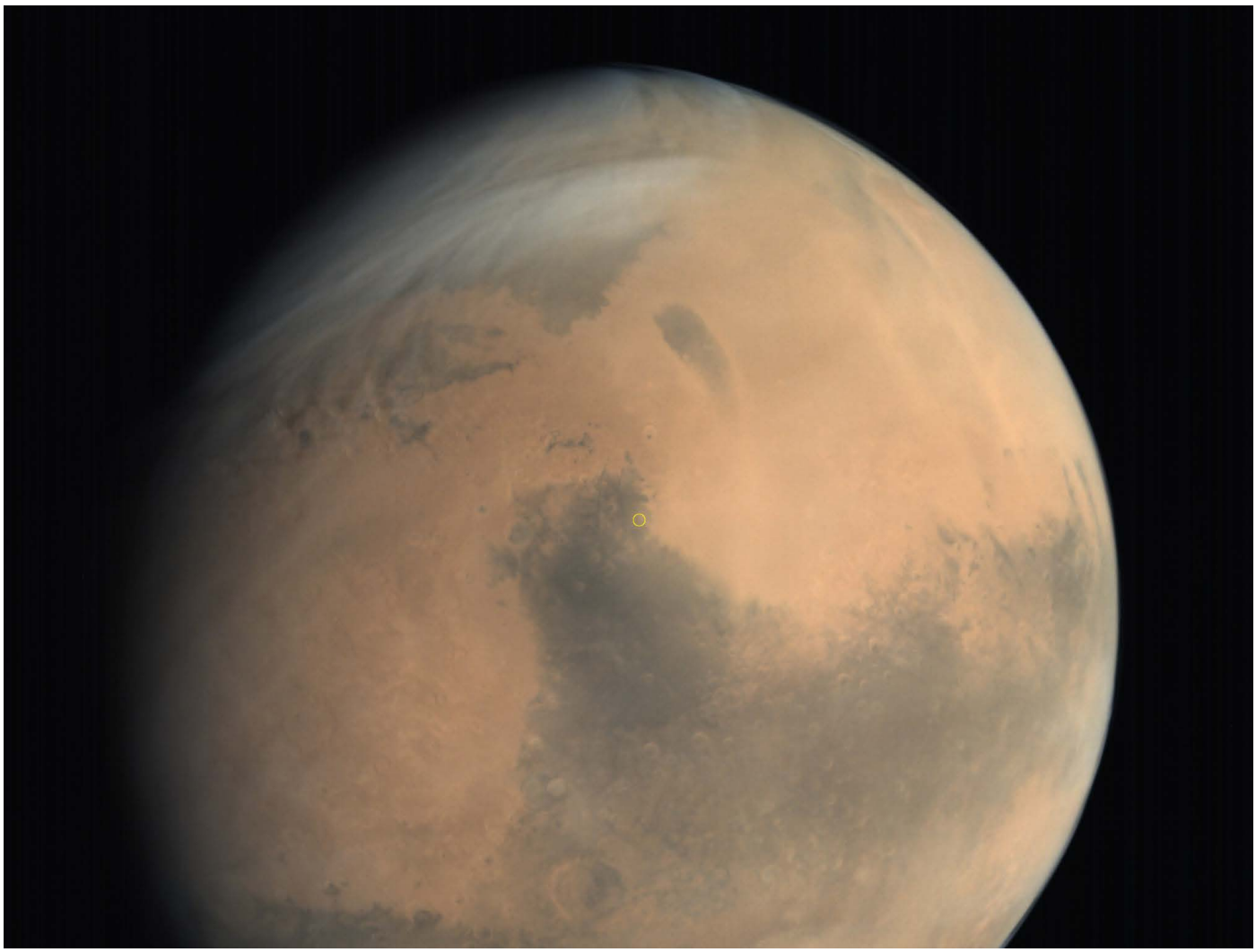


EMILY LAKDAWALLA/ISRO/ISSDC

The US rover Perseverance will land in Mars's Jezero Crater (circled in yellow).

