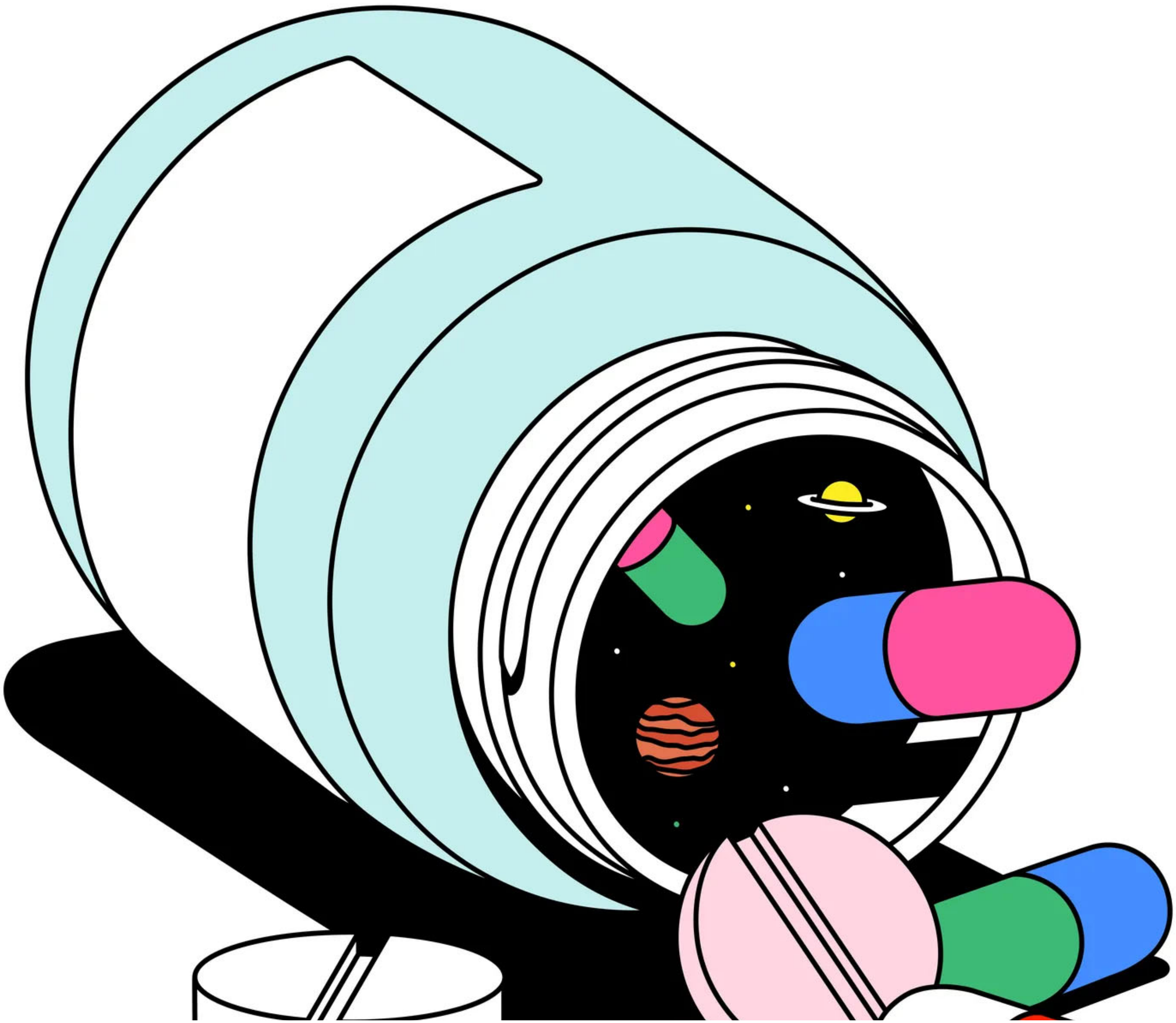
ANNALS OF MEDICINE

CAN THE HUMAN BODY ENDURE A VOYAGE TO MARS?

In the coming years, an unprecedented number of people will leave planet Earth—but it's becoming increasingly clear that deep space will make us sick.

By Dhruv Khullar

February 10, 2025



Only twenty-four astronauts have exited low Earth orbit—and that was fifty years ago, for less than two weeks at a time. A "short" round-trip Mars mission might leave the safety of our planet for years. Illustration by Rob en Robin

