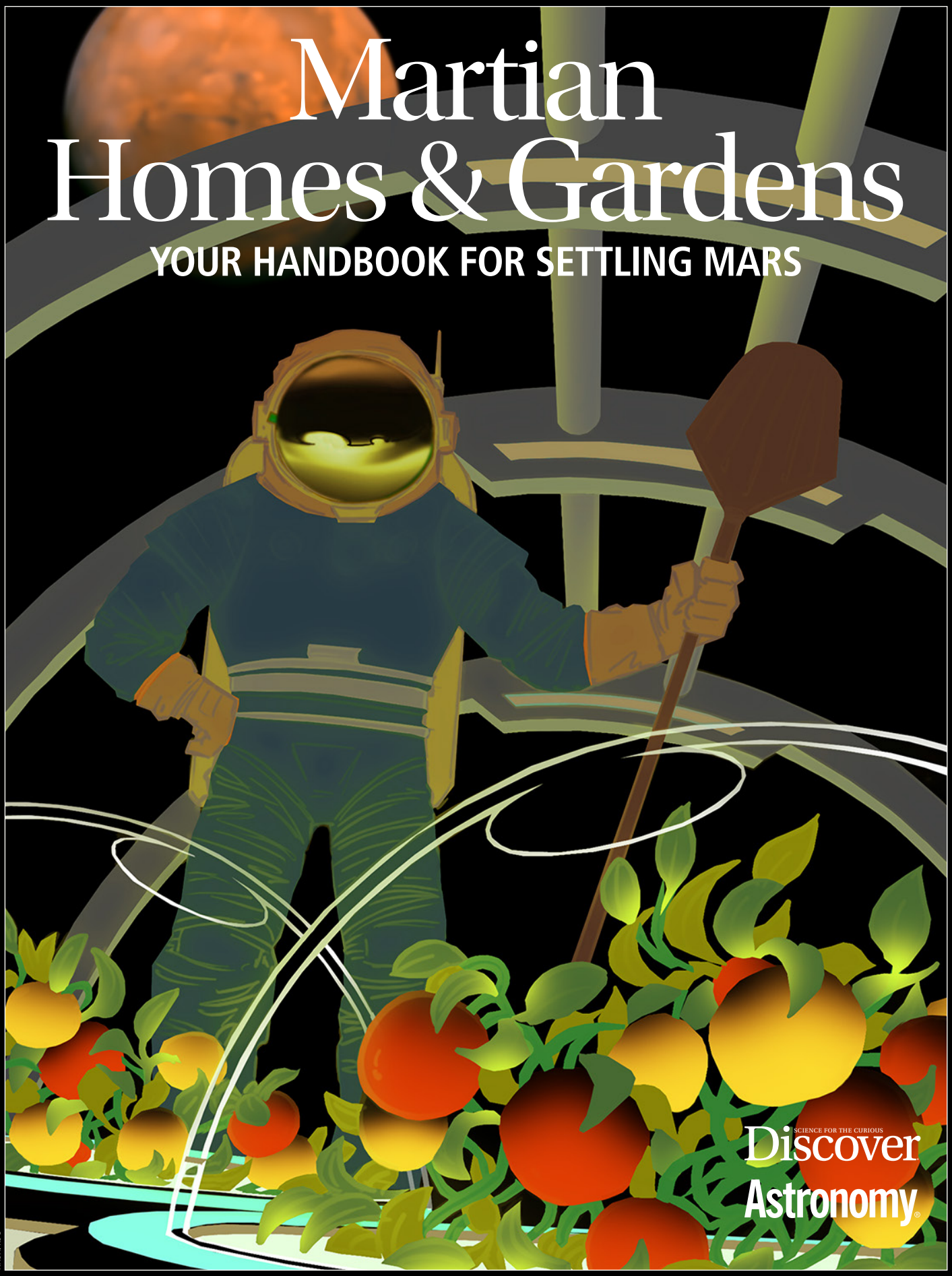
Martian
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YOUR HANDBOOK FOR SETTLING MARS
SCIENCE FOR THE CURIOUS
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If We Successfully Land on Mars, Could We Live There?

Landing is one thing. Thriving is another.

BY **MEGAN RAY NICHOLS**

NASA

It seems like everyone has Mars on the mind these days. NASA wants to send humans to the red planet by 2030, and SpaceX wants to get there even sooner, with plans to have people there by 2024

Mars is a favorite theme in Hollywood, with movies like The Martian and this year's Life exploring what we might find once we finally reach our celestial neighbor, but most of them aren't addressing the biggest questions — once we get there, how will we survive long-term?

The atmosphere of Mars is mostly carbon dioxide, the surface of the planet is too cold to sustain human life, and the planet's gravity is a mere 38% of Earth's. Plus, the atmosphere on Mars is equivalent to about 1% of the Earth's atmosphere at sea level. That makes getting to the surface tricky. How will NASA get there? How can we hope to survive against such odds?

LANDING IDEAS: THEN AND NOW

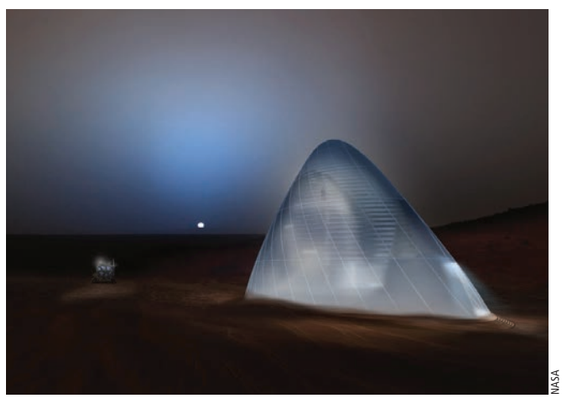
Traveling to Mars is just the first leg of the journey — when Earth and Mars are closest to each other, the trip will take a mere 260 days. Once we get there, the challenge becomes landing on the planet's surface. What type of landing system will get our astronauts and colonists safely to the surface?

Back in 2007, scientists considered four possible solutions to get astronauts to the surface. One idea was a Legged Landing System based off the Lunar Lander. This system could provide the option to both land and take off from the red planet. Secondly, the SLS System, or Sky-Crane Landing System, would use population systems to lower rovers and other equipment onto the surface. This system can unload cargo and take off again. The third design discussed was an Air Bag Landing System, which would rely on a rocket that cuts its thrust above the surface of the planet as well as an air bag for the equipment to land on. However, this wouldn't be the best option for people. Lastly, scientists considered Touchdown Sensing. Equipment senses the surface and the landing site, and compensates accordingly.

Ten years later, scientists have other ideas on how to land manned missions to Mars. According to Richard (Rick) McGuire Davis, Jr., Assistant Director for Science and Exploration and co-leader of the Mars Human Landing Sites Study at NASA, "landers will have to dive deep into the Martian atmosphere and skirt closer to the surface than we have done in the past… [since] the Martian atmosphere is thickest near the surface." When asked about the previous methods of technology mentioned above he said, "The lander is so heavy that many technologies will not work, such as airbags, sky-cranes and parachutes. In fact, to slow down, we will be heavily reliant on jets." How heavy will the crewed missions be? This supersonic retro-propulsion technology is required to be able to deliver the "projected 20 metric ton" spacecraft to the surface of Mars. For comparison, the Curiosity rover was only 1 metric ton.

NASA/JPL-CALTECH

Above: An artist's depiction of the sky crane during NASA's Curiosity rover's descent to Mars



NASA

Lower Left: The 2015 Habitat Challenge Design Competition winner, Mars Ice House by Team Space Exploration Architecture and Clouds Architecture Office.

Once we make it to Mars, what comes next?

HABITATION BUILT TO LAST

NASA is already considering what kind of habitation we'll need to survive on the surface of Mars. Six companies began designing possible habitat prototypes in 2016, with completed prototypes expected in 24 months.

All these habitats will likely have a few things in common — they have to be self-sustaining, sealed against the thin atmosphere, and capable of supporting life for extended periods without support from Earth. To get an idea for what to expect, think about the ISS. "The International Space Station has really taught us a tremendous amount of what is needed in a deep space habitat," said Davis. "We'll need things like environmental control and life support systems (ECLSS), power systems, docking ports, [and] air locks so that crew can perform space walks to repair things that break or to add new capabilities." Expect big robust equipment to travel across the stars to Mars during the first manned mission. Whatever the astronauts use must be up for the long journey.

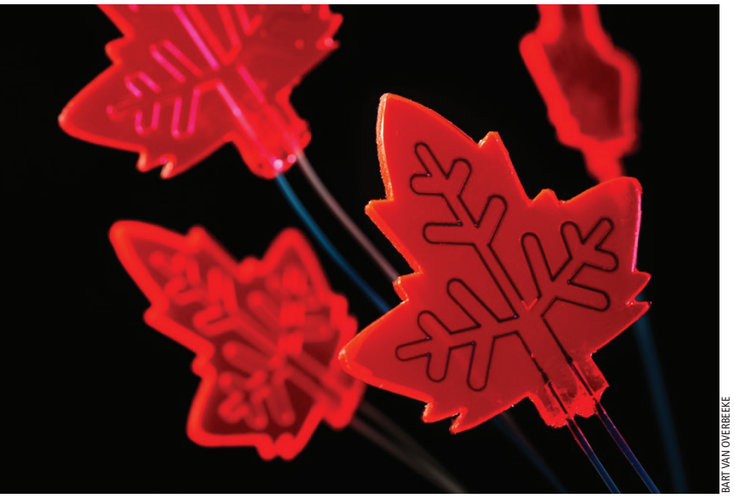
Davis also posed an interesting question: how much space is needed for each crewmember? Could you imagine spending months in one location, surrounded by the same walls day in and day out? How far apart would they have to be to keep claustrophobia at bay? "In the days of the Space Shuttle, missions ran for 7-15 days, and there was not a lot of space for each crewmember. In a space station, where crewmembers are onboard for a much longer time (typically 6 months), we have found that crewmembers simply

need more space." Based on this logic, it's possible that habitable bases on Mars will require more square footage for inhabitants.

Science fiction also does a great job helping the public imagine what this future mission will look like. The recent film The Martian, portrayed the kind of habitats NASA is investigating for a Mars. Nine pieces of technology showcased in the movie are accurate to the kind of equipment astronauts on the planet will use.

GROWTH

Keeping the food and medicine supplies stocked on Mars is the best way to make a habitat self-sustaining, but with a thin atmosphere and reduced sunlight, it can be difficult to get anything to grow. Artificial leaves, designed to work in harsh conditions, could offer a solution for first aid.



