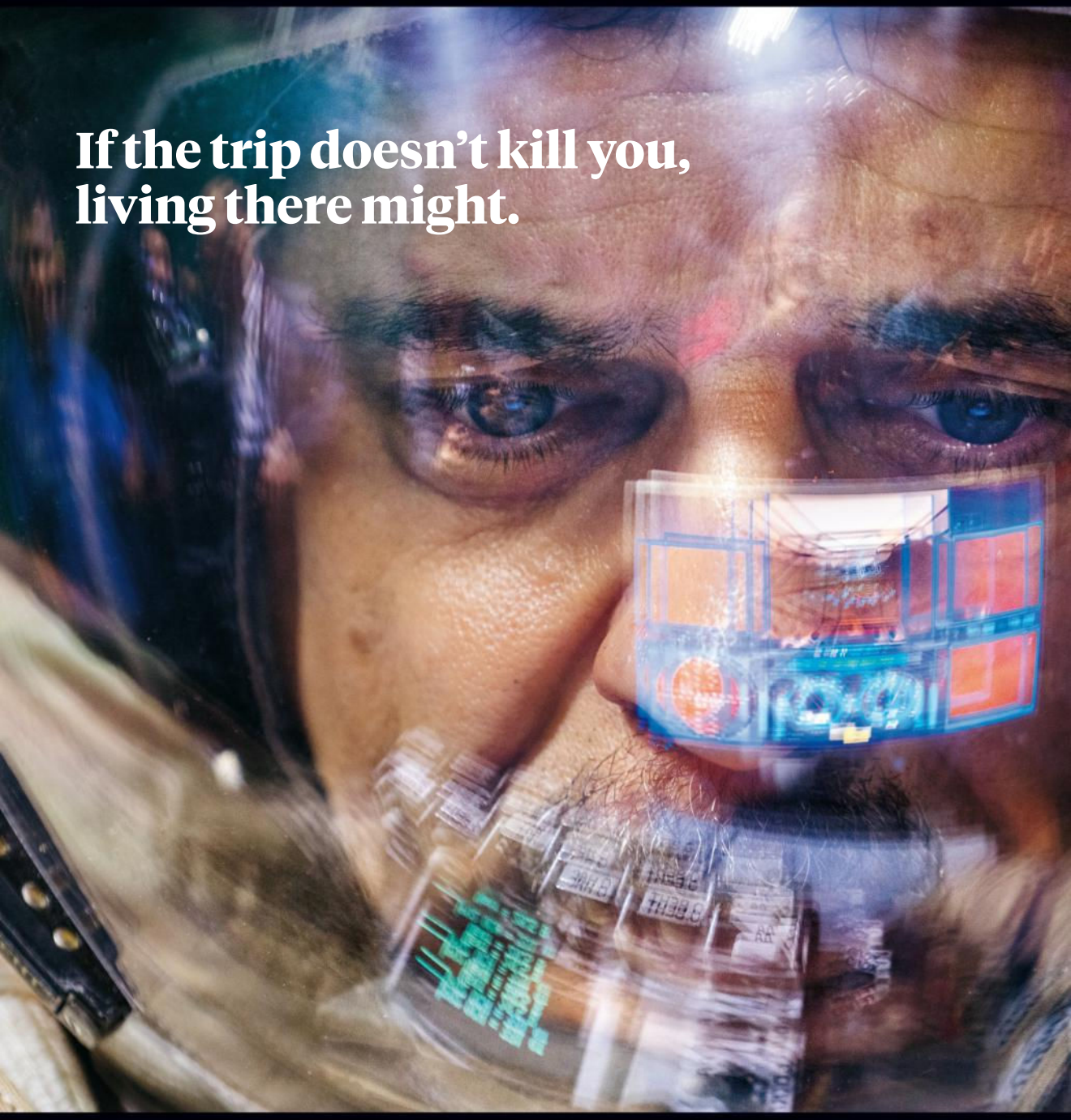
NATIONAL GEOGRAPHIC

RACE TO THE RED PLANET

NOVEMBER 2016


If the trip doesn't kill you,
living there might.

Mars

The race to the red planet

Four days after returning from nearly a year on the International Space Station – a dry run for a Mars voyage – Mikhail Kornienko drives a simulated Mars rover at Star City, the Russian cosmonaut training center. How well Mars explorers would perform on arrival is uncertain: Hazards of the trip include bone loss and brain damage.

PHOTO: PHILLIP TOLEDANO (LEFT). MARS MOSAIC COMPOSED OF 102 IMAGES: VIKING PROJECT, USGS/NASA


SPACEX

Landing softly, so as to fly again

Aerospace company SpaceX is developing a technology it says may one day enable humans to land on Mars: reusable rockets. Here a Falcon 9 rocket lifts off (far left) from Cape Canaveral, Florida, to deliver supplies to the space station. After a few minutes the booster separates from the second stage, which continues toward orbit. Instead of falling into the ocean, the booster flips over and fires its engines twice more to slow and guide it to a soft landing at a nearby pad (right). A long exposure (center) captures the whole sequence; the straight light streak at right is the booster's return path.

PHOTOS: SPACEX (FAR LEFT); MICHAEL SEELEY (CENTER); SPACEX

Dressed for Mars, University of North Dakota space engineer Pablo de León tests a prototype space suit in the "regolith bin" at NASA's Kennedy Space Center. Inside the chamber, fine soil and fans simulate the dust storms that could bedevil astronauts on Mars.

PHOTO: PHILLIP TOLEDANO


AC SUPPLY
Valkyrie Safety
Valkyrie Safety
If Valkyrie falls, don't worry! She is tethered such that she will not collide with the ground.
However, it may be very loud and surprising, so please be alert.
FOR YOUR SAFETY
Please remain behind the yellow stanchions

The first footprints on Mars might be those of robots like Valkyrie, being tested by Northeastern University engineers Taskin Padir (right) and Velin Dimitrov. Robots could build a base before humans arrived. Later they'd do chores, such as cleaning dust off solar panels.