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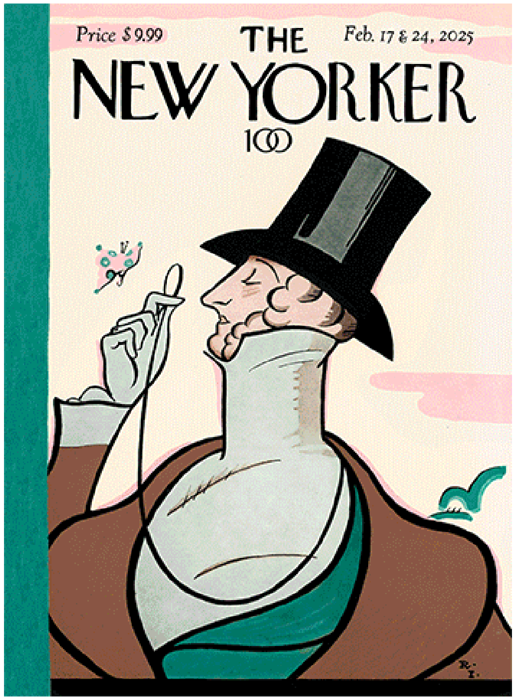
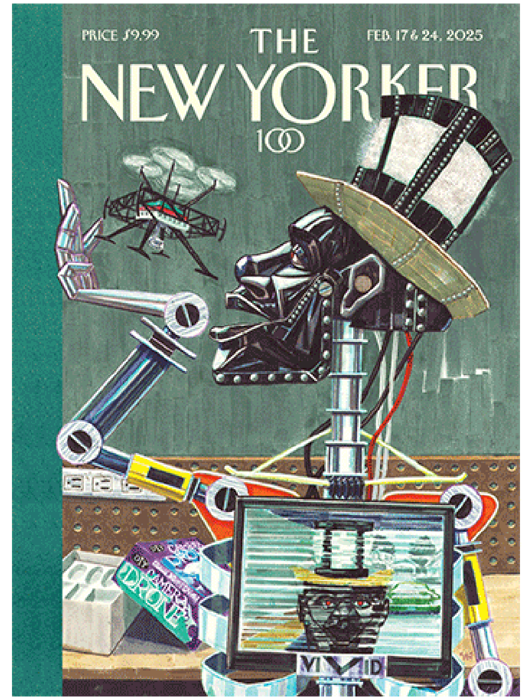
On March 2, 2016, at around 9 A.M. local time, in Kazakhstan, Scott Kelly plunged through the Earth's atmosphere in a Soyuz spacecraft travelling at seventeen thousand miles an hour. As expected, atmospheric friction warmed up its heat shield so much that molten debris flew off. Rapid deceleration imposed more than six times the force of gravity on Kelly and his crewmates, the cosmonauts Mikhail Kornienko and Sergey Volkov. The Soyuz's descent module, a black sphere measuring about seven feet in diameter, deployed a red-and-white parachute and floated to the surface of the planet, landing in the desert.

A search-and-rescue team, wearing furry *ushanka* hats and shouting in Russian, rushed to the capsule, twisted open its circular lid, and hoisted Kelly out. He gave a thumbs-up, then grimaced as they lowered him gently into a recliner that sat conspicuously on the barren plain. Someone covered him with a thick blanket and fitted his bald head with a knit hat. Then he lifted a satellite phone to his ear and made his first call back on Earth.

Kelly had spent more time in space than almost any other person—four missions, each longer than the last, totalling five hundred and twenty days. On this trip, he had taken the longest spaceflight of any American: nearly a year on the International Space Station. He was, in a sense, as accustomed to space as anyone alive. And yet, he told me, "as I flew longer, the symptoms of returning to Earth were worse." After he got back to his home, in Houston, he felt nauseated and dizzy. His joints ached under the force of gravity, and the pressure of simply sitting in a chair felt uncomfortable. A ponderous fatigue set in.





Some medical effects of space travel are well understood. For decades, scientists have known that near-weightlessness lengthens the spine and causes the wasting of muscle and bone, which is why astronauts have to exercise frequently. Kelly returned to Earth two inches taller than when he left; his body mass declined by seven per cent, in part because his appetite for packaged and freeze-dried fare was lower than NASA planners had anticipated. Some of his other symptoms, however, were strange and unfamiliar. When he stood, his blood seemed to rush downward, causing a painful swelling in his legs. “That was probably most disturbing,” he told me. An angry rash spread across his neck, back, and legs.

Kelly has an identical twin brother, the Arizona senator and retired astronaut Mark Kelly. Before the mission, both men had agreed to participate in a comparative study of their bodies—Mark from Earth, Scott from space and Earth. Because they have the same DNA, the study was a rare opportunity to isolate the physiological effects of long-term missions. And so, before, during, and after Scott's stay on the I.S.S., a team of more than eighty researchers from twelve universities studied him more closely than perhaps any other human in history. "I wish every person was a twin," Christopher Mason, a principal investigator of the NASA Twins Study, has said. Mason and his colleagues were troubled by some of their findings. Cognitive testing, for example, showed declines in Scott's mental speed and accuracy. Markers of inflammation in his blood spiked to levels that laboratory tests had difficulty measuring—thousands of per cent above normal, which suggested an extreme stress response. "Are these the highest levels ever seen in a human body?" Mason remembers one of his colleagues asking. "How did he survive?"

Fewer than seven hundred people, most of them relatively young and fit men, have gone to space. In the coming decades, this number could grow exponentially as more and more governments and companies—among them SpaceX, Blue Origin, and Virgin Galactic—inaugurate what has been called the second space age. Yet many peculiar effects of space travel are only now being identified and investigated. Latent herpes infections often get reactivated; certain medications can become less effective; microgravity, the technical term for near-weightlessness, redistributes blood to veins in the head and neck that aren't used to handling the flow, increasing the risk of clots. Scott Kelly wrote in "Endurance," a memoir, that humans can explore more of the universe only if they strengthen "the weakest links in the chain that makes spaceflight possible: the human body and mind."

