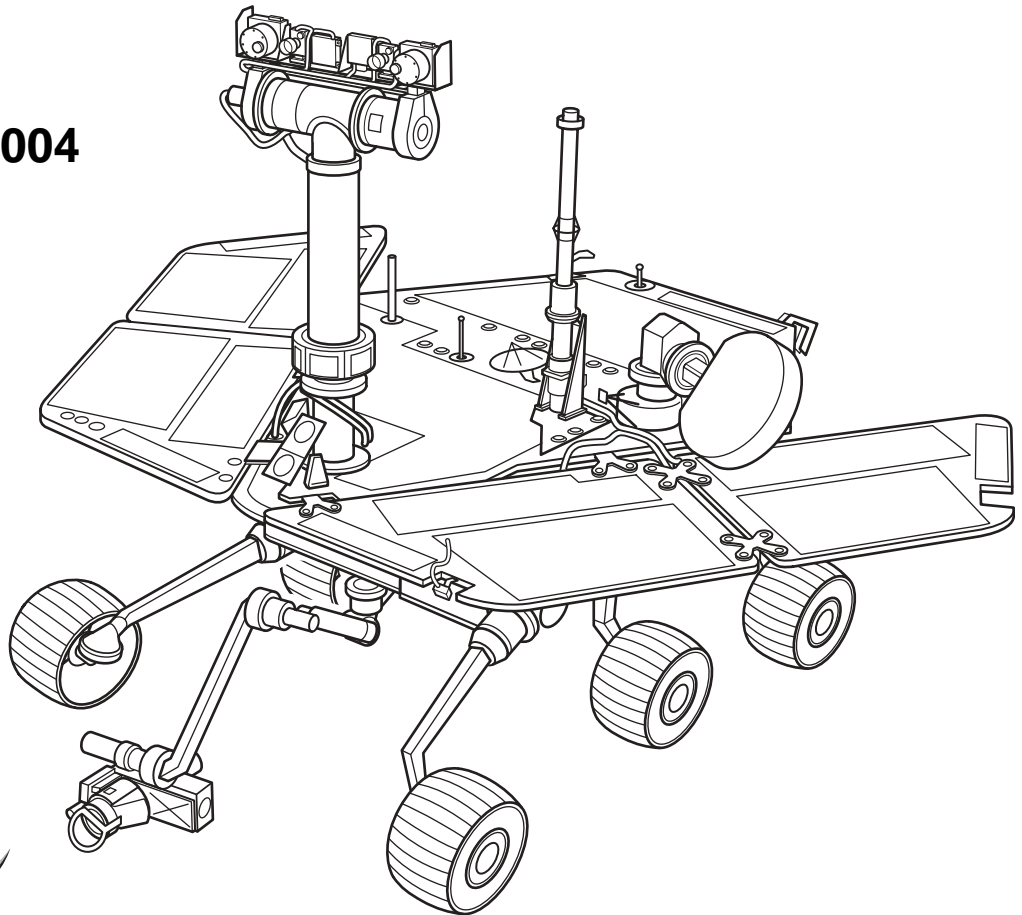


NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mars Exploration Rover Landings

Press Kit
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GENERAL RELEASE:

MARS ROVERS HEAD FOR EXCITING LANDINGS IN JANUARY

NASA'S robotic Mars geologist, Spirit, embodying America's enthusiasm for exploration, must run a grueling gauntlet of challenges before it can start examining the red planet. Spirit's twin Mars Exploration Rover, Opportunity, also faces tough martian challenges.

"The risk is real, but so is the potential reward of using these advanced rovers to improve our understanding of how planets work," said Dr. Ed Weiler, associate administrator for space science at NASA Headquarters, Washington.

Spirit is the first of two golf-cart-sized rovers headed for Mars landings in January. The rovers will seek evidence about whether the environment in two regions might once have been capable of supporting life. Engineers at NASA's Jet Propulsion Laboratory (JPL), Pasadena, Calif., have navigated Spirit to arrive early on Jan. 4, 2004, Universal Time (evening of Jan. 3, PST/EST).

Spirit will land near the center of Gusev Crater, which may have once held a lake. Three weeks later, Opportunity will reach the Meridiani Planum, a region containing exposed deposits of a mineral that usually forms under watery conditions.

