SCIENTIFIC AMERICAN

AI Could Help Us Talk to Animals

New Origins of Wine

The Geoengineering Gamble Begins

Will Humans Ever Live in Space?

Here's what it would take to leave planet Earth

OCTOBER 2023
SCIENTIFICAMERICAN.COM

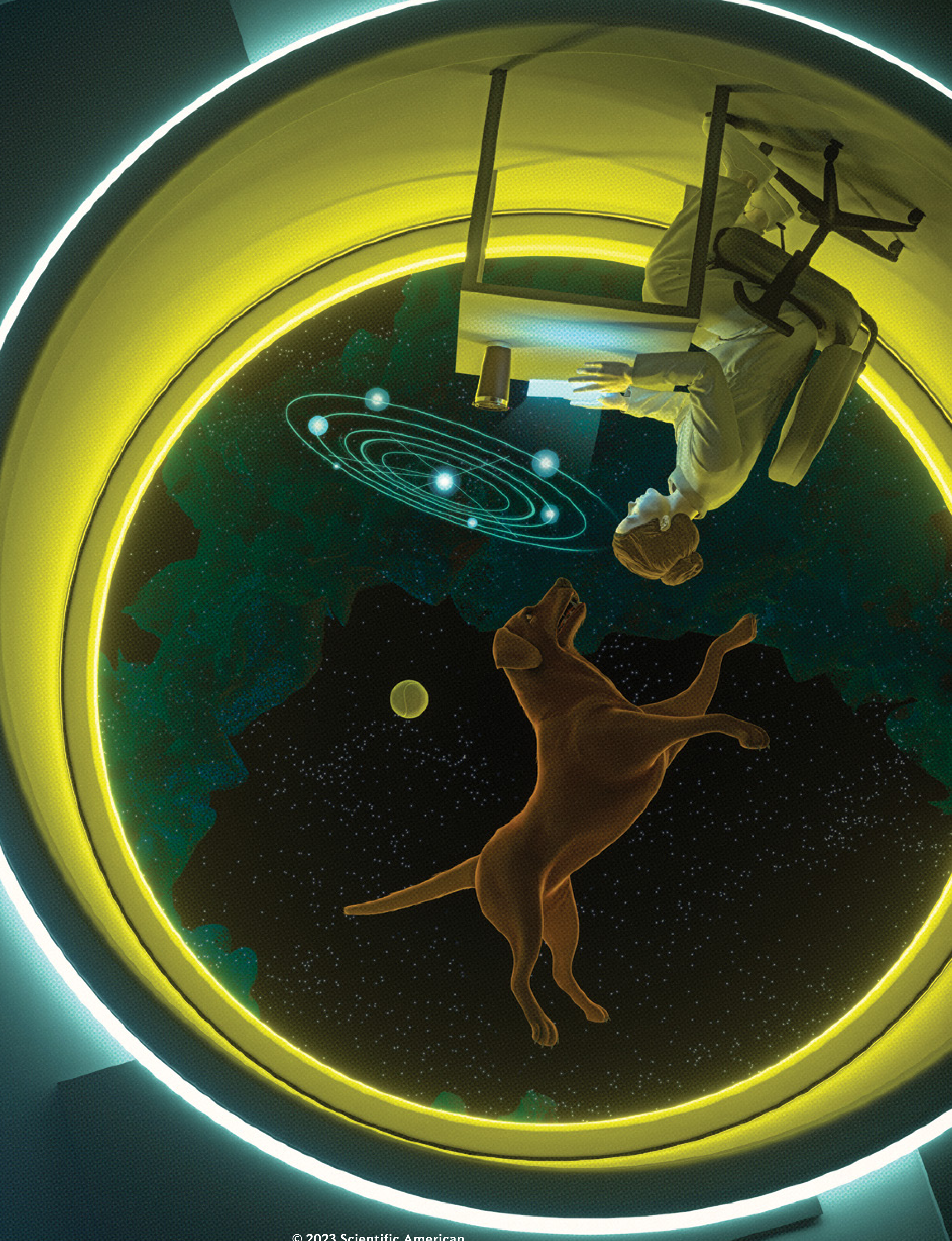
SPACE TRAVEL

WHY WE'LL NEVER LIVE IN SPACE

The technological, biological, psychological and ethical challenges to leaving Earth