Mason is optimistic that we will be able to do so. "At some point, we're going to have thousands of people living or working in space," he told me. "We need to understand how to do that safely." Others have grave concerns. Mathias Basner, a psychiatry professor at the University of Pennsylvania and a member of the Twins Study research consortium, told me that space travel causes profound structural changes in the brain. "Most are probably reversible," he told me. "Some may not be." In microgravity, the brain moves to the top of the skull and compresses an area responsible for absorbing cerebrospinal fluid, leading to a swelling of brain cavities and potentially to an increase in intracranial pressure. Certain biomarkers associated with neurodegenerative disease appear to rise significantly after a long trip. "This could suggest something quite bad is happening in the brain," Basner said. "We need more data."

The record holder for the longest continuous stay in space, a Russian cosmonaut and doctor named Valery Polyakov, spent a little more than fourteen months in low Earth orbit, which is relatively protected from space radiation and communication lags. Only twenty-four people, the Americans who crewed the Apollo missions, have ever exited low Earth orbit—and that was more than fifty years ago, for less than two weeks at a time. Still, the U.S. and China have already raised the possibility of crewed trips to Mars in the twenty-thirties. Elon Musk, the C.E.O. of SpaceX, who has said that he would like to die there—"just not on impact"—has indicated that he wants to send a million settlers. (He noted in 2018 that the job postings would read "like Shackleton's ad for Antarctic explorers: difficult, dangerous, good chance you'll die. Excitement for those who survive.") But Bill Nye, former Science Guy and current C.E.O. of the Planetary Society, has portrayed the dream of Mars colonization as a dangerous delusion. "We can't even take care of this planet where we live, and we're perfectly suited for it," he has said. "Are you guys high?" The truth is that we still know precious little about how humans will fare in deep space. It's also true that we'll never find out until we try.

The Cornell Aerospace Medicine Biobank (CAMbank), where Mason works, is on the fourth floor of a sleek glass building in Manhattan. It contains more than fifteen thousand biological samples from twenty-two astronauts, making it one of the largest repositories of its kind. On a crisp morning in September, I arrived at a nearby hematology clinic to meet Hayley Arceneaux and Sian Proctor, two crew members from Inspiration4, a private SpaceX mission that took off from Florida in 2021. They had come to donate saliva, blood, and urine, as well as microbes from their skin, to science.

Proctor, a community-college geology professor and a futurist with a buzz cut, had visited several times before and seemed to know what to do: she tore a square of gauze out of a plastic wrapper, chewed it as though it were a piece of gum, and placed the wet lump in a box. (Mason developed this method after astronauts complained about the difficulty of spitting into a tube in space.) Next, she removed her socks and swabbed between her toes.

Arceneaux, a health-care worker with wavy auburn hair, pulled up the sleeves of her blue T-shirt, which was decorated with a rocket logo, to show me small scars from skin biopsies. "When you're voluntarily getting sutures for research, you know you're committed," she told me. Then she swabbed her nostril as if she were giving herself a COVID test.

When Inspiration4 was first planned, scientists were eager to study its crew: civilian astronauts greatly expand the pool of potential research subjects, and they also offer more diversity in terms of age, gender, background, training, and fitness levels. (In 2021, William Shatner, of "Star Trek" fame, spent ten minutes in suborbital space at the age of ninety, on a reusable Blue Origin rocket system. He later wrote in the *Guardian*, "I had to get to space to understand that Earth is, and will remain, our only home. And we have been ravaging it, relentlessly, making it uninhabitable.") Saliva contains inflammatory molecules and hormones, which can indicate an increased risk of heart disease or endocrine problems. Skin swabs and biopsies can reveal alterations in the microbiome and in gene pathways that are linked to cancer. "The Inspiration4 crew are some of the most enthusiastic astronaut research subjects we have," Mason told me.

Proctor's father was an Apollo-era engineering technician, and in 2009 Proctor was a finalist in NASA's astronaut-selection program. But she did not have a chance to go to space until she applied to an entrepreneurship competition organized by Jared Isaacman, a tech billionaire who was the commander of Inspiration4. (Isaacman has been nominated to serve as Donald Trump's head of NASA.) Proctor became the first African American woman to pilot a space mission; afterward, she wrote a review for TripAdvisor: "The atmosphere was out of this world!"

Arceneaux became an astronaut by accident. When she was ten, she was treated for bone cancer in her leg at St. Jude Children's Research Hospital, in Memphis. "Ever since then, I knew I wanted to work at St. Jude," she told me. In 2020, the hospital hired her as a physician assistant, and the next year, an administrator called her. Isaacman wanted Inspiration4 to be a fund-raiser for St. Jude; the spacecraft would circle the planet for three days and splash down in the Atlantic. Did she want to go?

