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NATIONAL GEOGRAPHIC

MARS

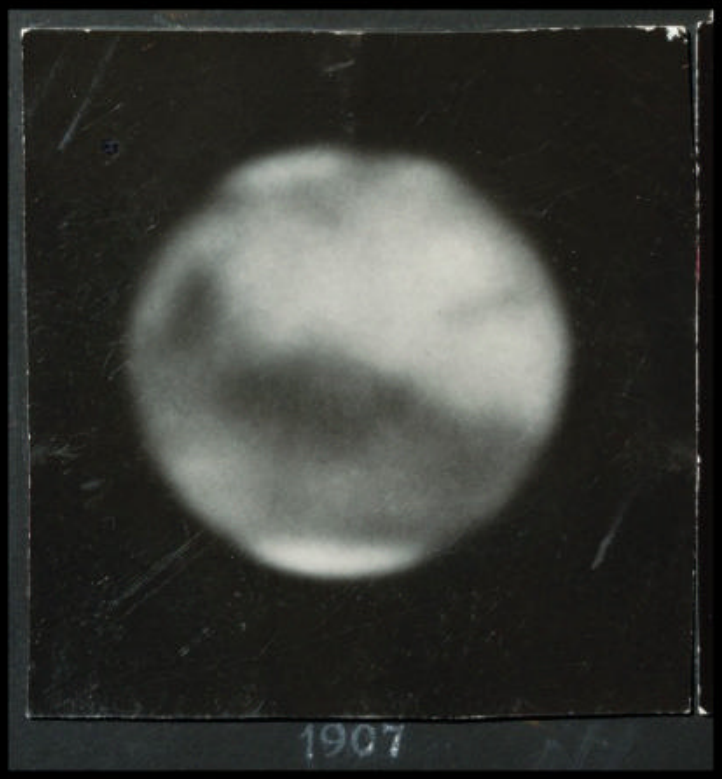
We can't get enough of the red planet

BY **NADIA DRAKE**

PHOTOGRAPHS BY **CRAIG CUTLER** AND **SPENCER LOWELL**

Our Obsession With MARS

THE DUSTY RED PLANET HAS FASCINATED US FOR CENTURIES. EVEN AS WE LEARN MORE, ITS MYSTERIES KEEP US IN SUSPENSE.



Then and Now

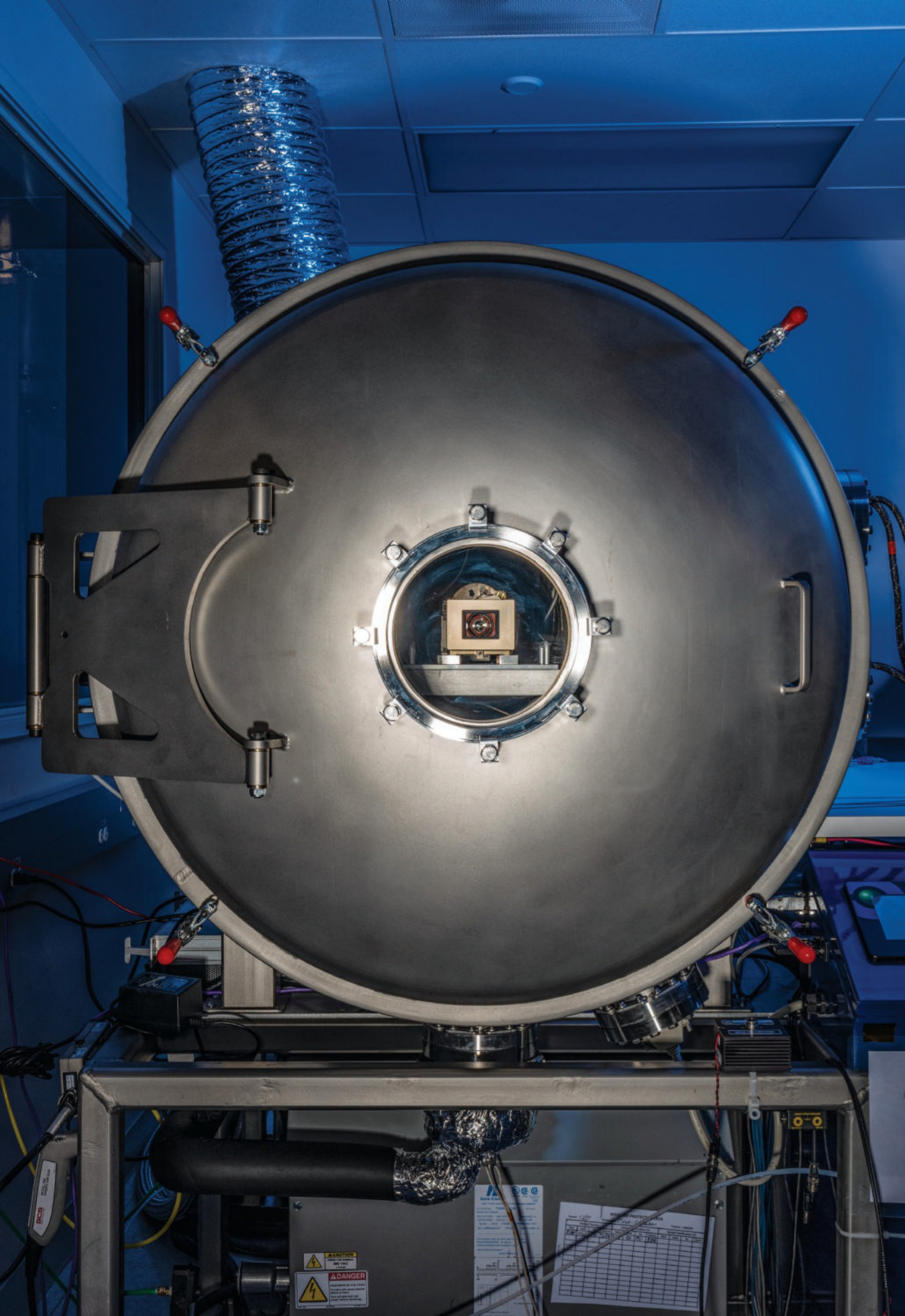
Early, blurry views of Mars inspired stories of canal-building aliens. While intelligent civilizations never flourished there, rovers such as Curiosity (right) now drive the search for microbial Martians.

PERCIVAL LOWELL, LOWELL OBSERVATORY ARCHIVES (ABOVE); MOSAIC OF 57 IMAGES BY NASA/JPL/MICHAEL RAVINE, MALIN SPACE SCIENCE SYSTEMS

Assembling Mastcam-Z

Flight assembly technician Olawale Oluwo of Malin Space Science Systems in San Diego, California, holds part of Mastcam-Z, a pair of cameras with zoom capabilities installed on NASA's Perseverance rover. A Mastcam-Z camera is tested in a chamber (right) that simulates the planet's wide swings in surface temperature.

CRAIG CUTLER (BOTH)

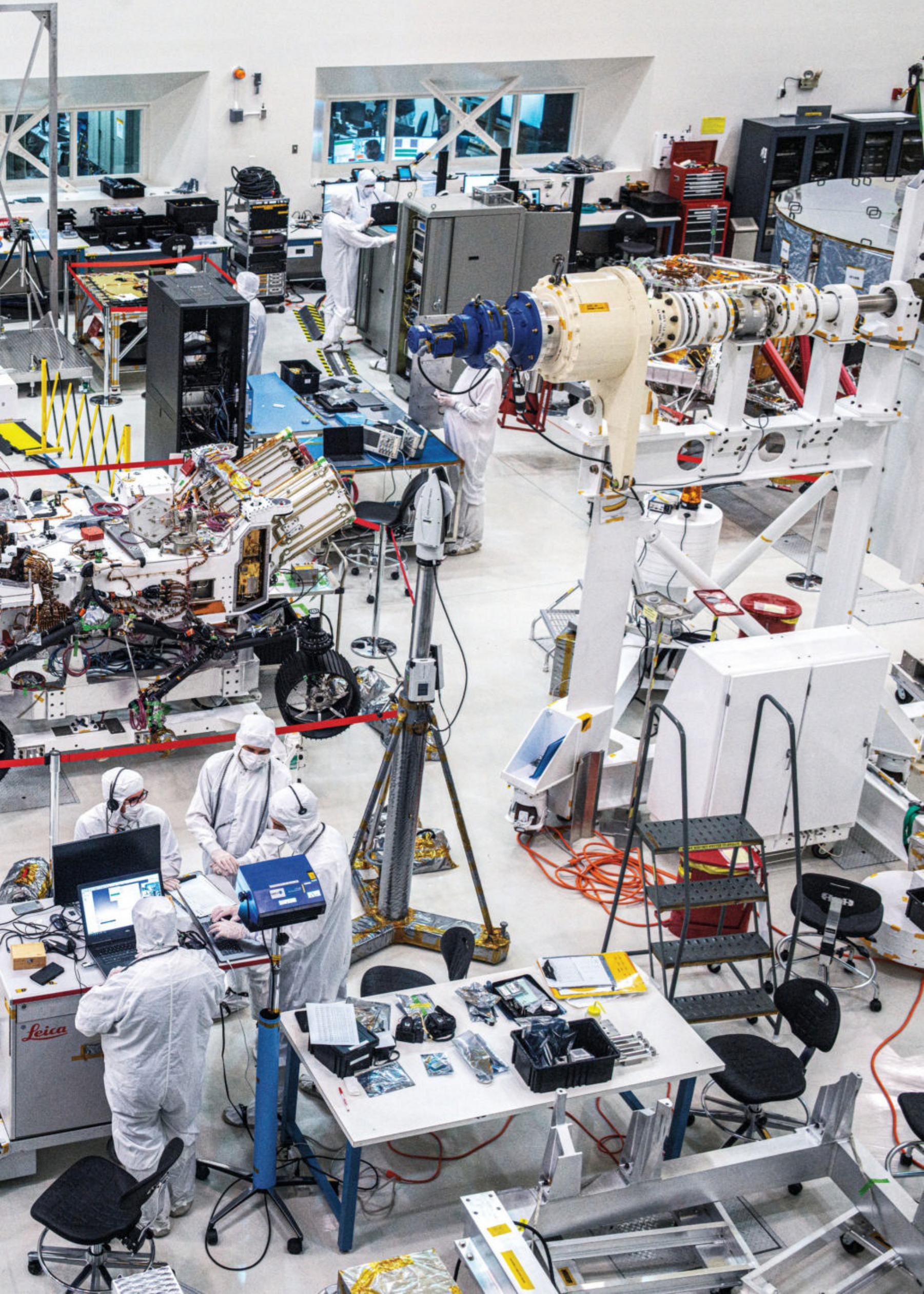

CAUTION
DANGER

Eight spacecraft are operating in orbit around Mars or exploring its dusty surface. In February 2021, as of press time, three more robotic emissaries are scheduled to rendezvous with the red planet, including the flagship NASA rover, Perseverance.