ALL ABOARD TO MARS

The United States, China and the United Arab Emirates all plan groundbreaking trips to the red planet — a notoriously dangerous destination for space missions.

By Alexandra Witze, Smriti Mallapaty and Elizabeth Gibney

Three times in the coming month or so, rockets will light their engines and set course for Mars. A trio of nations — the United States, China and the United Arab Emirates (UAE) — will be sending robotic emissaries to the red planet, hoping to start new chapters of exploration there.

Each mission is a pioneer in its own right. The United States is sending its fifth rover, NASA's most capable ever, in the hope of finding evidence of past life on Mars and collecting a set of rocks that will one day be the first samples flown back to Earth. China aims to build on its lunar-exploration successes by taking one of its rovers to Mars for the first time. And the UAE will be launching an orbiter — the first interplanetary mission by any Arab nation — as a test of its young but ambitious space agency.

It is far from a given that all these missions will make it; Mars is notorious as a graveyard for failed spacecraft. But if they do, they will substantially rewrite scientific understanding of the planet. The two rovers are heading for parts of Mars that have never been explored, and the UAE's orbiter will track the changing Martian atmosphere (see 'Mars invasion').

The teams behind the missions have managed to keep their projects on track despite the coronavirus pandemic that has derailed

so many other plans, including a European–Russian Mars mission that has been delayed by two years. When the three craft lift off in the next few weeks, they will give residents of Earth a chance – however briefly – to look upwards and beyond the problems at home.

NASA's hunt for rocks

NASA hopes that its mission to Mars – a six-wheeled, three-metre-long rover named Perseverance – will be the start of a much bigger journey. If all goes to plan, Perseverance will extract and store samples of Martian rocks that a future mission will one day pick up and bring back to Earth, possibly by 2031. It would be the first-ever sample return from Mars.

That means the stakes for Perseverance are sky-high. NASA's four previous Mars rovers – 1997's Sojourner; 2004's Spirit and Opportunity; and 2012's Curiosity – were all about exploration. Mission controllers could take their time driving those machines, sidling them up to interesting-looking rocks or setting them off across vast plains. But Perseverance will arrive at Mars with the focused task of identifying and collecting a broad range of rocks representing the geological history of the area. And it is supposed to fulfil that mission in one Mars year – nearly two Earth years. Whatever the rover picks up will help to shape the course of Mars science for decades to come.

Most significantly, Perseverance represents the best chance yet for scientists to learn whether life ever arose on the red planet. If it collects the right kinds of rock, then scientists in laboratories back on Earth might be able to tease out signatures of Martian life.

"This mission gives us the first opportunity to take fundamental questions about whether there was or wasn't life on Mars to the next level," says Sherry Cady, an astrobiologist at the Pacific Northwest National Laboratory in Sequim, Washington, who is not directly involved with the mission.

Perseverance will do this with a suite of scientific instruments for poking and probing the Martian surface and atmosphere. It is a familiar-looking rover – basically a copy of the Curiosity rover that has been exploring Gale Crater for the past eight years. NASA's goal was to save money by using the same design with some tweaks, such as adding a system to store samples and upgrading the wheels. Despite its aim to cut costs, the mission's price tag has risen to US$2.7 billion, nearly $360 million over budget, because of problems developing some of the instruments.

The rover carries advanced versions of some of Curiosity's sensors, including a chemical analyser that blasts rocks with a laser to identify the atoms and molecules they are made of, and a sharp-eyed camera system that can zoom in on areas of interest to produce stereo and 3D pictures. Perseverance also sports an experiment that will try to produce oxygen from Mars's carbon dioxide-rich atmosphere, as a test of ways to support future human explorers. The rover has X-ray and ultraviolet spectrometers for analysing mineralogy in detail – and, for a bit more novelty, microphones for listening to Martian sounds, plus a squat, solar-powered helicopter.