The crew of Inspiration4 prepared for six months. Arceneaux, its medical officer, told me that as part of her training she climbed Mt. Rainier and completed puzzles inside a chamber while the oxygen was slowly removed. She worked with a personal trainer, met with a psychiatrist, and underwent a battery of medical tests, including a mammogram, an echocardiogram, a stress test, a bone-density scan, and a dental evaluation. In September, 2021, at thirty-three, she became the youngest American to orbit the Earth. From space, she spoke via a live feed to children who were being treated at St. Jude. "I was a little girl going through cancer treatment just like a lot of you," she told them. "If I can do this, you can do this."

Three days was long enough for the Inspiration4 crew to experience many of the side effects of space travel. While in orbit, Proctor needed to take medicine for nausea. "Hayley hit me with some Phenergan," she told me, referring to a motion-sickness drug that has been closely studied in space. Arceneaux experienced headaches, nasal congestion, and intense back pain as her spinal column stretched in microgravity. After landing, she felt dizzy and weak. At first, she didn't think she'd had any cognitive issues, but then Proctor posted a video on social media of them waving wands at a levitating stuffed dog as though they were characters from "Harry Potter." "I thought, Huh, that feels like something I would have remembered," Arceneaux told me. "It was completely gone." It's possible that the memory was missing because of a surge of adrenaline, but it's hard to say for sure.

When Proctor and Arceneaux were done giving specimens, I helped Jeremy Wain Hirschberg, a research specialist in a Hawaiian shirt, ferry boxes of samples across the street to the CAMbank. Wain Hirschberg had previously worked for an eccentric entrepreneur who wanted to build a space elevator. ("For reasons of gravity and physics, I don't think this can work from Earth," Wain Hirschberg said. "But I'm optimistic about the moon.") We took a non-space elevator to the fourth floor.

In the CAMbank, I walked past a transparent refrigerator whose stash of test tubes reminded me of ketchup and mayonnaise bottles. A flat black DNA sequencer sat on a lab bench. Wain Hirschberg opened an industrial freezer kept at negative eighty degrees Celsius, exposing snow-covered buckets of urine that looked like treasures under an avalanche. After he placed some of our boxes inside, I followed him to a liquid-nitrogen tank that was the size and shape of R2-D2. He pried the capsule open with gloved hands. Water vapor poured out; I thought of a miniature rocket launch. "This is where we keep the most sensitive samples," he said. Some immune cells, for example, can be scrutinized for subtle genetic changes but need to be stored with extreme care.

Mason, a geneticist at Weill Cornell (where I also practice as a physician), was wearing jeans without a lab coat and had sunglasses perched atop his head. He and his colleagues have an immediate practical goal: to gather enough biomedical data to identify, and hopefully neutralize, the most dangerous health effects of space travel. Some of his personal views are more provocative. In a 2021 book, "The Next 500 Years: Engineering Life to Reach New Worlds," Mason suggests that humans could one day modify their genes to better survive in space. "We do everything we can to keep astronauts safe through engineering their rockets and ships, but could we make some of the protections on the inside, within the astronauts themselves?" he writes. He notes that elephants have many more cells than humans but develop cancer at much lower rates. One reason may be that they have twenty copies of a gene called TP53, which produces proteins that scan and repair DNA; humans have one. "Extremophiles" such as tardigrades, microscopic invertebrates that resemble tiny bears, can survive in almost any environment, perhaps owing to a gene that encodes a damage-suppressor protein. In the lab, Mason has introduced the gene into human cells and produced substantial reductions in DNA damage. ("The gene-editing stuff is still a little bit out there," Basner told me.)

Mason's book makes a cosmic version of Jean-Paul Sartre's argument that existence precedes essence: humanity must first persist if it hopes to become or achieve anything. In Mason's view, humans, as the only species known to have an awareness of extinction, have a unique moral obligation to preserve other life-forms from dangers such as asteroid strikes, nuclear war, or climate catastrophes. He describes Mars and other planets as "a backup plan for all life, including humanity."

In the months after Kelly told scientists about his mysterious medical issues, Mason and his colleagues retested biological samples from during and after the astronaut's yearlong flight. They recorded numerous worrying data points. Kelly's vision had deteriorated. "I can't see without glasses," he told me. The walls of his carotid arteries had thickened and were inflamed. The return of gravity had been even more punishing. The levels of inflammatory markers in his body were as high as they'd be in a person experiencing a heart attack or septic shock. Proteins that are mostly found in the brain were detected in his bloodstream, suggesting that the blood-brain barrier had lost some of its integrity. Mitochondria, which generate energy inside various kinds of cells, had pumped distress signals throughout his body.

There were even changes in Kelly's genetics. The expression of about nine thousand genes, some of which might increase the risk of cancer and immune-system problems, had been altered. Although most of them normalized in the course of a few months, some continued to show signs of damage, including breaks and inversions in their DNA, long after Kelly was back on Earth. (During his mission, Kelly had been exposed to about fifty times as much radiation as his brother had on Earth.) Curiously, Kelly's telomeres—caps at the ends of DNA that normally shrink as we get older—had grown longer while he was in space. But, after his return, they contracted until they were shorter than when he'd first taken off. In many ways, space seemed to accelerate the aging process.

