

## *Quo vadis*, NASA: The Moon, Mars, or both?

NASA

Fifty years after *Apollo 11*, the US spaceflight program is juggling political and technological factors as it moves toward the red planet, its ultimate destination.

**P**resident Trump, NASA's leadership, Congress, and advocates for human space exploration agree that Mars should be the ultimate destination for the US spaceflight program. But will the administration's plan to send astronauts back to the Moon advance a Mars mission, or could the lunar program draw resources away from Mars and thus delay an excursion to the red planet?

In March of this year, Vice President Pence announced the administration's decision to move up by four years, to 2024, its target date for sending astronauts, including the first woman, to the Moon. But congressional appropriators' rejection of the administration's request to add \$1.6 billion to NASA's fiscal year 2020 budget to accelerate the Moon landing program casts doubt on the 2024 goal.

Trump's December 2017 executive order, Space Policy Directive 1, acknowledged the goal of getting to Mars even as it ordered a return to the Moon. The 2017 NASA authorization act—which does not provide funding—also confirmed Mars as the ultimate destination for human exploration.

Regardless of exactly when it may happen, is putting humans back on the lunar surface truly a prerequisite for going to Mars? "I wish I could give you a really crisp, black and white answer, but it is a bit nuanced," says Scott Hubbard, who was director of NASA's Ames Research Center and NASA's first Mars program manager.

"This debate has been going on for decades," says Hubbard. "You can make a solid case that you can send people to Mars with only minimal testing at the Moon." As far back as 1991, aerospace engineer Robert Zubrin and colleagues at Martin Marietta (now Lockheed Martin) floated a Mars Direct plan, which es-



**NASA ADMINISTRATOR JIM BRIDENSTINE** stands in front of an artist's depiction of a lunar lander as he addresses an industry forum on the agency's lunar exploration plans.

chewed a return to the Moon and the associated components of NASA's proposed lunar and Martian flight architecture.

Hubbard points to another proposal by three scientists at NASA's Jet Propulsion Laboratory (JPL) in 2015. It relied heavily on a set of elements already built or planned by NASA, such as the Space Launch System (SLS) heavy-lift rocket, the four-person Orion capsule, a deep-space habitat, and a 100 kW solar-electric-propelled "tug" for transporting supplies ahead of a human landing. The plan entailed few if any operations on the lunar surface and avoided complicated development programs such as nuclear-thermal propulsion. The JPL proposal envisioned an initial human mission landing on Phobos, the larger of Mars's two moons, in 2033, with a Mars touchdown in 2039.

More recently, SpaceX has proposed flying humans directly to Mars aboard its planned "starship." Paul Wooster, SpaceX's principal Mars engineer, told the Humans to Mars Summit (H2M) in May, "It's not unreasonable" that the

company will put people on the planet by the mid 2020s.

Jonathan Lunine, a Cornell University astronomer who cochaired a National Academy of Sciences (NAS) review of NASA's human spaceflight program in 2014, says that "from a strictly engineering point of view," a direct-to-Mars approach is feasible. "But you increase the risk tremendously, from two points of view: One, you're not going to be testing a lot of technologies until you actually get to Mars; and two, politically, because you don't have an intermediate goal in a program that is going to stretch significantly in time beyond what Apollo was."

Returning to the Moon would build momentum in a human spaceflight program that hasn't ventured beyond low-Earth orbit since the Apollo program ended in 1972. "If we wait until Mars, the whole government spaceflight program will collapse of its own weight," says John Logsdon, emeritus professor of space policy at George Washington University. "There's a pretty convincing case

for making the Moon a first goal, but not the last goal.”

Ken Bowersox, deputy associate administrator for NASA’s human exploration and operations mission directorate, told H2M attendees that “everything we do [on the Moon] is intended to inform our journey to Mars.” A timetable for when humans could make such a trip could come as soon as 2025, he said.