PHOTO: MAX AGUILERA-HELLWEG. PHOTOGRAPHED AT THE NEW ENGLAND ROBOTICS VALIDATION AND EXPERIMENTATION CENTER, UNIVERSITY OF MASSACHUSETTS, LOWELL

This past May a South Carolina tree briefly framed the second stage (left) and the returning booster of a Falcon 9. "It really quite dramatically improves my confidence that a city on Mars is possible," SpaceX founder Elon Musk said after an earlier soft landing.

PHOTO: ZACH GRETHER

By Joel Achenbach

Photographs by Phillip Toledano, Robert Clark, Max Aguilera-Hellweg, and Mark Thiessen

Elon Musk wants to go to Mars.

He has said, famously, that he wants to die on Mars, just not on impact. A technology that might help prevent such a mishap passed a crucial test one night last December, when a Falcon 9 rocket built by Musk's company SpaceX lifted off from Cape Canaveral in Florida, carrying 11 communications satellites.

A few minutes into the flight the booster separated from the rest of the rocket, as thousands of spent boosters have done since the dawn of the space age; normally they burn up in the atmosphere, and their fragments rain into the ocean. But this booster wasn't spent. Instead of falling, it flipped over, and its engines reignited to slow and guide its descent toward a nearby landing pad. Essentially it flew backward. From the ground it looked as if the launch movie were being rewound.

Inside the launch control center on the cape,

Everyone seems to agree: If humanity has a next great destination in space, Mars is it. But how attainable is it?

and inside SpaceX mission control in Hawthorne, California, hundreds of young engineer faces watched the approaching ball of light on video screens, transfixed. At launch control Musk ran outside to get a direct look. Seconds later there was an ominous boom. No one had ever succeeded in landing an orbital-class booster rocket like this; the first couple of times SpaceX had tried, the rocket had exploded. But this noise turned out to be merely a sonic boom from the booster's rapid descent through the atmosphere. It reached Musk's ears just as the booster was landing—gently, safely, and successfully at last. In front of their screens the engineers were whooping.

SpaceX had just achieved a milestone in the quest for reusable rockets. Musk figures the technology could cut launch costs by a factor of a hundred, giving SpaceX a competitive advantage in its business of launching satellites and delivering supplies to the International Space Station. But that has never been the point for Musk. The first soft landing of a booster rocket, he said during a news teleconference that night, was "a critical step along the way toward being able to establish a city on Mars."

Elon Musk doesn't just want to land on Mars, the way Apollo astronauts landed on the moon. He wants to build a new civilization there before some calamity, possibly self-inflicted, wipes us out on Earth. SpaceX employees in Hawthorne often wear "Occupy Mars" T-shirts. Just around the corner from Musk's no-frills desk, twin images of Mars hang on a wall: One shows the red, parched planet today, and the other shows a blue Mars, "terraformed" by engineers, with seas and rivers. Musk imagines colonizing Mars with a flotilla of interplanetary *Mayflowers,* each carrying a hundred settlers, like the original, except that many of these pilgrims would be ponying up $500,000 or more for a berth on the spaceship.

SpaceX, founded in 2002, has yet to launch a single human into space, though it hopes to change that next year by carrying NASA astronauts to the space station on a Falcon 9. It has been building a larger rocket, the Falcon Heavy, but even that won't be large enough to carry humans to Mars. Musk promised to unveil details of his Mars plans in late September, after this story went to press (and just weeks after another SpaceX rocket exploded on the launchpad). But in advance there was no indication that SpaceX had developed, much less tested, the other technologies necessary to keep humans alive and healthy on Mars or on the long journey. Nevertheless, Musk announced this past June that SpaceX aims to dispatch its first astronauts to Mars in 2024. They'd land (softly, he hopes) in 2025.

"There'll be fame and that kind of thing for them," Musk says. "But in the grander historical context, what really matters is being able to send a large number of people, like tens of thousands if not hundreds of thousands of people, and ultimately millions of tons of cargo." That's why he thinks reusable rockets are so important.

NASA, which landed men on the moon in 1969 and began exploring Mars with robotic probes even before that, says it plans to send astronauts to Mars too—but not until the 2030s, and then only to orbit the red planet. The dangerous, tricky feat of actually landing a large craft on the surface, NASA says, is a "horizon goal" that it would achieve only in a later decade. NASA doesn't talk about Martian cities.

Everyone seems to agree on one thing: If humanity has a next great destination in space, Mars is it. But clearly there are conflicting visions of how attainable it is. Legendary NASA astronaut John Grunsfeld, who fixed the Hubble Space Telescope three times and retired this past spring as the agency's science chief, remembers being told, back in 1992, that he was in the class of astronauts that would someday go to Mars. This year, thanks in part to the success of *The Martian,* a best-selling book and blockbuster movie, NASA received 18,300 applications for its next class—in which there are at most 14 openings. Grunsfeld still wants humans to go to Mars, but he also stands by the advice he gave a few years ago to NASA administrator and fellow

astronaut Charles Bolden. It was about talking to new recruits. "Don't tell these folks they're going to Mars, because there's no chance," Grunsfeld said. "They'll be in their 70s or 60s."

