What's Next for Mars

In the coming decade the planet named for the god of war will be the target of a scientific armada from Earth. Researchers hope to settle many questions about Mars, including whether life ever flourished there

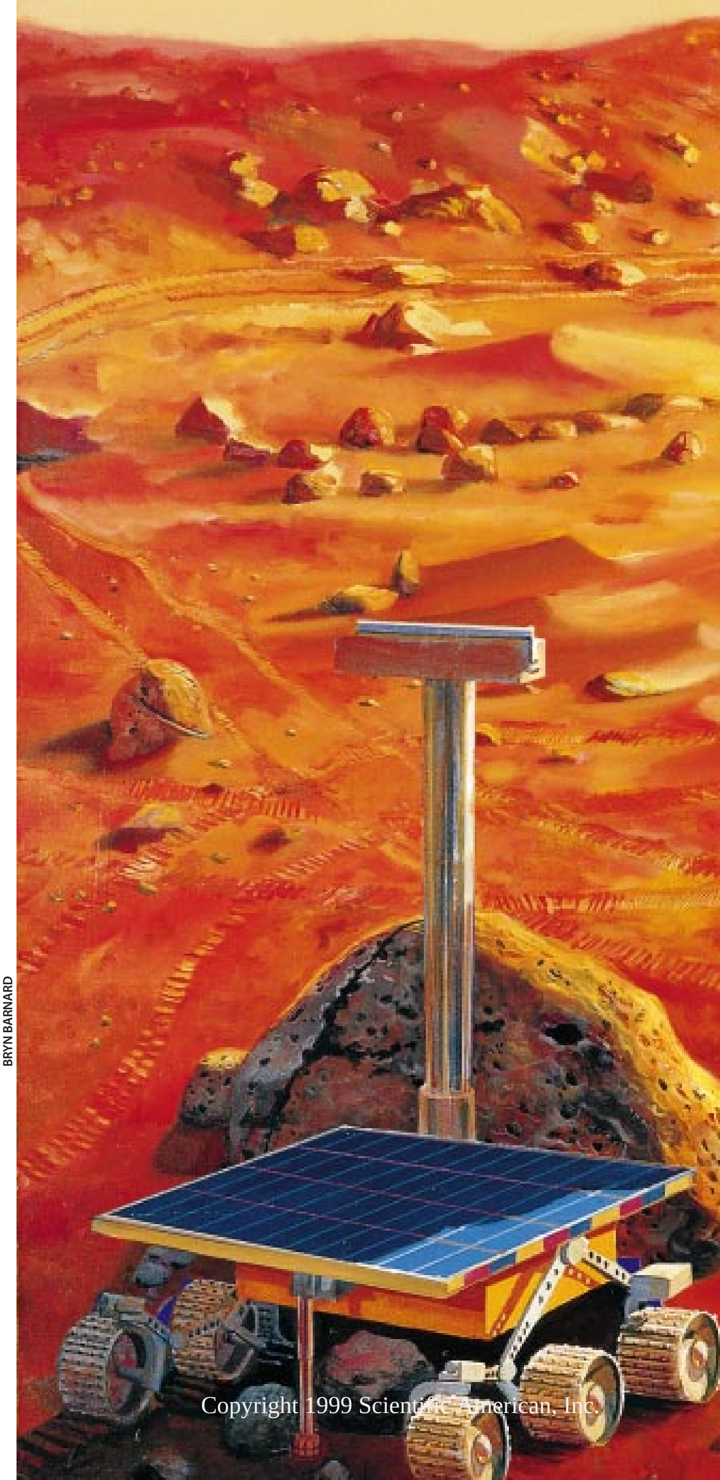
by Glenn Zorpette, *staff writer*

An invasion of Earth by a Martian fleet has been one of the staples of science fiction, from H. G. Wells's 1898 *The War of the Worlds* to the 1996 motion picture *Mars Attacks!* But although there have been many imaginative outpourings from countless writers and directors, few foresaw that the invasion would actually be in the reverse direction, by a robotic fleet from Earth.