## An alternate route

“Mars is the ultimate destination for human exploration of the inner solar system; but it is not the best first destination,” concluded the 2009 report of an advisory committee commissioned by the Obama administration. The findings of the panel, chaired by retired Lockheed Martin CEO Norman Augustine, led to the administration’s decision to excise the Moon as a destination for NASA’s exploration program (see *PHYSICS TODAY*, December 2009, page 25). The committee advised that alternate destinations—a lunar orbit, an asteroid, or a Lagrange point—were equally as useful as the surface of the Moon.

Obama chose an approach, outlined in the report, of sending a crewed spacecraft into a stable orbit near the Moon, from which a manned mission would

embark to a small asteroid. The rock would be physically redirected into an orbit near the Moon. In addition to being less expensive than landing on the Moon, a lunar orbiting spacecraft, the Augustine committee noted, could be a launching point for a Mars mission that would avoid the energy and fuel required to escape the Moon’s gravity. But the asteroid-redirect plan garnered little support from scientists.

Obama science adviser John Holdren says the administration concluded that “there was little point in putting astronauts on the Moon again, more than 50 years after we did it the first time, unless we were going to do significantly more when we got there—meaning in our view setting up a crewed base.” At the time, NASA estimated the cost of putting a crewed base on the Moon at \$60 billion to \$80 billion, he says. “We saw no prospect of such a sum materializing on any time scale of planning interest.”

Although the Augustine panel said no viable human spaceflight program could be carried out for less than a \$3 billion addition to NASA’s budget, Holdren says Obama decided that the asteroid-redirect route could at least be started for an extra \$1 billion per year, the amount of additional funding Obama was willing to request from Congress.

Holdren estimates NASA will have to find an additional \$5 billion each year to meet its 2024 Moon-landing target.

## A proving ground

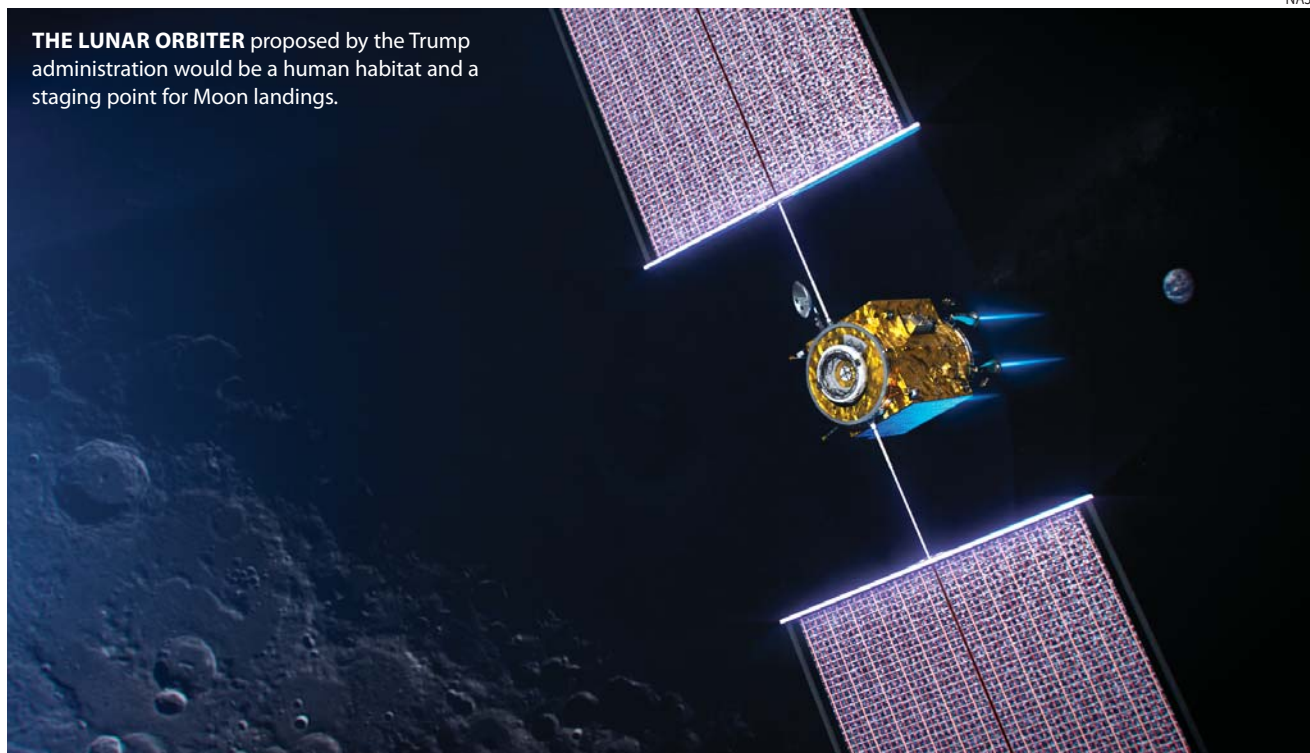
To NASA administrator Jim Bridenstine, who assumed NASA’s helm in April 2018, the Moon is “the proving ground” and “the path to get to Mars in the safest, fastest way possible. When we accelerate humans to the Moon we are by definition accelerating humans to Mars,” he told the H2M conference. In following Trump’s directive, NASA plans to establish a permanently staffed outpost on the lunar surface in 2028.