What NASA has been doing, besides designing its own rocket to go to Mars, is a lot of work on how to take care of the passengers. In March, for example, astronaut Scott Kelly and Russian cosmonaut Mikhail Kornienko returned to Earth after 340 days on the space station. On their "One-Year Mission" they served as guinea pigs for studies of what long stints in space (a round-trip to Mars might take nearly three years) do to the human body and mind. As they plunged back into the atmosphere, Kornienko recalls, their Soyuz capsule was rattling like a car on a cobblestone road, and fist-size sparks from the flaming heat shield were flying past the portholes. He and Kelly could barely breathe: After a year of weightlessness their lungs and chest muscles were weak. And once they landed on the steppes of Kazakhstan, they could barely walk. The ground crew carried them from the capsule, for fear they might stumble and break a bone. In May, Kelly was still saying that his feet hurt.

Hollywood movies convey the fun of weightlessness. Interviews with Kelly and Kornienko from the space station hint at the other side. Their faces are puffy, because fluid doesn't drain out of them. Their arms are folded across their chests, lest they extend straight ahead in the dreaded "zombie pose." Astronauts can get used to strapping themselves onto a suction toilet and even, Kornienko says, to a whole year of wiping off with a wet washcloth, for lack of a shower. On a much longer, much more hazardous Mars journey, in which Earth is not 250 miles but millions of miles away, with no option to turn back or bail out, what space can do to a human body could be a huge problem. "They're going to be sick when they get there," says Jennifer Fogarty, deputy chief scientist for the Human Research Program at NASA's Johnson Space Center, in Houston.

Bones waste away in zero gravity: The rule of thumb is you lose one percent of your bone mass per month. Vigorous exercise helps, but the jumbo equipment used on the space station weighs too much for a Mars mission. Some astronauts on the station have also experienced serious vision impairment, apparently because fluid collects in the brain and presses on their eyeballs. The nightmare scenario is that astronauts land on Mars with blurred vision and brittle bones and immediately break a leg. Theoretically the risk could be reduced by spinning the spacecraft rapidly, replacing gravity with centrifugal force. But NASA engineers see that as adding too much complexity to an already challenging mission.

Radiation is another hazard. The astronauts on the space station are still mostly protected by Earth's magnetic field. But on a journey to Mars they'd be vulnerable to radiation from solar flares and cosmic rays, which are high-energy particles coming from across the galaxy at nearly the speed of light. The latter especially can damage DNA and brain cells—which means astronauts could arrive on Mars a little dimmer, as well as blurry eyed and brittle boned. One possibility would be to line the habitat module with a thick layer of water, or even plants growing in soil, as a partial radiation shield. But so far nothing has been proved to solve the problem.

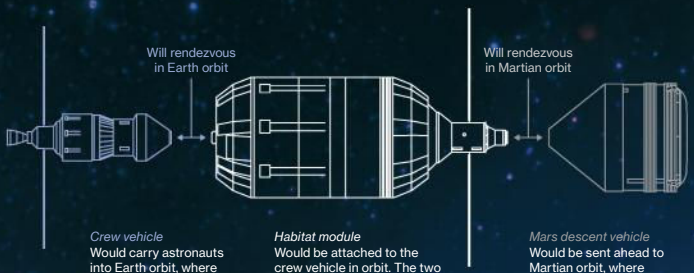
Just keeping astronauts supplied with drinkable water and breathable air is a challenge. One day at Johnson Space Center I met Kenny Todd, whose title is operations integration manager for the space station. He looked weary. It was midmorning, but he'd been at the office for many hours, working overnight to supervise one of the unheralded but critically important cargo flights. A conversation between the station and mission control squawked quietly from a speaker on his desk as we talked about urine, among other things.

Some of the water on the space station comes from filtering and recycling urine and sweat. But those filters can get clogged with calcium—from the astronauts' dwindling bones—and the water sometimes gets contaminated by microbes. "Working with urine—it's very finicky," Todd said. The scrubbers that remove carbon dioxide from air break down too—like nearly every other device on the station. In low Earth orbit, that's not critical; NASA can send up spare parts. A Mars-bound spacecraft would have only the spares it could carry with it. All the life-support equipment, Todd said, would need to be much more reliable than it is now, essentially unbreakable.

That doesn't mean he doesn't want to send people to Mars. Nor does he criticize the dreamers who are ready to blast off tomorrow morning. "You gotta start somewhere. You gotta start with dreaming," Todd said. "And sometime in there,

SURVIVING THE VOYAGE

Mars is never less than 34 million miles away – more than 140 times farther than the moon. To send astronauts would require a new kind of spacecraft that could house them comfortably for months, shield them from cosmic radiation, and carry enough supplies for the voyage home. This artist's conception, based on a NASA study, shows one possible scheme.



Crew vehicle
Would carry astronauts into Earth orbit, where they'd rendezvous with a habitat module.

Habitat module
Would be attached to the crew vehicle in orbit. The two vehicles would make the long voyage to Mars together.

Mars descent vehicle
Would be sent ahead to Martian orbit, where it would ferry arriving crew to the surface and back.

Living in Space

The crew vehicle would get astronauts into
too cramped for six people – NASA's baseli
to Mars – to live in comfortably for long stre
module, perhaps an inflatable one, could be
Earth orbit for the long interplanetary missi

Getting There

Getting to Mars would require a lot of fuel. Getting back could require making chemical fuel – and the oxygen to burn it – on Mars. Nuclear or solar power might help.

CHEMICAL
Traditional rockets would be needed at least for liftoff: They burn fuel so fast that their exhaust generates huge thrust. But they're inefficient.

NUCLEAR
A nuclear reactor can create thrust more efficiently by heating and expelling hydrogen. But putting a reactor on a rocket raises safety concerns.

SOLAR
In this system, solar electricity ionizes a gas, which is then expelled by a magnetic field. The thrust is weak but may be enough for a slow cargo ship.

1 MORALE
Having enough space and good food would help keep the crew comfortable and positive. Crops from "green walls" could supplement a space-food diet.