A Clean Start

Engineers at NASA's Jet Propulsion Laboratory in Pasadena, California, work in a sterile room to calibrate the Perseverance rover's 23 cameras before launch. Given the rover's goal of looking for signs of life on Mars, technicians took many precautions to avoid contaminating the machine with Earth-based microbes.

SPENCER LOWELL


Leica

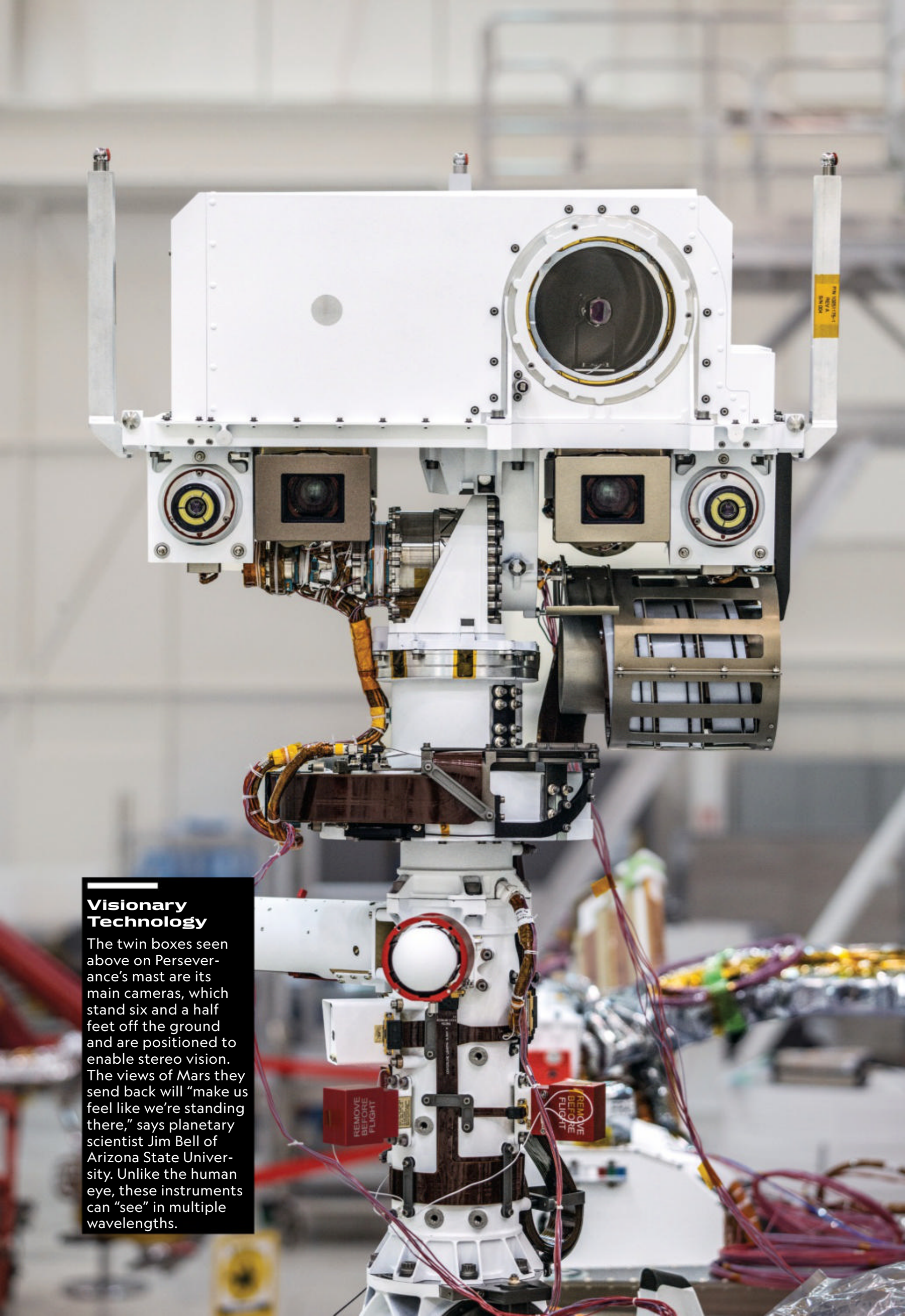
It's a warm night in mid-October, and I'm winding my way up to the University of Virginia's McCormick Observatory on a quest to solve an abiding mystery: Why are Earthlings so dang obsessed with Mars?

The observatory's hilltop dome is open, etching a glowing amber crescent into the autumn darkness. Inside stands a telescope that will help me see Mars as it appeared to observers more than a century ago, when eager astronomers used this instrument in 1877 to confirm the discovery of the two tiny Martian moons, Phobos and Deimos.

Tonight UVA astronomer Ed Murphy has made a special trip up to the observatory, which is closed to the public because of the ongoing coronavirus pandemic. The whirling dance of orbital dynamics has put Mars at its biggest and brightest in the sky right now, and Murphy calculated that this would be the best time to see it from central Virginia, where the turbulent air can sometimes complicate nighttime sky-gazing.

He climbs up a ladder and settles onto the viewing platform, a wooden perch constructed in 1885,

SPENCER LOWELL (RIGHT)



Visionary Technology

The twin boxes seen above on Perseverance's mast are its main cameras, which stand six and a half feet off the ground and are positioned to enable stereo vision. The views of Mars they send back will "make us feel like we're standing there," says planetary scientist Jim Bell of Arizona State University. Unlike the human eye, these instruments can "see" in multiple wavelengths.

Rolling in the Deep

Getting a spacecraft to Mars is not easy, and many early missions failed. But in 1997 NASA's Pathfinder mission successfully landed and released Sojourner, the first wheeled rover on the planet. This pioneering robot has a supporting role in the 2015 film *The Martian*.

NASA/JPL

and nudges the giant telescope toward the conspicuous orange dot of light. He fiddles with a knob, bringing the planet into focus. "Wait for those few moments when the atmosphere settles down, and you'll actually see Mars looking crisp and clear … and then it will all get blurry again," he says through his space-themed face mask.

We swap places. Through the telescope, Mars is an upside-down, peach-pink sphere that swims in and out of resolution. I hesitantly sketch its shadowy features during fleeting moments of clarity, doing my best to channel the 19th-century scholars who once charted its landscapes, some fervently believing that its alien face bore the markings of an advanced civilization.

Today we know there are no immense engineering scars crisscrossing the planet's vermilion surface. But that doesn't really matter. Human interest in Mars is ageless. For millennia we've made sense of Mars by attaching our deities to it, charting its motion, and mapping its face. We've worked Mars into our art, our songs, our literature, our cinema. Since the beginning of the space age, we've also hurled more than 50 pieces of hardware—engineering marvels that collectively cost billions of dollars—at Mars. Many, especially early on, have failed. And still our Mars mania marches on.

As I meet with Murphy in October, eight spacecraft are operating in orbit around Mars or exploring its dusty surface. In February 2021, as of press time, three more robotic emissaries are scheduled to rendezvous with the red planet, including a flagship life-seeking NASA rover called Perseverance and two potentially history-making missions from China and the United Arab Emirates.

But, why? Among the worlds we know, Mars is not superlative in any way. It's not the brightest, the closest, the smallest, or even the easiest to get to. It's not as mysterious as Venus; not as spectacularly adorned as jewel-toned Jupiter or ringed Saturn. It's arguably not even the most likely place to find extraterrestrial life—that would be the icy ocean moons of the outer solar system.

"A bunch of red dirt on Mars is not as interesting as some of these other worlds," says Paul Byrne, a planetary scientist at North Carolina State University. "I don't advocate for a second that we shouldn't be exploring it. I do advocate, loudly, that we should be considering how Mars fits into the overall space exploration strategy."

The scientific reasons why Mars is a compelling target are complex and evolving, propelled by a cornucopia of images and information from all those orbiters, landers, and rovers. Mars is a perpetual enigma, a place we're always on the cusp of knowing but don't truly understand. "This is one of the world's longest unfolding discoveries," says Kathryn Denning, a York University anthropologist specializing in the human elements of space exploration. "It's this giant exercise in suspense."

And the reason Mars remains lodged in the popular zeitgeist might be witheringly simple: Even as our picture of it has sharpened over time, we can still easily envision ourselves there, building a new home beyond the confines of Earth. "It's just blank enough," Denning says.

With a sloppy sketch of Mars in my hand, I think of the decades we've spent chasing little

green men, and microbes, and human settlements, and how Mars fervor has returned after every setback. At the same time, I know plenty of scientists are ready to heap our dreams—and our robots—onto other inviting destinations across the solar system. As scientists juggle limited resources and increasing competition, I can't help but wonder if we'll ever shake ourselves loose from the allure of Mars.

SINCE CIVILIZATIONS first gazed skyward, humans have followed Mars and charted its capricious path through the heavens. As the Sumerians tracked this "wandering star" crossing the sky in the third millennium B.C.E., they noted its foreboding color and associated it with the malevolent deity Nergal, god of pestilence and war. Its movements and varying brightness portended the deaths of kings and horses or the fates of crops and battles.

Aboriginal cultures also note its color, describing it as something that has been burned in flames or linking it to Kogolongo, the native red-tailed black cockatoo. The pre-Columbian Maya carefully plotted the object's position relative to the stars, tying its movements to shifting terrestrial seasons. The Greeks associated it with Ares, after their god of war, whom the Romans recast as Mars.

"There was always only one actual planet Mars, but there are a lot of different cultural Marses in play," Denning says.

By the mid-1800s, telescopes had transformed Mars from a mythological figure into a world. As it came into focus, Mars became a planet with weather, shifting terrains, and ice caps like Earth's. "The very first time we had a way to look at Mars through the eyepiece, we started discovering things that were changing," says the SETI Institute's Nathalie Cabrol, who has studied Mars for decades. With more advanced instruments, this dynamic place could be studied—and mapped.