The NASA Twins Study had to contend with a fundamental challenge of space research: sample size. A scholar of diabetes or breast cancer might analyze data from hundreds of thousands of patients; Kelly is just one person, and the effects of space travel for different individuals may vary as widely as the effects of a COVID infection. Even so, patterns are emerging. Studies of the Inspiration4 crew detected genetic modifications in immune cells, changes to the organization of DNA, and spikes in inflammation (although not to the level that Kelly had exhibited). Women seemed to experience milder changes than men, a finding that earlier studies had also reported. Throughout the crew's bodies, there were markers of oxidative stress, which is often inflicted when radiation damages proteins and DNA. And, during flight, the crew had experienced temporary cognitive declines that affected their attention and their working memory.

Most of these health effects eventually faded, the research team wrote in *Nature* last year, but a small number—certain forms of damage to DNA, for example—didn't even appear until after the crew's return to Earth. Other effects, including abnormalities in mitochondria, persisted for the six months that the team studied them. “The body is adapting to an unusual and complex environment in unusual and complex ways,” Mason told me. “We’re starting to see a biological signature of space. Soon, we’ll be able to say, *This* is what will happen to you if you get a three-day dose of space. *That* is what will happen with a three-month dose.” The microorganisms that coexist with humans changed, too. Biopsies revealed a rise in the number of viruses on the skin; mouth and gut bacteria shifted in composition. A bacterium that causes dental plaque formed a defensive biofilm around itself, helping it to multiply and persist. (Bacteria can become more virulent and resistant to antibiotics in space.)

There was still much to learn, but a plausible story was emerging. “Space is a foreign environment for the human species,” Basner told me. “We grew up here on Earth. All of our biology and physiology evolved around its features.” Our bodies are calibrated to Earth’s atmosphere and microbiome. We’re used to specific levels of gravity and radiation; when spaceflight subtracts the former and multiplies the latter, numerous complex systems are thrown out of balance. The researchers who studied the Kelly brothers concluded that human health could be “mostly sustained” during a year in orbit. But they could not predict how much these risks would increase during a longer mission, such as a voyage to Mars. Perhaps the dangers would grow slowly and steadily; perhaps they would grow exponentially. “I simply don’t think we can extrapolate from shorter missions to longer missions,” Basner said. “These are biological systems. At some point, they may just run out of the ability to compensate.” A “short” round-trip Mars mission, which would pose unprecedented technical and medical challenges, could leave the safety of orbit for two years or more. Astronauts would also have to withstand life on another planet.

nce upon a time, the core of Mars, made of nickel and iron, used to spin. This generated a magnetic f

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Advocates of interplanetary exploration seem undaunted. “We will settle Mars,” Jeff Bezos, who founded the space company Blue Origin, said in 2016. “And we should, because it’s cool.” Last month, President Trump declared in his Inaugural Address that “we will pursue our Manifest Destiny into the stars” and plant “the Stars and Stripes on the planet Mars.” Musk, the President’s patron and frequent adviser, predicted in 2017 that crewed Mars missions would take off by 2024; he spoke of sending about a hundred people on a spacecraft code-named B.F.R. (Big Fucking Rocket). He has also proposed a terraforming process that includes the detonation of nuclear bombs, and has been seen wearing a T-shirt that says “NUKE MARS.” SpaceX notes on its Web site that the red planet “is a little cold, but we can warm it up.” Its case for settling Mars mentions the low gravity and the theoretical possibility of agriculture, but it doesn’t discuss radiation.

The International Space Station orbits at a height of about two hundred and fifty miles. Earth’s magnetic field extends tens of thousands of miles into space on the planet’s sun-facing side, and even farther on the other side. This means that, for all the radiation that I.S.S. astronauts experience, they are still protected. In orbit, Scott Kelly incurred the equivalent of perhaps four chest X-rays a day; Mason guessed that a round trip to Mars would inflict more than six times as much. A single voyage would approach the lifetime radiation limits that space programs set for their astronauts.

In October, I travelled to Long Island to visit Brookhaven National Laboratory, a nuclear-physics research center that was formed after the Second World War. Work conducted at B.N.L. has led to seven Nobel Prizes. Since the early two-thousands, it has been home to the NASA Space Radiation Laboratory, a U.S. Department of Energy project that houses one of the world’s most powerful particle accelerators. The lab simulates galactic radiation and analyzes its effects on living tissue.

Inside a biology building, I met Afshin Beheshti, the director of the Center for Space Medicine at the University of Pittsburgh, and Robert Schwartz, a hepatologist at Weill Cornell. Schwartz, who has wavy hair that falls almost to his waist, creates "organoids"—tiny clumps of human tissue that have the architecture and the functionality of organs. He was bent over a lab bench, carefully pipetting thousands of liver organoids, each one the size of an espresso granule, into little plastic tubes.

Schwartz and Beheshti were preparing to blast these organoids with different levels of radiation: one dose to simulate the radiation from a lunar mission, and a second, higher dose to approximate a round trip to Mars. They also wanted to identify factors that increase or decrease the radiation's effects. "We're the first ones to do this," Beheshti, a bespectacled man with a salt-and-pepper goatee, said.