BART VAN OVERBEEKE

Artificial leaves designed by scientists at Eindhoven University of Technology, Netherlands December 16, 2016.

These leaves, made of silicone rubber, can take a little bit of sunlight and turn it into enough power to fuel the necessary chemical reactions to make medicine and other compounds. Lead researcher Tim Noel, assistant professor at Eindhoven University of Technology said, "[The] device harvests solar energy and re-emits it to a wavelength region which is useful for the chemistry within the channels. [It has the ability to make the] reaction conditions…uniform wherever you are."

In other words, it can use sunlight during the day on Mars, even though it is potentially exposed to more harmful UV rays. The channels inside the leaf are protected because your device can re-emit the energy it collects at a safer wavelength, which allows any chemical processes to take place. "This could be helpful when the irradiation on a certain planet is too energetic. [Since] light is basically everywhere … [theoretically] you can use that energy to start making the required molecules, whether they are pharmaceuticals, agrochemcials or solar fuels."

Right now, methylene blue is being used as the photocatalyst to produce drugs. A catalyst's job is to speed up a reaction, so the methylene blue allows the scientists to produce drugs faster than they could without it. Tim and his team are working hard now to make a diverse set of reactors. They hope to have the device onboard for the trip to Mars. Nature has given us the perfect tools to survive nearly anywhere. They just need a little bit of tweaking to survive off Earth.

TERRAFORMING: IT WON'T BE QUITE LIKE THE MOVIES AT FIRST

When you think of astronauts on Mars, what comes to mind? Did you picture a red planet turning green with time and continued human colonization? Unfortunately, those days are far in the future, if they even happen at all. During the interview, Davis explained, "Terraforming has a connotation of humans making another planetary body, like Mars, Earth-like. But really, it's about humans changing their environment to make it more supportive of our need." What does this mean?

The first few trips to Mars will only include the essentials. One of NASA's first goals for its astronauts is to learn how to live on the planet. Since it differs greatly from Earth, survival is an important skill for astronauts to master. "The initial base will probably include a habitat and a science lab. [The inside of] these modules will be much like the space station, but there will be differences." One example Davis gave included preventing toxic dust from getting into the habitat and lab. Microbial life is another threat to astronauts. Without more research on the planet, NASA can't say for certain what dangers could threaten human life. With this in mind, all scientists involved with the Mars mission will take these and other potential risks under consideration.

After the NASA base is well established and the astronauts learned survival basics, things get more interesting. "Eventually, since it costs so much to send things from Earth, we will want to farm on Mars. Such a farm will really be green houses to protect the plants against the challenging Martian environment," said Davis. Keep in mind the Martian soil isn't like the soil on Earth. It lacks organics "[the] rotting biological materials that plants need." Fortunately, it contains the minerals they require. Davis said that his team calls this soil regolith and it will need to be cleansed of some toxic materials. And NASA scientists can get the job done.

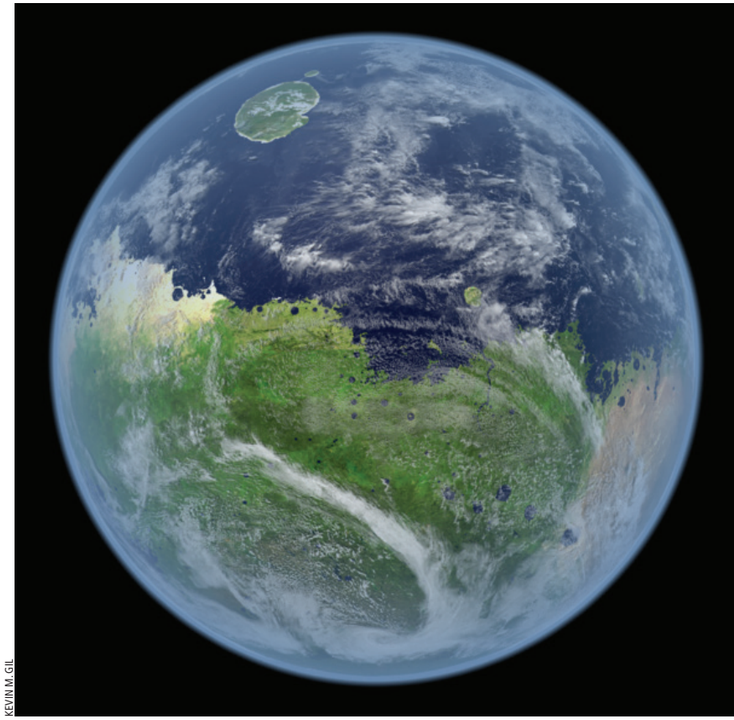
Detoxified soil isn't the only thing astronauts will need to grow plants. They'll also need to utilize the water from Mar's ice-capped poles. Davis said, "Many anticipate that the first human base will be located adjacent to these billion-year-old ice deposits, so that humans can easily produce the volumes of water that they will need to support water intensive activities like farming." As of yet there is no word about which pole will be more beneficial, if there's a difference at all.

Before speaking to Davis, I believed that future Martian farms would be equivalent to greenhouses here on Earth. It seemed logical. That's how people control plant growth here. However, while the plants will need a higher pressure to grow, the plants "[don't] have to be [at] an Earth-like pressure. In fact, we can pressurize the greenhouse with carbon dioxide, which is the main component of the Martian atmosphere." This sounds like a win-win for both the scientists and the plants. Instead of the astronauts having to wear cumbersome space suits, they could "just wear lightweight oxygen masks" in the greenhouses. The key takeaway is that the planet doesn't have to transform into Earth2.0. Maybe one day it will, but for the time being, it just has to function for NASA scientists to live and work.

TIME WILL TELL

Mars has captured the imagination of humans for decades. These plans are just the next step in the process of getting the Mars Mission from the 'drawing room floor' to a funded mission with a launch date. NASA isn't the only ones with their eyes on Mars. Others are already coming up with their own plans for the red planet. Scientists and enthusiasts have speculated on everything from nuking the planet into habitability to creating a magnetic shield around the planet to encourage it to 'grow' its own atmosphere.

Mars is hopefully just our first step into the universe. Once we've dipped our toes out into the solar system, it will be easier to expand out into the asteroid belt and beyond. Mars' low gravity provides the perfect platform for constructing and launching other deep space vehicles. After we've got that foothold, the only thing holding us back is our technology. As it is technology is the Achilles heel of the mission now. We might have a way to get to Mars before we have a means of safe exploration.



KEVIN M. GIL

A visualization of an Earth-like Mars, be it ancient or a future of terraforming.

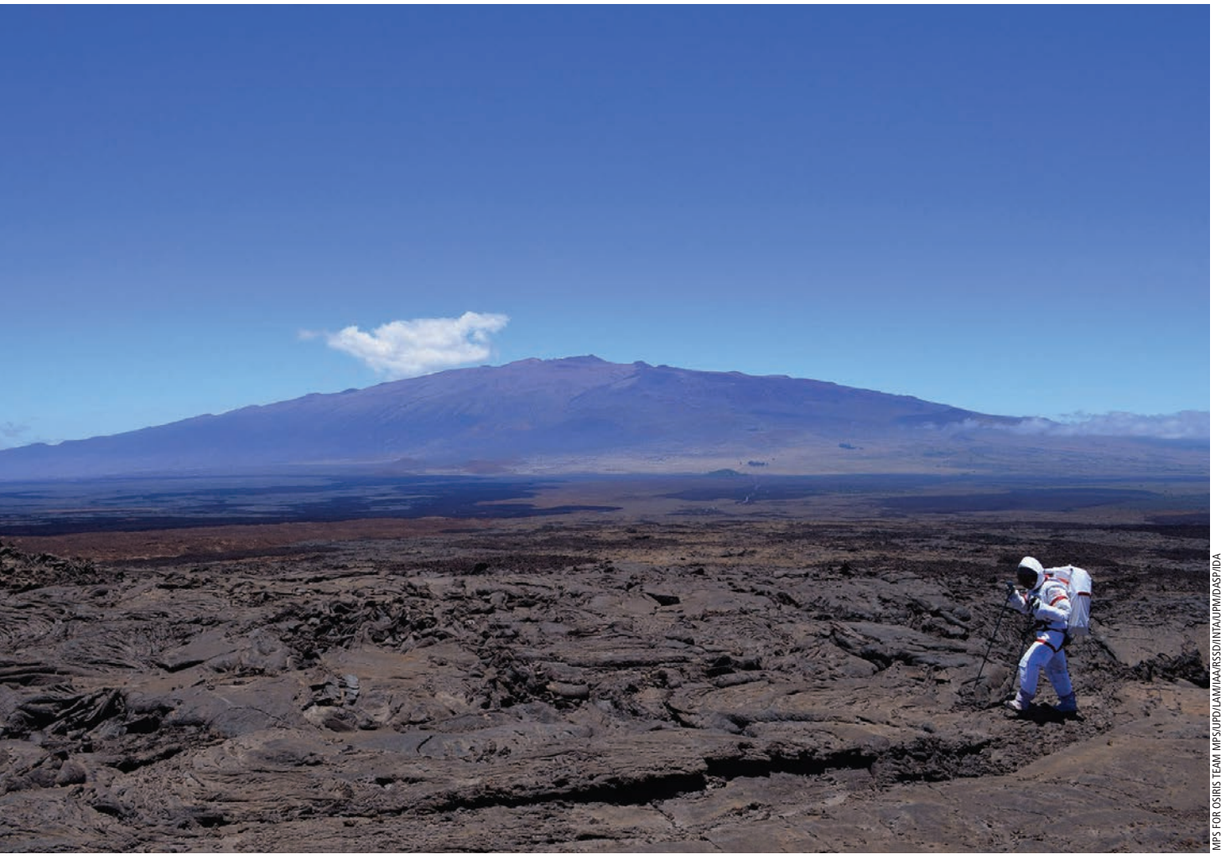
Those of us who have grown up watching the Apollo missions, space shuttles take-off and now the Falcon rockets climbing through the atmosphere likely won't see Mars colonized in our lifetimes, but that doesn't negate the wonder we all feel every time one of those rockets soars into the sky. It's not just a rocket, but a source of inspiration for generations to come – one of which will step foot on Martian soil.

Megan Ray Nichols is a freelance science writer and the editor of Schooled By Science. When she isn't writing, Megan enjoys hiking, swimming and going to the movies.

Suppose You Were A Martian

Inside a four-month simulated mission on the Red Planet.