BY SARAH SCOLES

ILLUSTRATION BY TAVIS COBURN



NASA WANTS ASTRONAUT boots back on the moon a few years from now, and the space agency is investing heavily in its Artemis program to make it happen. It's part of an ambitious and risky plan to establish a more permanent human presence off-world. Companies such as United Launch Alliance and Lockheed Martin are designing infrastructure for lunar habitation. Elon Musk has claimed SpaceX will colonize Mars. But are any of these plans realistic? Just how profoundly difficult would it be to live beyond Earth—especially considering that outer space seems designed to kill us?

Humans evolved for and adapted to conditions on Earth. Move us off our planet, and we start to fail—physically and psychologically. The cancer risk from cosmic rays and the problems that human bodies experience in microgravity could be deal-breakers on their own. Moreover, there may not be a viable economic case for sustaining a presence on another world. Historically, there hasn't been much public support for spending big money on it. Endeavors toward interplanetary colonization also bring up thorny ethical issues that most space optimists haven't fully grappled with.

At this year's Analog Astronaut Conference, none of these problems seemed unsolvable. Scientists and space enthusiasts were gathered at Biosphere 2, a miniature Earth near Tucson, Ariz., which researchers had built partly to simulate a space outpost. Amid this crowd, the conclusion seemed foregone: living in space is humans' destiny, an inevitable goal that we must reach toward.

The conference attendees know it's a big dream. But their general outlook was summed up by Phil Hawes, chief architect for Biosphere 2, who gave the opening talk at the meeting. He recited a toast made by the first team to camp out here decades ago: "Here's to throwing your heart out in front of you and running to catch up with it."

The question remains as to whether we can—and will—ever run fast enough.

IN 1991 EIGHT PEOPLE ENTERED BIOSPHERE 2 AND lived inside for two years. This strange facility is a 3.14-acre oasis where scientists have re-created different terrestrial environments—not unlike an overgrown botanical garden. There's an ocean, mangrove wetlands, a tropical rainforest, a savanna grassland and a fog desert, all set apart from the rest of the planet they're mimicking. One goal, alongside learning about ecology and Earth itself, was to learn about how humans might someday live in space, where they would have to create a self-contained and self-sustaining place for themselves. Biosphere 2, located on Biosphere 1 (Earth), was practice. The practice, though, didn't quite work out. The encapsulated environment didn't produce enough oxygen, water or food for the inhabitants—a set of problems that, of course, future moon or Mars dwellers could also encounter. The first mission and a second one a few years later were also disrupted by interpersonal conflicts and psychological problems among the residents.

Today the people who participate in projects like Biosphere 2—simulating some aspect of long-term space travel while remaining firmly on Earth—are called analog astronauts. And although it's a niche pursuit, it's also popular: There are analog astronaut facilities in places such as Utah, Hawaii, Texas and Antarctica. People are building or planning them in Oman, Kenya and Israel. And they all share the goal of learning how to live off Earth while on Earth.

Sarah Scoles is a Colorado-based science journalist, a contributing editor at *Popular Science,* and a senior contributor at *Undark*. She is author of *Making Contact* (2017) and *They Are Already Here* (2020), both published by Pegasus Books. Her book *Countdown: The Blinding Future of Nuclear Weapons* (Public Affairs) will be out in 2024.