At the most basic level, radiation is made up of particles or waves that speed through space. It can come from a variety of sources—stars, volcanoes, certain elements (uranium, for instance), and even food (bananas emit a tiny amount)—and its impact depends on the amount of energy it contains. Non-ionizing radiation, such as visible light or microwaves, might heat things up but is considered relatively safe. Ionizing radiation, however, penetrates tissue and damages DNA, both by rupturing chemical bonds and by turning stable atoms into unstable "free radicals." Free radicals bang into DNA, causing breaks, mutations, and inappropriate linkages. Engineers can limit radiation by surrounding living areas with metal, plastic, or water, but thick layers of traditional materials could make spaceships too heavy to launch from Earth and propel to Mars. "Radiation is one of the potential showstoppers of spaceflight," Basner had told me. "And it's really hard to shield ourselves from it."

Schwartz added some artificial moondust—regolith—to certain organoid tubes to approximate its impact combined with that of radiation. (Inhaling regolith is thought to be toxic; Schwartz was working under a fume hood and wearing a high-grade mask.) In other tubes, he added dietary supplements that function as antioxidants in mitochondria, which could perhaps reduce radiation's harmful effects. Beheshti is a self-described "mitochondriac": he suspects that shielding mitochondria during space missions could have a wide range of protective effects.

We gingerly carried the samples to Schwartz's car and drove a few minutes to a concrete building that houses NASA's Space Radiation Laboratory. Inside, bright-yellow caution signs warned of radioactivity; photographs of lunar missions hung on the walls. We put on booties so that we wouldn't accidentally track hazardous materials out of the facility. At the end of the hall, above heavy gray doors, a one-word sign lit up whenever the particle accelerator was on: "BEAM!"

From a nearby break room, I watched a live feed of the radiation room, alongside a graph of various colors shooting up and down. Each color represented a different charged particle, from compact hydrogen ions to larger, heavier ones such as silicon and iron. "Small ions are like grains of sand," Beheshti said. "Iron is like a bowling ball." He punched a fist into his palm. During a year in deep space, it's estimated that every cell in an astronaut's body would be exposed to a heavy ion.

Schwartz taped his samples to a Styrofoam platform and placed them on a metal bench in the radiation room. When he returned, the beam light flashed on; a thick red line, representing iron ions, shot up the monitor. I imagined bowling pins scattering. "Not blast off," Beheshti said. "Blast *on!*"

Every fifteen minutes or so, a different ion irradiated the cells, and, after several cycles were complete, Schwartz let the samples rest. Then he drove carefully back to his laboratory, where a postdoctoral researcher was ready to start analyzing them.

I caught up with Beheshti and Schwartz a few months later, when they were preparing to submit preliminary findings to a scientific journal. The liver is usually considered more radiation-resistant than some other organs, but their experiment detected a profound loss of liver cells. The Mars dose was significantly worse than the moon dose; the cells that survived were less able to perform basic functions such as producing proteins and metabolizing waste. Schwartz outlined the likely cycle of destruction. Mitochondria normally neutralize free radicals, but, when radiation injures them, this process becomes more difficult; the free radicals then damage mitochondrial DNA, and that weakens the mitochondria further. This progression could harm the immune system, accelerate aging, and cause cancer.

Another result was more reassuring. Mitochondria that were fortified with supplements were much less likely to lose their integrity and die; in some cases, they worked nearly as well as mitochondria that hadn't been irradiated. Beheshti and Schwartz suggested that supplements might one day help astronauts stave off the worst effects of radiation. Even earthbound humans could benefit. "Mitochondrial dysfunction is a global process that underlies a variety of human diseases," Schwartz said. "This opens up an entirely different way of thinking about how one could go about treating any number of disorders—cancer, aging, infectious disease."

n "The Martian," the 2011 novel by Andy Weir (it became a film, in 2015, starring Matt Damon), a

I violent dust storm forces one of the first crews on Mars to evacuate. When flying debris appears to kill their botanist, Mark Watney, they reluctantly leave him behind, only to find out later that he has survived. In a series of grimly humorous logs, he describes his struggles to fertilize potatoes with his own waste; produce water from the hydrogen in rocket fuel; and jury-rig a rover to communicate with Earth. A psychologist back home observes that "the biggest threat is giving up hope. If he decides there's no chance to survive, he'll stop trying." "The Martian" isn't strictly realistic—it exaggerates the risks from winds on Mars and understates the dangers of radiation—but it highlights the fundamental inhospitableness of a planet for which our species didn't evolve. It also makes clear the difficulty of simulating such an environment on the planet for which we did.

In December, to experience a rough approximation of Mars, I flew to Salt Lake City and drove two hundred and fifty miles to the red-brown canyon country of southern Utah. I spent a night in a hotel and woke before dawn, when temperatures were in the teens. As I drove up Cow Dung Road, a fiery orange sun crested some faraway hills, illuminating a sea of red boulders and ravines. I parked near a weathered sign. "RESTRICTED AREA," it read. "MARS DESERT RESEARCH STATION."