2 PROTE
Cosmic radi
hazard to ar
Earth's mag
filled green
shield astro

space, but it would be
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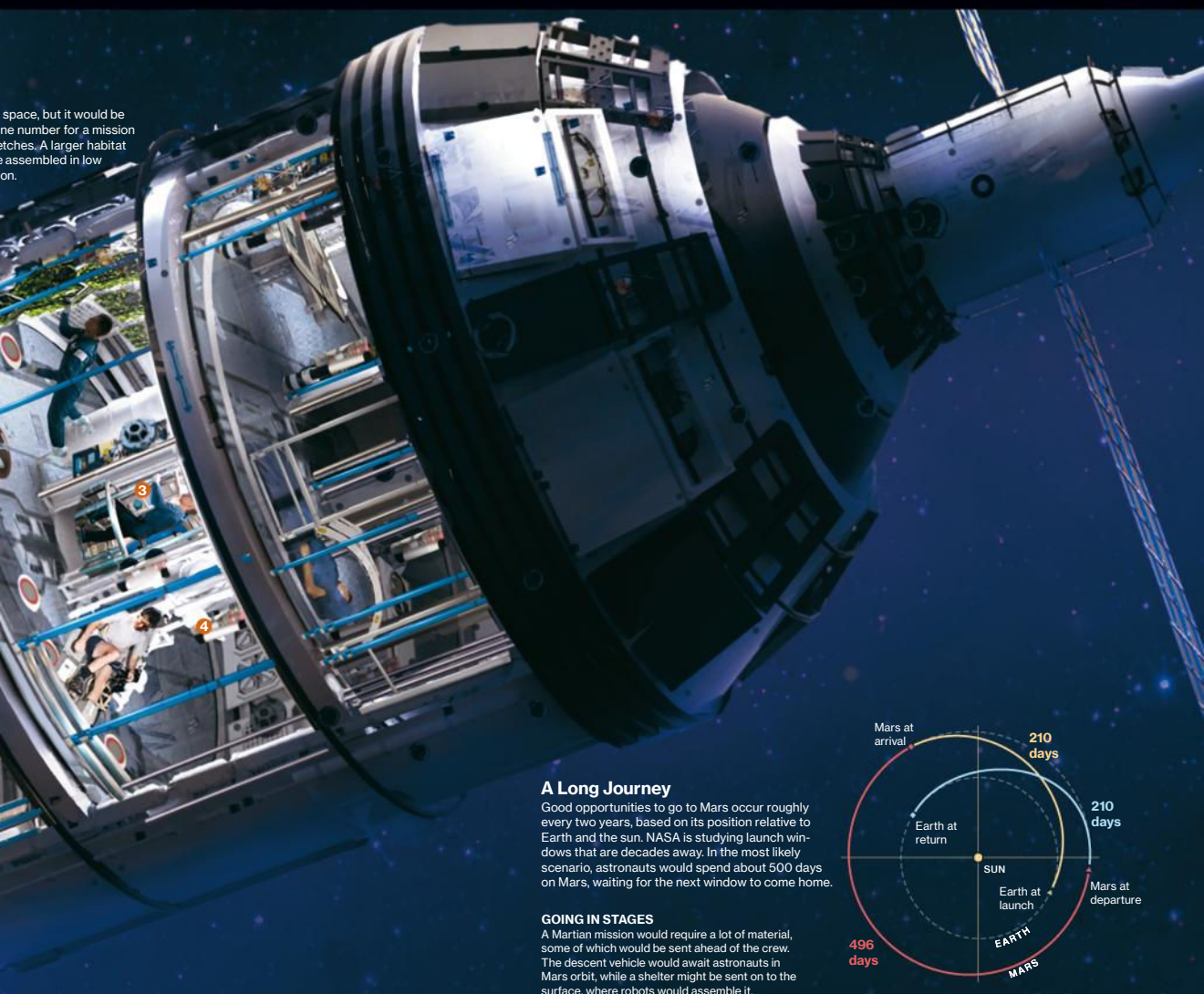


A Long Journey

Good opportunities to go to Mars occur roughly every two years, based on its position relative to Earth and the sun. NASA is studying launch windows that are decades away. In the most likely scenario, astronauts would spend about 500 days on Mars, waiting for the next window to come home.

GOING IN STAGES

A Martian mission would require a lot of material, some of which would be sent ahead of the crew. The descent vehicle would await astronauts in Mars orbit, while a shelter might be sent on to the surface, where robots would assemble it.

CTION
ation is a constant
nyone outside
netic field. Water-
walls would help
nauts from it.

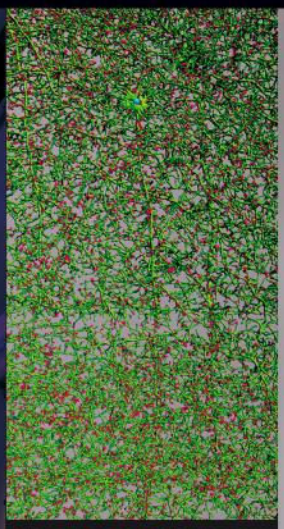
3 REPAIRS
Critical systems for navigation and for recycling air and water would be kept in the core of the habitat module, making repairs and maintenance convenient.

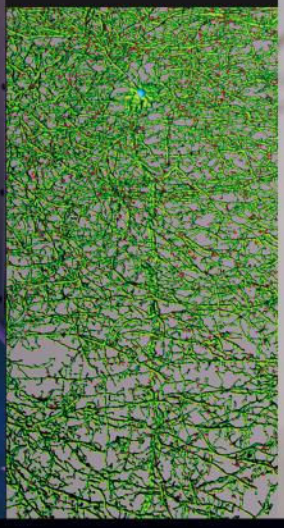
4 EXERCISE
Living in zero gravity for long periods would take a major toll on the human mind and body. Exercise would be critical for mental and physical health.