The people who are mingling on Biosphere's patio, where the desert sunset casts a pink light on the habitat's glass exterior, are part of that analog world. Some of them have participated in simulation projects or have built their own analog astronaut facilities; others are just analog-curious. They are astronomers, geologists, former military personnel, mail carriers, medical professionals, FedEx employees, musicians, artists, analysts, lawyers and the owner of the Tetris Company. On this night many have donned Star Wars costumes. As the sun goes down, they watch the rising moon, where many here would like to see humans settle.

HUMAN BODIES REALLY CAN'T handle space. Spaceflight damages DNA, changes the microbiome, disrupts circadian rhythms, impairs vision, increases the risk of cancer, causes muscle and bone loss, inhibits the immune system, weakens the heart, and shifts fluids toward the head, which may be pathological for the brain over the long term—among other things.

At the University of California, San Francisco, medical researcher Sonja Schrepfer has dug into two of the conditions that afflict space explorers. Her research, using mice floating within the International Space Station, has revealed that blood vessels leading to the brain get stiffer in microgravity. It's part of why today's astronauts can't simply walk out of their capsules once they return to Earth, and it would play out the same way on Mars—where there's no one to wheel them to their new habitat on arrival. Schrepfer and her colleagues did, however, uncover a molecular pathway that might prevent those cardiovascular changes. "But now the question I try to understand is, Do we want that?" she says. Maybe the vessels' stiffening is a protective mechanism, Schrepfer suggests, and limbering them up might cause other problems.

She also wants to figure out how to help astronauts' faltering immune systems, which look older and have a harder time repairing tissue damage than they should after spending time in space. "The immune system is aging quite fast in microgravity," Schrepfer says. She sends biological samples from young, healthy people on Earth up to orbit on tissue chips and tracks how they degrade.

Vision and bone problems are also among the more serious side effects. When astronauts spend a month or more in space, their eyeballs flatten, one aspect of a condition called spaceflight-associated neuro-ocular syndrome, which can cause long-lasting damage to eyesight. Bones and muscles are built for life on Earth, which involves the ever present pull of gravity. The work the body does against gravity to stay upright and move around keeps muscles from atrophying and stimulates bone growth. In space, without a force to push against, astronauts can experience bone loss that outpaces bone growth, and their muscles shrink. That's why they must do hours of exercise every day, using specialized equipment that helps to simulate some of the forces their anatomy would feel on the ground—and even this training doesn't fully alleviate the loss.

Perhaps the most significant concern about bodies in space, though, is radiation, something that is manageable for today's astronauts flying in low-Earth orbit but would be a bigger deal for people traveling farther and for longer. Some of it comes from the sun, which spews naked protons that can damage DNA, particularly during solar storms. "[That] could make you very, very sick and give you acute radiation syndrome," says Dorit Donoviel, a professor at the Baylor College of Medicine and director of the Translational Research Institute for Space Health (TRISH).

Future astronauts could use water—perhaps pumped into the walls of a shelter—to shield themselves from these protons. But scientists don't always know when the sun will be spitting out lots of particles. "So if, for example, astronauts are exploring the surface of the moon, and there is a solar particle event coming, we probably have the capability of predicting it within about 20 to 30 minutes max," Donoviel says. That means we need better prediction and detection—and we'd need astronauts to stay close to their H_2O shield.

Perhaps the most significant concern is radiation, something that is manageable for today's astronauts flying in low-Earth orbit but would be a bigger deal for people traveling farther and for longer.

If you didn't get to safety in time, the nausea would come first. "You would vomit into your spacesuit," Donoviel says, "which now becomes a life-threatening situation" because the vomit could interfere with life-support systems, or you might breathe it in. Then comes the depletion of cells such as neutrophils and red blood cells, meaning you can't battle germs or give your tissues oxygen effectively. You'll be tired, anemic, unable to fight infection, and throwing up. Maybe you'll die. See why lots of kids want to be astronauts when they grow up?