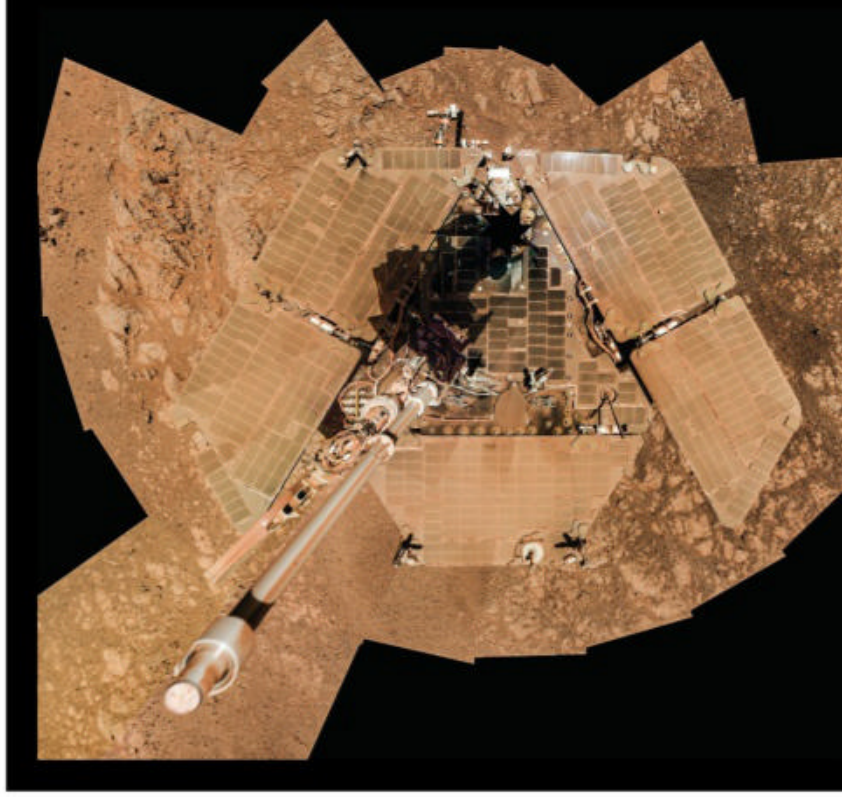
During the Victorian era, astronomers sketched the Martian surface and presented their drawings as fact, although the whims and biases of the mapmakers influenced their final products. In 1877 one of those maps captured international attention. As drawn by the Italian astronomer Giovanni Schiaparelli, Mars had harshly delineated topography, with islands that erupted from dozens of canals, which he colored blue. Schiaparelli stuffed his map with detail, and instead of conforming to contemporary naming conventions, he labeled the exotic features on his version of the planet after places in Mediterranean mythologies.

"That was a really massively bold statement to make," says Maria Lane, a historical geographer at the University of New Mexico. "It's basically him saying, I saw so much stuff that was so different from what anyone else had seen, I can't even use the same names."

As a result, Lane says, Schiaparelli's map was instantly authoritative. Scientific and popular opinion pronounced it a powerful representation of truth. Three decades of unconstrained Mars mania followed, and by the end, any reasonable person would be forgiven for believing intelligent Martians had built a planet-spanning network of canals. Much of that *Continued on page 56*

The View From Above

Pictures from NASA's Mars rovers not only advance science, they also can endear the robots to the public. In 2014 the Opportunity rover sent back this selfie, made of multiple combined images. It showed the rover's solar panels coated with sun-blocking dust.



MOSAIC IMAGE BY NASA/JPL/CORNELL UNIVERSITY/ARIZONA STATE UNIVERSITY

SCIENCE PERSEVERES

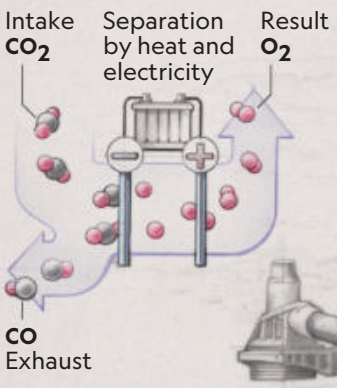
The COVID-19 pandemic hit as NASA scientists and engineers were readying their newest Mars rover for liftoff. The aptly named Perseverance conquered its first challenge by launching last July, on target for landing in February 2021. The rover's mission was planned for at least one Martian year—or 687 days, as humans calculate time on Earth.

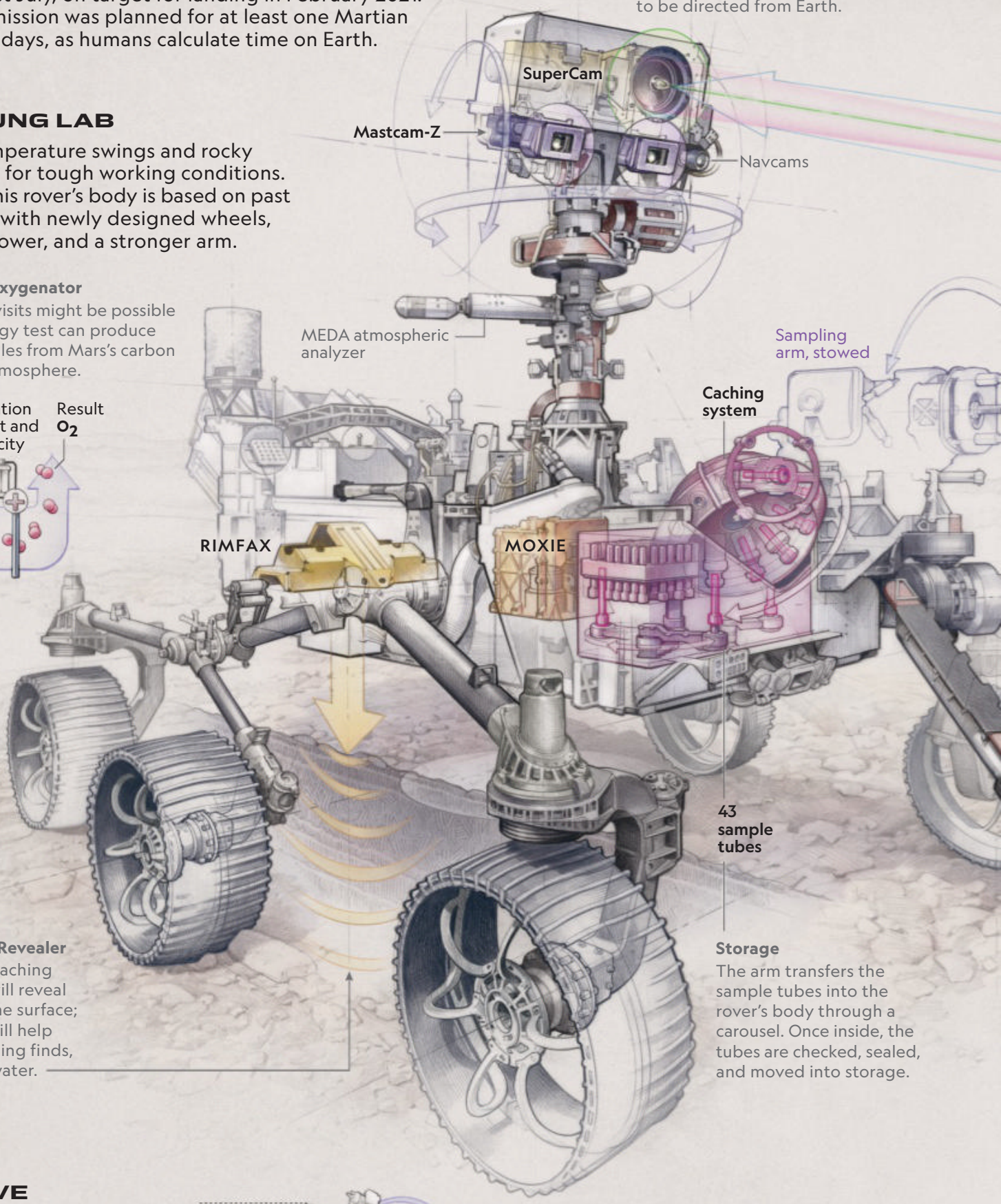
FAR-FLUNG LAB

Big daily temperature swings and rocky terrain make for tough working conditions. To survive, this rover's body is based on past vehicles but with newly designed wheels, more brainpower, and a stronger arm.

A CLEAR VIEW
Mastcam-Z assesses Mars's geology and atmosphere. The Navcams allow the rover to be directed from Earth.

MOXIE: The Oxygenator
Future human visits might be possible if this technology test can produce oxygen molecules from Mars's carbon dioxide-rich atmosphere.



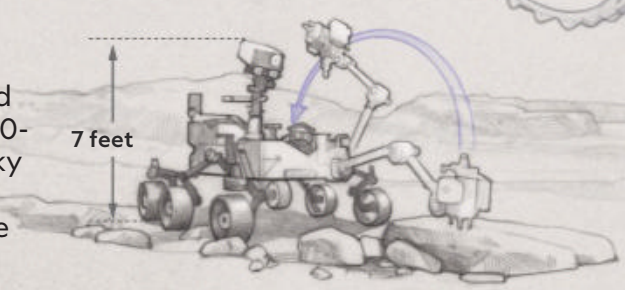


RIMFAX: The Revealer
Radar waves reaching 30 feet deep will reveal what's under the surface; 3D modeling will help identify intriguing finds, such as ice or water.

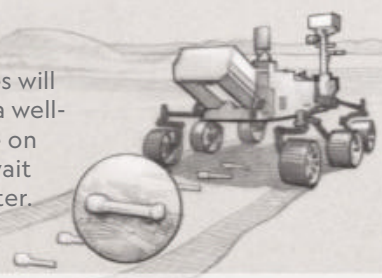
Storage
The arm transfers the sample tubes into the rover's body through a carousel. Once inside, the tubes are checked, sealed, and moved into storage.

RETRIEVE AND RETURN

Rolling along at a top speed of 0.1 miles an hour, the 2,260-pound rover will collect rocky samples from Jezero crater for eventual return to secure laboratories on Earth.

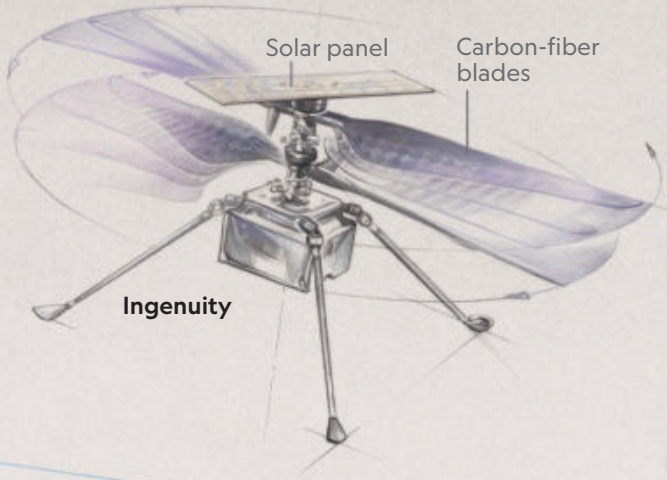


Collected samples will be deposited at a well-documented site on the surface to await retrieval years later.



