites of NASA instruments to Schrödinger Basin to study geophysical activity on the lunar far side, shielded from Earth's electromagnetic field. The Farside Seismic Suite of seismometers built by NASA's Jet Propulsion Laboratory will determine how often meteorites crash into the lunar far side.

Launch details:
2025 by a rocket not yet chosen

*Missions for which landing sites and providers have been designated



▲ At 21 kilometers in diameter, the moon's Shackleton Crater is about the size of Washington, D.C. The massive crater could harbor water ice in its permanently shadowed floor, making it a contender for human and robotic missions under the Artemis program.

Lunar and Planetary Institute/CLSE

Why the south pole?

Given all the constraints on operating in the extreme environment, why not aim for another equatorial site? After all, the low sun angle and terrain in the south pole will produce long, dark shadows that could be disorienting to astronauts and make generating powerful more difficult to boot.

"I'm sure you've driven down the road right as the sun is setting, and your visor just isn't low enough and you're frustrated that your sunglasses aren't the greatest," George says. "That illumination in your face and those long shadows are going to be very challenging."

NASA has been practicing for those difficult conditions by taking astronauts to the Arizona desert at night to walk about with bright spotlights in their eyes.

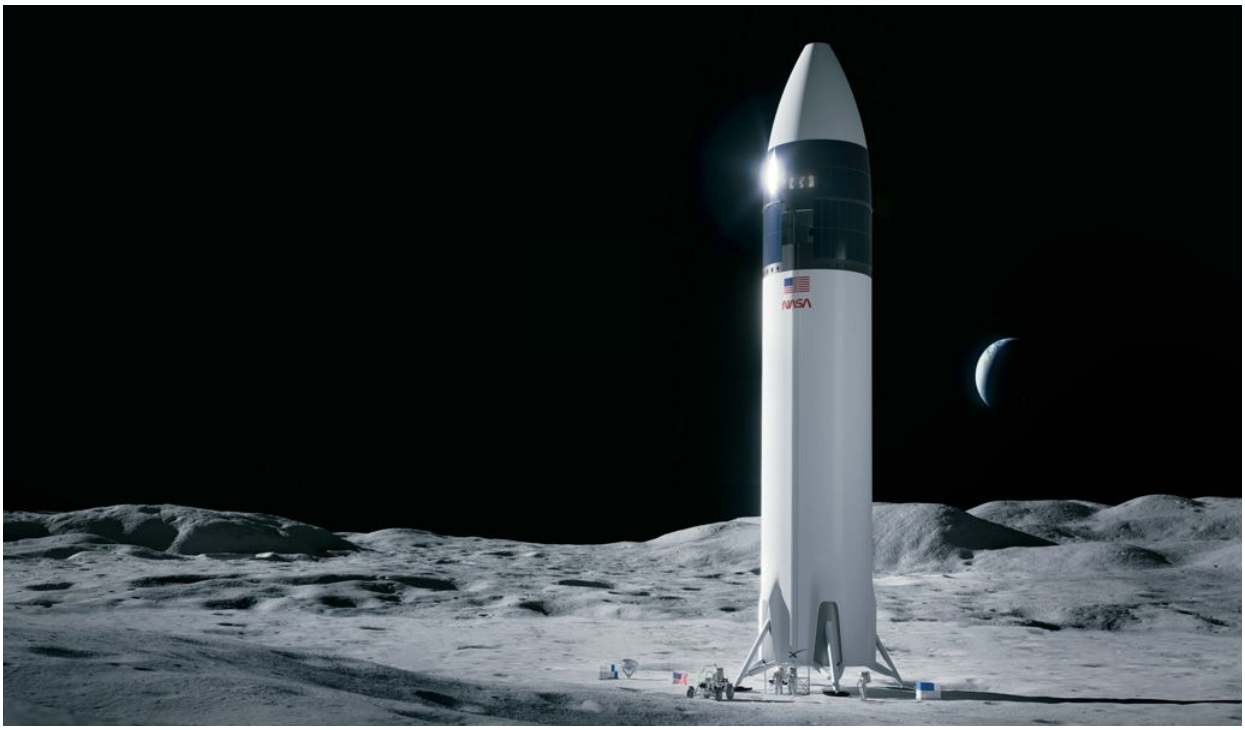
On the other side of the balance sheet are the potentially huge rewards of exploring the south pole, particularly when it comes to water ice. NASA views water on the moon as the key to long-term habitability, not just as a resource for drinking water but also for creating rocket fuel in space, which at least in theory should be far less costly than flying it up from Earth.