Over the next 10 years the National Aeronautics and Space Administration and its European partners plan to send at least four orbiters and four landers to the Martian surface, culminating in a mission that will use highly sophisticated rovers to collect samples of rock and soil that will be delivered to Earth by 2008. The agenda holds out the possibility of seven or so additional trips to the Red Planet, including several relatively inexpensive "micromissions" and a second series of flights that would return dozens more samples between 2008 and 2012. The ambitious series of probes is in addition to the Mars Global Surveyor spacecraft, which has been orbiting the planet since 1997, and a Japanese orbiter called Planet-B, launched last July on a two-year mission to study Mars's atmosphere and ionosphere. Not since the heady days of the space race to the moon more than three decades ago has a single celestial body been the target of so many spacecraft in so short a period.

The upcoming Mars missions are being designed to pursue a couple of relatively well defined goals: expanding what is known about Mars's climate, geology and hydrology, both past and present, particularly in relation to the question of whether life has ever existed on the planet, and laying the groundwork for future human exploration of the planet, possibly as soon as 2020. Robotic vehicles will roam several kilometers, taking scores of samples as part of the most extensive search yet for signs that microbial life persists in the soil below the surface of the red world or that organic matter exists in its rocks or soil.

These goals emerged from the scientific furor over a meteorite found in Antarctica in 1984. Analysis showed that the rock came from Mars, apparently after having been hurled into space when a big meteoroid smashed into the planet 16 million years ago. In 1996 a team of researchers from



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BLASTOFF ON MARS of an ascent vehicle containing a kilogram of Martian soil is planned for 2004. The solid-fuel rocket, a little over a meter tall, will probably destroy the lander as it lofts its precious payload for an orbital rendezvous, two years later, with a spacecraft that will bring it and another set of samples to Earth. But the solar-powered sample-gathering rover (*foreground, at left*) could continue to function for up to a year, transmitting data to Earth via satellites in orbit around Mars.

DENDRITIC PATTERN (*near right*), such as this one photographed in California, is extremely common on Earth. The pattern is similar in some respects to that of box canyons, which have been photographed on Mars by the Viking spacecraft (*center, next page*) and in the Al Ghaydah region of Yemen by a Landsat satellite orbiting Earth (*far right*). Their similarities notwithstanding, box canyons—unlike dendritic streams—are not considered conclusive evidence of rainfall.

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the NASA Johnson Space Center and Stanford University announced its conclusion that unusual features of the rock could most plausibly be interpreted as vestiges of ancient Martian bacterial life. Lately a growing number of scientists studying the same evidence have discounted that idea. Nevertheless, says director Norman R. Haynes of the Mars Exploration Directorate at the Jet Propulsion Laboratory in Pasadena, Calif., the surge of interest in the Martian meteorite was a "bombshell" that "raised the question 'What is the proper response of the Mars program?'"

NASA's answer was to focus its planned Mars missions more strongly on the search for evidence of past life and the gathering of data on the history of water and climate on the planet. To make good progress in these reemphasized endeavors, a panel of scientists convened by JPL concluded that it would be necessary to return soil and rock samples from the Red Planet to Earth.

Although the mission is daunting, it has the felicitous quality of being both inspiring to nonscientists and compelling to researchers. Says Steven W. Squyres, a professor of astronomy at Cornell University and the principal investigator of the project to build rovers for the sample-return missions: "To build a robotic field geologist to go to what I find to be the most interesting planet in the solar system and to return samples to distribute them to the best laboratories on Earth—what could be more exciting? If we do our job right, if we get the samples back in one piece, some very interesting science is going to come out of them."

From Earth to Mars

Opportunities to send spacecraft from Earth to Mars—or from Mars to Earth—occur every 26 Earth-months, when the planets are positioned so the trip takes just 10 or 11 months. NASA intends to capitalize on every one of these launch windows until at least 2005. The agency plans to spend about $250 million a year for the next decade or so on Mars exploration, a sum officials hope to augment with contributions of launch vehicles, spacecraft and other hardware from NASA's counterparts in France, Italy and possibly other countries.

NASA's Mars missions constitute a program called Surveyor. The first of the group is the Mars Global Surveyor, an orbiter that arrived at the planet in September 1997. Since then, mission controllers have been easing the spacecraft into a circular polar orbit using a new aerobraking technique. The orbiter's speed is slowed by aerodynamic drag as it grazes the top of Mars's thin atmosphere. Controllers are aerobraking very slowly and gently to minimize stress on one of the craft's solar panels, on which a surface piece has cracked.