JASON TREAT, NGM STAFF; TONY SCHICK. ART: STEPHAN MARTINIERE

SOURCES: JAMES B. GARVIN, NASA GODDARD SPACE FLIGHT CENTER; JASON C. CRUSAN, NASA HUMAN EXPLORATION AND OPERATIONS MISSION DIRECTORATE; BRET G. DRAKE, THE AEROSPACE CORPORATION; MARIA BANKS, PLANETARY SCIENCE INSTITUTE

Water tanks lining a spaceship could partially shield astronauts from radiation while boosting their mood and diet by letting them garden. Bob Morrow of NASA-funded Orbitec shows off lettuce ripened in a prototype system.





COSMIC RAYS AND BRAINS Astronauts leaving Earth's protective magnetic field would be vulnerable to fast-moving particles called cosmic rays. Compared with a healthy mouse brain (top), a mouse hit by "space-relevant" radiation (bottom) has fewer nerve-cell branches (green) and connections (red) in its prefrontal cortex. Such mice explore less and have worse spatial memory – "a cause for concern" for Mars explorers, says Charles Limoli of the University of California, Irvine.

PHOTOS: ROBERT CLARK (LEFT); CHARLES LIMOLI, DEPARTMENT OF RADIATION ONCOLOGY, UNIVERSITY OF CALIFORNIA, IRVINE (MOUSE BRAINS); PHILLIP TOLEDANO

Russian cosmonaut Sergey Volkov undergoes a battery of physical tests at Star City after returning from six months on the International Space Station. Long stays in space – a trip to Mars might take seven months each way – can affect the body profoundly.

No experiment on Earth can quite simulate the feeling of being locked in a small can millions of miles away.

things become actual." Which means a lot of things have to be figured out.

That includes more complicated things like human psychology. "We've done so well with robotic missions, we think we've got the hardware part of it figured out," says Fogarty. "But now we're going to throw in self-aware, self-deterministic individuals that are part of this team. Have we truly understood all the risks they bring and given them the tools to handle it?"

NASA works on that problem by conducting analog missions on Earth. At Johnson Space Center I visited one. Inside a cavernous, windowless warehouse, beyond a DO NOT ENTER sign, sat a three-level, domed structure, also windowless, that was covered in soundproofing material—like a chunk of space station specially wrapped for a long and dangerous journey. Inside were four volunteers, each making $160 a day to be sealed up for a month, physically cut off from the outside world. Thirteen cameras inside their habitat allowed researchers in "mission control," a few strides away, to watch their every move and see how they dealt with the isolation, individually and as a crew.

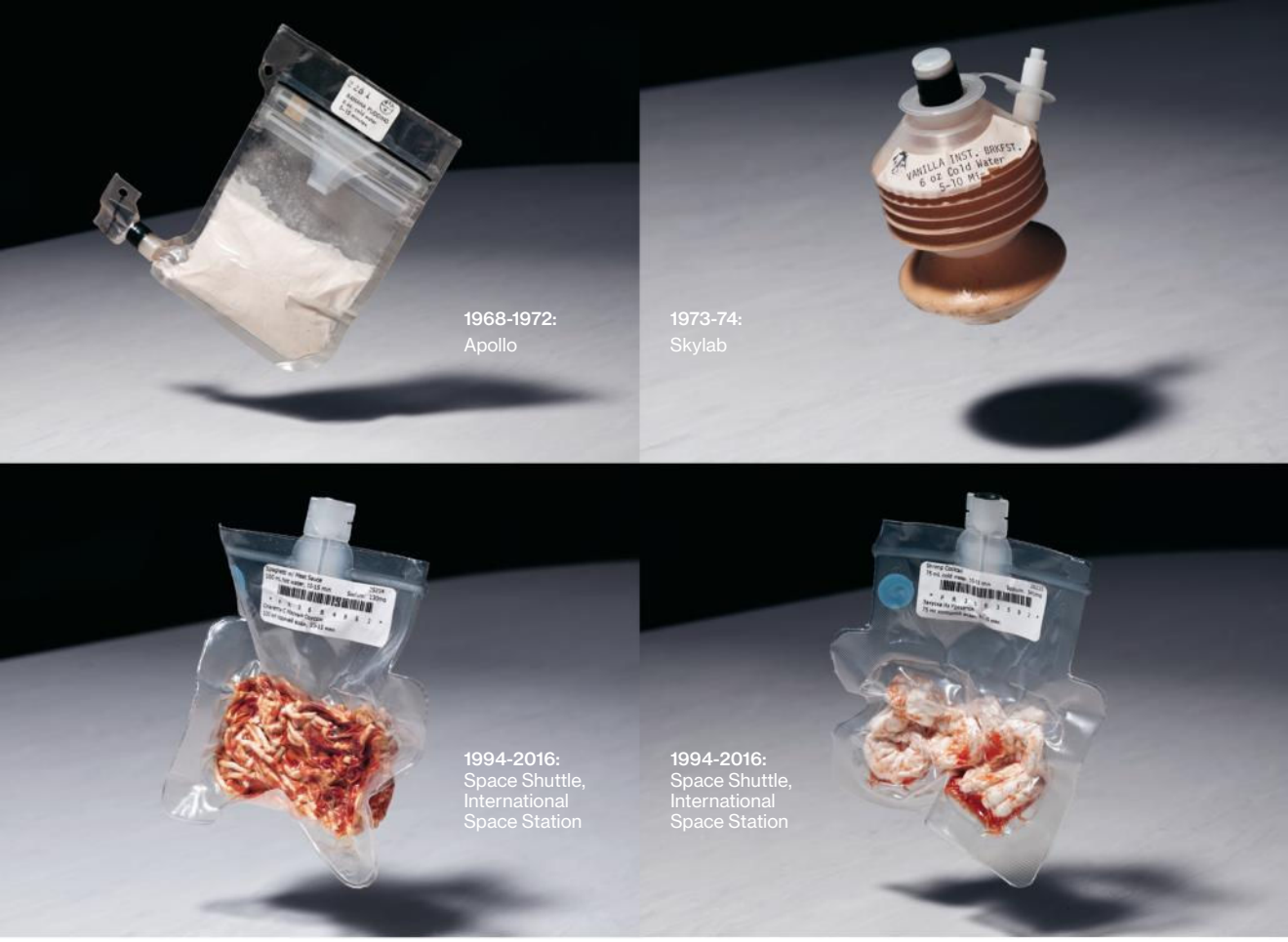
The simulation has its limits. "Obviously we don't have a zero-g switch," said project manager Lisa Spence; these astronauts get to enjoy a flush toilet and a shower. But Spence and her colleagues strive for as much verisimilitude as possible. As we watched two volunteers huddled in a darkened air lock, wearing virtual reality visors and experiencing a simulated space walk, we spoke in hushed voices, lest they hear us. A huge storm had just blown through, a real toad-strangler, with booming thunderclaps; if anyone inside the module asks about thunder, Spence said, "we make up a cockamamy story about space weather."

