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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

The Race to MARS

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 by Benjamin Skuse

THE RACE TO MARS

Timing is everything in space exploration, and in 2020 the time will be right to launch an armada of explorers to the Red Planet in search of signs of life.

RED PLANET ROVING This artist's concept depicts NASA's Mars 2020 rover drilling into Martian rock. The rover is one of four government missions scheduled to launch toward the Red Planet in 2020.

NASA / JPL-CALTECH

Every 26 months, Earth and Mars hurtle close to each other in space, offering a short window during which a voyage to the Red Planet is as efficient a trip as possible. Apart from 2009, engineers have used each such window this century to send spacecraft to Mars. The next, in 2018, will see NASA launch its Insight robotic lander, aiming to study the planet's geological evolution.

But 2020 will be special. Here on Earth, a conflation of technological progress, exploration strategies, and delayed missions will mean that not one but four (or more) spacecraft will be rocketing to the Red Planet.

Not only are the usual suspects NASA and ESA sending missions in 2020, but first-time voyagers are going, too. The United Arab Emirates's Hope orbiter will join six other spacecraft already looping around Mars, as the first-ever mission to the Red Planet by an Arab country. Meanwhile, China will send its first independent mission to the Red Planet, a payload consisting of three elements: an orbiter, lander, and rover.

Outwardly, Mars is a dead red rock. So why the fascination? Why send so many spacecraft to the same planet? The plain truth is that Mars is Earth's most similar neighbor. Observations from previous missions suggest that this world once had a thicker atmosphere, flowing water, and all the ingredients necessary to sustain life. As a result, beyond the desire to physically set foot on a new world, the possibility of finding hidden alien life awakens the natural human urge to explore.

Dusting for Fingerprints

After a barren period following the 1976 touchdowns of the audacious Viking landers (an interval broken only by two doomed USSR missions), a concerted effort to reach the Red Planet began in the 1990s, later morphing into NASA's "follow the water" strategy (see page 16). Using the orbital lineups as opportunities, NASA — joined by other agencies — has since undertaken a series of missions designed to slice away, piece by piece, the mysteries of the Red Planet.

Mars Pathfinder and its tiny Sojourner rover gave this quest wheels, and NASA teams later followed up on their success by dropping two Mars Exploration Rovers — Spirit and Opportunity — onto the planet's surface in 2004 and a much larger third — Curiosity — in 2012. These latter three rovers have trundled across the surface uncovering compelling evidence that Mars might once have been able to harbor life.

Yet this life — if it existed at all — was microscopic, perhaps only leaving the tiniest trace of its former existence. Although the Viking landers did test interesting samples suggestive of ancient life, their results were judged inconclusive — hardly surprising given that NASA conducted the mission nearly 20 years before the term "biosignature" had even been coined to describe evidence pointing to past or present life.

"It's actually really hard to tell what was made by life and what wasn't . . . unless you're looking at dinosaur bones," notes planetary scientist Briony Horgan (Purdue University), co-investigator on the Mastcam-Z camera system for NASA's Mars 2020 rover — the first NASA mission since Viking with the stated objective of seeking direct evidence for ancient life. This is why today's search takes a more holistic view. "You start with what was the type of environment you are in, what was the chemistry of that environment, and then — given that — what kind of life could survive here and what kinds of biosignatures would that life leave behind."

If found, these biosignatures will be subtle: "We look for shapes preserved in the rocks that are suggestive of the past presence or activity of life," says Kenneth Williford (Jet Propulsion Laboratory), Mars 2020's deputy project scientist. "And then we look for chemical disequilibria, organic matter, or biologically important elements distributed in a way that is correlated with those shapes in the rock."

A great example here on Earth of ancient life providing vestigial clues to its former existence is stromatolites. Stromatolites form from mats of photosynthetic bacteria that trap sediments and microbes, building layer upon layer until eventually they become dome-like rock structures, sometimes reaching basketball proportions. Modern ones are still developing in the shallow waters of the Bahamas and *(continued on page 18)*

▲ **STROMATOLITES** These structures form when microbial mats catch sediment and build it up, layer by layer. Ancient stromatolites' unique combination of composition and structure provides some of the earliest records of life on Earth. Scientists would like to find similarly convincing fossils on Mars.

History of MARS MISSIONS

Camille M. Carlisle
Illustration by Terri Dubé

The spacecraft launching in 2020 build on more than a half century of exploration, much of it unsuccessful. A revamped, strategic approach by NASA fostered a string of achievements since 2000.