William Gerstenmaier, NASA associate administrator for human exploration and operations, told the House Science, Space, and Technology Committee in May that the Moon “provides an opportunity to demonstrate new technologies that we will use on crewed Mars missions: power and propulsion systems, human habitats, in-space manufacturing, life support systems, and *in situ* resource utilization.”

Clive Neal, a University of Notre Dame engineering professor and lunar exploration advocate, says going directly to Mars risks a repeat of the Apollo experience. Despite its success, Apollo was canceled due to its expense, and NASA

NASA

**THE LUNAR ORBITER** proposed by the Trump administration would be a human habitat and a staging point for Moon landings.





lacked any follow-on program. “You’ll wind up doing a one-and-done,” Neal says. “There won’t be longevity or sustainability in a program.” Unlike distant Mars, he adds, the Moon offers opportunities for commercial participation.

NASA in late May awarded 10-year contracts totaling \$250 million to three companies to begin transporting nearly two dozen payloads of instruments and other equipment to the lunar surface in late 2020. The agency’s FY 2020 budget request included \$1 billion for development of lunar landers by the private sector. Billionaire Jeff Bezos recently unveiled a mockup of a lunar lander being developed by his company, Blue Origin, although he provided no design details.

The poles of the Moon could hold, in permanently shaded craters, millions of tons of water ice that could be used to produce liquid oxygen and hydrogen to fuel a Mars-bound spacecraft, Neal and other experts say. Developing that resource could obviate the need to transport fuel from Earth. Additionally, surrounding a spacecraft with a meter-thick coating of water could protect astronauts from radiation on the way to a Mars orbit, says Neal.

NASA plans to use the Moon program, which it calls Artemis, to demonstrate several major components of the proposed Mars mission architecture. They include the lunar-orbiting command and control platform, to be assembled in space, from which reusable landers would embark from and return to the Moon and where astronauts would be stationed for months at a time. The gateway, as the platform is known, could also be useful for assessing the psychosocial and physical effects of long-duration space travel beyond near-Earth orbit. NASA officials envision initial crew visits of up to 30 days to the gateway and longer visits as additional modules are delivered. NASA in May awarded a \$375 million contract to Maxar Technologies of Colorado to build the first section of the gateway, the power and propulsion element. It’s due for launch in 2022. At least one other section will be needed to accommodate the planned 2024 landing.