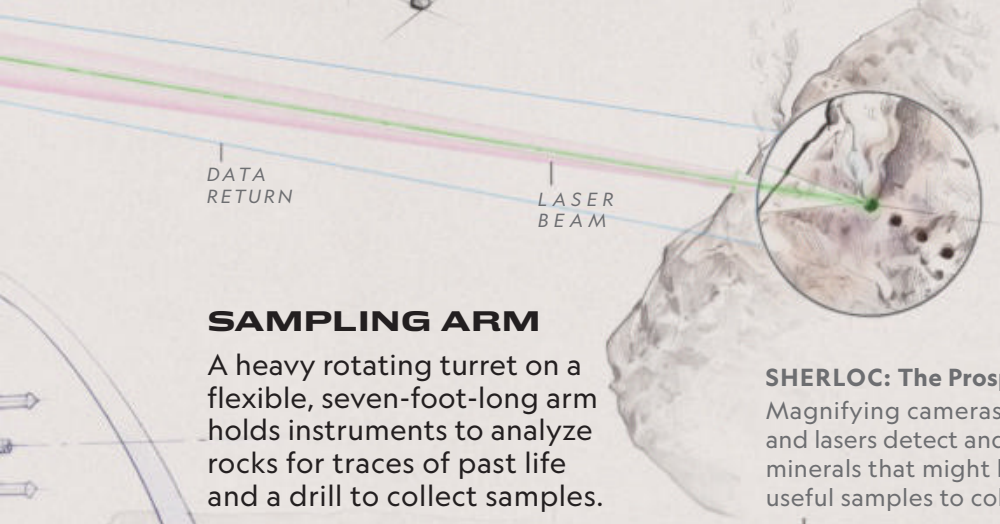
COLLECT 2021-2023 DEPOSIT

MANUEL CANALES, NGM STAFF; PATRICIA HEALY. ART: BRUCE MORSER. SOURCES: NASA/JPL; NASA



TEST FLIGHT
Ingenuity, a small helicopter, will test if vehicles can fly in Mars's thin atmosphere.

The return capsule will detach from the orbiter to enter Earth's atmosphere.



Laser scan
SuperCam's lasers vaporize rock and reflect back information about its composition and chemical makeup.

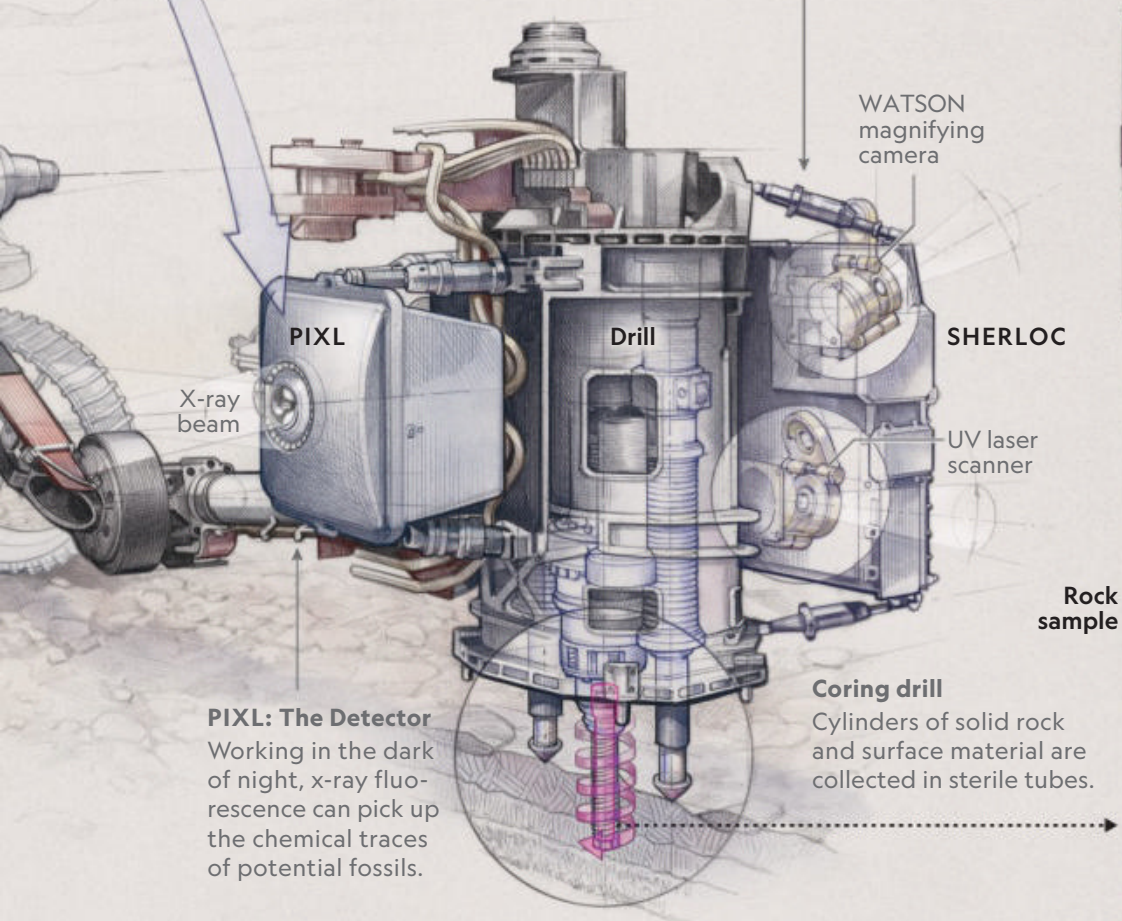
SAMPLE TUBE
ACTUAL SIZE

Earth Return Orbiter

SAMPLING ARM

A heavy rotating turret on a flexible, seven-foot-long arm holds instruments to analyze rocks for traces of past life and a drill to collect samples.

SHERLOC: The Prospector
Magnifying cameras and lasers detect and map minerals that might be useful samples to collect.



Sample return capsule

Mars Ascent Vehicle

The rocket settles into low orbit and releases the sample container to the Earth Return Orbiter for the trip home.

PIXL: The Detector
Working in the dark of night, x-ray fluorescence can pick up the chemical traces of potential fossils.

Coring drill
Cylinders of solid rock and surface material are collected in sterile tubes.

Sample Return Lander

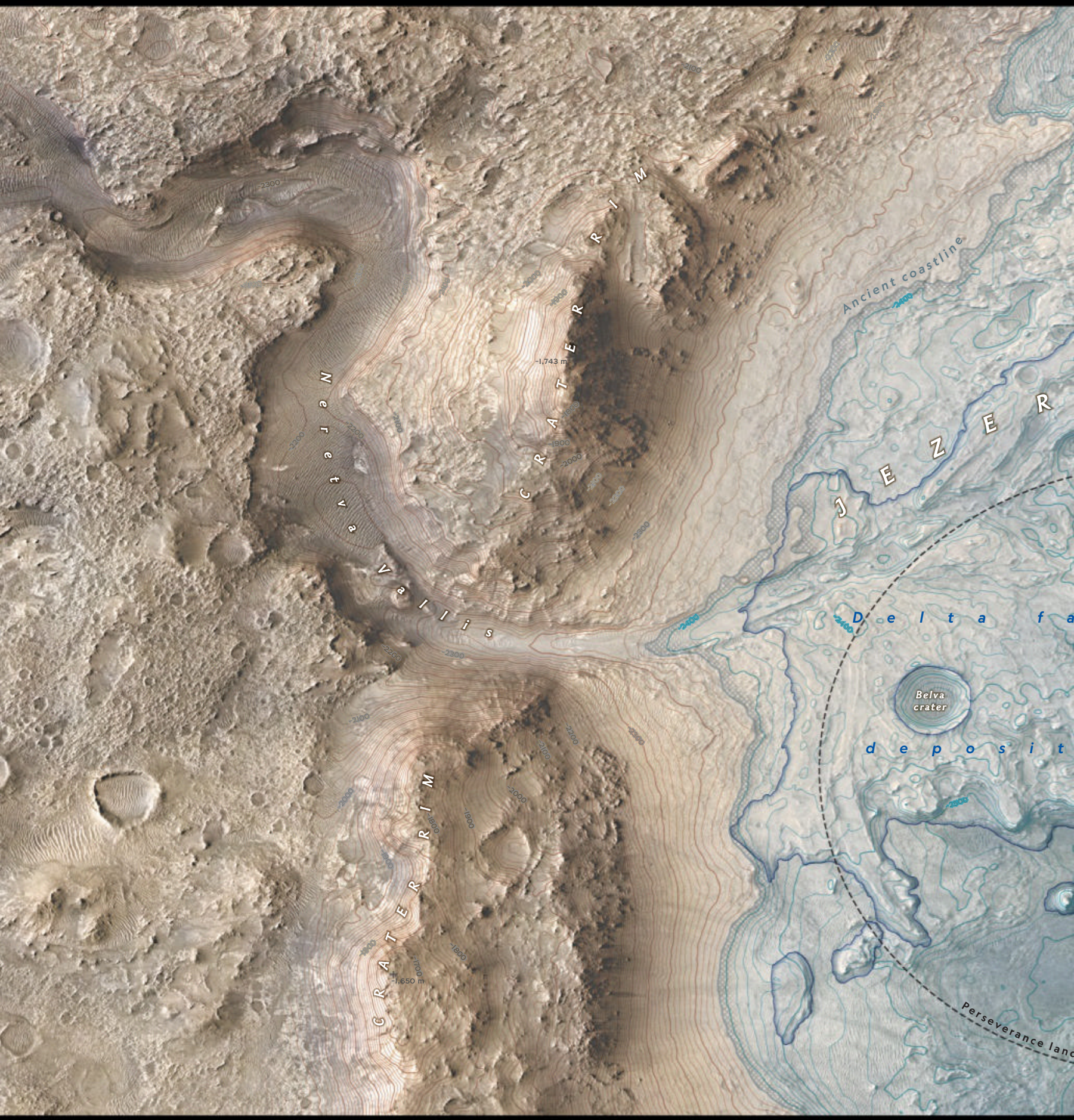
Sample Fetch Rover

The European Space Agency's solar-powered Sample Fetch Rover will collect the filled tubes and drive them to a NASA lander.

An arm on the lander will transfer the tubes into a container that will be rocketed into orbit on the Mars Ascent Vehicle.

RE-COLLECT 2028

RETRIEVE


CRATER RIM
Neretva Vallis
CRATER RIM
Ancient coastline
JEZERO
Delta fa
deposit
Belva crater
Perseverance lan
-1,743 m
-1,650 m
-2300
-2200
-2100
-2000
-1900
-1800
-2400
-2500

SIGNATURE OF FLOW

Ancient river deltas on Mars formed much as they do on Earth. Fast-flowing water meets standing water, depositing bits of sand, minerals, and silt eroded from the surrounding valley. Scientists hope sediments collected from Jezero crater might hold traces of life that washed into the basin.