BY **KATE GREENE** PHOTOS BY **SIAN PROCTOR**



MPS FOR OSIRIS TEAM MPS/UPD/LAM/IAA/RSSD/INTA/UPM/DASP/IDA

And so I found myself standing in the middle of a lava field, a rocky, alien landscape stretched out before me. On the horizon, a dormant volcano carved a sharp profile, low and long across the sky. Three of us were on an excursion that June day to explore the area surrounding our base station, but the going was slow.

Per protocol, we each wore a kind of spacesuit, isolating us from the elements. Oversized and made of thick, neon-green vinyl, the suits challenged my every step. The semi-flexible, plastic faceplates didn't help, either. They gave a warped view of the ground, itself a collection of shifting rocks of unusual and varying shapes. I might as well have been walking over broken dinner plates or thick cords of frozen rope — ankle-breakers lying in wait.

Breathing the humid air inside the suit, I looked up and out and considered my place in the solar system. The lava field on which we stood was terrestrial, but it could just as easily have been on the next planet over. That mountain in the distance was simply a scaled-down version of another ancient, extinguished volcano called Olympus Mons. And that was the point, really. This was our Mars.

We were astronaut stand-ins, a crew of six hired for a 120-day mission. This so-called Mars-surface analog was designed to be a mock-up of a possible expedition on the Red Planet — a place to test specific questions about a potential future Mars mission. In truth, we were in Hawaii, living in a two-story domed habitat called HI-SEAS (Hawaii Space Exploration Analog and Simulation), and we were its first residents.

We'd arrived there just weeks before, bringing minimal personal belongings; for me, this meant a large backpack of clothes, my laptop and a box of books. We were to live inside this dome as scientists, as well as research subjects, for four months. Simulating the loneliness of the real Red Planet, we removed the SIM cards from our phones and were issued new email addresses to communicate with mission support, with a 20-minute delay on either end — the time it would take for the data packets to span the gap between Earth and Mars when Mars is at its farthest.

Stumbling across craggy rocks, breathing my recycled air, I'd never felt so aware of just how much it was going to take to get us there.

PREPARING FOR MARS

Mars' popularity has soared in recent years. The dramatic landing of the Curiosity rover in 2012 (viewed by at least 3.2 million people on the Internet alone) spurred the funding of another rover to search for microbial life on the planet, scheduled to launch in 2020.

The peopled rush to Mars is also building steam. Aside from NASA's, there are three other newsworthy initiatives: the one-way trip from the Dutch nonprofit Mars One, multimillionaire Dennis Tito's proposed flyby Inspiration Mars and entrepreneur Elon Musk's plan for colonization.

Our eyes are watching Mars for a variety of reasons. Earth continues to crowd and heat, forcing us to question whether we will be a single-planet species. It's also been decades since space travel has meant anything other than uninspiring low Earth orbit. To many, the moon is passé, and President Obama's plan to visit a near-Earth asteroid seems a sideshow at best. Why not shoot for something grander? With the retirement of the space shuttle in 2011, a void in manned space exploration has opened, exactly the size and shape of Mars.

A journey of millions of miles must begin with tests. That's where analogs, including HI-SEAS, come in. Mars analog missions exist around the world in sandy deserts, icy Arctic and Antarctic locales and, in one case, fully submerged underwater. Not any are perfect replicas of a real Martian experience, but they aim to provide pieces of the puzzle. And in our case, odd as it may sound, that central question was food.

NASA has identified 33 major risks in sending people into space. One such risk for a 2 ½-year trip to Mars is "performance decrement and crew illness due to an inadequate food system." The inadequacy in question isn't just the challenge of making meals that keep their flavor, form and nutritional content for at least five years, although this is still a real hurdle. It's also an issue of menu fatigue. Astronauts on long International Space Station missions tend to lose interest in food and, consequently, eat less of it, which can harm their health, moods and productivity. Bad food or bad feelings toward food could legitimately jeopardize

a yearslong mission to Mars.

The change would impact more than just diet. It could have trickle-down effects on crew interaction and bonding, the way astronauts spend their time, the way space missions are supplied and overall mission success. If it's to ever happen, there needs to be foundational data on many of these effects.

And that's where we come in.

It's unglamorous, but true, that most of our four-month mission was spent inside the puffy white walls of the dome. Nestled 8,000 feet up the northern slope of Mauna Loa on the Big Island, our base consisted of a two-story domed habitat complete with a kitchen, dining room, workspaces, lab, two bathrooms and six bedrooms roughly the size of large closets. The two antechambers on the first floor acted as air locks to the outside. The

livable space was about 1,400 square feet, roughly the size of a two- or three-bedroom apartment.

A shipping container connected to the main air lock was used as a robot garage and extra storage. Just outside the dome were tanks for water and waste, a solar-diesel hybrid generator, a lot of lava rocks and a number of distressingly deep holes in the ground.

On most mornings, I'd wake around 6:30 a.m. to the sound of two of my crew mates doing their P90X workouts. (We were testing antimicrobial shirts for NASA, so we all exercised at least 45 minutes a day, five days a week.) For my own study, on sleep, I'd take a dose of bright blue-white light before getting out of bed, then fill out a sleep questionnaire.

Dozens of other survey questions awaited me throughout the day — how hungry I was, how often I talked to a specific crewmember, how

smelly my exercise shirt was, how much I liked spending time with a pet robot. These surveys — along with daily chores, reports to be written and emails to family back home — accounted for much of the crew's time.

And the center for much of our daily routine was our dining room table. This is where we met for breakfast at 8:45 a.m. every day except Sunday. It's where we completed meal surveys, rating each food item and our interest in eating each food item. It's where we sat for our morning meetings, and where many of us worked long into the night under the white-yellow glow of LED track lights.

The six of us were brought together by a grant from NASA's Human Research Program. From a worldwide applicant pool of 700, a selection committee narrowed it down to 40 finalists who all possessed astronautlike qualities in terms of education, experience and temperament.

The next step was to put together a crew that could get along on a largely autonomous four-month mission. We would be a crew that wouldn't receive much day-to-day input from "Earth-based" mission-support, a setup very different from that experienced by astronauts on the International Space Station or those who went to the moon.

Human spaceflight researchers believe crew autonomy will be critical on a Mars mission, mostly because of the hundreds of millions of miles that will delay communications. Mars analogs are a good place to get ideas for how to make it work.

NASA generally tends to pick crews composed of similar people, according to Kim Binsted, professor of information and computer sciences at the University of Hawaii and one of the lead researchers on the HI-SEAS project. But she and co-investigator Jean Hunter, professor of biological and environmental engineering at Cornell, decided to go the opposite route: They suspected that diversity could work just as well, and that it could provide benefits in problem-solving and crew cohesion. Even more importantly, Binsted said, they wanted to make sure that no one type of person was singled out. There would need to be at least two men or two women and at least two non-native English speakers among the group.

So, the inaugural HI-SEAS mission was about more than food. It was about proving the possibility of a brand-new Mars analog, demonstrating the effectiveness of a diverse crew and testing how that crew would fare when left largely to its own devices.

WINDOW ON THE OUTSIDE WORLD

One month in, we had a party to celebrate our first big milestone. We'd had a busy honeymoon period, so some scheduled downtime felt crucial. We rearranged furniture and made a special menu: sushi, spam musubi, chocolate cake and punch spiked with bits of dehydrated fruit. (NASA rules disallowed alcohol on the mission.) We listened to a playlist of the Monkees and Alanis Morissette, and set up an LED strip that blinked colored lights.

Then, after dinner, we came to the crux of the celebration: the window. For a month we hadn't had any access to sunlight inside the dome. It had been built with a hole for a round window, but the clear plastic wasn't installed when we arrived. Earlier that day, the extravehicular activity (EVA) team of Angelo, Yajaira and Oleg had installed the window, slipping it into the porthole already covered with an opaque plastic disk.

Inside, as Angelo pulled off the porthole cover, I saw the setting sun for the first time in weeks, casting long shadows on the jagged red and brown rocks that surrounded us. It was glorious. As the sun sank below the horizon, our celebration lit up the dome in reds, yellows, blues and greens — bright enough, we suspected, to be visible to careful observers all the way back on Earth.

MARTIAN MEALS

Actually, the food throughout the mission wasn't too bad. For breakfast we often had scrambled eggs, made from so-called egg crystals, which were surprisingly good. As an outreach project, Sian organized a cooking contest where we tested recipes from all over the world. The beef tagine with couscous was one of my favorites.

The only meals we dreaded were a handful of pre-made meals from a can — the add-water-and-heat kind. Kung-fu chicken came out slimy and overly salty, as did the beef stroganoff. But even the canned meals had some surprises. The lasagna wasn't bad, and one dessert, a raspberry chocolate crumble, was actually delicious.

We were lucky to have a creative crew who did wonders with freeze-dried/powdered/dehydrated

ingredients. Oleg was the master of borscht and cabbage pie. Sian could conjure delicious soups and stir-fries and Yajaira was a magician with curries and breakfast smoothies. Angelo made rice dishes and a delicious bread pudding. Simon, as engineer, focused on efficiency with single-pot

pastas with vegetables. As for me, I stuck to the basics, making egg scrambles and latkes from a box — although, in a spate of inspiration one day, I came up with a sort of calzone made with tortillas, powdered tomato sauce, freeze-dried cheese, pepperonis, onions, garlic, herbs and spices. The dish was a hit with our crew, and I briefly had visions of grandeur where the calzone recipe was cooked on the first manned mission to Mars. Only time will tell.

WEARING THIN

It's well known that on extended missions, especially those in which the crew is isolated, small irritants can grow into larger, ongoing issues. What initially seems to be a speck of sand somehow becomes a boulder that crashes down a cliff when you least expect it. But it was surprising just how prominently food — that very thing that we were here to study — factored in to the irritations we felt.

In one case, I noticed a crew member regularly taking more than I thought was a fair share of chocolate milk powder, a commodity rationed each month and shared by the group. Instead of saying anything, I had silently hoped he would back off on his own. He didn't. One day, when I went to make chocolate milk and found just a dusting, an emotional dam inside me cracked. With venom in my voice, I accused him of being "a chocolate monster," whatever that is.

Later, regretting my words, I apologized. He easily accepted, and I noticed his subsequent chocolate-powder consumption was moderate. But it became less important in the remaining weeks of the mission as we began to run low on powdered milk, too.

Another time, after dinner, a different crew member scooped a spoonful of Nutella out of the jar, a gooey-chocolate glob for dessert. This blatant enjoyment of a shared resource upset another crew member so much that he immediately scolded the scooper. A lengthy, crew-wide discussion ensued. The offended crew member evidently hadn't heard the scooper's prior public inquiry about the state of our Nutella stock (there was plenty at that point), hence the confusion. Apologies swiftly followed.