Last year, the Sixth Community Workshop for Achievability and Sustainability of Human Exploration of Mars, a group of 70 experts on lunar and Martian exploration and science operations, compiled a list of technologies required for



**THIS SELF-PORTRAIT OF THE MARS CURIOSITY ROVER** at a location known as Mount Sharp shows the dusty and rocky terrain that future astronauts may encounter. For scale, the rover’s wheels are 50 centimeters in diameter and about 40 centimeters wide.

Mars that would benefit from experience gained from lunar operations. Among the transportation and propulsion needs were cryogenic propellant management, landers, and vehicle servicing and refueling. Operations on the Martian surface that could be advanced with knowledge from the Moon included human health and biomedicine, power systems, manned exploration rovers, and space suits. Others were *in situ* resource utilization—essentially living off the land—communications, and habitats and labs. The 2014 NAS report listed entry, descent, landing, advanced in-space propulsion and power, and radiation safety among key requirements for a Martian mission.

The proposed 2024 Moon landing will use the SLS and the Orion crew vehicle. Both were designed with lunar travel in mind. The first crewed flight of the SLS–Orion system is planned to orbit the Moon in 2022. The Government Accountability Office (GAO) reports that as of September 2018, the cost of the SLS, which NASA had scheduled for its initial launch last November, had grown by \$1 billion, or 10% over its 2014 baseline estimate, and will not meet its rescheduled June 2020 launch target. NASA officials remain hopeful of an SLS launch late next year. Orion, which was sup-

posed to fly uncrewed atop the SLS last fall, was at least \$379 million, or 6%, over budget as of mid 2018, according to the GAO. Prime contractor Lockheed Martin expects further cost growth.

## Maintaining focus

The NAS report stressed that systems developed for the Moon or other intermediate destinations should keep the Mars mission in mind. Lunine and others worry that relevance to Mars may be “traded away” in a sprint to get to the Moon by 2024. “The danger is that we will end up repeating an Apollo style landing on the Moon as an accomplishment in itself, and once again that will be the end,” Lunine says, mirroring Neal’s concern. Once humans return, “people will say that’s great, what’s next? And the what’s next is you would have to start from scratch, and there’s no impetus to start from scratch.”

Casey Dreier, chief advocate and senior space policy adviser at the Planetary Society, agrees. “You have to have very disciplined, focused, and deliberative decisions made on what to do if Mars is your long-term goal. If you say we have to land in 2024, do you really have the time or ability to focus on how that will work in a Mars environment? Probably not.”

Going to the Moon “would still represent a remarkable increase in capability from what we have right now for human spaceflight,” Dreier says. “I’ll happily see humans walking on the Moon if that means getting out of low-Earth orbit.”

Another problem with NASA’s current course, says Hubbard, is the high cost of maintaining humans in space, as evidenced by the more than \$3 billion NASA spends on the International Space Station (ISS) each year. The maintenance burden on NASA’s budget will grow much greater if a permanent habitation is set up on the Moon, and that will leave far less money for a Mars development program, he notes.

Key differences between Moon and Mars environments won’t allow for direct transfer of some elements, such as landers and manned rovers. Martian surface gravity is 38% of Earth’s, compared with the Moon’s 17% terrestrial fraction. Mars’s atmosphere provides some protection from radiation, whereas the Moon’s does not. Although dust is a hazard for humans and equipment on both bodies, dust storms occur only on Mars.

The NAS cautioned against wasting NASA resources and time on “dead-end” development programs that won’t be of use on Mars. Notably, the academy listed the single-use descent stage of the lander design for the 2024 lunar surface mission.

Propulsion systems are likely to differ from one destination to the other. Whereas the SLS–Orion system is conventionally fueled, NASA is eyeing both solar-electric and nuclear propulsion for Mars travel. The NAS study recommended nuclear propulsion for Mars travel, saying the power levels of the best solar-electric systems are far too low to use in human transit. Specifically, it called for developing both nuclear-thermal, in which a fluid such as liquid hydrogen is heated to high temperature to create thrust, and nuclear-electric, in which electricity generated by a nuclear reactor is used to drive a propellant at high speed. Neither has been deployed in space.