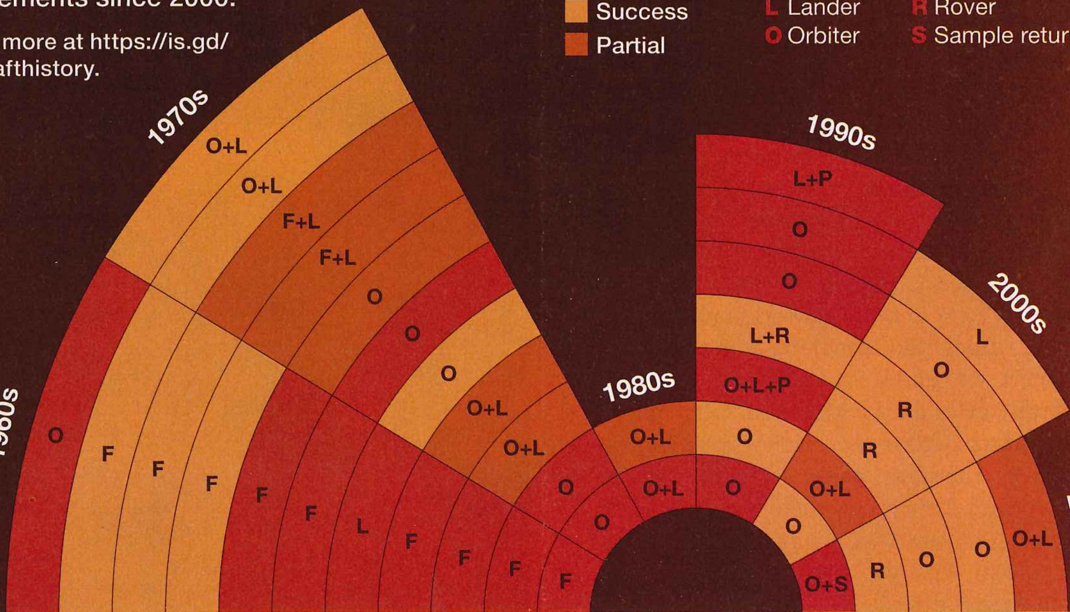
• Learn more at https://is.gd/marscrafthistory.

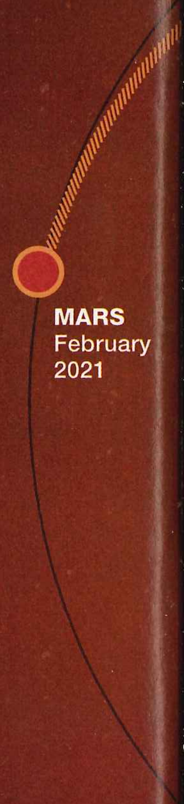
Success or Failure?

So far, humans have launched 42 missions to the Red Planet. Of those, 43% have failed, 38% succeeded, and 19% were partial successes. The low success rate has led scientists to joke about the "Martian ghoul."

- Failure
- Success
- Partial

- F Flyby
- L Lander
- O Orbiter
- P Penetrator
- R Rover
- S Sample return





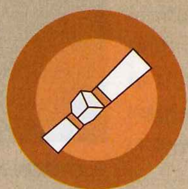
Mars Exploration
Missions and NASA Strategies

NASA began a "Follow the Water" strategy for its Mars Exploration Program in the early 2000s. The evolving approach includes ESA missions NASA has collaborated on. Although not formally part of the Mars Exploration Program, other projects (off-white) are joining the effort and are shown here for timeline completeness.

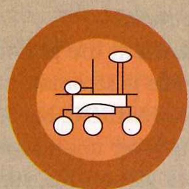
- Follow the water
- Prepare for human exploration
- Explore habitability
- Seek signs of life
- Not part of program