Then there is the sampling system, which engineers designed from scratch. Perseverance carries 43 tubes in its belly. When it encounters a rock that mission scientists want to sample, the rover will reach out its 2.1-metre-long robotic arm and drill a sample about the size of a penlight: 60 millimetres long and 13 millimetres across. The sample goes into a tube and is sealed. Eventually, once Perseverance has filled at least 20 of its tubes, it will cache them on the surface of Mars until some future, yet-to-be-funded robot arrives to retrieve them. NASA currently plans to work with the European Space Agency (ESA) to launch a mission in 2026 that would return the rocks to Earth in 2031.

Perseverance will land in the 45-kilometre-wide Jezero Crater, just north of the Martian equator and in a spot that was once home to a lake and a river delta. That ancient delta offers a rich variety of geological landscapes – where Perseverance could collect many samples that might contain signs of past life, says Kennda Lynch, a planetary scientist at the Lunar and Planetary Institute in Houston, Texas, who has studied the Jezero landing site. Engineers at the Jet Propulsion Laboratory in Pasadena, California, which built the craft, have already mapped out several routes that it could take around the delta, covering on the order of 15 kilometres. Cady says the rover will do best if it first rolls around the region to survey the landscape, then returns to collect samples.

"We'll be able to cover all of Mars, through all times of day, through an entire Martian year."

Perseverance is scheduled to launch from Cape Canaveral Air Force Station in Florida between 30 July and 15 August, and land on Mars on 18 February 2021.

China's Mars debut

China has ambitious plans for its first exploration of Mars. An orbiter, lander and rover packed with 13 scientific instruments are set to launch from an island in southern China in late July. The mission, named Tianwen-1, which means 'quest for heavenly truth', will be China's deepest probe into space. When it arrives, in February next year, the mission will aim to conduct a comprehensive survey of the planet's atmosphere, internal structures and surface environment – including searching for the presence of water and signs of life.

A previous attempt by China to send an orbiter to Mars, aboard a Russian spacecraft in 2011, ended with the probes going missing. But after that loss, China has racked up a string of wins in space. In 2013, it became the third country to land a spacecraft on the Moon. And last year, a Chinese lander touched down on the Moon's far side – the first one from any country to do so. In May, China successfully test-launched a spaceship that will shuttle crew to the country's new space station – expected to be finished in 2022.

But the Mars project is in a different league from China's previous space missions, researchers at the China Academy of Space Technology in Beijing said in a 2017 paper (P. J. Ye *et al. Sci. China Technol. Sci.* **60**, 649–657; 2017). The voyage to Mars is 1,000 times longer than that to the Moon, and the planet has twice the surface gravity, an atmosphere and is littered with dense rock, which makes the effort much more risky.

The Chinese government has been tight-lipped about the mission: most public information has come from published articles and state-media reports, which omit key details about its budget, the exact launch date and where the probe will land on the planet. Scientists involved with the mission have declined interview requests until after the launch. But Wang Chi, a space physicist and director-general of the National Space Science Center (NSSC) in Beijing, said in an e-mail that the mission is moving forward as planned. "Our team is working in the Wenchang launch centre right now, and everything goes smoothly," he said, referring to the facility on Hainan Island. Wang is responsible for the scientific payloads involved in the mission, which is being led by the China National Space Administration.

If everything goes as planned, Tianwen-1 will be the first mission to successfully study the red planet with an orbiter, lander and rover. Once the combined craft reaches Mars, the hexagonal orbiter will release the lander and rover – protected by a spherical cone – into the Martian atmosphere. The Chinese team has identified two potential landing areas north of the equator on the plains of Utopia Planitia, according to a presentation made by Wei Yan of the National Astronomical Observatories in Beijing, who spoke at the European Planetary Science Congress in Geneva, Switzerland, last September.