The two technologies are separate from radioisotope thermal generators, a nuclear technology that has powered more than two dozen spacecraft since the 1960s. Those devices generate thermal energy from the radioactive decay of plutonium-238, but aren’t powerful

enough for propulsion. (See PHYSICS TODAY, December 2017, page 26.)

Time-frame estimates for a crewed Mars landing range from 2033 to the 2040s and beyond. The launch window to the quickest path to Mars opens only every other year. The Science and Technology Policy Institute (STPI), which supports the White House Office of Science and Technology Policy, concluded that 2037 would be the earliest feasible date and 2039 the more likely date for a

launch to the red planet. It said that 2033, the date proposed in the 2017 NASA authorization act, “is infeasible under any budget scenario and technology development and testing schedules.”

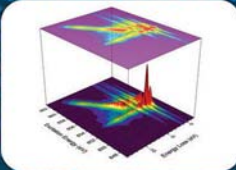
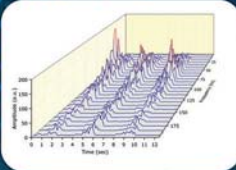
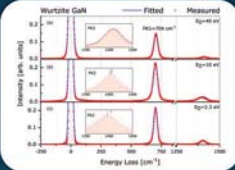
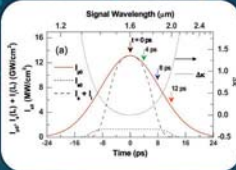
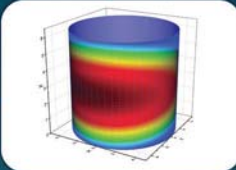
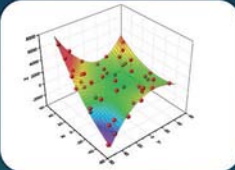
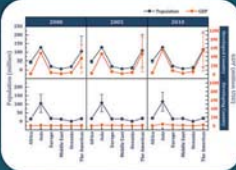
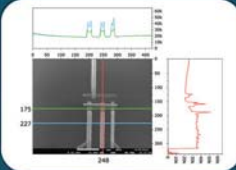
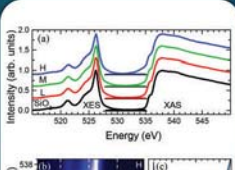
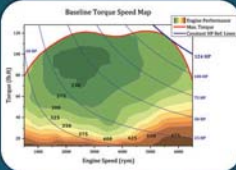
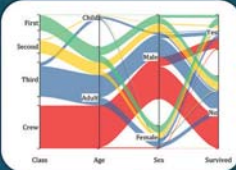
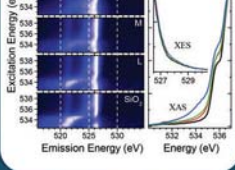
The NAS report committee estimated that the earliest crewed surface mission to Mars will occur between 2040 and 2050, assuming that the ISS is extended to 2028 and that the human spaceflight budget is increased at twice the rate of inflation.

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The STPI put the total cost of a NASA spaceflight program leading to a Mars landing in 2037 at \$217 billion, including \$121 billion devoted to Mars-related hardware development. Of the total, \$34 billion has been spent to date for the SLS and Orion programs. Lunine was less definitive when he told a House hearing in May that it would require hundreds of billions of dollars.

Although Bridenstine and other officials have repeatedly insisted that the cost will be shared with international partners, there have been few if any specifics. If the US wants to reduce the cost, says Lunine, "it will need the kind of international contributions that we have never seen before in human-piloted programs." For example, the US has borne 85% of the cost of the ISS and even pays for seats on Soyuz flights to the station. Moreover, he and others note, relations with China have deteriorated to the point that cooperation may not be possible. The other big challenge, Lunine adds, is how to cooperate with other nations without giving away US technologies.