LAUNCH YEAR AND NAME
(F) Flown
(ID) In Development

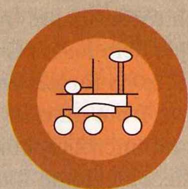
2001 (F)
Mars Odyssey



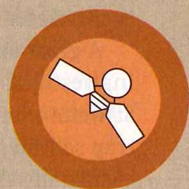
2003 (F)
Mars Express



2003 (F)
MER Spirit



2003 (F)
MER Opportunity



2005 (F)
Mars Reconnaissance Orbiter

Flight Plan 2020

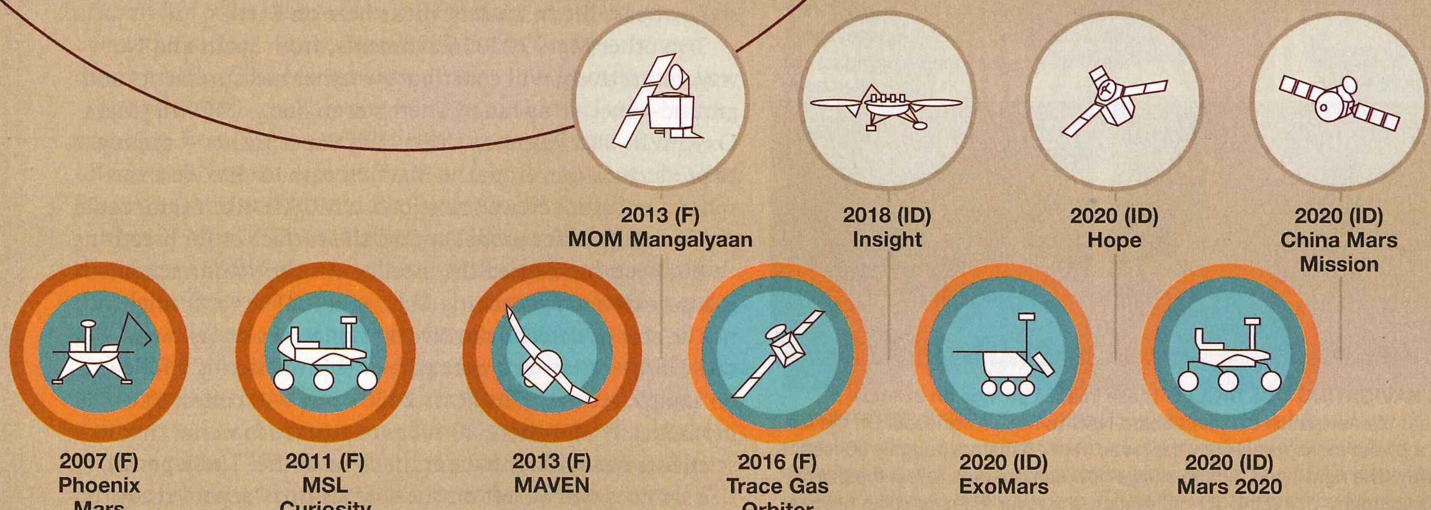
To minimize propellant, Mars-bound spacecraft take the most efficient path from Earth to Mars. Sitting on the launch pad, the spacecraft already orbits the Sun (with Earth). After it launches, it boosts itself out of an Earthlike orbit into a more elliptical one, with an aphelion that matches up with Mars's orbit. The craft's trajectory follows the outgoing arc of this ellipse (approximate path shown). When it reaches Mars, the spacecraft enters orbit or, if a lander, hits the planet "in a controlled way."

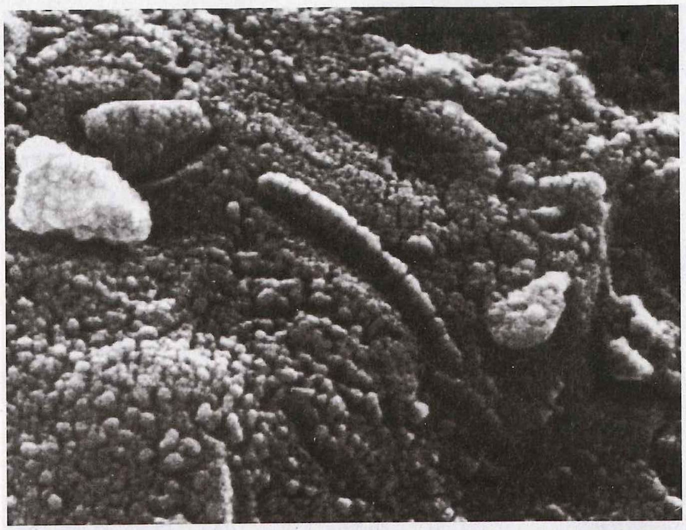
123,000 km/hr

Mars 2020 spacecraft's speed relative to the Sun at launch

64,000 km/hr

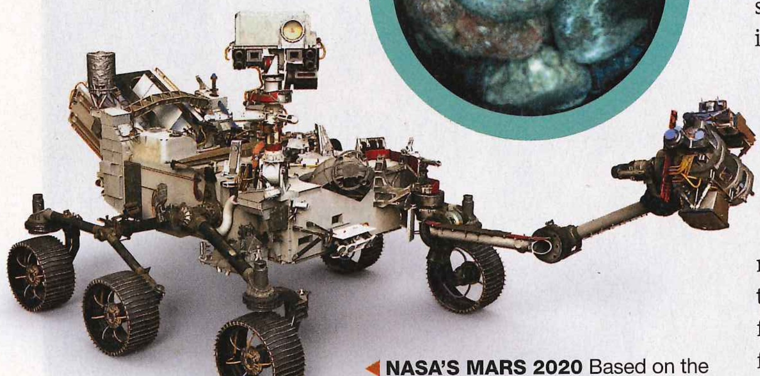
Mars 2020 spacecraft's speed relative to Mars at launch