LAKES OF A BYGONE ERA
Geologists are looking for telltale patterns that ancient bodies of water leave on rocks and minerals. Erosion at the edges of a lake leaves beach sands and wave-cut terraces, while certain clays and hydrated minerals can form or be deposited only in the presence of water.

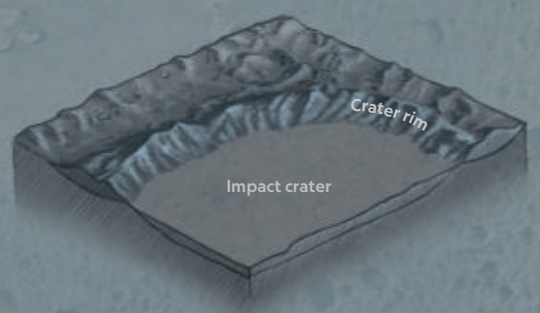
MOVING UP THE DELTA
Perseverance will use its suite of scientific instruments to plumb the mysteries of how the delta formed at at Jezero crater and to see whether fossilized microbes might be trapped in its layers of sediments.

HEADED FOR THE PLAINS
Slated to land on the flat surface of the crater floor, Perseverance eventually will climb up the channels of the delta into the river valley—then on to the plains beyond.

Contour interval: 10 meters
1 mi
1 km
*Elevations are referenced to a 3,390-kilometer-radius sphere.**

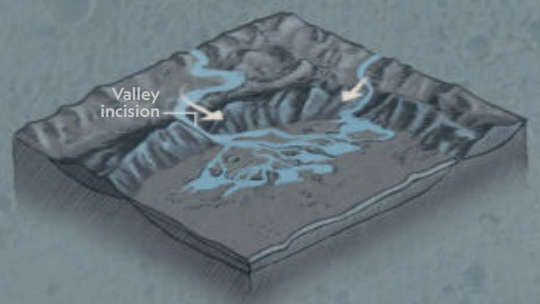
COSMIC COLLISION

A meteorite formed the 28-mile-wide Jezero crater some four billion years ago. Over time, the crater filled with volcanic debris.



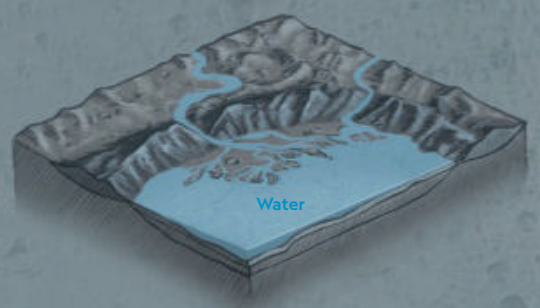
WATER FILLS THE CRATER

Roughly half a billion years later, during Mars's wet era, two flowing channels broke through the crater's rim, creating a lake inside the basin.



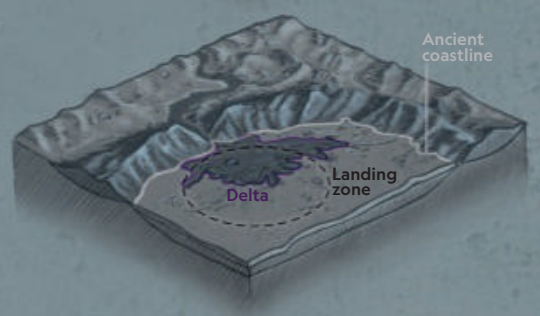
MINERALS ACCUMULATE

Moving water continued to deposit materials at the basin's edge, forming a delta lined with sediments washed in from afar.



MARS DRIES UP

Liquid water and much of the ice disappeared from the red planet 3.5 billion years ago, leaving behind a dried lake bed at Jezero. The remaining delta has shrunk over time from wind erosion.

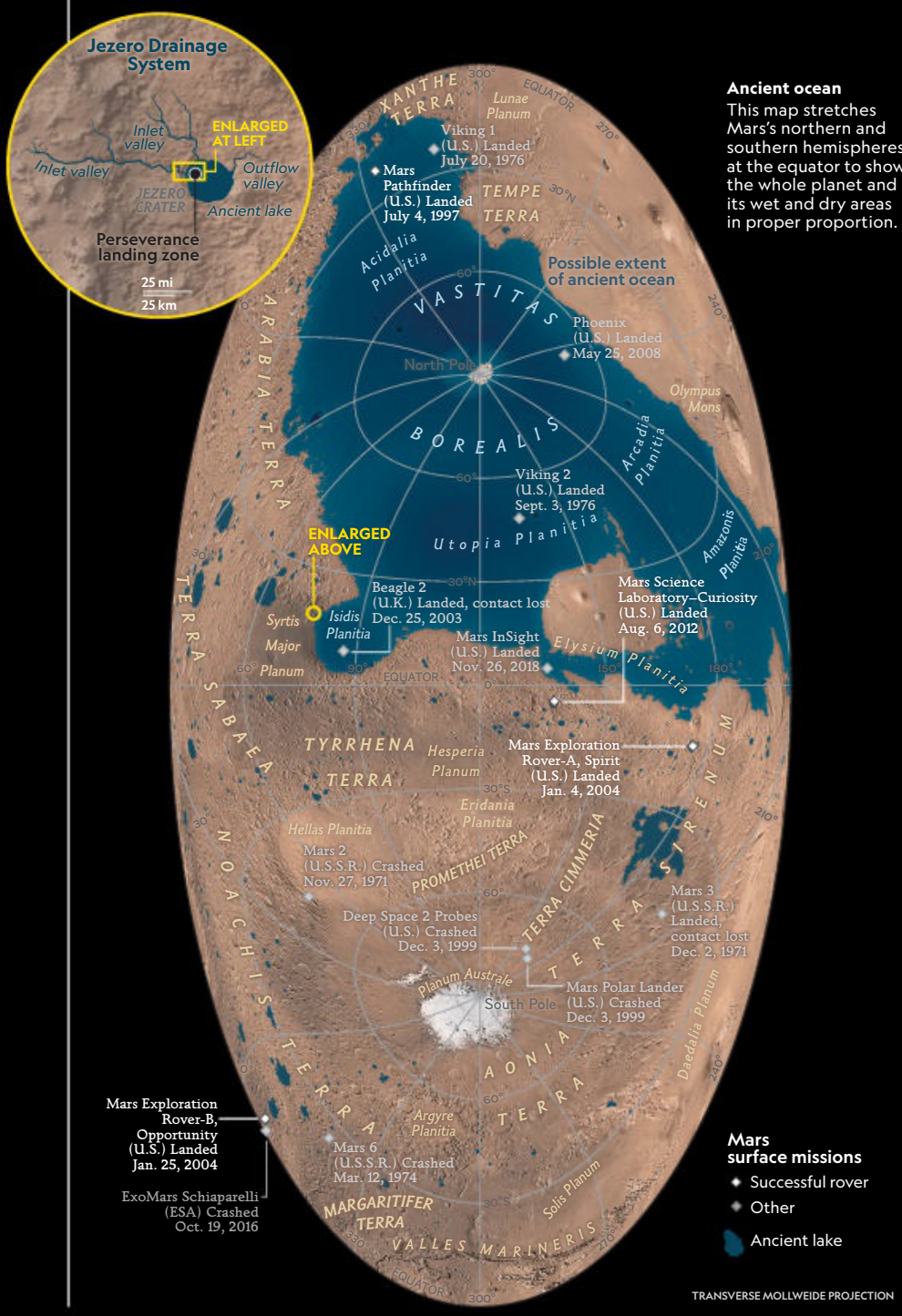


MATTHEW W. CHWASTYK AND MANUEL CANALES, NGM STAFF
ALEXANDER STEGMAIER. CRATER TIME LINE ART: MATTHEW TWOMBLY
SOURCES: USGS ASTROGEOLOGY RESEARCH CENTER; NASA; TIMOTHY A. GOUDGE, UNIVERSITY OF TEXAS AT AUSTIN; BRIONY HORGAN, PURDUE UNIVERSITY

* WITH THE ABSENCE OF SEA LEVEL, HEIGHTS ON MARS ARE CALIBRATED TO THE ALTITUDE WHERE WATER COULD EXIST AS LIQUID, A SOLID, OR A GAS. THIS ELEVATION ON THE PLANET'S SURFACE IS DESIGNATED AS ZERO AND PLACES THAT ARE LOWER ARE EXPRESSED AS NEGATIVE NUMBERS.

IMPRINTS OF A WATERY PAST

Early visions of alien-made canals turned out to be fantasy, but Mars does boast geologic features such as river channels and deltas that hint at a wet history. Now, after more than 40 years of exploration, scientists have a deeper understanding of the planet's surface—and how parts of the landscape were transformed by flowing water some three and a half billion years ago.



Ancient ocean
This map stretches Mars's northern and southern hemispheres at the equator to show the whole planet and its wet and dry areas in proper proportion.

WARM AND WET

Warmer weather, closer to Earth's average of 57°F, would have allowed for running water and even rain. Storms might have cleared the air of most dust to create bluer skies. The wet and rocky Martian landscape could not have supported vegetation.

COLD AND ICY

Temperatures colder than Antarctica would have kept any surface water frozen, with ice and snow at high elevations. Volcanic lava and steam might have briefly warmed some regions. Ancient Mars would have appeared more gray; today oxidized iron gives its soil a ruddy hue.

ANCIENT HORIZONS

In 2003 a rover found evidence that water once flowed on Mars, but early climatic conditions on the red planet are still up for debate. Models suggest two extremes that would have allowed some liquid to exist on the surface, illustrated here; scientists suspect Mars may have cycled between both states.

MANUEL CANALES AND MATTHEW W. CHWASTYK, NGM STAFF; ALEXANDER STEGMAIER. ART: ANTOINE COLLIGNON
SOURCES: ASHLEY PALUMBO, BROWN UNIVERSITY; ROBIN WORDSWORTH, HARVARD UNIVERSITY; NASA

Continued from page 47 fervor can be linked directly to Percival Lowell, a quirky aristocrat with a serious Mars obsession.

A WEALTHY BOSTONIAN and Harvard University alum, Lowell had more than a passing interest in astronomy, and he was an avid reader of scientific and popular texts. Inspired in part by Schiaparelli's maps, and believing that alien technology had crafted the Martian canals, Lowell raced to build a hilltop observatory before the autumn of 1894, when Mars would make a close approach to Earth and its fully sunlit face would be prime for observing those supposed canals.