The probe will parachute and then hover to the ground, settling on the circular lander's four legs. The rover, weighing some 200 kilograms, will then extend its solar panels, drive down a ramp and begin to autonomously explore its surroundings for the rest of its lifetime of around 90 Martian days, each of which lasts 24 hours and 37 minutes. During the rover's mission, the orbiter will act as a

MARS INVASION

Three spacecraft heading to the red planet this year will send back an unprecedented stream of information about the alien world.

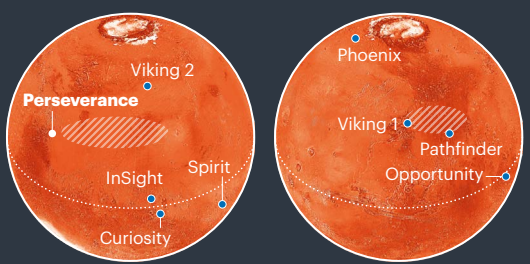
By Richard Monastersky
Design by Jasiek Krzysztofiak

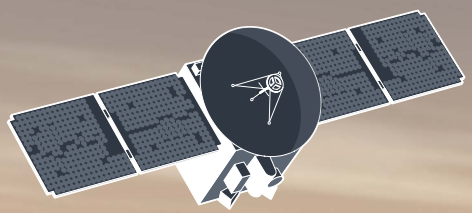
Never before will such a diverse array of scientific gear have arrived at a foreign planet at the same time, and with such broad ambitions. Missions from China, the United States and the United Arab Emirates (UAE) will include two orbiters, two rovers, a stationary surface laboratory and even a helicopter. They aim to study everything from Mars's buried water deposits to the top of its atmosphere, with a particular focus on the search for life.

Landing sites

A US rover called Perseverance will land in Jezero Crater, near a delta formed by an ancient river — a prime location for finding signs of past life if it existed. China is considering several landing sites for its Tianwen-1 mission.

▨ **Tianwen-1** potential landing sites ● Previous missions



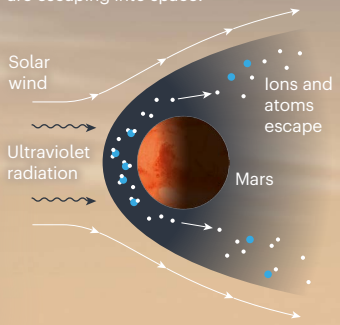


HOPE

The UAE mission will travel around Mars in an elliptical orbit ranging from about 22,000 to 44,000 kilometres. It carries two spectrometers and a high-resolution imager to capture information about how the atmosphere changes over the day and throughout the seasons.

The escaping atmosphere

Mars once had a thick atmosphere and a significant amount of liquid water on the surface, but much of the atmosphere has leaked away over billions of years. Hope will assess how oxygen and hydrogen atoms and ions are escaping into space.