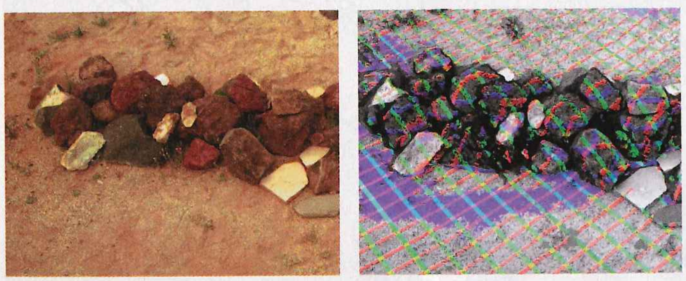


▲ **LIFE FROM MARS?** These globule structures in the meteorite ALH 84001 are similar in texture and size to some made by bacteria on Earth. However, life isn't *required* to explain their formation.

▶ **CACHE CLOSEUP** The Mars 2020's CacheCam provides a top-down view into the rover's sample tube.



◀ **NASA'S MARS 2020** Based on the Curiosity rover design, Mars 2020 is about 3 meters long and 2.2 meters tall (10 feet and 7 feet, respectively), and it weighs less than a compact car.



▲ **NAVIGATING OBSTACLES** These images provide an example of what the navigation camera aboard NASA's 2020 rover sees. On the left is a pile of rocks as seen by the rover, from 15 meters (roughly 50 feet) away. The right-hand picture shows how camera data reveal the pile's 3D contours. Using the 3D information, the rover team can plan precise travel and arm movements.

(continued from page 15)

Australia, but ancient stromatolites date as far back as 3½ billion years, leaving behind a structure, trapped organics, and unusual chemical isotopes that together cannot easily be explained without life having been present.

Caching In

Loaded up with a panoply of instruments, the car-sized Mars 2020 rover should be able to detect any stromatolite-like Martian biosignatures. The most prominent of these instruments from the outside will be the rover's eyes: Mastcam-Z and Supercam, perched on a mast 2 meters above ground level. The former can take high-definition video, panoramic color, and 3D images of the Martian surface and features in the atmosphere. "Mastcam-Z will play a major role in helping to select the samples, as well as helping to characterize the geology and geological context of the landing site," says Mastcam-Z principal investigator Jim Bell (Arizona State University).

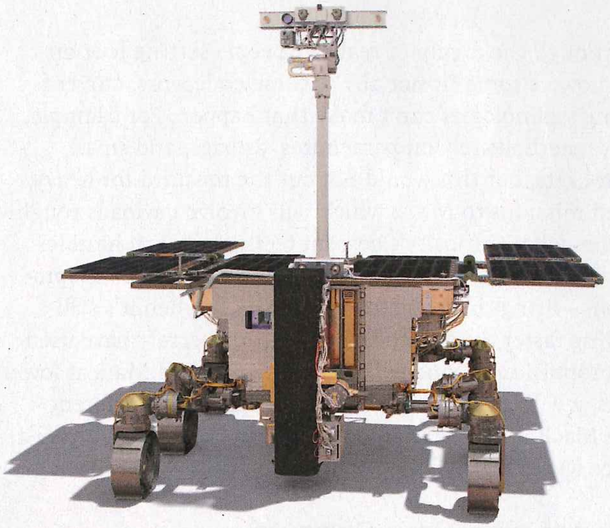
Meanwhile, Supercam will dissect organic compounds from a distance, identifying the chemical and mineral makeup of targets as small as a pencil point from 7 meters away. Supercam does this in part by using Raman spectroscopy — a technique whereby laser light is shone on a sample and the scattered light offers information about molecular vibrations inside the material, which scientists interpret to identify the sample's makeup. This versatile instrument also performs color imaging and visible and near-infrared spectroscopy.

Although used in chemistry labs across the world for decades to analyze the fingerprints of molecules, Raman spectroscopy is a new technology for the surface of Mars. And Mars 2020 will actually be carrying two of these spectrometers: Supercam on the mast and SHERLOC (Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals) on the robotic arm's turret. Also out on a turret is PIXL (Planetary Instrument for X-ray Lithochemistry), an X-ray spectrometer. It identifies chemical elements at a tiny scale. Both instruments are cutting-edge and are what geologists utilize when hunting for signs of past life in ancient rocks here on Earth.

Two other Mars 2020 instruments, from Spain and Norway, respectively, will contribute weather measurements and ground-penetrating radar. There's even one — MOXIE (Mars Oxygen In-Situ Resource Utilization Experiment) — aiming to produce oxygen from the Martian carbon-dioxide atmosphere. In future crewed missions, a MOXIE-like device could produce oxygen for propellant off the surface or for breathing.