With the help of some friends and his family fortune, the Lowell Observatory emerged that year near Flagstaff, Arizona, on a steep bluff that the locals named Mars Hill. From there, among the conifers, he dutifully studied the red planet, waiting night after night for the shimmering world to come into focus. Based on his observations and sketches, Lowell not only thought he could confirm Schiaparelli's maps, he believed he spotted an additional 116 canals. "The more you look through the eyepiece, the more you're going to start seeing straight lines," Cabrol says. "Because this is what the human brain does."

In Lowell's estimation, the Martian canal builders were supremely intelligent beings capable of planetary-scale engineering—an alien race intent on surviving a devastating change in climate that forced them to build mammoth irrigation canals stretching from the poles to the equator. Lowell published his observations prodigiously, and his conviction was infectious. Even Nikola Tesla, the electric pioneer who famously sparred with rival inventor Thomas Edison, got caught up in the moment and reported detecting radio signals coming from Mars in the early 1900s.

But Lowell's story began to fall apart in 1907, in part because of a project he funded. That year, astronomers took thousands of photos of Mars through a telescope and shared them with the world. Planetary photography eventually replaced cartography as "truth," Lane says. Once people could see for themselves how the photos and maps of Mars didn't match, they no longer bought into the authority of Lowell's maps.

Still, by the turn of the 20th century, Mars had become a familiar neighbor with changing landscapes and the lingering promise of inhabitants. The next wave of observations revealed that seasonally, the Martian polar caps shrank and expanded, unleashing a swath of darkness that crawled toward the equator. Some scientists in the 1950s thought those shadowy areas had to be vegetation that flourished and died back, theories that made it into top-tier journals. All this scientific fervor fueled a trove of speculative fiction, from H.G. Wells's *War of the Worlds* and Edgar Rice Burroughs's *Barsoom* serials to Ray Bradbury's *Martian Chronicles*.

"In the days before we'd really explored Mars, pre-1960s, there was just a wealth of imagination," says Andy Weir, author of *The Martian*. "A science fiction author could say, I don't know anything about Mars, so I can say whatever I want about Mars."

Then, in 1965, NASA's Mariner 4 probe swept

CRAIG CUTLER

In Command From Afar

Angela Magee of Malin Space Science Systems works on instructions for a camera on Curiosity, which landed on Mars in 2012. For now, the Martian surface is a place humans can explore only remotely. Scientists must program command sequences to tell their robotic avatars what to do, where to go, and which hazards to avoid.

by the red planet. It captured the first close-up images of the Martian surface in black and white, transforming the rich pop culture playground into a grainy, cratered landscape. Seen at last, the planet's arid sterility was a stark disappointment. But it didn't take long for the idea of life on Mars to rekindle in human imaginations.

IN A SENSE, the isolation of the COVID-19 pandemic has given me a feel for what workdays must be like for Mars scientists. I usually travel extensively, getting my notebooks dirty as I chase stories across deserts, sweltering jungles, and sea ice. Currently, Mars explorers spend their lives trying to understand a place that will come into focus only through a lens or on a computer screen. They won't soon plunge a glove into its alien soil or brush dust from their visored faces; remotely guided rovers must do the work instead.

On a Tuesday morning in October, I've turned on videoconferencing to talk to the SETI Institute's Cabrol, who is across the continent in California. Instead of a bookshelf, artfully arranged, she has a vision of Mars as her backdrop. It's an expansive vista, with dark, boulder-strewn peaks straddling rusty plains and distant ridgelines in the orange haze. That's fitting, I think, for a scientist who's spent decades immersing herself indirectly in Martian landscapes.

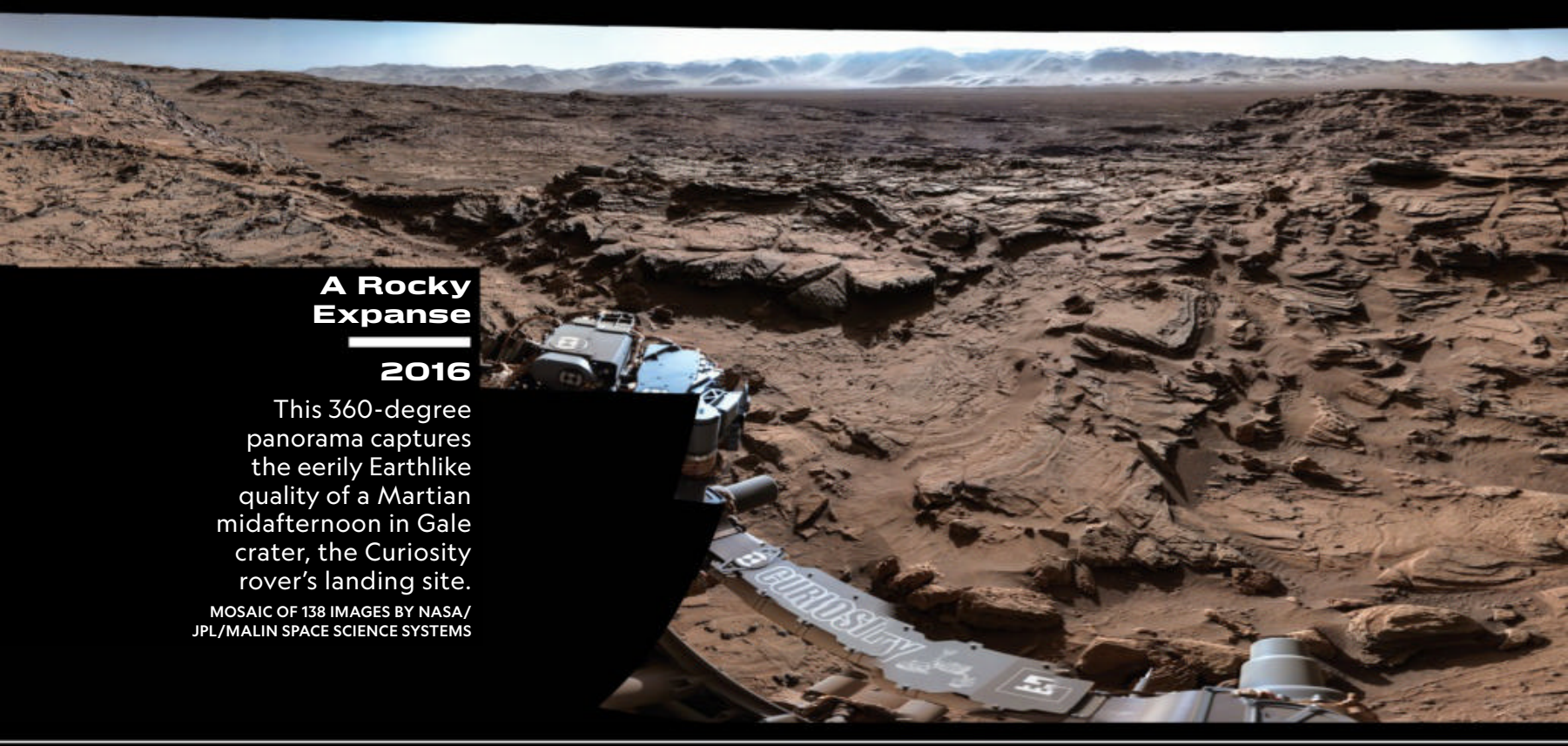
Then Cabrol shifts. Tire treads, trucks, and a cluster of bright orange tents appear in the foreground. Instead of staring at Mars, I'm seeing an image of one of Cabrol's field sites in the Chilean

Undulating Vista

2015

Dunes ripple across the landscape in a panorama made using NASA's Curiosity rover. The dunes appear dark because of morning shadows and the color of minerals in the sand.

MOSAIC OF 14 IMAGES BY NASA/ JPL/MALIN SPACE SCIENCE SYSTEMS



A Rocky Expanse

2016

This 360-degree panorama captures the eerily Earthlike quality of a Martian midafternoon in Gale crater, the Curiosity rover's landing site.

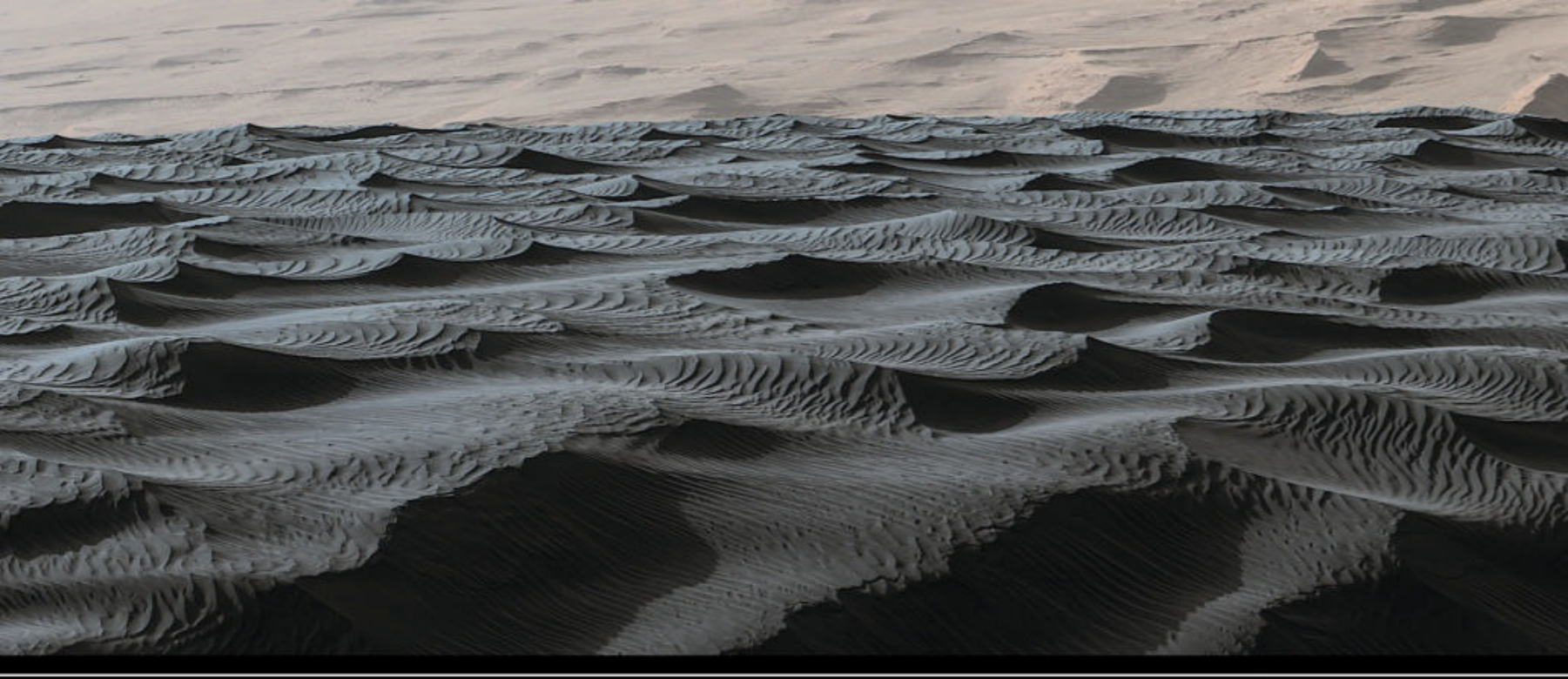
MOSAIC OF 138 IMAGES BY NASA/ JPL/MALIN SPACE SCIENCE SYSTEMS

Getting Sharper

2019

The Curiosity team made this high-resolution panorama from the side of Mount Sharp, a mound inside Gale crater, by assembling more than a thousand images taken over four days.