And as the mission wore on, I noticed my conversations with my spouse back on Earth becoming more strained, with more frequent misunderstandings. We consistently emailed each other; she had committed to sending me a poem a day from a variety of poets, which was the true highlight of my day. But it was a difficult type of correspondence to keep up. The longer I was gone, the more I felt like her life, the life that had been ours, was, in some ways, moving further away from me. Toward the end of the mission, as much as I enjoyed the contained tidiness of our life on Mars, I was ready to come home.

GLIMPSING MARS

From the perspective of being Earth-bound once again, I've had time to reflect on those strange four months. Data from our various experiments are still in the process of being analyzed. Anecdotally, I can say that I sometimes enjoyed cooking and found it to be a morale boost, and other times I found it to be a total drag. There were days when ready-to-eat meals were just what I wanted and other days when I couldn't even choke down a few bites.

But, in addition to the data, we were also in it for the adventure. By being selected for this mission, we were, in effect, given permission to step out of our day-to-day routines, test ourselves with an unusual challenge and believe — fully sanctioned by NASA and as nondelusional adults — that we were living on another planet.

Now, for the truth. I'm afraid I only just glimpsed life on Mars. Much of my time was spent inside the dome, partially because so many of my research goals were best done indoors and partially because it seemed like a hassle to take half the work day to suit up and go outside. As such, I could have been cooped up anywhere where there was a view of a red-colored rock field out the window.

Some of my crew members said they had their most realistic experiences of "Mars" after putting on their simulated spacesuits, communicating by radio, hiking to lava tubes and imagining the possibilities. During these EVAs, however, I found I was far too concerned with practical matters such as walking and not falling to drift into a Martian reverie.

For me, my most "Mars" feeling came not in Hawaii, but during our two-week practice mission in Utah at a site called the Mars Desert Research Station. Outside, on a spacesuited hike, I took a moment to sit on a rock and think. Here I was, I told myself, having landed on the next planet over after an eight-month journey. Even though the people of Earth were wishing us the best, hanging on our every correspondence, the planet itself was just a speck of blue in the sky, more than 30 million miles away.

With that thought, a vision, vivid and unexpected, appeared before me: grassy hills and trees with shimmering leaves. I held onto it as long as I could, but the mirage quickly vanished. Later, after the mission was over, I realized that many of my dreams while living in the dome had also featured various kinds of green. In one I was picnicking with family under a weeping willow gently swaying in the breeze. Odd that when I finally convinced myself I was the farthest I had ever been from home, all I could actually imagine was a lush and beautiful Earth.

It would be shameful for me to claim to have experienced the kind of "overview effect" real astronauts talk about when they've been to space, the way they begin to see our planet as more precious and fragile and realize that we're all on it together. Having never seen Earth from the heavens, I simply cannot know this. But I do know that while away, I felt a change in the way I processed news from home. I felt removed from global events. It was like I was looking at it all from the wrong end of a telescope. Those wonderful and troubled people, I thought. Why does it have to be so hard?

And personal events, too, produced surprising effects. A good friend moved away from San Francisco without much warning, and I was devastated to know that I'd be coming home to an emptier city. But then I celebrated my 34th birthday on the inside, and the messages, videos and pictures I received from my friends and family lofted my mood for days. I couldn't remember a time I had felt so loved.

It made me think of a prompt that physicist Richard Feynman would use to get people to think in creative ways. One of these began, "Suppose you were a Martian … " He would follow up with another proposition such as, " … who never slept." He would go on to explain that you, a sleepless Martian, would visit Earth and see all these sleeping creatures. Naturally, you'd wonder why they slept and how it worked. It's a question that might not occur to an Earthling in day-to-day life. But Feynman reminds us that with some perspective, brought to us by Mars of all places, our planet and our species become ever more fascinating.

On the last day of the HI-SEAS mission, the crew lined up in the air lock to prepare to greet reporters and photographers, to have sunshine on our faces and fresh air in our lungs. I wish I could say I was thinking grand thoughts about what it all meant for the future of space exploration, but I was more concerned with making sure I didn't trip on my way out the door. Once outside, though, I was actually startled by the breeze on my arms. It was something I evidently hadn't expected. Every time it danced across my skin, I paid attention.

Kate Greene covers science and technology for publications including Wired, Discover, The Economist, and Pacific Standard. She lives in San Francisco *and tweets at @kgreene.*

What Do the Stars Look Like from Mars?

BY **ERIC BETZ**

NASA/JPL-CALTECH

The Mars-like deserts of the American Southwest are some of Earth's most iconic stargazing grounds. Far from pestering city lights and free from regular cloud cover, they provide a starry-skied sanctuary for lovers of the night.

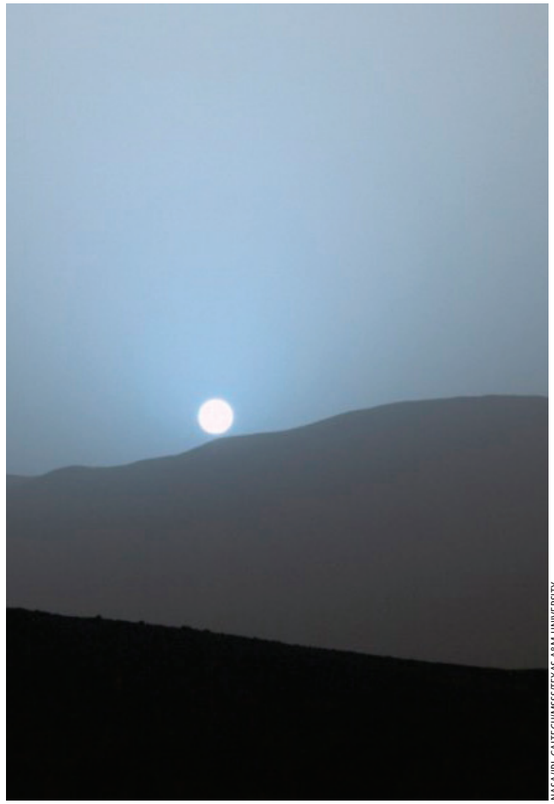
So, it would stand to reason that the deserts of Mars itself would be even more idyllic. After all, there's no light pollution and cloud cover is hard to come by.

And to some degree, that's true. It doesn't get much darker than nighttime on the Red Planet. And Mars' atmosphere is so weak — just one percent of Earth's — that the stars don't twinkle.

DUST TROUBLE

But the Red Planet provides another complication: dust. Even straight overhead at zenith — the region where atmospheric interference is the least — the dust decreases a star's brightness by one whole magnitude. That gets drastically worse toward the horizon, where dust can dim stars by as much as 4 magnitudes.

Astronomers know this from watching the night sky with the Mars rovers, which have cameras about as sensitive as the unaided human eye. When the sky is perfectly clear, NASA's Opportunity rover can just make out magnitude 6 stars — generally considered the limit for human viewing.



NASA/JPL-CALTECH/MSSS/TEXAS A&M UNIVERSITY

A ROVER'S-EYE VIEW

Astronomers have turned those rover eyes toward the heavens to watch lunar eclipses and comet flybys. In 2014, NASA's Curiosity rover caught Comet Siding Spring (C/2013 A1) as it buzzed Mars at a distance of just 87,000 miles. That's 10 times closer than the famous Comet Hyakutake (C/1996 B2) that squeaked passed Earth back in 1996. It even messed with Mars' magnetic field.

NASA's Maven orbiter shows that the more dramatic result was a meteor shower that peaked at thousands per hour, or maybe even tens of thousands. That's more dramatic than anything in recorded history on Earth. But the dust would have obscured many of those.

SUNSETS WORTH A VISIT

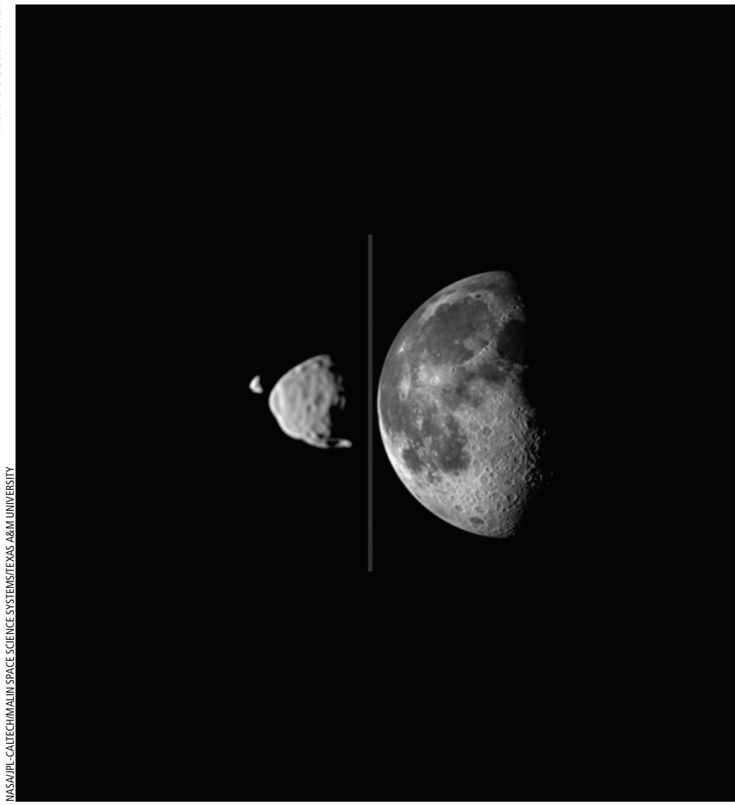
And for human eyes, there are other factors than dust. On Mars, it also takes longer for night to settle in. The Red Planet can have absurdly long twilights that last for hours. That messes with nighttime observing, but makes for stunning sunsets, which can shift from blue into shades of butterscotch as evening emerges.

As darkness finally settles in — if you weren't too scared of Mission to Mars-style killer aliens to head outside — another strange spectacle would await.

When they're not hidden by dust, the Red Planet's two moons, Phobos and Deimos, are both visible from the surface. And as your evening butterscotch skies faded to black, you could watch the cratered and potato-shaped Phobos — the larger of the two — rise from the west and then change phases from crescent to gibbous over the course of just four hours before it set again. You could watch it rise and set multiple times in one night. Deimos would look like the brightest star in the sky.

You could also spy some earthly deep-sky observing favorites like the Orion Nebula and the Andromeda Galaxy.

That sounds like it would be worth braving temperatures below -100 degrees Fahrenheit.