But what has caused the most controversy and excitement is a new system for caching Mars rocks. "The rover might not be able to detect definitive biosignatures on its own," says Horgan. "Hence a core part of this mission is a follow-on sample return." The Mars 2020 rover will collect and hermetically seal about 30 tubes of surface material that its scientists deem likely to contain signs of life. These pencil-size samples will be left on the surface in a "depot" ready to be collected in the future.

METEORITE: NASA; SAMPLE VIEW: NASA / JPL-CALTECH; ROVER: NASA; ROCKS: NASA / JPL-CALTECH



▲ **EURASIAN MARS ROVER** ExoMars's standout feature is its drill (tall black cylinder), which will penetrate 2 meters beneath the surface.

Why go to the trouble of returning samples to Earth? One word: skepticism. A decade ago scientists probed a Martian meteorite (ALH 84001), found in Antarctica in 1984, and concluded that it contained microscopic fossilized evidence of bacteria. The resulting media attention even led to a statement from then U.S. President Bill Clinton in which he proclaimed: "If this discovery is confirmed, it will surely be one of the most stunning insights into our universe that science has ever uncovered." But when other teams scrutinized the results using every possible instrument and various independent labs, they found that the Martian rock's unusual features could all be explained without life.

"I think we'd be in the same situation, so we need to bring those samples back and run the best possible analyses on them," says Bell.

Drilling for Life

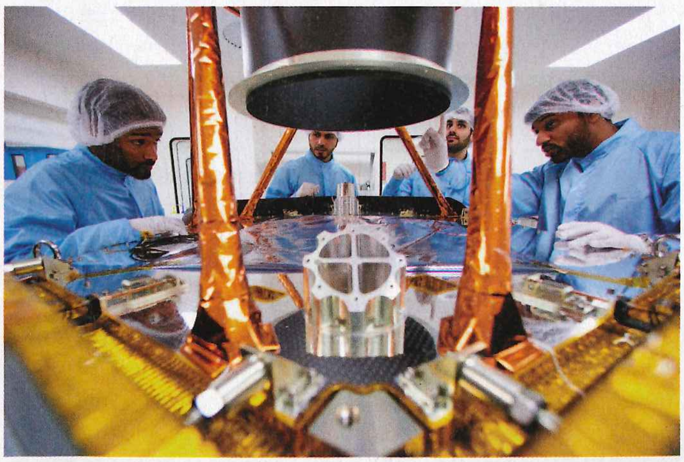
While caching and returning samples is universally acknowledged as the best solution to quelling skepticism, many think ancient life or its vestiges can only remain preserved deep below the surface. Sadly, Mars 2020 doesn't carry any deep digging tools. "The Martian atmosphere is extremely tenuous — the pressure is roughly one hundredth that of Earth — so radiation from the center of the galaxy and Sun penetrates unimpeded," explains Jorge Vago, project scientist on the ESA/Roscosmos mission to send the ExoMars 2020 rover to the surface of Mars. "This radiation acts like a million little knives that over millions of years cuts away the functional groups of the molecules you are trying to study, degrading them eventually beyond the point where you can recognize them."

To solve this issue, the ExoMars rover will carry the longest drill ever sent to the Red Planet, in order to tunnel a full 2 meters below the radiation-affected upper layers to more pristine rocks. "We think that it's going to be a big deal in terms of gaining access to better or more well-preserved samples for analysis," Vago enthuses.

The ESA/Roscosmos ExoMars mission is a two-part project to launch an orbiter and lander in 2016 and then a rover in 2020. With the first part of the mission being less than a stellar success (*S&T:* Feb. 2017, p. 10), whether the rover will land successfully or tragically crash is an open question. But if it does gently touch down on the Red Planet, ExoMars will be a highly capable machine, with a raft of instruments to rival Mars 2020's.

Like NASA's rover, it boasts cameras, infrared/visible and Raman spectrometers, and ground-penetrating radar. However, unfortunately bringing the deep drill means there is simply not enough room for a cache system. "It's very difficult to combine nice instruments, a large caching system, and a deep drill," notes Vago. "We tried, but found that it is almost impossible to do these three things on a single rover." Hence, ExoMars will have to rely on its onboard instruments' tests if it is to find evidence of life.