There's another type of radiation, galactic cosmic rays, that even a lot of water won't block. This radiation is made of fast-moving elements—mostly hydrogen but also every natural substance in the periodic table. The rays burst forth from celestial events such as supernovae and have a lot more energy and mass than a mere proton. "We really cannot fully shield astronauts" from them, Donoviel says. And inadequately

From September 1991 to September 1993, eight people lived inside the Biosphere 2 research facility in Arizona, helping scientists learn how humans might live in outer space. The facility houses a greenhouse (*right*).

shielding explorers makes the problem worse: the rays would split when they hit a barrier, making more, smaller particles.

The radiation an astronaut en route to Mars might get from galactic cosmic rays at any one time is a small dose. But if you're on a spaceship or a planetary surface for years, the calculus changes. Imagine, Donoviel says, being in a room with a few mosquitoes. Five or 10 minutes? Fine. Days? Months? You're in for a whole lot more itching—or, in this case, cancer risk.

Because shielding astronauts isn't realistic, Donoviel's TRISH is researching how to help the body repair radiative damage and developing chemical compounds astronauts could take to help fix DNA damage in wounds as they occur. "Everybody's worried about waiting for the cancer to happen and then killing the cancer," Donoviel says. "We're really taking the preventive approach."

Even if most of the body's issues can be fixed, the brain remains a problem. A 2021 review paper in *Clinical Neuropsychiatry* laid out the psychological risks that astronauts face on their journey, according to existing research on spacefarers and analog astronauts: poor emotional regulation, reduced resilience, increased anxiety and depression, communication problems within the team, sleep disturbances, and decreased cognitive and motor functioning brought on by stress. To imagine why these issues arise, picture yourself in a tin can with a small crew, a deadly environment outside, a monotonous schedule, an unnatural daytime-nighttime cycle and mission controllers constantly on your case.

PHYSICAL AND MENTAL HEALTH PROBLEMS—though dire—aren't even necessarily the most immediate hurdles to making a space settlement happen. The larger issue is the cost. And who's going to pay for it? Those who think a billionaire space entrepreneur is likely to fund a space colony out of a sense of adventure or altruism (or bad judgment) should think again. Commercial space companies are businesses, and businesses' goals include making money. "What is the business case?" asks Matthew Weinzierl, a professor at Harvard Business School and head of its Economics of Space research efforts.

For the past couple of years Weinzierl and his colleague Brendan Rousseau have been trying to work out what the demand is for space exploration and pursuits beyond Earth. "There's been a ton of increase in supply and cutting of costs of space activity," Weinzierl says, "but who's on the other side?" Space companies have historically been insular: specialists creating things for specialists, not marketing wares or services to the broader world. Even commercial undertakings such as SpaceX are supported mostly by government contracts. Company leaders haven't always thought through the capitalism of their ideas; they're just excited the rockets and widgets work.

Science History Images/Alamy Stock Photo

Kike Calvo/Universal Images Group via Getty Images

"Technical feasibility does not equal a strong business case," Rousseau says.

Today private spaceflight companies target tourists for business when they're not targeting federal contracts. But those tourists aren't protected by the same safety regulations that apply to government astronauts, and an accident could stifle the space tourism industry. Stifling, too, is the fact that only so many people with money are likely to want to live on a place like Mars rather than take a short joyride above the atmosphere, so the vacation business case for permanent space outposts breaks down there as well.

People tend to liken space exploration to expansion on Earth—pushing the frontier. But on the edge of terrestrial frontiers, people were seeking, say, gold or more farmable land. In space, explorers can't be sure of the value proposition at their destination. "So we have to be a little bit careful about thinking that it will just somehow pay off," Weinzierl points out.

Weinzierl and Rousseau find the idea of a sustained human presence in space inspiring, but they're not sure when or how it will work from a financial perspective. After all, inspiration doesn't pay invoices. "We'd love to see that happening," Rousseau says—he thinks lots of people would. "As long as we're not the ones footing the bill."