NASA/JPL-CALTECH/MALIN SPACE SCIENCE SYSTEMS/TEXAS A&M UNIVERSITY

Behind the scenes of THE MARTIAN

Self-proclaimed science geek Andy Weir never thought The Martian *would be published. Now, the* New York Times *best-seller is about to put NASA's Red Planet plans in the limelight.* **BY ERIC BETZ**

A small white sprinter van kicks up red dust as it slides across the "martian" sand toward a yurt-like astronaut habitat. Its path winds past the scorched remains of a Mars Ascent Vehicle built to launch crew to orbit.

Above this fictional Mars-scape, a ceiling vaults some six stories tall, placing the cavernous soundstage among the largest in the world. Small blimps bolster legions of lights. Green screen sheets line the stadium-sized walls. Eventually, images of blue Mars sunsets and butterscotch evening skies captured by NASA's rovers will become a backdrop, along with shots of Wadi Rum, Jordan — a red desert stand-in for Mars.

But for now, it's more like a surreal sandbox here at the last day of filming on set at *The Martian*. And a group of young Hungarian men are stepping out of the van to start the long disassembly process. Their present task, removing laboratory equipment from the astronaut habitat, or Hab, is easy in comparison to the one to come — someone has to remove all 1,200 tons of this carefully color-matched Mars dirt.

For 12 weeks, this movie set, through suburbs and past Hungarian countryside homes on the outskirts of Budapest, has seen many of Hollywood's biggest stars and most celebrated filmmakers.

The scene is what every crazed Moon landing conspiracy theorist imagines Stanley Kubrick doing half a century earlier.

Some of NASA's most senior scientists believe that when *The Martian* hits big screens October 2, the movie's obsessive adherence to science fact will be enough to make their nonfictional "Journey to Mars" real for millions of Americans. Because in contrast to the silver screen space agency of the same name, NASA's actual program is nowhere near ready for prime time.

If humanity is to put astronauts on Mars, NASA is going to need a surge in support to levels unseen in generations. That's an unlikely achievement for a Hollywood film, but *The Martian* is just one part of NASA's growing publicity machine.

A LOVE LETTER TO SCIENCE

In the film, Matt Damon plays Mark Watney, one of the first astronauts to walk on Mars. He's what John Irwin was to the actual Apollo program — an "also went." That is, until a mishap leaves Watney alone on the Red Planet with only his considerable wit and scientific ingenuity to survive while NASA mounts a heroic rescue attempt.

Author Andy Weir's book *The Martian* is a stroke of sci-fi genius. The novel does for space adventure fans what the soft core romance novel does for jilted lovers. It's a true love letter to science — space escapism at its best. But can filmmakers turn science-based fiction into a Hollywood hit?

Eric Betz *is an associate editor for* Astronomy. *Follow him on Twitter: @ericbetz.*


Ares 3 rover

Last December, NASA launched *The Martian*'s screenplay cover into space on board Orion, which could someday carry actual astronauts to Mars. The title page features Ridley Scott's hand-drawn sketch and an often quoted line from the movie.

I've come halfway across the planet — at the invitation of Twentieth Century Fox — to find out.

To a large extent, *The Martian*'s success or failure sits on the shoulders of one man.

For decades, legendary director Ridley Scott has simultaneously been hailed as a cinematic genius and languished with some of Hollywood's biggest flops. But he gave film lovers *Thelma and Louise*, winner of six Academy Awards, as well as *Blade Runner*, *Gladiator*, *Black Hawk Down*, and the entire *Alien* universe.

Scott is known for epics with great attention to detail, and this movie lives up to that legacy. The rockets, modules, and space suits were built — and 3-D printed — with heavy guidance from NASA. The filmmakers even hired Rudi Schmidt, former project manager of the European Space Agency's Mars Express spacecraft, to test all the experiments done in the movie, including turning water into rocket fuel — which I'm told works, by the way.

"We want to make the film as much science fact as science fiction," says executive producer Mark Huffam (*World War Z*, *Saving Private Ryan*).

MARS CZAR MEETS *DARK SIDE OF THE MOON*

As I shuffle into a nearby soundstage, a crowd gathers behind a horde of cameras pointed at a section of the Hermes spacecraft — an ion-powered ship that ferries astronauts back and forth to Mars. One crew member calls out a countdown, and I realize most everyone but me has orange earplugs buried deep in their ear canals.

Arthur Max, veteran set designer and frequent Scott collaborator, supplies a pair shortly before an explosive blast rings out and the spacecraft's airlock erupts in flames.

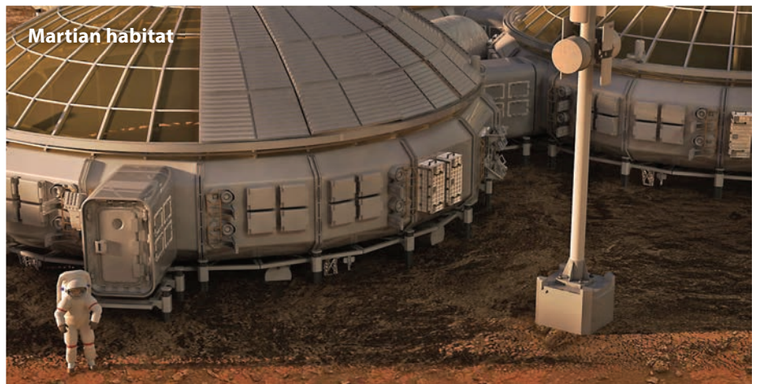
Of all the characters on Scott's regular filmmaking crew, Max is the most captivating. He's a towering man with penetrating eyes and a face weather-lined from years of filming in desert climes and empty parking lots. He's a native New Yorker, but his accent betrays a career spent with Brits. Max's first big break came working stage lights at Woodstock in the summer of 1969. That landed him a gig designing Pink Floyd's *Dark Side of the Moon* shows. Then, 30 years ago, Scott asked him to help make a Coca-Cola commercial. They've since created some of Hollywood's greatest epics together.

Once the excitement clears from the airlock explosion, Max guides our small group of science writers around the rest of Hermes — or what hasn't been loaded into crates.

"The challenge of this film, really, for myself and those people who work with me in the art department, has been to generate what NASA does with billions of dollars of funding over several decades, with millions of dollars over several months," Max says.

For Max, that process began with trips to the Jet Propulsion Laboratory in Pasadena and the Johnson Space Center in Houston, where he tore apart prototype space suits and astronaut habitats with Jim Green, head of NASA's planetary science program. Green, the space agency's one-time "Mars czar" and current overseer of robotic solar system exploration, also served as a consultant on *The Martian*.

NASA checked off on every aspect of the set and script.


Martian habitat

And that came as a relief to Max. He used real NASA blueprints of an ion-engined Mars crew carrier to make Hermes. Filmmakers turned a six-wheeled industrial crop sprayer into a massive Mars rover that looks like a beefed-up version of the one NASA's Desert RATS use to play space explorer on test missions in the Arizona desert. The filmmakers drove their rover in the studio and then flew it to Jordan, where they shot Damon romping across the desert.

"I love restrictions because you play off the constraints," Max says. "If you have no constraints, it's just a big white canvas. Where do you start? But if they give you rules and limits, it's easier, and so within that you find your aesthetic."

MAKING MARS REAL

I get the sense that despite NASA's armada of real spacecraft across the solar system, Green enjoys working on this fake Mars mission too. The no-nonsense bureaucrat started at the space agency fresh out of grad school in 1980 and made his way up through the ranks, writing hundreds of scientific and technical articles along the way.

Green says he realized the Red Planet wasn't real for people after astronaut Stanley Love asked him to watch an online talk about traveling to Mars. At the end of the video, Love points to a Hubble image of that planet and says, "Let's go to Mars."

"It's like saying you're going to take a vacation on Earth," Green says. "It has mountains. It has valleys. It has an enormous diversity in its climate and its activity and seasons. It has polar caps. And then I realized: It's not real to him. That's what the book does, it makes it real by going there and saying, 'Here is what Mars is like.'"

Not long after that realization, Green met with NASA Johnson Space Center director and former astronaut Ellen Ochoa. The scientist told Ochoa she had to read *The Martian*. She did. And the book is now "required reading" at Johnson, home of NASA's human space exploration program. Ochoa even liked it so much that she invited the author out for lunch and a tour.

Eventually, she made her astronauts available to the cast and crew. Actress Jessica Chastain, who plays NASA Commander Melissa Lewis, spent days at Johnson shadowing real-life astronaut and chemist Tracy Caldwell Dyson.

FROM GEEK TO SUPERGEEK

In an ironic twist for a man who concocts NASA heroics, Weir, a self-proclaimed science geek, is scared of flying. So he reluctantly refused when Scott invited him to Budapest. Instead, I interviewed Weir via Skype in his rather ordinary-looking home where his cat, Jojo, jumped onto his desk as we chatted.

Weir says he only broke his no flying rule for the trip to Houston. And sitting at a cafeteria lunch with Ochoa, he heard the kind of stories that would make even a suddenly famous writer blush. NASA astronauts told him they love his book and called it "98 percent correct." He got the VIP treatment.

Instead of sitting in a cubicle working all day, Weir says he now gets to hang out with astronauts and celebrities.

The son of a particle physicist, Weir worked for 25 years as a computer programmer, helping code everything from word processors to games like *Warcraft II*. He took three years off from programming in the late '90s to chase writing full time but failed to land a contract or even an agent. However, the evolution of the Web allowed him a creative outlet to post his comics and serials.

But Weir's life didn't start to change until late September 2012. That's when he posted *The Martian* on Amazon.com for the site's minimum price — 99 cents. For years, he'd been writing the book and posting it to his website, galactanet.com, one

BUZZ LIGHTYEAR GETS SEXY

PERUSING *THE MARTIAN*'S COSTUME room feels like being let loose in the bowels of the Smithsonian. Space suits crusted and baked with red sand hang on coat racks next to astronaut exercise attire and hulking white extravehicular activity suits. The spaces in between are cluttered with more common clothes, giving the wardrobe a Space Age thrift store sort of feel. In the film's final days, helmets, gloves, and hats are pulled from shelves and neatly packed up into boxes in case they're ever needed again.

I'm told this is a common Hollywood practice. Nothing is discarded, lest someone makes a sequel — or six.

NASA still doesn't know exactly what a mission to Mars will look like. And that's given filmmakers plenty of room for interpretation. Janty Yates is a longtime member of director Ridley Scott's crew and an Academy Award winner for *Gladiator*. When she first started designing costumes for *The Martian*, she says she saw herself as a facilitator and not an inventor.