The craft carries more advanced sensors than any other orbiter in the Surveyor series. Key instruments include a thermal-emission spectrometer for analyzing the planet's atmosphere and mineral composition from the heat it emits, and two magnetometers for studying the planet's magnetic field. The orbiter's most unique instrument, however, is a visible-light camera capable of resolving surface features as small as about five meters (16 feet). For comparison, the best images of Mars before Global Surveyor—taken during the Viking missions in the late 1970s—have 35-meter resolution.

Mission controllers began operating some of the instruments as soon as the spacecraft went into orbit around Mars. In its very first orbits, Global Surveyor contributed a significant finding: the fact that Mars does not have a global magnetic field. Subsequently, the orbiter dipped beneath the region in which the solar wind interacts with the planet's atmosphere and ionosphere and found that the planet has many small magnetic fields, oriented differently and scattered all over its surface. The discovery is interesting because it gives scientists another clue to the thermal history of the planet. It may help them understand how the planet cooled, thereby placing constraints on the history of water on Mars.

Earth's single magnetic field is generated by the motion of an electrically conductive fluid core, which acts as a kind of dynamo. Mars's many fragmentary fields are be-

lieved to be what was left when the planet's fluid dynamo stopped working, probably because it had solidified. Planetary geologists hope that further study of the remnant fields will reveal when the dynamo became extinguished and how the planet's crust evolved.

This March, after Global Surveyor is in its intended circular orbit, mission controllers will use the spacecraft's laser altimeter to map systematically the surface features of the entire planet. "We'll have a better global topography for Mars than we have for Earth," notes Arden L. Albee, Global Surveyor's project scientist and dean of graduate studies at the California Institute of Technology. The controllers will use the orbiter's camera to shoot relatively low-resolution, wide-angle images of the whole planet each day and to chart daily meteorological changes and seasonal climatic variation.

Higher-resolution images will be crucial for what many scientists regard as the central subject of Mars studies: the history of liquid water on the planet. Researchers have abundant evidence that liquid water, a necessary requirement for life as we know it, once sculpted Mars's surface. They do not know, however, whether that water came from rain or from permafrost that was occasionally but only temporarily converted to liquid water—and even massive flash floods—by catastrophic events such as lava flows and meteorite strikes. The distinction is important because many scientists believe that life could not have flourished without rain. Rain could only occur, they note, in a wet, warm atmosphere, above a surface on which liquid water was stable—and which could therefore support life.

A strong sign that rain once fell on a piece of land is evidence of dendritic streams, in which successively smaller tributaries branch out from fewer, larger ones, like limbs on a tree. So far this pattern has never been seen unambiguously on Mars—but if it exists there, Global Surveyor's high-resolution camera will be able to distinguish it. According to Albee, basically all the evidence seen on Mars of ancient streams is in formations that resemble box canyons on Earth. Box canyons are formed when water seeps out between layers in a cliff and flows down, eroding the soil and rock underneath. They are evidence of flowing water but not necessarily of rainfall.

"Nothing that we've seen so far," Albee notes, "rules out Mars having lost most of its atmosphere very early on"—perhaps 3.5 billion to 3.9 billion years ago, only a few hundred million years after the planet formed. If that was the case, then the chances that Mars ever had large amounts of liquid water on its surface for extended periods are slim indeed.

Global Surveyor's planetwide studies will be extended by the next mission in the series, Mars Surveyor 1998, which includes an orbiter and lander that were launched separately. The Mars Climate Orbiter, which left Earth last December 11, will arrive at Mars this coming September. Like Global Surveyor, the Climate Orbiter will fly in a nearly circular polar orbit and will carry a sophisticated thermal sensor, a camera and a radio transceiver for relaying signals from landers to Earth. The Climate Orbiter's thermal sensor, technically an infrared radiometer, will sense atmospheric variations in temperature, pressure, and concentrations of dust, water vapor and condensates.

The other half of the recently launched Surveyor pair is the Mars Polar Lander, which blasted off early this year and is expected to descend next December to a spot near the northern edge of the planet's southern polar region. Mars's polar caps are of particular interest because they are believed to contain a sizable part of the planet's water, as ice. One of the craft's key goals is to dig down with its robotic arm into the layered deposits of dust, carbon dioxide ice and snow and possibly water ice, to determine mineralogical compositions and to try to piece together a record of how the planet's climate changed in geologically recent times.

Another novel feature of the Polar Lander will be its two "passengers." These microprobes, as they are known, will ride to Mars attached to the lander, each one underneath a solar panel. Just before the lander enters the planet's atmosphere, it will separate from a structural piece, called a cruise ring, to which the microprobes will remain attached for another 18 seconds. Then they, too, will separate and plunge through the atmosphere, smashing into the planet about 50 to 100 kilometers away from where the lander touches down.