A certain kind of personality is needed for a Mars mission, the experts say: someone who can tolerate isolation and boredom during the long transit, then shift into overdrive on Mars. Someone who's mentally resilient and has excellent social skills. These traits may or may not correlate with the ability to pay $500,000, which is the SpaceX criterion. "We select very low-drama people. Nonetheless, there's bound to be conflict," says Kim Binsted of the University of Hawaii at Manoa, who directs other NASA-funded analog missions. In the most recent one, six volunteers were sealed for a year into a mock Mars habitat halfway up the side of a volcano. They could exit only if they donned space suits.

No experiment on Earth, however, can quite simulate the feeling that will come from being locked in a small can millions of miles away. William Gerstenmaier, NASA's chief of human spaceflight, has noticed something about astronauts on the space station. "They tweet a lot of pictures of their hometown," he told me. "They take pictures of their college football stadiums. There's still a really strong tie back to the Earth."

Kornienko felt it. "This is not even nostalgia, you understand; this is not a business trip to a different city, when you miss your apartment, your home, family," he said, shortly after he returned from his year in orbit. "This is about missing the Earth as a whole. It is a completely different emotion. There is a shortage of greenery, for real, like not enough forest, summer, winter, snow."

In June, six months after SpaceX triumphantly landed its booster, NASA held its own rocket test in the hills of northern Utah. This was a "ground test" of a solid-fuel booster that will be an integral element of the Space Launch System, the blandly named rocket that NASA says will someday take humans into deep space. Thousands of people gathered a mile away, intently watching through the clear desert air as an announcer went through the countdown. At zero, the booster, lying on its side and bolted fast to the ground, ignited ferociously. The announcer reminded everyone that this was part of NASA's "Journey to Mars." The jet of flame roared for more than two minutes as a great pillar of smoke



NASA menus have progressed from banana pudding (top left) through vanilla instant breakfast (top right) to recognizable spaghetti (bottom left) and even shrimp cocktail. But foodies should think twice before signing up for a Mars trip.

rose into the sky and onlookers cheered.

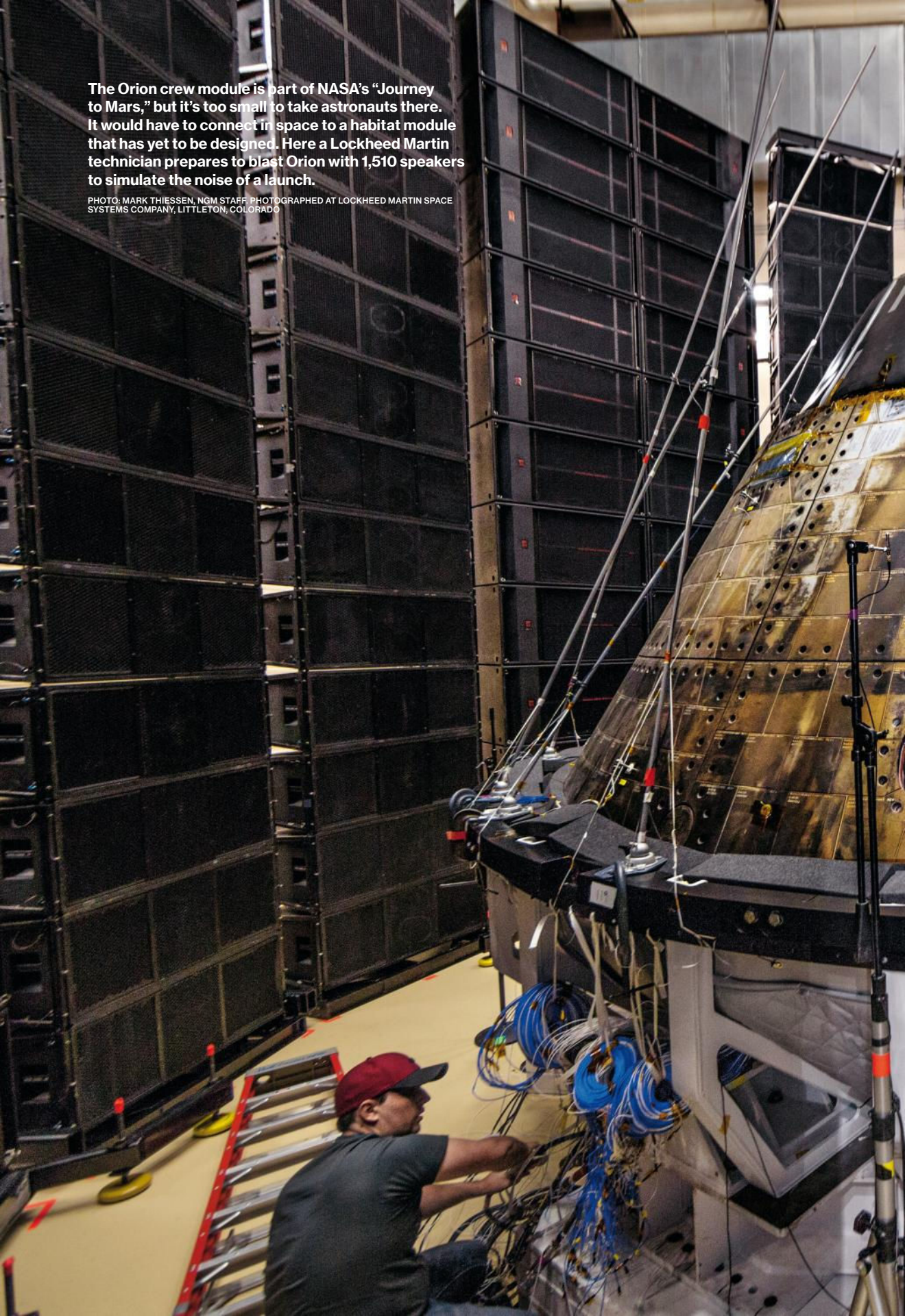
"What an absolutely amazing day today!" Gerstenmaier said at a news conference afterward. And the test was indeed spectacular—as spectacular as it could possibly be, given that the rocket didn't actually fly.