With help from the Smithsonian National Air and Space Museum's space suit curator, Valerie Neal, she pulled together "Bibles" of all the potential Mars suits and settled on Z-2 — NASA's current prototype. Yates calls it the Buzz Lightyear, and it looks a lot like someone plopped a space helmet onto the Pillsbury doughboy. It's dorky. Scott rejected it outright. Instead, they took the minimum size possible for life support and ran with it. "We basically invented this space suit, which is far more linear, far more elegant, and I think quite sexy," Yates says.

They added creases. They tightened it. And they made the suit more comfortable for actors to live in eight or 10 hours a day through background breaks and meals thanks to breathable fabrics and cooling suits.

"You get it, and you have to throw it against a wall 20 times a day and still expect it to work," says Michael Mooney, associate space suit costume designer. — *E. B.*

AIDAN MONAGHAN

chapter at a time. He also sent the novel out to 3,000 email subscribers who gave the computer programmer eager feedback.

"It was cool because they egged me on, and then also they're all science-minded geeks like me, so it was awesome because they'd point out anything that was wrong," Weir says. "I called them beta readers."

But Weir says he never expected his book to be publishable. Then, when the story was done, that core fan group asked for a reader-friendly version, and he self-published it to Amazon without a second thought.

That's when things got crazy. The book quickly climbed through the top-seller ranks. An agent lured him in. The movie exclusivity rights sold to Twentieth Century Fox. And *The Martian* became a *New York Times* best-seller, where it's remained for 42 weeks and counting.

"It's like people are contacting me through the Internet telling me my dreams are starting to come true," Weir says. "I thought it might be a scam until they started sending checks."

It wasn't long before Weir was talking with writer and director Drew Goddard (*World War Z*, *The Cabin in the Woods*) as he crafted the screenplay. Damon agreed to star in the movie. Then, when Goddard dropped out to make the new Spider-Man spinoff, Scott signed on to direct.

THE SECRET LANGUAGE OF RIDLEY SCOTT

Back in Budapest, Damon enters a decidedly dingy VIP room wearing sweatpants and a T-shirt. His hair is ragged, grown out with extensions. "I think we're on [sol] 547," he says of his unkempt beard — a sol, or Mars day, is 39 minutes longer than an earthly one. "I'm living on Mars time."

The movie is part *Apollo 13* and part *Castaway* — it's also hard not to conjure up Damon in *Saving Private Ryan* — but unlike those films, Damon's character has a well-developed sense of humor about the experience. And beyond the difficulties of a one-person dialogue, the actor says his biggest challenge was capturing the hilarious aspects of the book without making his character look glib or like he didn't care if he survived or not.

"Ridley and I talked from the beginning about how we wanted to preserve all that humor, but also not lose all the stakes," he says. "Especially when we got here and we saw the set that Arthur [Max] had built."

The pair put considerable effort into keeping the true terror for the character. "Or else it's just a popcorn kind of whiz-bang he's-never-really-in-danger type of experience," Damon says.

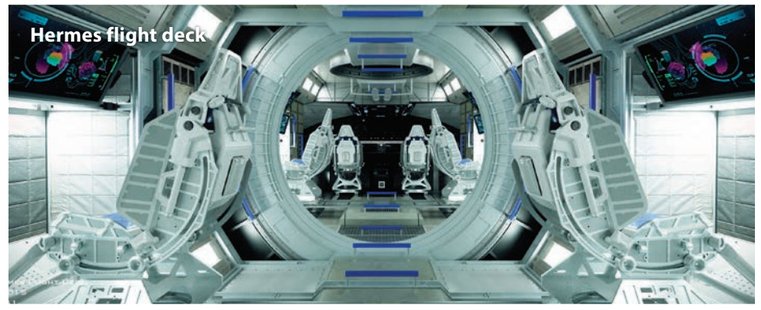
This devotion is what defines a Ridley Scott epic — even the unsuccessful ones. But Scott needs his sci-fi return to be a hit. His latest attempt, *Prometheus* — an *Alien* prequel — got a chilly response from fans.

However, on this stage outside Budapest, it's clear his fellow filmmakers don't see any need for Red Planet redemption.

It's late on the final day of filming, and a stunt double for Damon is mounted in a space suit as cameras shoot and reshoot the film's final action sequence, titled "The Final Rescue." It's easy to lose track of someone amid the chaos of a movie set. Not Scott. He barks out commands to the crew, forcing them to repeat scenes ad nauseam until he sees what he's looking for. No one gets upset by the lashings.


The Hermes

"It's a Ridley Scott movie whether it's ancient world, present day, or future," Max says. "He always wants there to be a logic driving the story and great attention to detail. Once you learn the secret language of Ridley Scott, you can do any period with him."


Hermes flight deck

MARTIAN MANIFEST DESTINY

Green, the former Mars czar, says NASA employees love *The Martian* not only for its devotion to realism, but also for the heroics Mark Watney embodies. For many Americans, NASA post-Apollo is an $18 billion bureaucracy stuck in low Earth orbit. That's not how its employees see themselves.

"NASA does miracles all the time," Green says. "It's unbelievable what we do. I'm always in awe, and I've lived it for 35 years of my career. I keep getting surprised by how resourceful our people are."

"It's one of those things that make this agency special and important for the nation," he adds. "We've got to be thinking about colonizing the solar system. A single-planet species is not going to survive — the dinosaurs didn't. They didn't have a space program."

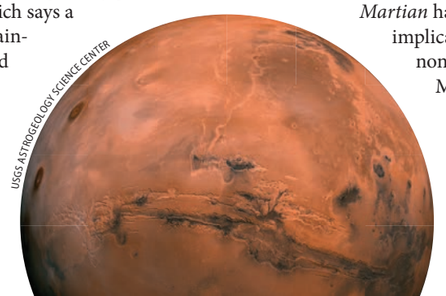
And increasingly, NASA is using pop culture to make a play for American heart — and purse — strings. Bert Ulrich is NASA's guy in Hollywood. If a filmmaker wants to use a NASA logo, they go through him. Ulrich says a flood of recent mainstream movies and documentaries have planted the space agency in a new golden age.

"I haven't seen this upswing in interest in sort of a cultural way before, and I've been with NASA for a very long time," he says.

That rockstardom for NASA science was on full display this summer as Green walked San Diego's Comic-Con International — the largest convention of its kind in the world. More than 2,000 people filled a hall for discussions with space agency scientists and *The Martian* filmmakers. Newly named astronaut Victor Glover speculated about the first humans to walk on Mars. And Space Launch System manager Todd May talked about what it will take to get there.

Green tells me all this effort is to reach what he calls "the Mars generation" — millennials who've never seen humans leave low Earth orbit. Instead, they were raised on a robust robotic exploration of the Red Planet.

And Green's work on *The Martian* has had very real implications for the nonfictional NASA Mars program. He asked Ochoa, his human spaceflight counterpart, to detail him a Johnson Space Center employee for one year. She assigned Rick Davis, a NASA veteran who formerly served as the primary communicator between Mission Control and the International Space Station. Davis was tasked with spearheading a list of places to put humans on Mars. That way, NASA can tell the public "here's what the real sites look like, and here's why we're looking at them," Green says.


USGS ASTROGEOLOGY SCIENCE CENTER

In October, NASA will host the First Landing Site/Exploration Zone Workshop for human missions to Mars at the Lunar and Planetary Institute in Texas. Green says it's very likely the places they choose will be where future Mark Watneys land and begin the next step in the evolution of humankind.

There will be no little green men. No robots with a taste for blood. But there will be the same NASA audacity that once took 12 Americans to the surface of the Moon and returned every last one of them safely.

"The solar system is ours. Let's take it," Green told me recently without a hint of hollowness. "And there's no question, the first place we should be going is Mars."

For now, we'll have to settle for watching the Red Planet through rose-colored 3-D glasses.

These Experiments Are Building the Case to Terraform Mars

BY **NATHANIEL SCHARPING**

DAEIN BALLARD/WIKIMEDIA COMMONS

Whether it's extreme climate change, an impending asteroid impact, scientific curiosity or even space tourism, there are compelling reasons to think about calling Mars our second home. But before expanding humanity's cosmic real estate holdings, scientists will need to make the Red Planet feel a little more like our blue marble.

That, in a nutshell, is the goal of researchers thinking about ways to terraform another planet.

Elon Musk, of Tesla and SpaceX fame, has suggested we nuke the polar ice caps on Mars to unlock liquid water and release clouds of CO_2 that would thicken the atmosphere and warm the planet. This notion got some press last year when Major League Baseball player and amateur astrophysicist Jose Canseco tweeted: "By my calculations if we nuked the polar ice caps on Mars we would make an ocean of 36 feet deep across the whole planet," thereby enshrining the idea in our popular imagination. Giant mirrors concentrating sunlight on the poles and smashing an entire moon into Mars also top the list of grandiose proposals to Earth-ify the Red Planet.

While we may not utilize the kind of cataclysmic forces that some futurists imagine, there are very real efforts, backed up by solid science, currently underway that are building a case for terraforming, one small step for mankind at a time.

MARTIAN GREENHOUSE

Technically, we're already getting practice terraforming at a planet-wide scale.

"There's one solution to terraforming that makes sense when you work out the numbers and it's something that we know how to do," says Chris McKay, a planetary scientist at NASA's Ames Research Center. "And that's warming the planet by greenhouse gases. That's basically how we're warming up the Earth."

The basic plan for creating a livable environment on Mars goes like this: Introduce enough greenhouse gases into the atmosphere to begin a cycle of warming, melting the polar ice caps and releasing CO_2. This would kickstart a feedback loop of warming as more and more greenhouse gases enter the atmosphere. When the atmosphere thickens and temperatures warm to the point where life could survive, scientists would introduce hardy microbes that would synthesize the gaseous chemicals, beef up the atmosphere and add molecular diversity to the once-barren planet.

Over time, we'd plant trees to provide oxygen, and at some point the Red Planet would be fit for human habitation. All that's left is patience. Generations and generations of patience.

Based on this plan, McKay estimates that we could fully terraform Mars in about 100,000 years.