The microprobes are built to withstand the shock, separating on impact into two units, one of which will penetrate up to two meters into the soil to analyze it. The other will transmit the experimental results to the Global Surveyor for retransmission to Earth.

The parade from blue planet to Red Planet will continue in the spring of 2001, when NASA plans to launch another pair of Surveyors, a lander and an orbiter. The Mars Surveyor 2001 orbiter will carry a high-resolution infrared-imaging spectrometer and a gamma-ray spectrometer for mapping the distribution of minerals and elements, respectively, on the surface. The gamma-ray device will also indicate the abundance of hydrogen just below the surface.

"I see the 2001 mission as pivotal in the program," says R. Stephen Saunders, the project scientist for the mission. "It's the end of one era and the beginning of another in Mars exploration. It will complete the global characterization of Mars"—and add to the "data set we need to find the right rocks on Mars, the rocks that are the most promising in the search for evidence of past life on Mars." After 2001, Saunders notes, NASA's missions to Mars will concentrate on returning samples and on preparing for possible human exploration of the planet.

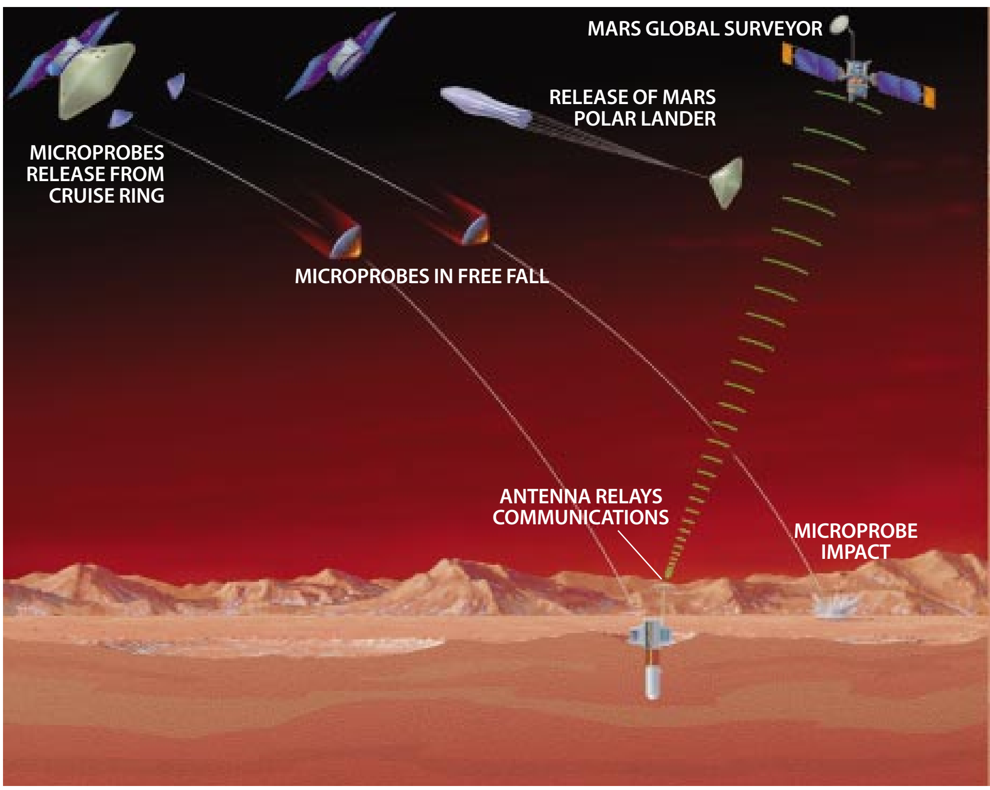
The 2001 lander will start laying the groundwork, so to speak, for these rousing goals. It will carry an infrared spectrometer, the first on a landing craft, to study the mineral composition of nearby rocks. It will also deliver a small roving vehicle. Most stirringly, perhaps, the 2001 lander will perform the first experiments aimed at finding out how harmful the Martian environment would be to people and whether rocket fuel could be made from the atmosphere.