MOSAIC OF 1,139 IMAGES BY NASA/JPL/ MALIN SPACE SCIENCE SYSTEMS



Altiplano. For decades she has scoured this high desert for Mars-like environments, looking for life on volcanic peaks and in high lakes and trying to imagine how a robotic avatar might accomplish the same task, tens of millions of miles away.

Cabrol and other modern scientists focused on Mars owe a debt to Mariner 9, the first spacecraft to orbit Mars in 1971. At first, Mariner couldn't see through a massive planetwide dust storm. "Mars was still trying, until the last minute, to keep a veil of mystery," Cabrol says. But as the sand settled, the camera spied the summits of the humongous Tharsis Montes, a trio of volcanoes dwarfed only by neighboring Olympus Mons. To the east was mammoth Valles Marineris, a rift valley that resembles Arizona's Grand Canyon, only nine times longer.

Most importantly, in the thousands of photographs taken by Mariner 9, scientists saw ancient river-carved valleys, floodplains, channels, and deltas. They also picked up chemical clues of water ice. These were all signs that flowing water once sculpted exotic Martian landscapes.

"The geologic evidence is overwhelming that the climate was very different than it is today," says Ramses Ramirez, who studies the ancient Martian climate at the Earth-Life Science Institute in Tokyo, Japan. That realization changed the course of Mars exploration. "It was so much more profound than all the folklore we could have in mind," Cabrol says, "and another adventure started. The scientific one."

Knowing that ancient Mars may have been a somewhat Earthlike abode ignited a new set of questions in planetary evolution, and it reinvigorated interest in finding out whether life may have once existed on Mars or, with luck, still did. "I think it's fascinating that we're still dealing with the same themes as Percival Lowell would recognize," says Rich Zurek, chief scientist of the Mars Program Office at NASA's Jet Propulsion Laboratory (JPL). "Just … no canals."

NASA quickly followed Mariner 9 with an even more ambitious mission. In 1976 humans finally were able to gaze at the red planet from eye level when the twin Viking landers touched down in the northern hemisphere. By that time, scientists already knew vegetation didn't seasonally carpet Mars; those shifting shadows were the work of dust storms whipping up volcanic sand. They also already knew that water didn't flow abundantly over its surface anymore.

But they didn't know whether the planet's soils were devoid of life, and at least one astronomer—Carl Sagan—wasn't ready to completely abandon the idea of even larger life-forms.

Just in case Martians were nocturnal, "for a long time, we had a very high-intensity lamp planned to be on Viking so that we could take pictures at night," recalls Gentry Lee, a science fiction author and chief engineer at JPL. To Sagan's disappointment, the Viking team decided to remove the lamp from both landers, and if you had pressed Sagan about whether he truly expected to see Martians wandering by he'd probably demur, Lee says.

The Viking experiments found no Martian microbes and no footprints in the sand. Instead, they unveiled hints of perchlorates in the soil, compounds that can destroy organic molecules and potentially erase any traces of carbon-based life. "So, you couldn't even look for the bodies, if you will," Zurek says.

But Viking did send back images of ruddy, rock-strewn plains that looked like they could have been snapped from any arid place on Earth. New views of Mars kept flooding in, as NASA landed rover after rover on the planet's desolate surface: Pathfinder in 1997, then the twin Spirit and Opportunity rovers in 2004, followed by the Curiosity rover in 2012. Each vehicle arrived outfitted with increasingly sophisticated cameras, and together they sent back roughly 700,000 images. Now when we see those rover tracks in the soil or we see the robot selfies showing them perched on a colorful crater rim, we can more easily imagine ourselves in their treads.

"Once you land, there's this whole evocation of what it means to be a human in this place," says Yale University anthropologist Lisa Messeri, who studies how space-based imagery affects our perception of worlds.

ABOUT AN EIGHT-HOUR DRIVE from Istanbul, Lake Salda in southwest Turkey is a local haven. Dark volcanic rocks tumble toward the brilliant white sandy beach ringing the shore. Clear aquamarine waters become a deep abyssal blue near the lake's center, where the bottom is hundreds of feet down. It's an almost perfect modern analog for Jezero crater, the spot where NASA's Perseverance rover is targeting its search for signs of ancient life.

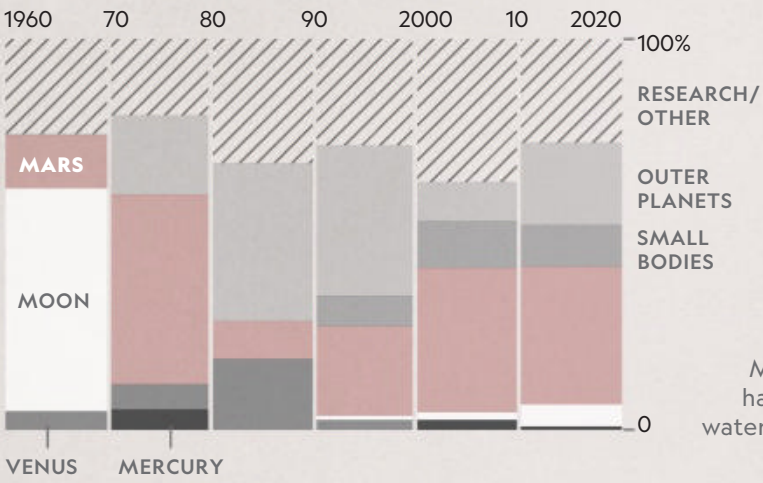
"The locals call it the Maldives of Turkey," says Brad Garczynski, a graduate student in planetary science at Purdue University who traveled to the

COSMIC BUDGETING

People are fascinated by two big questions about Mars: Did life ever exist on the red planet, and could humans survive there now? Satisfying our curiosity takes time and resources. But mission by mission, with ever larger investments of capital, NASA and its partners are using past successes and failures as scaffolding for the next big leaps.

CHANGING FOCUS

Since the 1960s NASA's planetary science budget has reflected priorities beyond the moon. Mars's share has grown, but total investment in the planet since then has been less than 2 percent of NASA's total spending.



$28 Billion

Mars 2020 ◆
The Perseverance rover uses a chassis similar to Curiosity's but has more complex instruments, including the first helicopter on Mars.

InSight ■

Mars Atmosphere and Volatile Evolution Mission ●

The Curiosity rover ◆ discovers carbon-bearing minerals and measures radiation levels.

Mars Science Laboratory (Curiosity)
$3.5 billion

21 B

Phoenix Mars Lander ■

Mars Reconnaissance Orbiter ●

Mars is found to have a warm and watery ancient past. ◆◆

Mars Exploration Rovers - Spirit & Opportunity
$1.6 billion

Mars Odyssey ●

14 B

MPL/MCO ○□

Mars Pathfinder ■◆

Technology for the rover Sojourner's cameras now makes panoramic smartphone photos possible.

Mars Global Surveyor ●

Mars Observer ○
$1.7 billion

■●■● One of some 50,000 images from Viking sparked theories of a face on Mars. It was just a mesa.

Viking 1 & 2
$7.1 billion

The '80s see a lull in exploration after the Viking missions.

Mariner 8 & 9 ○●
$1.3 billion

The first craft to orbit another planet, Mariner 9 sent back images of canyons, volcanoes, and moons.

Mariner 6 & 7 ✖✖
$1.3 billion

✖✖ *Failed*

Mariner 3 & 4
$1.1 billion

1960 70 80 90 2000 10 2020

$26.2 Billion IN MARS MISSIONS

Getting to Mars is a challenge. The Soviets saw nearly all their missions fail; more recently, Russia's, Japan's, and China's missions failed. But India and Europe have active Mars orbiters, and NASA's success rate is more than 70 percent.

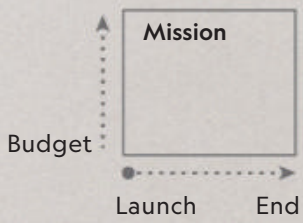
7 B

COSTS INCLUDE LAUNCHES AND ARE ADJUSTED FOR INFLATION TO 2019 DOLLARS.

Mission spacecraft

✖ Flyby ■ Lander ● Orbiter ◆ Rover

Outlined symbols represent failed missions



MANUEL CANALES, NGM STAFF; PATRICIA HEALY. SOURCE: NASA; PLANETARY SCIENCE BUDGET DATASET, COMPILED BY CASEY DREIER FOR THE PLANETARY SOCIETY

site in 2019. "You could imagine yourself as a little microbe tanning yourself on the shoreline of Jezero."

It's dry now, but the sculpted terrain suggests that Jezero once was filled with a deep, large crater lake fed by flowing rivers. More than 3.5 billion years ago, water likely rushed into Jezero from the north and west, depositing layers of sediments in fanning deltas near the crater walls. Over time, the crater filled and flooded, eventually sending water back out through a breach to the east.

From orbit, spacecraft have identified clays and carbonate minerals near Jezero's deltas that require water to form. Lake Salda's white sands similarly are made of busted-up carbonates called microbialites, rocky structures made when dissolved carbon dioxide forms carbonate ions that react with other elements, such as magnesium, and precipitate rapidly, trapping organic compounds. On Earth this process forms layered structures that preserve the oldest evidence of terrestrial microbial life, dating back 3.5 billion years. Scientists are hoping that Jezero's carbonates did the same, and that they trapped anything that once inhabited the lake or its ancient shores.

"It's one of the reasons we're excited about Jezero crater," says Purdue University planetary scientist Briony Horgan. It's also why Garczynski is practicing being a Mars rover in Turkey: He's looking for the most likely places for biosignatures to be preserved, and he's figuring out what they'd look like to Perseverance. To do that, he collected nearly a hundred pounds of samples from Lake Salda and flew them home in a suitcase.

Like Garczynski, Perseverance will be collecting rocks for a return trip, although maybe just 450 grams, at most. As the rover wheels around Jezero, its onboard cameras—which see Mars in multiple wavelengths—will help it identify the most tantalizing rocks to collect. The rover will cache those samples and leave them on Mars, where they'll wait for a ride home on a future spacecraft. Once they arrive in Earth-based laboratories, scientists will use the best possible instruments to read the record of Mars's ancient climate and tease out any possible signs of life.