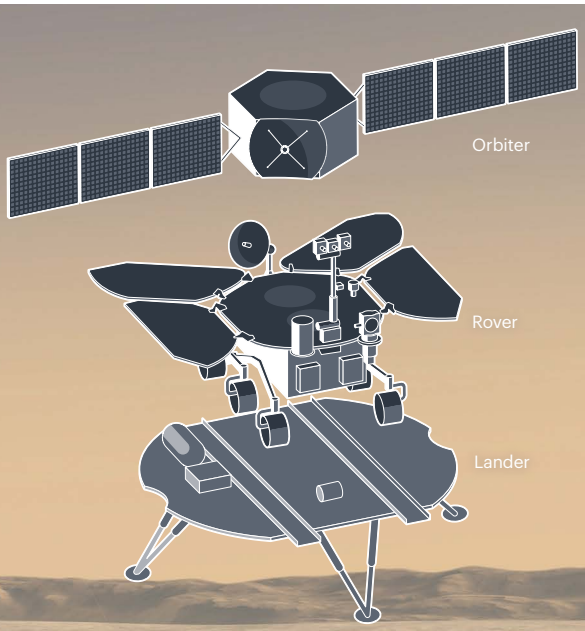


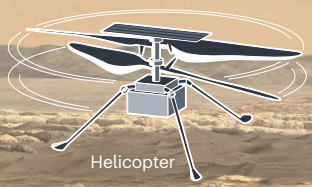
PERSEVERANCE

The US rover is a car-sized vehicle packed with seven instruments. Its main task is to collect rock samples destined to be carried back to Earth in a future mission. It will also study the planet's weather and geology, hunt for water, produce oxygen from carbon dioxide, record sounds for the first time and test a solar-powered helicopter.

TIANWEN-1

China's pioneering mission to Mars will carry an orbiter, rover and lander — it would be the first nation to achieve all three. Both the rover and orbiter have radar instruments for spotting water and ice on the surface and underground. They will also study the planet's geology and weather.

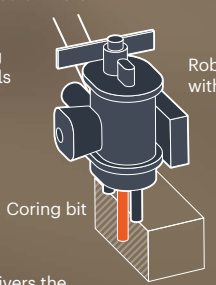




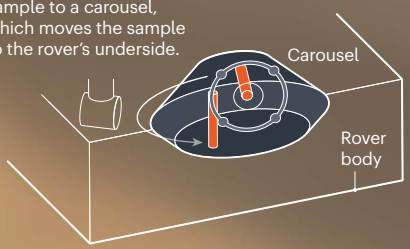
The robot geologist

Perseverance carries 43 tubes to hold rock samples collected and stored by a series of 3 robots. When the samples are eventually returned to Earth, they could provide the first definitive evidence of whether life once existed on Mars.

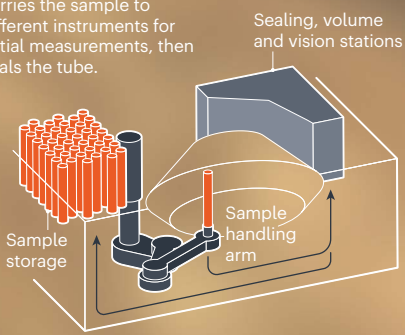
1 The 2.1-metre-long robot arm drills a thin sample of rock.



2 The arm delivers the sample to a carousel, which moves the sample to the rover's underside.



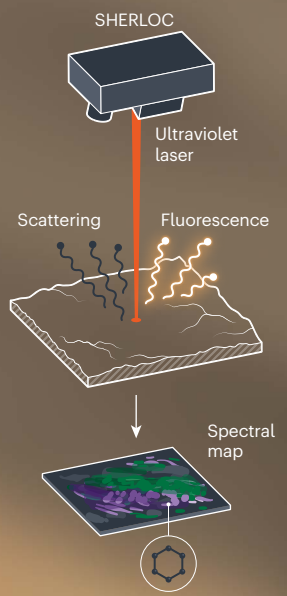
3 A second robotic arm carries the sample to different instruments for initial measurements, then seals the tube.



4 A future mission will aim to retrieve the cached samples and send them back to Earth.

Search for life

Perseverance has several instruments that will hunt for evidence of life. One of those is SHERLOC, which illuminates rocks with an ultraviolet laser and records spectra of the luminescence and reflectance. It can identify the signal of organic molecules and minerals that formed in watery environments.



SOURCES: LANDING SITES, COMPILED BY E. LAKDAWALLA/PLANETARY SOCIETY; ATMOSPHERE GRAPHIC, ADAPTED FROM ESA/HTTPS://GO.NATURE.COM/2ZDWJKA; HISTORICAL MISSIONS, NASA; NASA ROVER, NASA/JPL-CALTECH; MARS BASE MAP, US GEOLOGICAL SURVEY.