David Kramer

## Domestic quarrels cloud future of South Korea's Institute for Basic Science

The country's network of curiosity-driven research centers is a scientific and cultural experiment.

Since its founding in 2011, the Institute for Basic Science (IBS) in South Korea has largely lived up to its ambitious goals. It has attracted top scientists, produced world-class science, and made inroads in internationalizing the country's research community. For continued success, however, the IBS must win over both the country's other scientists and its current politicians and con-

vince them that the big federal investment in a relatively small number of investigators is worthwhile.

When the IBS was created, South Korea had an impressive track record in applied science and manufacturing; the auto and electronics industries are examples. In launching the new initiative, the country's then president Myung-bak Lee noted that countries at the forefront of

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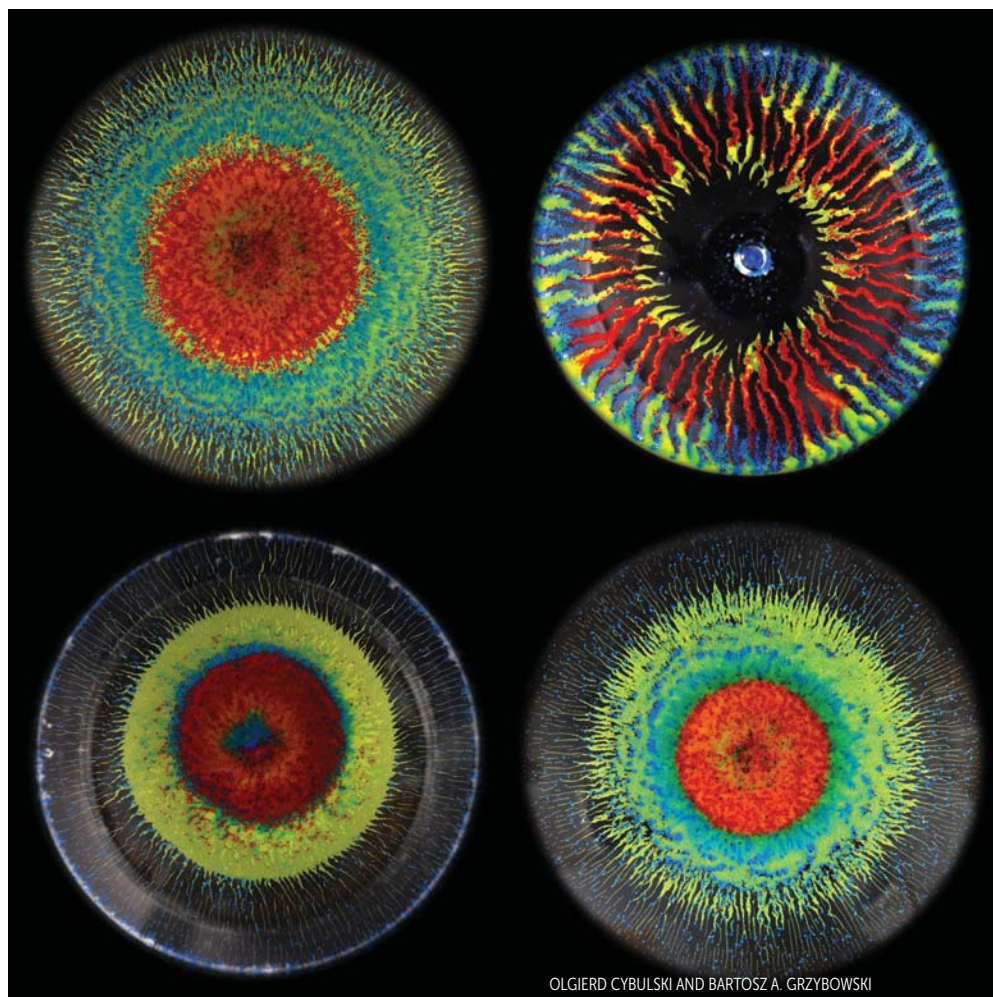
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