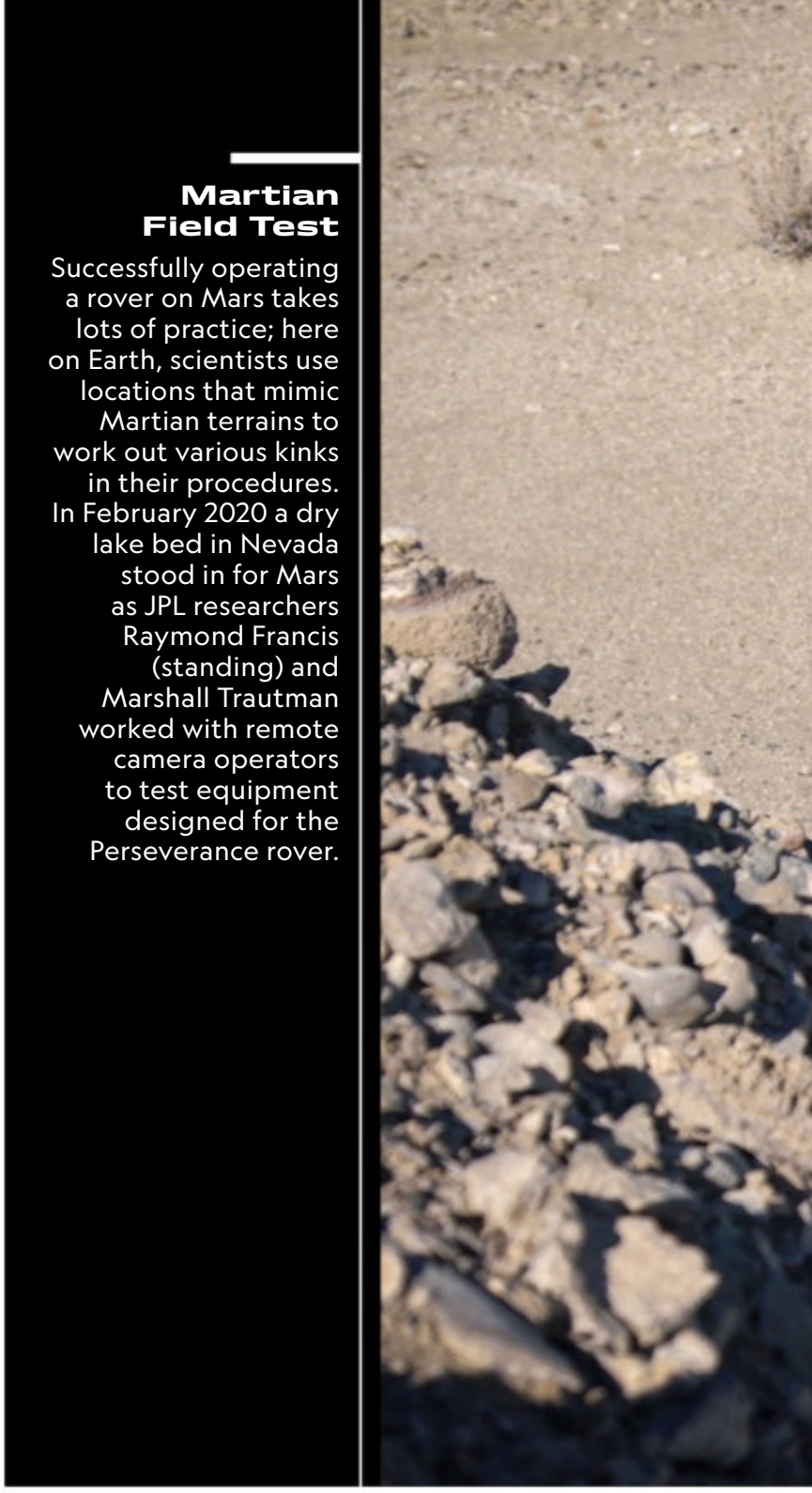
Or maybe, with luck, Perseverance's advanced cameras will be the first to glimpse evidence of fossilized Martians.

IF ANYTHING, though, Mars has taught humankind that we often fall prey to wishful thinking about life on its surface. From canals to vegetation to hotly debated hints of fossils in Mars meteorites, the red planet repeatedly has paved over our hopes with bleak, barren realities. So why, then, are we sending yet another spacecraft to look for life on Mars—not even for organisms that are alive today but for traces of organisms that may have flourished billions of years ago?

"We. Haven't. Looked. For. Life. On. Mars," Cabrol asserts, getting animated. "If you don't have a good understanding of the environment, how are you going to be able to decrypt or extract a life signal out of that?!" Even Viking, she says, which was purportedly a life-finding mission, carried an experiment that was designed without enough knowledge of the Martian environment to reasonably succeed.

Martian Field Test

Successfully operating a rover on Mars takes lots of practice; here on Earth, scientists use locations that mimic Martian terrains to work out various kinks in their procedures. In February 2020 a dry lake bed in Nevada stood in for Mars as JPL researchers Raymond Francis (standing) and Marshall Trautman worked with remote camera operators to test equipment designed for the Perseverance rover.



SAM MOLLEUR, NASA/JPL

But those ancient landscapes are still there, preserving a record of the planet's infancy and a time when life could have thrived in a slightly wetter period, blanketed by a thicker atmosphere.

"We know the canals don't exist, we know there is no pyramid on Mars, no alien civilization, no Tupperware," Cabrol says. But if we do find that some prebiotic chemistry littered the Martian surface, we may learn something about how life evolves on any rocky shores—including our own.

What if Perseverance finds no evidence for Martian fossils or even signs that places like Jezero could have been inhabited? Will we ever be able to give up on the idea of life on Mars? Probably not, admits David Grinspoon, senior scientist at the Planetary Science Institute. "It's very hard to kill the idea that Mars is somehow hiding life from us," he says. "It's very, very tenacious."

In a way, that stubbornness is perhaps the most blatant manifestation of our desire for companionship, a longing for communion, a need to know that we are not alone in the universe. Humans, for the most part, need other humans to survive, and maybe that's true on a planetary scale as well.

"We are not a solitary people," Weir says. "At a macroscopic level, we—humanity—we don't want to be alone." ▯

Contributing writer **Nadia Drake** last wrote for *National Geographic* about how spaceflight changes the way astronauts think about Earth. California-based photographers **Craig Cutler** and **Spencer Lowell** enjoy bringing complex science stories to life.

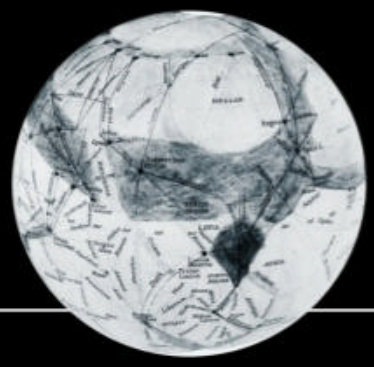
WE JUST CAN'T GET

PAINTING BY PAOLO VERONESE (PAOLO CALIARI), METROPOLITAN MUSEUM OF ART, JOHN STEWART KENNEDY FUND, 1910

1570s "Mars and Venus United by Love"
A joining of opposites: Cupid uses a special love knot to bind the Roman god Mars to the goddess Venus in a painting by Paolo Veronese.

1898 *The War of the Worlds*
A witness recounts an epic battle between Martians and Earthlings in H.G. Wells's now notorious thriller.

CHRONICLE/ALAMY STOCK PHOTO

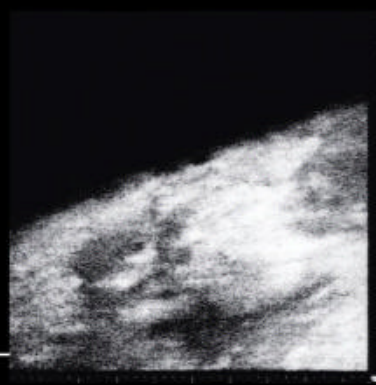


1906 Lowell's Canals
As he drew on his maps (above) and described in a 1906 book, Percival Lowell believed Mars was a dying world covered in irrigation canals.

LOWELL OBSERVATORY ARCHIVES

PAINTING BY DOUGLAS S. CHAFFEE, NATIONAL GEOGRAPHIC IMAGE COLLECTION

1967 Sagan's Vision
For *National Geographic,* Carl Sagan imagined radiation-resistant Martians shielded by glassy shells, eating cabbage-like plants that fold up at night.



1965 Mariner 4
When this spacecraft flew by Mars, it snapped images of a planet that looked disappointingly like the moon: cratered and sterile, without any signs of alien life.

NASA

1976 Mars Vikings
NASA's Viking mission included two orbiters and two landers, the first to take high-resolution images of Mars from its desolate surface.

NASA

1996 *Mars Attacks!*
Directed by Tim Burton, this film poked fun at 1950s science fiction movies. In it, murderous Martians terrorize Earth until they're defeated by a country song.

PICTORIAL PRESS LTD/ALAMY STOCK PHOTO

ENOUGH OF MARS

1918 *A Trip to Mars*
Like many early 20th-century depictions, this Danish silent film focused on Mars's supposed inhabitants—in this case, benevolent vegetarians.

PICTORIAL PRESS LTD/ALAMY STOCK PHOTO

1939 "The Man From Mars"
Drawn by Frank R. Paul for *Fantastic Adventures,* this Martian is telepathic and can retract his eyes and nose to protect them from freezing.

CHRONICLE/ALAMY STOCK PHOTO

1954 Full Color
Astronomer E.C. Slipher took this image from South Africa; he published his *Photographic Story of Mars (1905-1961)* in 1962.

E.C. SLIPHER, LOWELL OBSERVATORY ARCHIVES

1951 *Flight to Mars*
In this sci-fi drama, scientists arrive on Mars to find a planet populated by a subterranean, dying race similar to humans—who may be plotting a desperate invasion of Earth.

PICTORIAL PRESS LTD/ALAMY STOCK PHOTO

2015 *The Martian*
In Andy Weir's futuristic survival tale, astronaut Mark Watney, played by Matt Damon, is abandoned on Mars after crewmates mistake him for dead.

GENRE FILMS/INTERNATIONAL TRADERS/MID ATLANTIC FILMS/20TH CENTURY/ALBUM, ALAMY STOCK PHOTO

2019 Starship
If SpaceX CEO Elon Musk has his way, a version of the retro-looking launch vehicle seen here being built in Texas will one day shuttle humans to the moon, Mars, and beyond.

LOREN ELLIOTT, GETTY IMAGES