The M.D.R.S. can trace its origin to the nineties, when an aerospace engineer named Robert Zubrin, who believed that the U.S. was neglecting Mars exploration, co-wrote a popular book called "The Case for Mars." The book included detailed technical proposals alongside philosophical arguments. Zubrin wrote, "I would say that failure to terraform Mars constitutes failure to live up to our human nature and a betrayal of our responsibility as members of the community of life itself." Zubrin then founded the Mars Society, which attracted members including Buzz Aldrin, James Cameron, and Musk. In 2001, the society erected the "hab," a two-story cylindrical habitat that measures eight metres in diameter. Since then, it has hosted hundreds of simulated missions and has added a laboratory, a greenhouse, a solar observatory, and a maintenance shed built from a disused Chinook helicopter.

From my parking spot, I could see a solar array and some white structures tucked into the undulating landscape. Several gray A.T.V.s, which looked like Martian golf carts, were labelled with names from old NASA rovers. In the frigid weather outside the car, my toes felt as though they'd frozen inside my boots, but I reminded myself that they'd be even colder in space. A man with a neat brown beard and a heavy coat approached. "Welcome to Mars," he said.

The man was Sergii Iakymov, an aerospace engineer from Ukraine who directs the station. He and three others had recently spent forty-five days in a NASA simulation of a voyage to Mars. In a six-hundred-square-foot facility, he had contended with sleep deprivation and disorientation from a virtual view out the window. "All I could see was the sun and some distant stars," he told me. "My brain was, like, Where is Earth? I want to see Earth." Yet Iakymov's experience was mild compared with what some spacefarers have experienced. During the eighties, a Soviet crew reported possible hallucinations; another crew is thought to have grown depressed enough that its mission was prematurely terminated. And, in 1985, a failed space-shuttle experiment apparently caused a scientist such distress that a crew member duct-taped a hatch shut, fearing that he might open it and let the air out. (On subsequent missions, the hatch was locked.) NASA has referred to incidents like these as "behavioral health mishaps."

Iakymov pulled a two-way radio out of his pocket. "He's here," he said. "Should he come through the front or rear air lock? Over."

"Copy that," came a staticky reply. "Front air lock. Over."

I approached the hab, pulled hard on the heavy metal door, and entered a small circular chamber. Air locks prevent the atmosphere in a habitat from being sucked out through the door; they protect the bubble of breathable air that allows humans to survive in an otherwise unlivable environment. I thought of Weir's book, in which an air-lock breach destroys the protagonist's crops and nearly kills him. The door behind me closed. A few minutes later, a door in front of me opened.

I was greeted by barren white walls and flashing monitors. Six students from Purdue University, the alma mater of twenty-seven astronauts, were in the second half of a two-week simulation. I could see a digital sensor that warned them if parameters such as humidity, temperature, and carbon-dioxide levels left a safe range. (Without regular removal of CO_2, astronauts can exhale enough of the gas to cause headaches, fatigue, and even death.) As I took my first steps on "Mars," I tripped over a transparent wheeled box that contained a nest of colored wires—a not yet functional rover based on an open-source NASA blueprint. "I'm focussed on human-machine interactions," Spruha Vashi, the crew's engineer, told me. "How can we design machines that are maximally useful with extremely limited resources?"

She paused, then added, to much laughter, "I'm also in charge of making sure the toilet works."

"One of the more important human-machine interactions," I said. The crew had about three hundred gallons of water for fourteen days of flushing, cooking, cleaning, and drinking—about as much as an average American family uses in a day.

Peter Zoss, a tall, curly-haired Ph.D. student acting as the health-and-safety officer, had learned basic first aid and CPR. "Ideally, I don't have to use my new skills," he told me. On an earlier mission, someone had broken a bone; medical help didn't arrive for an hour and a half. Zoss was researching the effects of stress on physiology and cognitive performance. Mars exploration may take a profound toll on the psyche: the crew slept in tiny, windowless rooms, had minimal interaction with outsiders, and often spent several hours a day outside in the cold, carrying forty-pound packs to mimic scientific excursions. ("You have to use your own resources to make life interesting, to keep your motivation going," Andy Thomas, an American astronaut, said after a hundred and forty days on the Mir space station.) Zoss and his adviser later told me that one of his crewmates had experienced a slight dip in blood pressure, but also a dramatic reduction in heart-rate variability, which can indicate stress or lower cardiovascular health.

Hunter Vannier, a graduate student with a light beard who was the mission's commander, led me through an aboveground tunnel to the M.D.R.S. science dome, which was stocked with chemistry supplies, a first-aid kit, a fire extinguisher, and a blender with a label that said "For Lab Purposes Only," as if to ward off any errant scientist who wanted a smoothie. A metal table was covered with geological samples. Vannier explained that spectroscopy, the study of how light is absorbed and reflected by various materials, can suggest whether regolith might support crops. But the surface of Mars is already known to be high in perchlorates, which inhibit plant growth and are toxic to humans.

ettling a new planet sounds like the ultimate adventure, a dangerous dream worth almost any price.]

S The hab normally runs on solar electricity during the day and on power from a generator at night. A few days before my arrival, however, the lights and the heat had abruptly shut off. The generator—a luxury no Mars mission would be likely to have—had broken down. The crew had spent six hours hooking cables from the hab to a backup generator they retrieved from the maintenance shed, about twenty metres away. "The priority was making sure we didn't freeze at night," Vannier told me. In Utah, failure would have ended the mission; on Mars, it would have killed everyone. The lights had flickered back on at about 11 P.M.