The best chance ExoMars has of finding these biosignatures is by detecting organics, carbon-based molecules that on Earth are the building blocks of life. This responsibility rests on the unique Mars Organic Molecule Analyzer (MOMA) instrument. MOMA will analyze organic molecules in much the same way as the Viking landers or Curiosity rover. Essentially it has a number of ovens to heat up Martian dirt. Any volatile materials will evaporate in the heat, at which point they can be extracted to see if they are organic. One problem is that this technique is plagued by *perchlorates* — salts that decompose when heated and oxidize the sample being studied. Results from such experiments in the past have proven inconclusive. However, the ExoMars team believes it has



▲ **EMIRATES' ENTRY** The UAE's Hope orbiter *(schematic above)* measures about 2⅓ meters wide by 3 meters tall (7¾ by 9½ feet) and, including fuel, will weigh about half again as much as NASA's rover. Here, engineers discuss disassembling the craft's sun shield baffle for inspection in the lab.

EUROPEAN ROVER: ESA / ATG MEDIALAB; UAE IMAGES: MOHAMMED BIN RASHID SPACE CENTRE

TOWARD A PERMANENT PRESENCE

NASA has had an active robot on the surface or in orbit at Mars since 1997.

solved the issue: "We also have a new way to extract organics, which is by using a large UV laser," says Vago. The laser flash-heats the sample so fast that these perchlorates don't have time to dissociate, meaning MOMA can extract and analyze the organics unimpeded.

New Contenders

Joining NASA and ESA in 2020, China plans to send an orbiter and surface mission as part of its rapidly expanding space endeavors. The still-unnamed project is the nation's second attempt to reach Mars: Its first, a joint endeavor with Russia, failed to leave Earth orbit in 2011. The details of the 2020 program are still shrouded in mystery, but what is known is that the rover will have six wheels and be roughly the same size as the Spirit and Opportunity rovers. Carrying four solar panels with an expected operational lifetime of three Martian months, the rover will tote 13 instruments, including a remote-sensing camera, ground-penetrating radar, and likely a host of spectrometers.

Speaking at a press conference, chief designer Zhang Rongqiao said that the goal of the mission is to study the planet's features, including its soil and atmosphere and the distribution of water and ice. It remains unclear if the Chinese mission will actively hunt for life, though the orbiter might be able to detect atmospheric methane.

The UAE Space Agency may only be three years old, but its scientists and engineers also have their sights set on arriving at Mars in 2021, to coincide with the 50th anniversary of the UAE's founding. Sporting an imager and two spectrometers, the car-size Hope orbiter aims to create the first global picture of Mars's climate, recording daily and seasonal changes in temperature, water vapor, and dust, as well as how the upper and lower atmospheric layers interact. It will also search for connections between today's weather and the ancient, hospitable one we think existed.

But the science is only one piece of a much larger strategy that the UAE is putting together, whose endgame is colonizing Mars by 2117. By reaching for this goal, the national space program is intended to make the UAE a hub of scientific innovation, reducing the country's dependence on oil by inspiring and enabling young Emiratis to enter careers in science and technology.

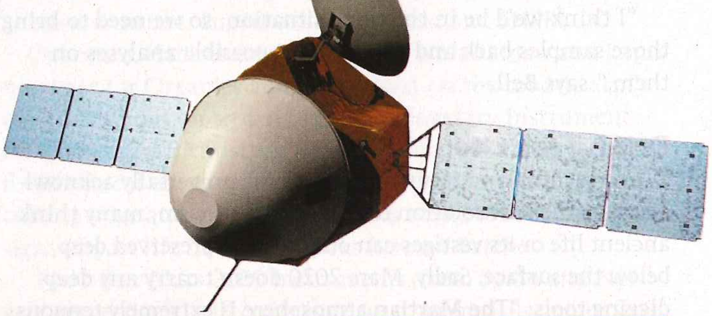
The private company SpaceX has lofty colonial ambitions for Mars, too, aiming to transport 1 million people to the planet in the next 50 to 100 years. The first step was to be an uncrewed Red Dragon spacecraft launch, also in 2020 and potentially landing somewhere in Arcadia Planitia. But recent statements by CEO Elon Musk suggest the Red Dragon's been nixed. It's unclear what will replace it, and when.