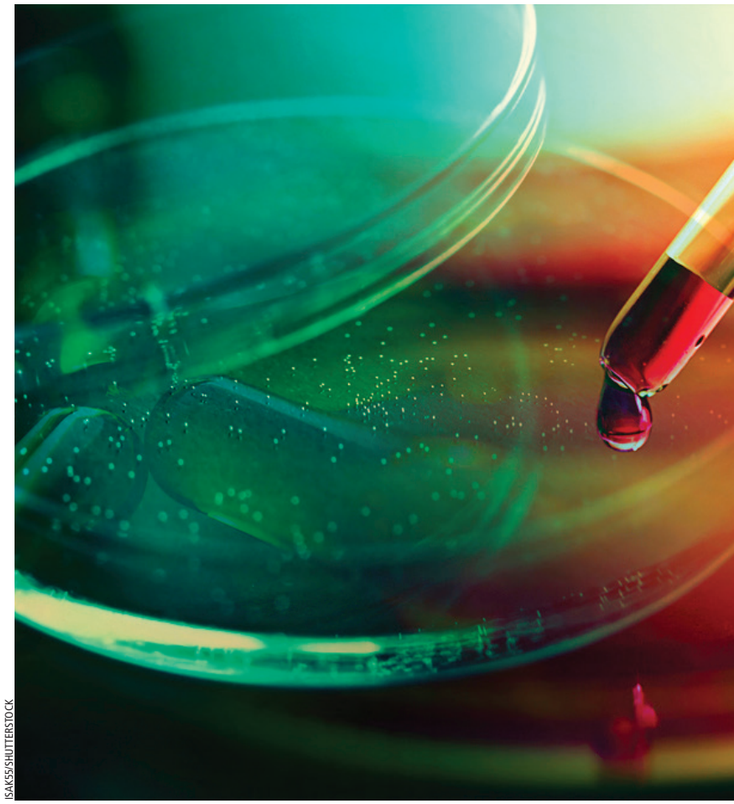
There are efforts currently under way to study how we might introduce extremophile bacteria and hardy plants to the Martian environment, once the process of warming is under way.

EXPOSE

The EXPOSE experiments were a collection of crates filled with different bacteria, lichens, fungi and seeds that were attached to the outside of the International Space Station and left exposed for months at a time. Scientists wanted to determine if microbes could withstand the punishing cold and damaging radiation of outer space. Organisms that could reawaken from a dormant stage once back on Earth could be good candidates to colonize another planet. In the first round of testing, a few organisms and seeds grew and reproduced once they returned to Earth — namely those that were shielded from solar radiation. Organisms placed in a simulated Martian environment in the experiment did even better.

This experiment showed that there are Earthly organisms that could theoretically survive on another planet. McKay notes that EXPOSE was designed to identify organisms could survive in space, not necessarily organisms that could populate another planet. Still, the research reveals the kinds of microbes that might thrive on an otherwise inhospitable planet. Part of the second round of the experiment, EXPOSE-R_2, just returned from the ISS in March along with Scott Kelly. The results of that experiment should come out in the fall.

NASA



ISAKSS/SHUTTERSTOCK

MAKING OUR OWN MICROBES

Instead of looking for Martian-ready microbes that already exist on Earth, scientists could someday build them. A group of scientists funded by DARPA is working on compiling a genetic library that they describe as the "Google Maps of genomes", according to *Motherboard*. The database would allow researchers to quickly find genes that encode for useful characteristics from a database of different organisms. In this way, they could pick and choose from multiple genomes to create a microbe that possesses resistance to cold, the ability to thrive in low-pressure environments and the capacity to produce its own food, among other things — all attributes needed to colonize Mars.

Having the genetic code for these characteristics at hand would allow researchers to use CRISPR and other gene-editing techniques to create an organism that combines a host of useful characteristics into one microbe. While we don't know if any one microorganism on Earth could survive on another planet, by picking and choosing from multiple genomes, we could, perhaps, engineer one that does.

IT'S ALL IN THE DOME

Instead of changing a whole planet, why not just terraform a few choice locations? This idea, called para-terraforming, would use large domes to enclose a parcel of land that could be engineered for sustainable habitation. Plants grown inside would provide both food and oxygen, supported by bacteria and microbes that would synthesize the chemicals necessary to support life.

An Indiana-based company called Space Hardware Optimization Technology (SHOT) has proposed such a concept, supported by funding from the NASA Institute for Advanced Concepts, and is working to develop technologies needed to bring the idea to fruition. SHOT hopes to one day send a test environment to Mars, filled with all of the organisms and systems needed to sustain life. It would take the form of a small dome, rooted in Martian soil, that would become a life raft of sorts for the microbes inside. It's basically the 100,000-year plan, but on a smaller scale.

SPACE POTATOES

Another NASA project comes straight out of the Mark Watney playbook: expose plants we grow on earth to simulated Martian conditions. In collaboration with Lima's International Potato Center (CIP), the researchers are attempting to grow 100 different varieties of potato in soil that is analogous to that found on Mars. They are hoping to find plant varieties that are well adapted to the Martian climate, and figure out how to cultivate plants in bleak environments. Potatoes were an easy choice because they are both calorie-dense and grow in harsh, dry conditions similar to those on Mars. There are also an apparently unlimited number of ways to cook them — useful for staving off the monotony of eating the same brown tuber every single day.

The Phoenix lander in 2008 found that the dirt on the Red Planet contains magnesium, sodium, potassium and chloride — all nutrients that plants need to grow. Proving that this step is feasible is a major hurdle for potential off-planet inhabitants to clear. Any colonies on other worlds will need to be self-sufficient, so colonists will need to alter the environment significantly enough that large-scale farming is possible. In case Martian soil proves to be barren, researchers are also exploring other methods of growing crops, such as aeroponics, or growing plants in a moist enclosure without dirt.

CREATING A FEEDBACK LOOP

NASA is also testing the limits of Earth's foliage in a separate experiment high in the mountains in Mexico. McKay serves as the project's senior advisor, and he says it is an initial exploration of how plants cope with extreme environments. Scientists will place several species of trees and plants in insulated domes above the tree line where they wouldn't otherwise survive.

They hope that sheltering the trees will "trigger a sort of a feedback where the organisms get going and they enrich the soil and they create conditions that are more favorable for life, which allows the organisms to continue growing even if we remove the domes," says McKay.

Such a process would likely be instrumental to terraforming Mars, where the alterations would have to proceed in a series of small steps, each increasing the capacity of the planet to support life.

"As you're warming up Mars, initially it will all have to be artificial," says McKay. "But, at some point, it gets warm enough that you can put in plants, simple hardy plants, and at some point it gets warm enough that you can put in trees."

And the process continues from there, slowly introducing greenhouse gases and breathable elements to the atmosphere, all in the hopes of creating a planet where humans could safely step outside on a Martian evening and look back fondly at our blue-green homeland.

Forget Mars. Here's Where We Should Build Our First Off-World Colonies

BY **DAVID WARMFLASH**

AARON RUTTEN / SHUTTERSTOCK

The collective space vision of all the world's countries at the moment seems to be Mars, Mars, Mars. The U.S. has two operational rovers on the planet; a NASA probe called MAVEN and an Indian Mars orbiter will both arrive in Mars orbit later this month; and European, Chinese and additional NASA missions are in the works. Meanwhile Mars One is in the process of selecting candidates for the first-ever Martian colony, and NASA's heavy launch vehicle is being developed specifically to launch human missions into deep space, with Mars as one of the prime potential destinations.

But is the Red Planet really the best target for a human colony, or should we look somewhere else? Should we pick a world closer to Earth, namely the moon? Or a world with a surface gravity close to Earth's, namely Venus?

To explore this issue, let's be clear about why we'd want an off-world colony in the first place. It's not because it would be cool to have people on multiple worlds (although it would). It's not because Earth is becoming overpopulated with humans (although it is). It's because off-world colonies would improve the chances of human civilization surviving in the event of a planetary disaster on Earth. Examining things from this perspective, let's consider what an off-world colony would need, and see how those requirements mesh with different locations.

CREATING A MARS COLONY

First, let's take a look at what the mooted Mars settlement schemes are offering. The Red Planet has an atmosphere containing carbon dioxide, which can be converted into fuel while also supporting plants that can make food and oxygen. These features could allow Martian colonists to be self-sufficient. They could live in pressurized habitats underground most of the time, to protect against space radiation, and grow food within pressurized domes at the planet's surface.

Over decades, continued expansion in that vein could achieve something called *paraterraforming*. This means creation of an Earthlike environment on the Mars surface that could include not only farms but also parks, forests, and lakes, all enclosed to maintain adequate air pressure. (The natural Martian atmosphere exerts a pressure of only 7 millibars at the planet's surface – equivalent to being at an altitude of 21 miles on Earth!)

Furthermore, in addition to adequate pressure, we'd need a specific mixture of gases: enough oxygen to support human life, plus nitrogen to dilute the oxygen to avoid fires and to allow microbes to support plant life. While the small spacecraft in which astronauts fly today carry food and oxygen as consumables and use a simply chemical method to remove carbon dioxide from the air, this type of life-support system will not swing on a colony. As on Earth, air, water, and food will have to come through carbon, nitrogen, and water cycles.

While it would cost a ton of money to build, paraterraforming sections of Mars with a sample of Earth's biosphere inside pressure domes, caves, and underground caverns is something that we could achieve within years of arrival of the first equipment. Moving beyond paraterraforming is a more ambitious goal that could require centuries, and that's full-scale *terraforming*. This means engineering the planet enough to support humans and other Earth life without domes and other enclosed structures.

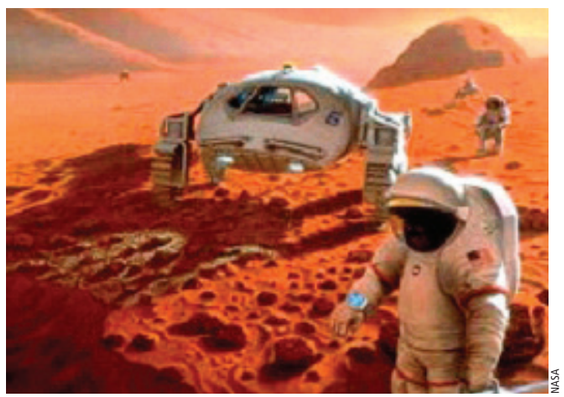
Terraforming Mars would require that the atmosphere be thickened and enriched with nitrogen and oxygen while the average temperature of the planet must be increased substantially. To get started, terraformers might seed the world with certain microorganisms to increase the amount of methane in the Martian air, because methane is a much stronger greenhouse gas than carbon dioxide. They also would seed dark plants and algae across the surface, thereby darkening the planet so that it absorbs more sunlight.

With the right combination of plants and well-selected microorganisms, planetary engineers could generate the needed oxygen and nitrogen. During all of the centuries needed for terraforming, colonists would inhabit and expand the system of paraterraformed structures.