Attached to the experiments is an essential NASA imprimatur—an acronym: HEDS, for Human Exploration and Development of Space. Some of these experiments will make use of a robotic arm, attached to the lander, that will dig up soil samples for chemical and microscopic analyses. HEDS specialists are keenly interested in the size of the smallest particles of quartz in Mars's soil. Grains smaller than about two or three microns are hazardous to humans. Inhaled into the lungs, the particles irritate the tissue and cause the formation of nodules, leading to a black-lung-like ailment known as silicosis. On Earth, water pushes quartz grains that small down into the soil. But the particles may be abundant on Mars's surface, which lacks liquid water.

In another HEDS experiment, a particle spectrometer will measure the radiation doses to which humans would be exposed on Mars. The sensor, known as the Martian Radiation Environment Experiment, will record the energy of the protons, neutrons and cosmic-ray particles bombarding Mars from space.

The third HEDS project on the 2001 lander will make liquid oxygen, a key component of rocket fuel. This "in situ propellant production" experiment will take in carbon dioxide, which constitutes 95 percent of Mars's atmosphere, and break it down to produce oxygen. The demonstration will be important because almost all scenarios for human exploration of Mars require the production on the planet of liquid oxygen, and possibly also hydrogen or methane, to fuel the return trip to Earth. Hauling enough fuel to Mars for the return trip would be impractical because it would necessitate an extremely costly launch vehicle [see "Sending Humans to Mars," on page 46].

The 2001 lander will also have a rover, called Marie Curie, which will be a twin of the Sojourner rover that captivated millions during its geologic field trip around the Pathfinder landing site in 1997. Sojourner traveled a total of 106 meters, investigating several rocks with an alpha-proton x-ray spectrometer, a key instrument that will have an encore on the Marie Curie rover. The system aims a stream of helium nuclei, also known as alpha particles, at a sample of rock or dust to determine its composition. The particles stimulate chemical elements in the rock to emit alpha particles, protons and x-rays. The intensity of the emitted radiation at different wavelengths reveals the proportions of different elements in the rock. This information, in turn, suggests which minerals may be present and also offers insights into how the



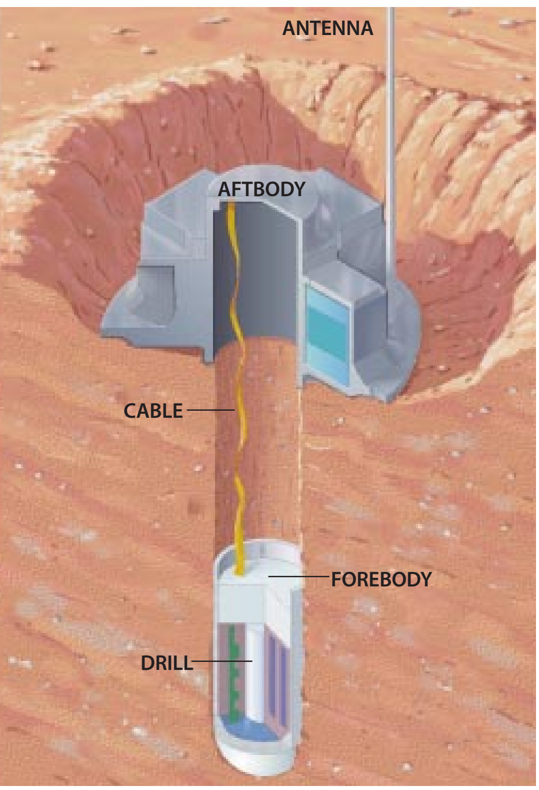
MARS MICROPROBES will separate from the Mars Polar Lander shortly before entry into the planet's atmosphere in December 1999 (*near right*). The two units will each divide on impact into two pieces connected by a cable. One part will burrow up to two meters into the Martian soil and make measurements of ground temperature, water and other characteristics (*far right*). The other piece will remain on the surface and transmit the data to an orbiter for retransmission to Earth.

rock weathered, how the planetary crust around it formed and whether water came into contact with it in the past.

Field Geology on Mars

Marie Curie's alpha-proton x-ray spectrometer is one of four instruments collectively known as APEX, for Athena Precursor Experiment. Athena is the name of the rover being designed for the sample-return missions expected to be launched in 2003 and 2005. This highly sophisticated vehicle will identify and collect geologically interesting bits of Mars that will be returned to the landers, collected in a capsule and blasted off for a rendezvous with a spacecraft that will carry them to Earth.