Historical Mars missions

- Soviet Union/Russia
- United States
- Europe
- Other
- Mission failure
- Flyby
- Lander
- Orbiter
- Rover

1960

Mariner 4 ← First flyby

Mars 3 First lander to send back data

1970

Mariner 9 First orbiter

Viking 1, Viking 2

1980

1990

Pathfinder

Sojourner First rover

2000

Mars Express European Space Agency's first orbiter

2010

Curiosity ← rover

← India's Mars Orbiter Mission

2020

Planned missions

communication link, and then will move into closer orbit to survey the planet for an entire Martian year.

The Chinese team has fitted the orbiter with seven instruments, and the rover with six. The subsurface radar on the orbiter can peer 100 metres deep to map geological structures and search for water and ice. Medium- and high-resolution cameras will collect images of features such as dunes, glaciers and volcanoes, providing clues to how they formed. Both the orbiter and rover will carry spectrometers to study the composition of soil and rocks, looking especially for evidence of how water has altered geological features. The team also plans to collect atmospheric data on temperature, air pressure, wind speed and direction, as well as study the magnetic and gravitational fields on Mars.

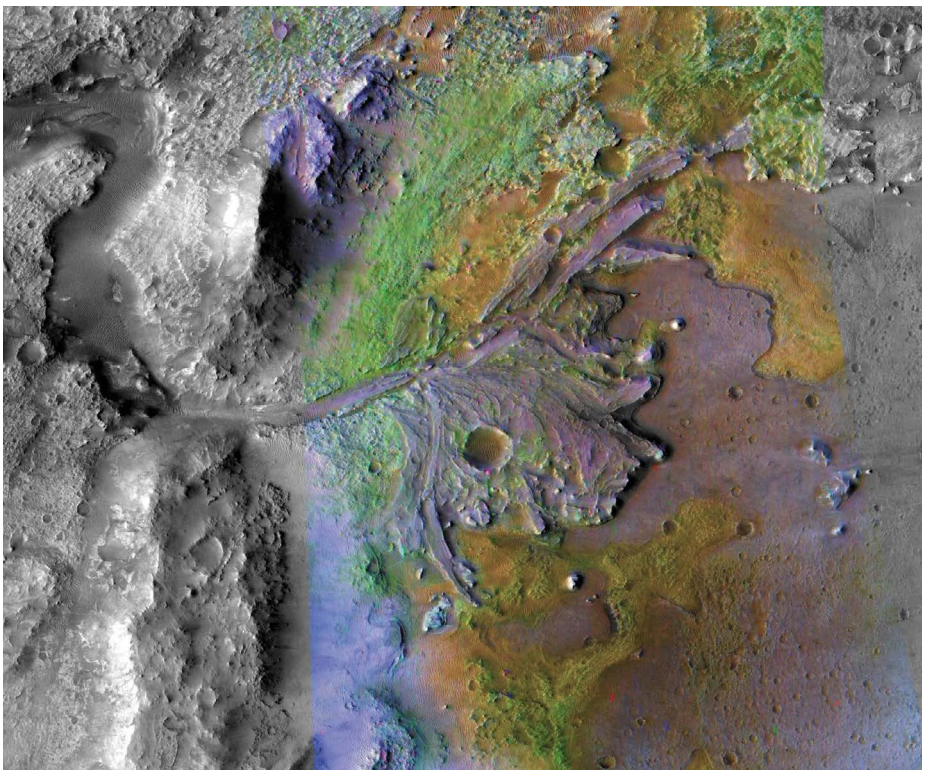
Similar instruments have been sent on previous missions to Mars, says Raymond Arvidson, a planetary geologist at Washington University in St Louis, Missouri. But Mars is big, and has a complicated geological history, so the data generated from Tianwen-1 could inform researchers' understanding about locations not covered by existing observations, he says. "If the Chinese instruments work, produce data, and the data are shared in a manner similar to what we do, it will all be worth the effort," says Arvidson, referring to a free public archive of geoscience data collected from many previous planetary explorations that is managed by his university and NASA.