Vannier showed me the M.D.R.S. greenhouse while our lunch, a black-bean-burger mix that looked like ashy gruel, was rehydrating. On the far side of another aboveground tunnel, I felt a rush of warmth. A thermometer read ninety degrees.

"This is where you do hot yoga?"

"Actually, people have done that."

Rows of plastic pots were arranged by crop on wooden pallets. Vannier caressed a fledgling cucumber. "We plant these now, but they won't be ready to eat during our time here," he told me. "You're creating something for future missions." A prior crew had planted some carrots close together; when Vannier had tried to thin their ranks, he'd inadvertently ripped out many of their roots. On another occasion, the cucumber plants wilted alarmingly until he increased their water allocation. He clipped some cilantro for lunch, weighing nine grams on a scale as though the herb were a rare truffle. Then he watered the plants, careful not to spill a drop. Gazing at the barren red expanse outside, he said, "It's just really nice to care for another living thing."

Extra-vehicular activities are among an astronaut's most dangerous undertakings. If the extreme temperatures and limited supplies of oxygen don't get you, a centimetre-size piece of space debris could puncture your spacesuit, leading to rapid depressurization and death. Simply entering or exiting a spacecraft can induce the bends—decompression sickness—in which dissolved nitrogen forms bubbles in the blood. In 2013, the Italian astronaut Luca Parmitano nearly drowned when a blockage in his suit's cooling system flooded his helmet with water.

I prepared for an E.V.A. with Vannier, Vashi, and a planetary-science graduate student named Ian Pamerleau. A replica space helmet was fitted over my head; I felt a wave of claustrophobia. We put on suits and mechanical backpacks, which circulated air through our helmets. Someone loaded my utility vest with a two-way radio and a G.P.S. tracker, in case I got lost, and I turned on a microphone near my face.

"This thing on?" I asked.

"Copy," Vannier said.

Pamerleau and I climbed into an A.T.V. called Perseverance. A freezing wind howled as we drove over rough terrain. After weaving between enormous boulders that appeared ready to fall on us, we stopped at a dry streambed. Pamerleau unspooled a steering-wheel-size measuring tape and knelt down to write on a yellow notepad. Vannier, who had met us there, read out our coördinates.

I squinted into the distance, imagining the vast expanse of untouched land that the first humans on Mars will find. On some level, I knew that we were playacting. As alien as the place looked, it had basically the same atmosphere and gravity as my living room. But the weight of my pack was real enough, and I could feel actual cold through the fabric of my suit. I thought about how, even in a place where we could breathe the air, our lives depended on a few pieces of breakable technology: radios, vehicles, generators. Without them, a night out here could kill us.

Vannier used a hammer and chisel to chip some samples off a ridge. I watched him carefully scoop loose rock into a bag. When we had completed the day's tasks, we drove back to the hab, cleaned ourselves off, and removed our helmets. I stayed with the crew until the sun started to fall toward the horizon. Before I left, we all shook hands; they retreated to their rooms to fill out daily activity logs. Then I stepped into the same air lock I'd entered through. My next step brought me back to Earth. ♦

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Dhruv Khullar, a contributing writer at The New Yorker, is a practicing physician and an associate professor at Weill Cornell Medical College. He writes about medicine, health care, and politics.

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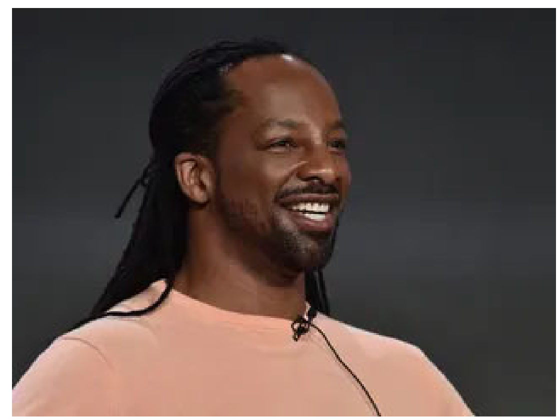

HUMOR

Daily Cartoon: Wednesday, February 26th

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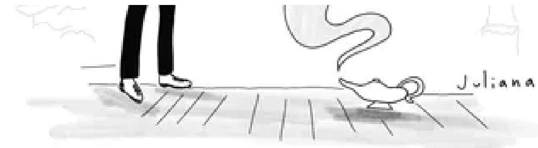
By Juliana Castro Varón



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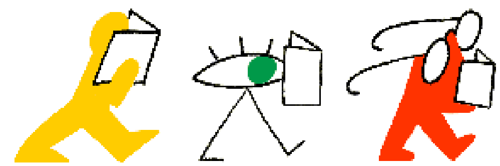

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Daily Cartoon: Tuesday, February 25th

"Look, I totally get it. But it's been two days now—maybe it's time to get out of the bath?"

By Habiba Nabisubi

HUMOR

What Your Sweater Says About You

Gray Wool Sweater: You are in a TV commercial, struggling to play with your grandchild because of your rheumatoid arthritis.

By Madeline Goetz