Many taxpayers would probably agree. As hard as it is for space fans to believe, most people don't place much value on astronaut adventures. A 2018 Pew poll asked participants to rate the importance of nine of NASA's key missions as "top priority," "important but lower priority," or "not too important/should not be done." Just 18 and 13 percent of people thought sending humans to Mars and to the moon, respectively, was a top priority. That placed those missions at the bottom of the list in terms of support, behind more popular efforts such as monitoring Earth's climate, watching for dangerous asteroids and doing basic scientific research on space in general.

A 2020 poll from Morning Consult found that just 7 to 8 percent of respondents thought sending humans to the moon or Mars should be a top priority. Although history tends to remember the previous moon exploration era as a time of universal excitement for human spaceflight, polls from the time demonstrate that that wasn't the case: "Consistently

On the edge of terrestrial frontiers, people were seeking, say, gold or more farmable land. In space, explorers can't be sure of the value proposition at their destination.

throughout the 1960s, a majority of Americans did not believe Apollo was worth the cost, with the one exception to this a poll taken at the time of the *Apollo 11* lunar landing in July 1969," wrote historian Roger Launius in a paper for *Space Policy*. "And consistently throughout the decade 45–60 percent of Americans believed that the government was spending too much on space, indicative of a lack of commitment to the spaceflight agenda."

Harmful extraterrestrial microbes could return with astronauts or equipment—a planetary-protection risk called backward contamination.

When space agency officials discuss why people should care about human exploration, they often say it's for the benefit of humanity. Sometimes they cite spin-offs that make their way to citizens as terrestrial technology—such as how telescope-mirror innovations improved laser eye surgery. But that argument doesn't do it for Linda Billings, a consultant who works with NASA. If you were interested in furthering a technology, she suggests, you could invest directly in the private sector instead of obliquely through a space agency, where its development will inevitably take longer, cost more and not be automatically tailored toward earthly use. "I don't see that NASA is producing any evidence that [human settlement of space] will be for the benefit of humanity," she says.

WHETHER TAX DOLLARS SHOULD support space travel is an ethical question, at least according to Brian Patrick Green of Santa Clara University. Green became interested in science's ethical issues when he worked in the Marshall Islands as a teacher. The U.S. used to detonate nuclear weapons there, causing lasting environmental and health damage. Now the islands face the threat of sea-level rise, which is likely to inundate much of its infrastructure, erode the coasts and shrink the usable land area. "That got me very interested in the social impacts of technology and what technology does to people and societies," he says.