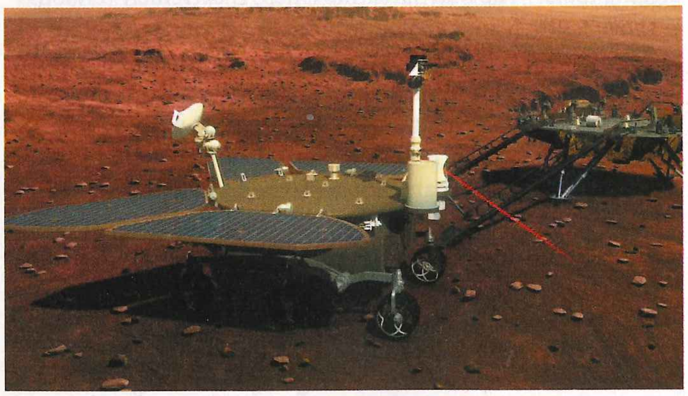
Although the dream of real-live people setting foot on Mars powers some (if not all) of these endeavors, current landing technologies can't make that happen. For example, NASA's methods rely on parachutes, airbags, and small retrorockets, but this would not cut the mustard for heavy, crewed missions to Mars, which will involve payloads roughly 20 times what Curiosity's descent technology can handle. Instead, some engineers are working on *supersonic retropropulsion* — firing thrusters to slow the craft when it's still traveling faster than sound. Although spacecraft have used retropropulsion to land on both the Moon and Mars at lower speeds, a vehicle's aerodynamics are completely different above Mach 1. It's unclear when this technology will have a chance to prove itself on Mars.

A Planet-size Time Capsule

Even if everything goes perfectly with these missions, the bad news for anyone hoping to find out if Martians once existed is that none of them is expected to find incontrovertible proof of past life. Simply put, the technology required is just too big to send to another planet. "We're just not there yet in terms of turning these super-sophisticated cutting-edge laboratories into instruments the size of a shoebox and putting them on a spacecraft," says Bell.

Searches for life present on Mars today will have to wait even longer. "When we say we will search for past or present life, what we really mean is that we concentrate on looking for signs of past life — from 3 to 4 billion years ago," explains





▲ **CHINA MISSION** China also plans to send an orbiter *(above)*, lander, and rover to Mars in 2020. The rover is in the foreground.

XINHUA (2)

GULLIES ON THE WALL This false-color image shows a crater wall in Utopia Planitia, with gully channels suggestive of water's activity. Some of the fractures resemble terrestrial ones that occur when ground ice is present.
NASA / JPL-CALTECH / UNIVERSITY OF ARIZONA

Vago. "I think if there is life on Mars now, it would have to be a couple of kilometers deep, and it would be a very expensive mission to drill to those depths."

If this is the case, then why not wait until society has developed the technology to determine if there is or isn't life on Mars once and for all? After all, part of the beauty of the Red Planet is that it is a planet-sized time capsule. "On Earth everything has been metamorphosed by burial and plate tectonics," says Horgan. "On Mars many of the rocks on the surface are in the exact place they were laid down 4 billion years ago — they're sitting there waiting for us to interpret them." Why rush?

Perhaps the reason comes less from the head and more from the heart. We want to know if we are not alone in the universe — and we want to know now. So hang waiting for technological advances: To steal from Tennyson, it is better to try and fail than never to try at all.

■ **BENJAMIN SKUSE** is a science writer based in Bristol, United Kingdom.

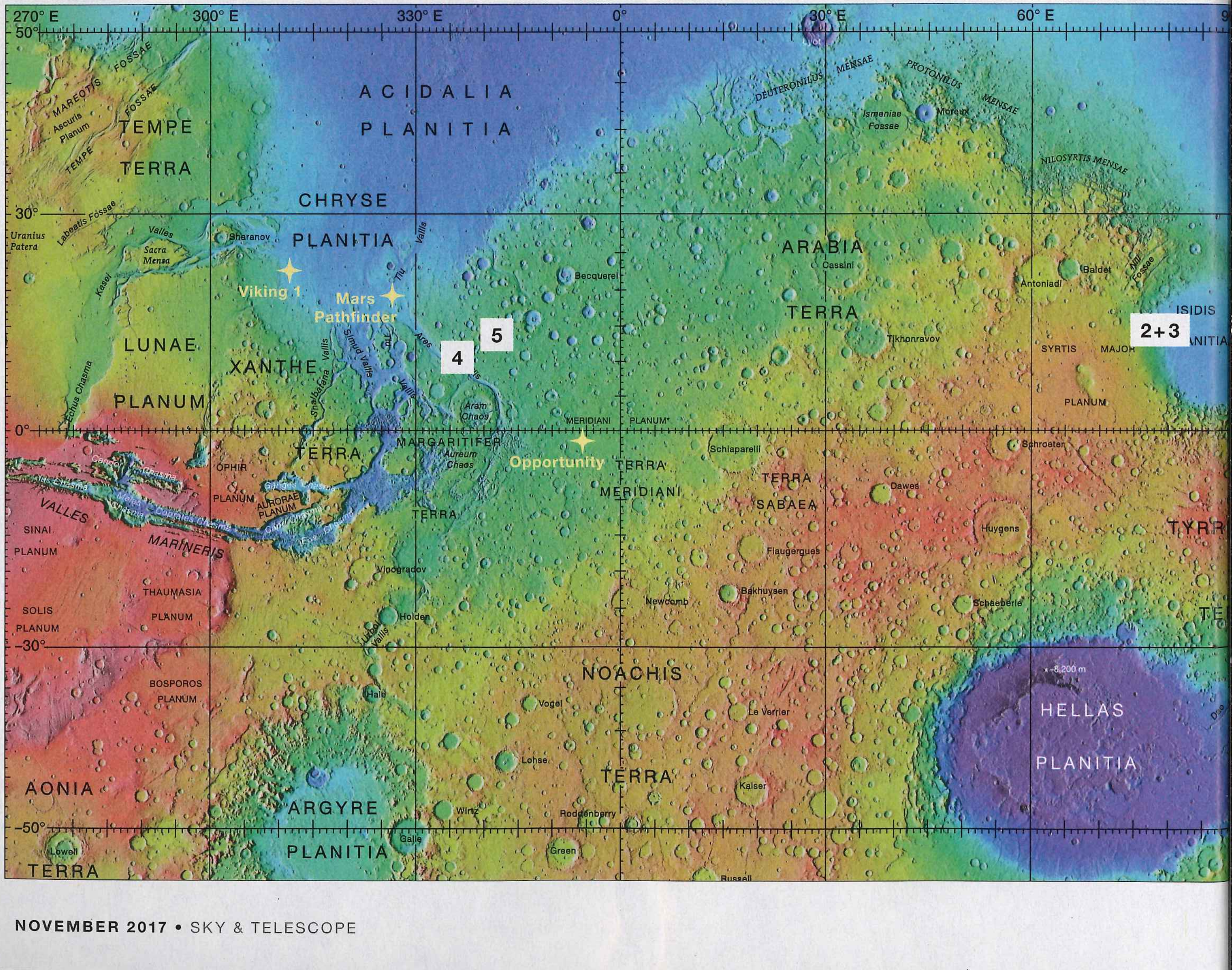
WHERE TO LAND?