The three other APEX instruments are a panoramic camera, a thermal-emission spectrometer and a Mössbauer spectrometer, which detects iron-bearing minerals. Such minerals, which probably predominate on Mars, offer clues to early environmental conditions. For the 2001 mission, the three systems will be on the lander, where they will function in concert with Marie Curie's alpha-proton device. Starting with the panoramic camera, controllers will be able to get an overview of the formations in an area, for which the thermal-emission spectrometer will give them a quick scan of mineralogical content. Then the controllers will zero in on the most geologically intriguing rocks with the Mössbauer and alpha-proton devices, which will provide more detailed information on mineralogical and elemental content.



For the 2003 and 2005 sample-return missions, all four of the instruments will be installed on the Athena rovers. As with the 2001 mission, controllers will use the panoramic camera and the thermal-emission spectrometer to pick the most interesting areas to explore and then use the other instruments to make more detailed tests on specific rocks and to select the best ones to sample from among the countless possibilities.

For that task, the Athena rovers will have another powerful, high-tech tool: a Raman spectrometer, the first ever to be transported into space. Such systems are now used in mineralogical and even medical applications, but the units are relatively large and delicate. Engineers at JPL are now at work on a tiny, rugged unit for inclusion on the Athenas. The Raman spectrometers will be the only instruments on board the Athena rovers that will be capable of detecting organic matter.

Two decades ago the Viking landers found evidence that Mars's atmosphere contains trace quantities of a strong oxidizing agent, possibly hydrogen peroxide. It would probably destroy any organic matter that might have once been on the outside of rocks or on top or just below the surface of the soil, so each Athena rover will be equipped to get samples from inside the rocks. As it identifies worthy candidates, the rover will drill into them with a "mini-corer" to extract samples. Using a mere 30 watts, the ingenious miniaturized system will take core samples of boulders and bedrock by drilling into them with concentric bits rotating at the same speed.

The Athena rover will store a few samples in a canister and then bring the canister back to the lander, inserting it into a container at the top of a Mars Ascent Vehicle, a solid-fuel rocket that will later launch the container into orbit around the planet. The rover will then repeat the procedure two or three more times, each time making successively farther excursions from the lander and depositing another canister in the ascent vehicle's nose. The 2003 and 2005 landers will also each have a robotic arm capable of taking samples close by the craft. All told, controllers hope they will be able to load as many as 40 samples weighing less than a kilogram in total.

On the 2003 and 2005 missions, the launch of the Mars Ascent Vehicle with the sample container will most likely destroy the lander, but the Athena rovers are expected to keep gathering and analyzing samples and radioing their findings to orbiters. The rovers may keep on truckin' for up to an Earth-year, traveling perhaps 10 or 20 kilometers.

Meanwhile the container and its precious contents will orbit the planet. The current plan is to send up the container from the 2003 mission and let it orbit for a couple of years, until the container from the 2005 mission can be similarly lofted. Both containers will then be retrieved in orbit by a spacecraft to be built under the aegis of the French space agency, CNES. That craft will have to not only dock with the containers but also insert them within an Earth-entry capsule and fly them back to Earth, where they will plunge through the atmosphere for a crash landing, probably in a desert in the western U.S.

Many aspects of the mission are daunting, perhaps none more than designing the sample canisters, which will have to interface with the lander, the rover, the ascent vehicle, the French-built spacecraft and the Earth-entry capsule. The canisters will also have to be tough enough to withstand an Earth landing that will probably be fairly ballistic.

The current NASA plan holds out the possibility of another round of sample-return missions, should the funds materialize, in 2007 and 2009. Administrators are also angling for five or more relatively low cost "micromissions," in which small spacecraft would "piggyback" on European Ariane 5 launch vehicles to a high-Earth orbit, from which they could get to the Red Planet using a lunar-gravity assist. They hope to use the micromissions to find landing sites for the sample-return missions, validate new technologies, relay communications or perhaps chemically analyze some samples before sending other ones to Earth.

Ten years from now scientists will have, at the very least, a much more complete and detailed picture of how Mars—and our solar system—came to be what it now is. Evidence that life flourished in the past or persisted in the present would be stunning, giving researchers their first hard data on one of the most profound and elusive of subjects: the prevalence of life in the universe. But even if Mars turns out to be as beautifully desolate as its ruddy landscapes seem, the mysterious world that has fascinated humanity for so long will at last begin yielding some of its ancient secrets. SA