"We are closer than ever before to sending American astronauts to Mars than anyone, anywhere, at any time has ever been," NASA Deputy Administrator Dava Newman wrote in a blog post this past April. To some of NASA's critics, it doesn't feel that way. It certainly wouldn't have felt that way to Wernher von Braun, builder of the Saturn V moon rocket. In 1969, in the euphoria after the first moon landing, von Braun pitched a plan to President Richard Nixon to land men on Mars in 1982. Nixon ordered NASA to build the space shuttle instead.

Since then grand plans for breaking out of low Earth orbit have come and gone. Gerstenmaier, who's been at NASA for decades, has survived the strategic lurches imposed by politicians. He was told to send astronauts back to the moon, then to send them to an asteroid instead, then to capture an asteroid and have astronauts visit it in lunar orbit. In news media coverage of NASA, "lost in space" has become a cliché. Gerst, as he's known, remains unruffled. He's a low-key engineer, kind of an anti-Musk, someone who doesn't want to overpromise. He'd like to go to Mars slowly, methodically, and sustainably.

That means glacially, some critics would argue. "To say NASA has a strategy [for going to Mars] is really an insult to the word 'strategy,'" declares Robert Zubrin, founder of the Mars Society, which advocates the settlement of Mars as "the greatest cause of our generation." Michael Griffin, who served as NASA administrator under President George W. Bush, believes a Mars mission would be hard, but no harder than the

PHOTOS: PHILLIP TOLEDANO. PHOTOGRAPHED AT NASA JOHNSON SPACE CENTER



The Orion crew module is part of NASA's "Journey to Mars," but it's too small to take astronauts there. It would have to connect in space to a habitat module that has yet to be designed. Here a Lockheed Martin technician prepares to blast Orion with 1,510 speakers to simulate the noise of a launch.

PHOTO: MARK THIESSEN, NGM STAFF. PHOTOGRAPHED AT LOCKHEED MARTIN SPACE SYSTEMS COMPANY, LITTLETON, COLORADO

Test dummies in an Orion model suit up for a drop test in a pool at NASA's Langley Research Center in Virginia. Like the Apollo modules, Orion will splash down in the ocean. One day it may take astronauts near the moon again but probably not before 2021.

PHOTO: DAVID C. BOWMAN, NASA

FIRST STEPS

The first humans to walk on Mars would be stepping into a harsh, unforgiving environment. The thin atmosphere would partially protect them from solar radiation, but they'd need to shield themselves from cosmic rays. They'd also have to utilize scant Martian resources for their oxygen and water.

Potential Landing Sites

Nearly 50 possibilities have been identified. They're in areas of scientific interest, with resources such as water-rich deposits – and within 50 degrees of the equator, where it's easiest to launch a rocket home.

1

TEMPORARY SHELTER
NASA is testing a flexible life-support structure that recycles all water, air, and waste. It would house working astronauts while permanent shelters were assembled.

2

LONG-TERM SHELTER
Shipping resources to Mars would be onerous and expensive. One option for creating permanent shelters involves using the soil found on Mars to create building materials.

3

THE Z-2 SUIT
Astronauts would slide into and out of this flexible space suit through a "suit port" in the back, which would attach directly to the outside of a pressurized shelter or rover.

4

GETTING AROUND
Pressurized rovers – able to support two people for a fortnight and travel about 60 miles at a time – could be used to aid exploration missions on the surface.

JASON TREAT AND MATTHEW W. CHWASTYK, NGM STAFF; TONY SCHICK
ART: STEPHAN MARTINIERE

SOURCES: JAMES B. GARVIN, NASA GODDARD SPACE FLIGHT CENTER; JASON C. CRUSAN, NASA HUMAN EXPLORATION AND OPERATIONS MISSION DIRECTORATE; BRET G. DRAKE, THE AEROSPACE CORPORATION; MARIA BANKS, PLANETARY SCIENCE INSTITUTE; LINDSAY E. HAYS, NASA/JPL

When and whether we go to Mars depends on technology, money, and what we consider an acceptable risk.