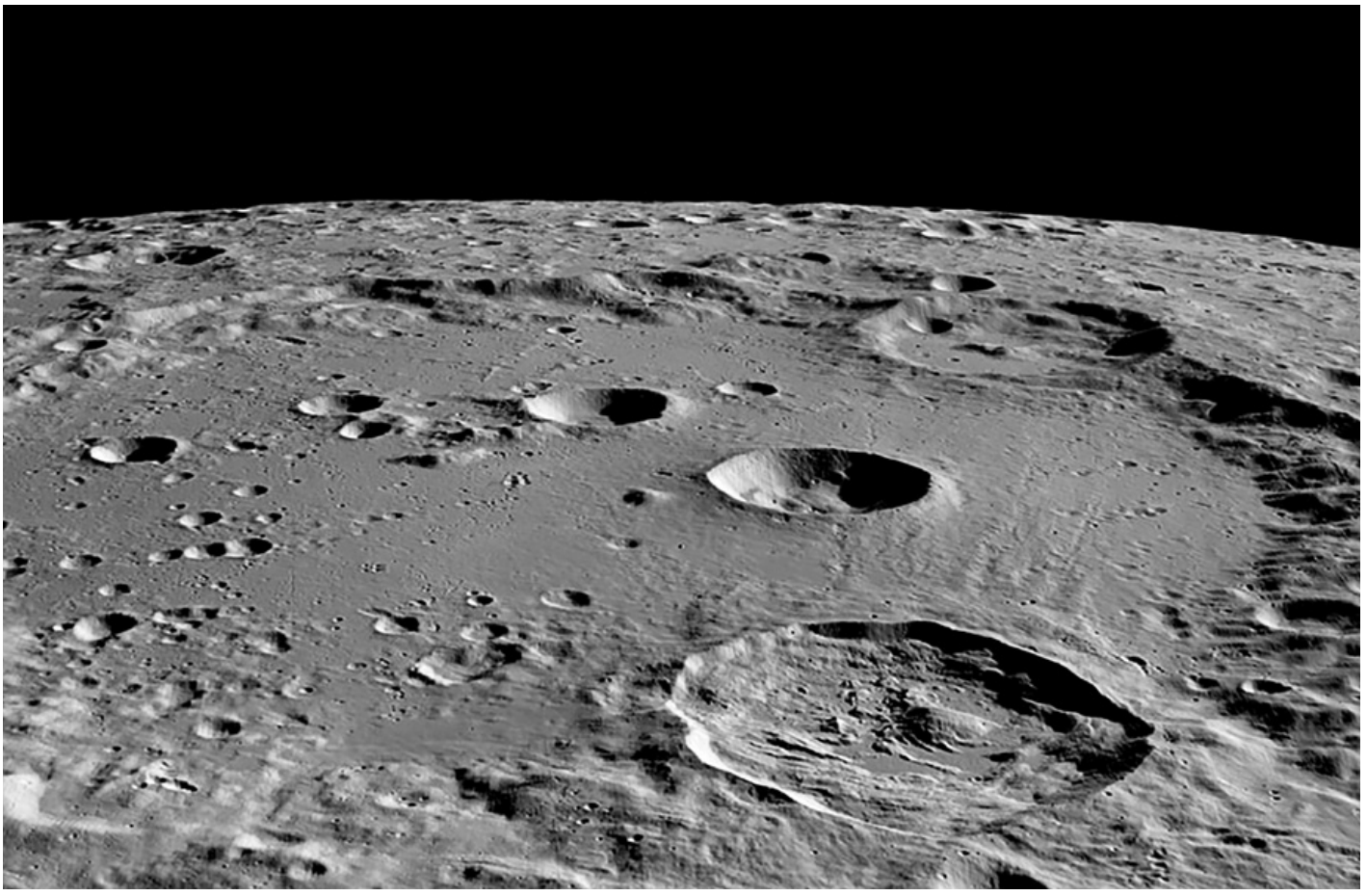
In space travel, "Why?" is perhaps the most important ethical question. "What's the purpose here? What are we accomplishing?" Green asks. His own answer goes something like this: "It serves the value of knowing that we can do things—if we try really hard, we can actually accomplish our goals. It brings people together." But those somewhat philosophical benefits must be weighed against much more concrete costs, such as which other projects—Earth science research, robotic missions to other planets or, you know, outfitting this planet with affordable housing—aren't happening because money is going to the moon or Mars or Alpha Centauri.

And an even simpler ethical question is, "Should we actually send people on these sorts of things?" Green says. Aside from incurring significant risks of cancer and overall body deterioration, astronauts aiming to settle another world have a sizable chance of losing their lives. Even if they do live, there are issues with what kind of an existence they might have. "It's one thing just to survive," Green says. "But it's another thing to actually enjoy your life. Is Mars going to be the equivalent of torture?"

If people make the attempt, we will also have to acknowledge the risks to *celestial* bodies—the ones humans want to travel to as well as this one, which they may return to if they haven't purchased a one-way ticket. The moon, Mars or Europa could become contaminated by microscopic Earth life, which NASA has never successfully eradicated from spacecraft, although it tries as part of a "planetary protection" program. And if destination worlds have undetected life, then harmful extraterrestrial microbes could also return with astronauts or equipment—a planetary-protection risk called backward contamination. What obligation do explorers have to keep places as they found them? Setting aside the question of whether we can establish ourselves beyond Earth, we also owe it to ourselves and the universe to consider whether we should.