That's a vision that's relatively cohesive. Still, there are some aspects of the plan that are less than ideal – and indeed, might point our skyward gazes toward a different destination altogether.

THE PROBLEM OF DISTANCE

A colony totally isolated from Earth would need significant genetic diversity to avoid the disease risks that plague smaller populations. According to a study published earlier this year, a multi-generation starship carrying people whose descendants would colonize a planet orbiting a nearby star would need a population of at least 10,000 and possibly closer to 40,000.



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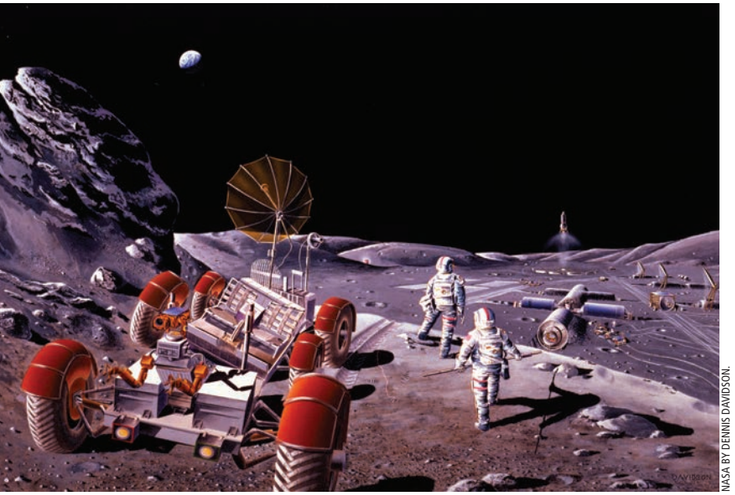
It's been reported that Elon Musk wants to build a Mars colony with a population of 80,000. This certainly would fulfill the population requirement, but a further distance is a challenge both in fuel and in time. First, fuel. The Musk plan involves sending multiple crafts each with a total payload of 15 tons per trip. To convert that to people onboard, consider that that's just under half the tonnage of NASA's new Orion spacecraft which carries a maximum of six astronauts. This gives us a ratio of approximately 5 tons per person.

Some of the tonnage is due to the fuel needed to accelerate the ship from low Earth orbit to escape velocity, and this may not differ between Mars and closer sites, such as the moon. But the tonnage per person also depends greatly on the travel time, because of life support and other issues related to consumables, so it's fair to say that for a given number of voyages we'll be able to relocate more people to sites in the Earth-moon system than to Mars.

Second, the time it takes to transport settlers. A colonization program will be efficient only if each transport ship is designed to make multiple trips back and forth. A 15-ton payload of the Musk plan currently translates into three colonists per ship, but to be optimistic let's imagine that we could increase that number to 20 people. In that case, transporting 10,000 people to Mars (the minimum number needed for healthy genetic diversity) requires 500 voyages from Earth, while 4,000 voyages would be needed to reach the 80,000 colonist milestone. Assuming that we'd build only a fraction of that number and have the ships

go back and forth, we can expect to be waiting around for ships taking a year or two to return to Earth to pick up a new load of settlers. Certainly, the advent of advanced propulsion technologies, shrinking the travel time between Earth and Mars from a year or so down to weeks would change these considerations, but right now the various Mars colonization proposals (at least the developed ones) are based on the old-fashioned chemical engines that have sent the current MAVEN probe toward Mars at turtle speed.

A two-year round trip time and a fleet of 25 ships transport ships gives us 50 years to relocate 10,000 people, and 400 years for 80,000 people. Certainly the time frame would shrink due to early waves of colonists having babies, and certainly technology could accelerate the program, but



NASA BY DENNIS DAVIDSON.

given that we're talking about many decades to reach the genetic diversity milestone, it seems worthwhile to make a similar calculation for the moon, for which the round trip time is only a week. Doing this, with the same type of program (25 ships each carrying 20 people), we get the first 10,000 to the moon in less than six months, and the first 80,000 in less than four years.

And, finally, being closer would help with ongoing rapid access to and from Earth. That may sound contradictory, given that the goal is to build a colony that's self-sufficient. But getting to that point could take some time, and at the beginning some colonists might need to be evacuated. There should be a growing medical capability on the colony, but initially cases of very serious illness and certain injuries might be better handled on Earth. This would not be an option if the travel time were measured in months, or even weeks. And what if there were a planetary disaster on Earth in the early decades of the colony? From a location close to Earth, the colony might actually be able to provide some help.

CLOSE TO HOME

A colony on the moon, on the other hand, would be within easy reach. Like Mars, the moon has caverns and caves that can be sealed for paraterraforming, along with craters that can be enclosed with pressure domes.

One fascinating lunar colony proposal would utilize the Shackleton crater at the moon's south pole, enclosing a domed city with a 5,000-foot ceiling and a diameter of 25 miles. A colony in that location would have access to large deposits of water ice and would be situated on the boundary between lunar sunlight and darkness. Its proponents estimate a Shackleton dome colony could support 10,000 settlers after just 15 years of assembly by autonomous robots.

In the event of an Earth-wide disaster, evacuating people to the moon would be far easier than to Mars. Another, even nearer option would be free space colonies. These would be built using materials mined from the moon or from near-Earth asteroids. The colonies could be located in the Earth-moon system at sites that are gravitationally advantageous, known as Lagrangian points. In these regions, a colony's distance and orientation to both the Earth and the moon, or to the Earth and the sun, would remain constant. Utilizing Earth-moon Lagrangian points, it would be relatively easy to transport lunar materials to the site of the planned colony and build it, and the travel time from Earth would be similar to the travel time to the moon, meaning a few days with current technology.

THE PROBLEM OF GRAVITY

All planets and large moons have enough gravity to hold an atmosphere, so terraforming in theory is widely possible. But in terms of human life not all gravities are created equal.

On Mars you weigh 0.38 your weight on Earth, and we're not entirely sure what this would do to human health. To keep Mars residents' bones from demineralizing, for instance, they might need to exercise inside large centrifuges every single day. Thus far, NASA and other organizations have studied effects of partial gravity to a limited extent on humans by producing Mars and lunar gravity for short periods (under a minute) during parabolic flight.

For long-term effects, which in weightlessness involve not only bone demineralization, but also muscle atrophy, immune system effects, and other complications throughout the body, there is no way to replicate partial gravity on Earth. We can simulate it with various contraptions that have allowed researchers to study things like walking on Mars and whatnot. We can put people in bed for long periods with the beds angled so as to simulate the shifting of fluids on Mars or other worlds. But until we actually send animals to those environments, we can't really be sure what will happen to various systems, including reproduction. The development of embryos depends on gravity and is known to be disrupted in weightlessness, but we don't know what will happen in environments with a fraction of Earth's gravity.

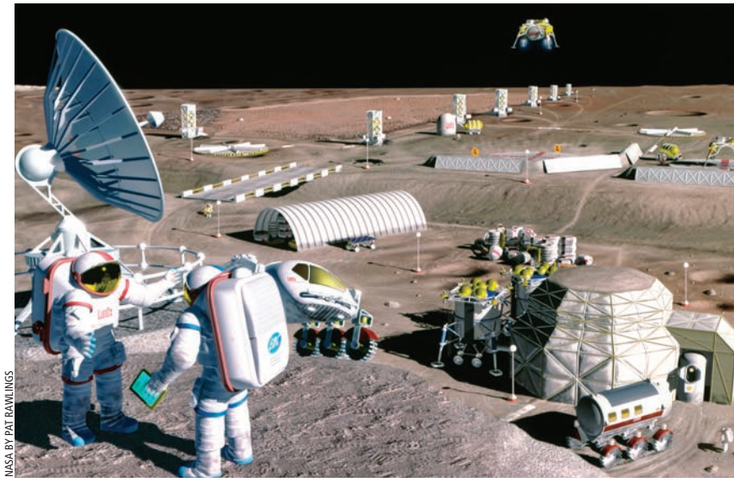
And while Martian gravity is low in terms of human physiology and movement (you could jump really high on Mars and that would be fun), it's high enough that spacecraft would consume a significant amount of energy in taking off from the planet or landing on it. Similarly, while the atmosphere is way too thin to support human life (until we terraform it), it's still thick enough to cause dust storms that can ruin colonial machinery. So considering the air and gravity along with the distance from Earth, Mars actually may not be the best candidate for an off-world colony.

LIGHTENING THE LOAD

Here Venus has one advantage over other worlds: its gravity, which is just a little less at the surface compared with Earth's. On the Venusian surface, the pull is approximately 91 percent what it is on the surface of Earth. That's close enough that it seems unreasonable to predict any long-term detrimental health effects from the gravity difference, which is a nice advantage. On the other hand, Venus would have to be terraformed before anyone could live on the surface at all, since the high pressure and temperature would not allow for paraterraforming. Nevertheless, we might be able to terraform Venus just as easily as Mars.

Going in an opposite direction as Mars terraformation, a Venusian project would begin by having planetary engineers interfere with the runaway greenhouse effect that cooked the planet billions of years ago. The process might start using heat-loving microorganisms and various chemical tricks to remove large amounts of carbon dioxide and other gases that we wouldn't want there.

Another gravitational fix could be found in free-space colonies. We already said that these could be built using lunar or asteroid materials, but another advantage is that we could build them in any shape. If built in the shape of a doughnut, such a colony could be rotated at the precise speed needed to produce the same gravitational pull as we feel



NASA BY PAT RAWLINGS

on Earth – meaning that keeping our bones, heart, and other body systems healthy would be as easy as hopping on an Earth-style treadmill, kicking a few handstands, playing tennis, or whatever physical activity you enjoy.

A NEW HOME IN THE SOLAR SYSTEM

I support an aggressive Mars exploration program. We're sending probe after probe there for good reason: geologically the planet is similar to Earth, and used to be even more similar. Moreover, it's one of the most interesting and vital sites for astrobiology in the solar system. Very likely, the Red Planet will become the first place where we confirm the existence of extraterrestrial microbial life, providing us with a second datum for biology. Since all life on Earth that we know has basically the same chemistry, comparing it with a newly discovered system could stimulate quantum leap advances in biotechnology and medicine here on Earth.

But while Mars science must advance at full speed, it does not mean that the same world is the best first site to settle families with children. Given all that we've discussed, until we have much faster propulsion, I think that colonization should begin closer to Earth, either on the moon, or in free space colonies in the Earth-moon system, depending on what studies on early lunar bases tell us about the long-term effects of lunar gravity – including, importantly, whether healthy pregnancies on the moon are possible.

After all, whichever of these locations we choose, we've got a long line of future space descendants to think about.