Dmitrij Titov, project scientist for ESA's Mars Express orbiter, which launched in 2003, says the Chinese orbiter could outlast some of the veterans that might be nearing the end of their life, including Mars Express, NASA's Mars Reconnaissance Orbiter and the Mars Atmosphere and Volatile Evolution orbiter, known as MAVEN. Continuous monitoring of the planet will benefit the community at a time when many other space agencies will be busy building sample-return missions, says Titov. In fact, China has its own plans to collect and bring back samples from Mars by 2030.

UAE's interplanetary hope

The United Arab Emirates had big dreams when it decided to shoot for Mars with its first probe to go beyond Earth orbit. So it chose the name 'Hope' for the orbiter, which is set to blast off from the Tanegashima Space Centre in Kagoshima, Japan, during a three-week window starting on 15 July.

If successful, the Emirates Mars Mission (EMM) will not only mark the first interplanetary venture of any Arab nation, but also produce the first global weather map of Mars. Although previous probes built up a picture of the planet's atmosphere from orbits that allowed them to monitor each part of the planet at limited times of day, Hope's huge elliptical orbit will enable the orbiter to observe big chunks of Mars under both day- and night-time conditions, covering almost the entire planet in each 55-hour orbit. "We'll be able to cover all of Mars, through all times of day, through an entire Martian year," says Sarah Al Amiri, science lead for the project and the country's minister for advanced sciences. The probe's visible-light camera and infrared spectrometer will study Martian clouds and dust storms in the lower atmosphere. Its ultraviolet spectrometer will monitor gases in the upper atmosphere. "This is the first mission that will give a global picture of the dynamics of the Mars atmosphere," says Hessa Al Matroushi, a member of the EMM science team.



NASA/JPL/JHUAPL/MSSS/BROWN UNIV.

Perseverance will explore an ancient river delta where water once flowed on Mars's surface.

During its two-year mission, Hope will track daily weather variations and changing seasons. As well as helping to prepare for future human missions, it should reveal how atmospheric conditions cause hydrogen and oxygen to escape into space. This could help scientists to understand Mars's climate and how it lost its once-thick atmosphere. The team worked with international collaborators to come up with its science goals, and the data will be made available to the international community with no embargo period, says Al Amiri. "The Emiratis were very keen to make this not just a technology demonstrator, but make it contribute to the scientific understanding of Mars," says Richard Zurek, who is the chief scientist for the Mars Program Office at NASA's Jet Propulsion Laboratory.

An interplanetary spacecraft was a significant leap in capability for the UAE, which hired seasoned engineers from previous NASA missions, mainly at the University of Colorado Boulder. The partnership has an explicit goal of transferring know-how to the team at the Mohammed Bin Rashid Space Centre, with whom the engineers worked on each element of the mission. "The reality is we are a young country and we couldn't do anything that we did without partners and international collaboration," says Ahmad Belhoul, minister for higher education and chair of the UAE Space Agency.

Unusually for an interplanetary project, the idea for the mission came not from scientists but from the government itself — and with a non-negotiable deadline of 2 December 2021, the country's 50th anniversary. Picking such an audacious task was designed not only to inspire young people in the region but also to kick-start the UAE's move to a knowledge-based economy, says Omran Sharaf, project director for the EMM.

And the mission is already having an impact, with universities offering five new undergraduate courses in pure sciences and growing enthusiasm for space among Emirati children.

In many ways, even if Hope blows up on the launch pad, the mission would be a success, says Al Amiri, who quickly reconsidered that point. "My heart just skipped a beat just thinking about it."

Alexandra Witze writes for *Nature* from Boulder, Colorado. **Smriti Mallapaty** is a senior reporter in Sydney, Australia, and **Elizabeth Gibney** is a senior reporter in London.

Correction
This feature misstated the number of instruments on the Chinese orbiter and rover. The orbiter has seven and the rover has six.