"We take that water ice, electrolyze it, turn it into hydrogen and oxygen; you get both your fuel and your oxidizer," Cannon says.

In terms of science, some of the permanently shadowed regions may contain water and other substances that vaporize easily. These have been undisturbed for billions of years, which could help scientists determine how water moved around in the early solar system and ultimately wound up on Earth.

"Where does that water come from?" Noble asks. "Where's it been?"

Meanwhile, the entire south polar region is blanketed in rocks from ancient impacts. According to Kring, these rocks could offer insights from deep within the moon. His group performed a close study of potential landing sites in the Connecting Ridge candidate region located near Shackleton, a 4.2-kilometer-deep, 21-kilometer-wide crater dug by an impact that scattered ejecta far beyond its rim. "So you have the potential of collecting material from 4.2 kilometers beneath the lunar surface," Kring says. At least 4 billion years old, such material is "the primordial crust of the moon."



▲ The Starship lander that will deliver two astronauts to the surface must land on a slope no greater than 8 degrees, to stay within NASA's safety criteria designed to keep the lander from tipping over. At 50 meters tall, the Statue of Liberty-sized design would tower over the 7-meter-tall Apollo Lunar Module.

SpaceX

Such samples would not only yield more insight into the formation of the moon, but also help scientists better estimate the age of our own planet and that of every planet in the solar system by providing a more refined timeline of when this cratering occurred.

"The impact cratering record, that is the timing that we derived for the moon, establishes a clock that is applied to all other planetary surfaces in the solar system," Kring says, "and that clock is calibrated on a very small number of sites."

By adding new samples to those collected during the Apollo missions, especially ancient rocks ejected from deep within the moon's crust that have never been directly studied and dated before, scientists could further refine the timing of impacts and planetary evolution for all planetary surfaces. And in some sense, that makes it difficult to pick a bad site from any of the 13 regions.

"Literally anywhere we go and pick up a rock, that rock is going to have a lot of value," Noble says, "because it's just a different part of the moon."

Making the call

Where does that leave NASA in the selection process? According to Kirasich's comments in August, NASA would like to firm up the shortlist of landing sites within each region where the Starship could touch down "about 18 months prior to launch."

"Sometime in 2024, we'll narrow down the list," he said.

But in the meantime, NASA hopes the lunar science community will weigh in, as Kring and Cannon have, to help NASA winnow down the choices.

"There is good science to be done at all 13 of these [regions], for sure," Noble says. "Is it all equally good? That's a harder question, and it's one that we're really looking to the science community now to help us explore."

Kring's group, for instance, has conducted detailed analyses of potential landing sites in the Connecting Ridge region. And in August, the group published a paper in the Geophysical Research Papers journal describing a technique for mapping the interiors of otherwise dark permanently shadowed regions ahead of the arrival of astronauts. NASA could then make a more informed decision about which shadowed areas to visit.

Still, there are considerations NASA must weigh that scientists cannot help with, such as whether the choice of region should be tied to planning for the planned Artemis Base Camp that would be constructed for later Artemis missions.

"It's my responsibility as a lunar scientist to provide an assessment of the geology," Kring says, "and it's the agency's responsibility to then use that information and make a decision."

That's going to involve a lot more discussions and back and forth between NASA and scientists, Cannon adds, and that's why the Artemis program is beginning to feel real and exciting.

"They put up these 13 candidate sites, and now," he says, "the fun starts: to actually look at these in a lot more detail and start planning." ★