Manhattan Project or the Apollo program: "We're closer to Mars in terms of the technology required to do it today than we were to the moon when President Kennedy set that goal in 1961. We are far closer."

We aren't closer to paying for a Mars trip, though—and it's the expense that killed the grand plans of the past. The Apollo moon landings cost about $140 billion in today's dollars. Experts assume a realistic journey to Mars would cost at least that much; a fully loaded plan put forward under President George H. W. Bush had a price tag of $450 billion. But NASA's annual budget for all human spaceflight is around nine billion dollars. To get to Mars before the 2040s would take a lot more money and a president with Kennedy-like commitment. During the moon race with the Soviet Union, NASA got more than 4 percent of the federal budget; now it gets about half a percent. If there were truly a "Mars race" with China, say, that might help, but the Chinese don't appear in a rush to get there.

When and whether we go to Mars doesn't just depend on technology and money. It depends on what we consider an acceptable level of risk. Advocates of an early landing say that NASA is too risk averse, that true explorers accept the possibility of failure or death, that the people who first tried to reach the poles or cross the oceans knew they might not make it—and often didn't. NASA could send people to Mars a lot sooner if it didn't worry so much about whether they'd arrive alive and eventually make it home.

At the end of Gerstenmaier's news conference in Utah, a local reporter stood up. He was 49 years old, he said, and he just wanted to know one thing: Would he live to see a man on Mars?

"Yes," Gerstenmaier said. He hesitated for a moment and then added: "'Man' may be the wrong word. You will see a human being."

Then, after the applause and appreciative laughter had subsided, Gerstenmaier proceeded to explain why it was going to take until the 2040s. NASA needed to begin its return to deep space with missions to the "Proving Ground," he said, meaning around the moon and nearby points in space. That would lead in the 2030s to putting astronauts in orbit around Mars. "When I look at challenges of getting a crew on the surface, it adds another order of magnitude of complexity to what we're trying to do," Gerstenmaier had told me earlier. "That's what drives me out of the 2030 time frame."

But that's where SpaceX might help. Mars is a much harder place than the moon to land a spacecraft softly. Its gravity is stronger, and its atmosphere—while too thin to be much help in slowing a spacecraft or to support life as we know it—is thick enough to cause overheating. Many unmanned probes have crashed on Mars. NASA has landed a one-ton rover, Curiosity, but a payload big enough to carry humans and keep them supplied would have to be the size of a house and weigh at least 20 tons. A parachute wouldn't work—it would have to be as big as the Rose Bowl, and it would never open quickly enough.

The most promising solution at the moment is the technology that SpaceX is developing: supersonic retropropulsion. When the Falcon 9 booster descends at supersonic speed through Earth's thin upper atmosphere, it's in Mars-like conditions. The success at Cape Canaveral last December, and subsequent landings on a ship offshore, are why so many people are now saying that sending humans to Mars is plausible—if far from a slam dunk. SpaceX has shared its data with NASA.

At Kennedy Space Center, SpaceX has leased Launch Pad 39A, where the Apollo 11 astronauts blasted off for the moon. The company is young, nimble, and daring, as NASA was then; NASA has grown slow, bureaucratic, and cautious. But the two aren't competitors, and they're not in a race. They're partners. SpaceX already delivers supplies to the space station in a Dragon capsule carried on a Falcon 9. In April, Musk announced

Since 2012, NASA's Curiosity rover has been looking for chemical evidence that Mars might once have supported life. "The most sophisticated robot ever sent to another planet," according to former chief scientist John Grotzinger, it needs no food or water and never gets lonely. It even takes selfies.

that SpaceX wants to send an unoccupied Dragon capsule to Mars as early as 2018. To do that, he'd need NASA's technical support, in particular its huge radio antennas, which allow spacecraft to communicate with Earth.

To send people to Mars, SpaceX would need far more help—those $500,000 tickets won't cover much of the costs, and it will take NASA know-how to keep the travelers alive. NASA, on the other hand, could benefit from SpaceX's rockets, capsules, and enthusiasm. The two will likely go to Mars together if they go at all. (Musk himself has suggested as much.) When will they go? If it's a partnership, it seems more likely to follow NASA's more cautious schedule. What will they do when they get there? It's a lot easier to imagine a few scientists spending a year or two at a small Martian research station, like the ones in Antarctica, than it is to imagine thousands of people emigrating permanently to a Martian metropolis.

"Those people who think they want to live on Mars—I would encourage them to spend a summer, or better yet a year, on South Pole station," says Chris McKay, a NASA scientist and Mars expert who has worked in Antarctica. Suggesting that humans might find refuge on Mars after messing up Earth is "ethically and technically absurd," says McKay. "I think we need to take the view that failure is not an option. The notion of Mars as a lifeboat makes the *Titanic* look like a happy ending."

Mikhail Kornienko recommends a long stay on the space station as a way to winnow out the enthusiasts who think they'd like to go on a one-way journey to Mars. Soon after he came back from space this year, he recalled the moment the ground crew opened the hatch on the Soyuz capsule. "The air of the steppe comes into the cabin after all the bustle of descent, and you understand that everything is over," he said. "And you can't get enough of this air. It's possible to cut it with a knife and spread it on bread." □

To learn more about colonizing the red planet, tune in to National Geographic's six-part series, *MARS*, on November 14 at 9/8c.

PHOTO: NASA/JPL/MALIN SPACE SCIENCE SYSTEMS; COMPOSITE OF 58 PHOTOS

“No nobler cause has ever been,” declared the founders of the Mars Society in 1998. They advocated sending humans to Mars “within a decade.” The society runs a research station in Utah where crews practice in a landscape that resembles Mars, but with breathable air.

PHOTO: PHILLIP TOLEDANO