ON THIS QUESTION, SCIENCE-FICTION scholar Gary Westfahl casts doubt on space travel's inherent value. In his vast analyses of sci-fi, he has come to view the logic and drive of the enterprise as faulty. "I inevitably encountered the same argument: space travel represents humanity's destiny," he says of the impetus for writing his essay "The Case against Space." Space explorers are often portrayed as braver and better than those who remain on their home planet: they're the ones pushing civilization forward. "Philosophically, I objected to the proposition that explorers into unknown realms represented the best and brightest of humanity; that progress could be achieved only by boldly venturing into unknown territories," Westfahl says. After all, a lot of smart and productive people (not to mention a lot of happy and stable people) don't spend their lives on the lam. "Clearly, history demonstrates no correlation between travel and virtue," he writes. "The history of our species powerfully suggests that progress will come from continued stable life on Earth, and that a vast new program of travel into space will lead to a new period of human stagnation," he concludes ominously.

In some ways, the desire for simpler living is part of what motivates space explorers. Astronauts are stuck with just a few people they have to get along with, or else they'll be miserable—a communal way of living that's more common to villages. They must make do with the nearby supplies or create their own, like



Celestial bodies, including our moon, are at risk of contamination by microscopic Earth life.

NASA's Scientific Visualization Studio

people did before Walmart and Amazon. Communication with those beyond their immediate sphere is slow and difficult. They have a strict but straightforward and prescribed work schedule. Everything is a struggle; there are no conveniences. Unlike in a modern, digitally connected environment, their attention isn't split in many directions—they are focused on the present. Or at least that's how analog astronaut Ashley Kowalski felt during the SIRIUS 21 endeavor, an eight-month-long joint U.S.-Russia "lunar mission" that took place in a sealed space in Moscow.

Kowalski's talk at the Analog Astronaut Conference at Biosphere 2 was called "Only Eight Months." The goal of those eight months was to study the medical and psychological effects of isolation. She and her teammates regularly provided blood, feces and skin samples so researchers could learn about their stress levels, metabolic function and immunological changes. Researchers also had them take psychological tests, sussing out their perception of time, changes in cognitive abilities and shifts in interpersonal interactions. Inside they had to eat like astronauts would, guzzling tubes of Sicilian pizza gel and burger gel. Kowalski would squeeze them into rehydrated soup to make meals heartier. Via their greenhouse, they got about a bowl of salad between the six of them every three weeks.

Kowalski missed freedom and food and friends, of course. But the real struggle came with her return to the real world once the isolation was over: "reentry, not to the atmosphere but to the planet," she told the conference audience. She didn't remember how to go about having friends, hobbies or a job and had trouble dealing with requests coming from lots of sources instead of just mission control. In the Q&A period after the talk, Tara Sweeney, a geologist in the audience, thanked Kowalski for talking about that part of the experience. Sweeney had just returned from a long stay in Antarctica and also didn't quite know how to reintegrate into life in a more hospitable place. They had both missed "Earth," the real world. But it was hard to come back.

Still, the Analog Astronaut Conference crowd remained optimistic. "Where do we go from here?" conference founder and actual astronaut Sian Proctor asked at one point. On cue, the audience members pointed upward and said, "To the moon!"

Analog-astronaut work can't solve space travel's hardest problems—the intractable medical troubles, the in-red money questions, the touchy ethical quandaries. But while we all wait to see whether we'll ever truly migrate off this planet, and whether we should, these grounded astronauts will continue to escape Earth, for a time at least, without leaving it. ●

FROM OUR ARCHIVES

Lunar Land Grab. Adam Mann; July 2019. ScientificAmerican.com/magazine/sa