While the Emirates Mars Mission has no intention of landing and the Chinese Mars Mission's landing site remains a secret (with officials only revealing it will touch down in the low latitudes of the northern hemisphere), NASA and ESA teams are busy whittling down where their spacecraft will land to a handful of contenders.

NASA (landing ellipse 18 km × 14 km)

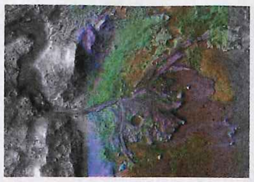
1. Gusev – Mars rover Spirit found that mineral springs once burbled up from the rocks of Columbia Hills, specifically uncovering evidence that past floods might have formed a shallow lake inside this crater. "The minerals that precipitate out of those hot waters can trap microbes and organics, and help preserve biosignatures," says Horgan. "So astrobiologists are really excited about the chance to go back."

TOPOGRAPHIC MAP: U.S. GEOLOGICAL SURVEY



1. Gusev

2. Jezero



3. NE Syrtis

4. Oxia Planum

5. Mawrth Vallis

GUSEV: NASA / JPL-CALTECH / CORNELL; JEZERO: NASA / JPL-CALTECH / MSSS / JHU-APL; NE SYRTIS: NASA/JPL-CALTECH/UNIV. OF ARIZONA; OXIA PLANUM: NASA / MRO / HIRISE / OXIA PLANUM TEAM / LSSWG; MAWRTH VALLIS: ESA / DLR / FU BERLIN, CC BY-SA 3.0 IGO

2. Jezero – This ancient crater contains evidence of a delta that formed when a river overran the crater's wall and flowed into it, creating a lake. Conceivably, microbial life could have lived in Jezero during one or more of the wet epochs the crater experienced. If so, signs of their remains might have been trapped in lakebed sediments.

3. Northeastern Syrtis Major Planum – Just upstream from Jezero, this broad plateau was once warmed by volcanic activity. Underground heat made springs flow and surface ice melt. "It's a layer cake stratigraphy of rocks containing all kinds of different minerals laid down in different environments," says Horgan. Some of these environments could have been ideal for microbes to flourish.

ExoMars (landing ellipse 104 km × 19 km)

4. Oxia Planum – This plain, covered in layers of clay-rich minerals, formed in wet conditions some 3.9 billion years ago and could have hosted microorganisms. The site features the remnants of a fan or delta near the outlet of Coogoon Valles, which might preserve biosignatures.

5. Mawrth Vallis – A few hundred kilometers away from Oxia Planum, Mawrth Vallis also contains layered, clay-rich sedimentary deposits, and hints at ancient localized ponds, subsurface aquifers, and possible hydrothermal activity. All of this could have provided the ideal conditions for life to thrive. Both sites lie just north of the equator and preserve a rich record of geological history from the planet's wetter past.