"We've cleared two of the big hurdles, building both spacecraft and launching them," said JPL's Peter Theisinger, project manager for the Mars Exploration Rover Project. "Now we're coming up on a third, getting them safely onto the ground," he said.

Since their launches on June 10 and July 7 respectively, each rover has been flying tucked inside a folded-up lander. The lander is wrapped in deflated airbags, cocooned within a protective aeroshell and attached to a cruise stage that provides solar panels, antennas and steering for the approximately seven month journey.

Spirit will cast off its cruise stage 15 minutes before hitting the top of the martian atmosphere at 5,400 meters per second (12,000 miles per hour). Atmospheric friction during the next four minutes will heat part of the aeroshell to about 1,400 C (2,600 F) and slow the descent to about 430 meters per second (960 mph). Less than two minutes before landing, the spacecraft will open its parachute.

Twenty seconds later, it will jettison the bottom half of its aeroshell, exposing the lander. The top half of the shell, still riding the parachute, will lower the lander on a tether. In the final six seconds, airbags will inflate, retro rockets on the upper shell will fire, and the tether will be cut about 15 meters (49 feet) above the ground.

Several bounces and rolls could take the airbag-cushioned lander about a kilometer (0.6 mile) from where it initially lands. If any of the initial few bounces hits a big rock

that's too sharp, or if the spacecraft doesn't complete each task at just the right point during the descent, the mission could be over. More than half of all the missions launched to Mars have failed.

JPL Director Dr. Charles Elachi said, "We have done everything we know that could be humanly done to ensure success. We have conducted more testing and external reviews for the Mars Exploration Rovers than for any previous interplanetary mission."

Landing safely is the first step for three months of Mars exploration by each rover. Before rolling off its lander, each rover will spend a week or more unfolding itself, rising to full height, and scanning surroundings. Spirit and Opportunity each weigh about 17 times as much as the Sojourner rover of the 1997 Mars Pathfinder mission. They are big enough to roll right over obstacles nearly as tall as Sojourner.

"Think of Spirit and Opportunity as robotic field geologists," said Dr. Steve Squyres of Cornell University, Ithaca, N.Y., principal investigator for the Rovers' identical sets of science instruments. "They look around with a stereo, color camera and with an infrared instrument that can classify rock types from a distance. They go to the rocks that seem most interesting. When they get to one, they reach out with a robotic arm that has a handful of tools, a microscope, two instruments for identifying what the rock is made of, and a grinder for getting to a fresh, unweathered surface inside the rock," he said.

JPL, a division of the California Institute of Technology in Pasadena, manages the Mars Exploration Rover project for NASA's Office of Space Science, Washington.

For information about the Mars Exploration Rover project on the Internet, visit:

<http://mars.jpl.nasa.gov/mer>

Cornell University's Web site about the science payload is: at:

<http://athena.cornell.edu>

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Media Services Information

NASA Television Transmission

NASA Television is broadcast on the satellite AMC-2, transponder 9C, C band, 85 degrees west longitude, frequency 3880.0 MHz, vertical polarization, audio monaural at 6.8 MHz. The schedule for Mars arrival television transmissions will be available from the Jet Propulsion Laboratory, Pasadena, CA; and NASA Headquarters, Washington.

Media Credentialing

News media representatives who wish to cover the rovers' landings and Mars surface operations from NASA's Jet Propulsion Laboratory must be accredited through the JPL Media Relations Office. Journalists may phone the newsroom at 818/354-5011 for more information.

Briefings

Frequent news briefings will be held at JPL during the landing and surface-operations periods. Information about upcoming briefings will be available on the Internet at JPL's Mars News site, <http://www.jpl.nasa.gov/mer> .

Internet Information

Extensive information on the Mars Exploration Rover project including an electronic copy of this press kit, press releases, fact sheets, status reports, briefing schedule and images, is available from the Jet Propulsion Laboratory's Mars Exploration Rover news site: <http://www.jpl.nasa.gov/mer> . Detailed information about the mission for a general public audience is available on the Mars Exploration Rover project's web site at: <http://mars.jpl.nasa.gov/mer> . Cornell University's web site on the science payload is at: <http://athena.cornell.edu> .

Quick Facts

Spacecraft

Cruise vehicle dimensions: 2.65 meters (8.7 feet) diameter, 1.6 meters (5.2 feet) tall

Rover dimensions: 1.5 meter (4.9 feet) high by 2.3 meters (7.5 feet) wide by 1.6 meter (5.2 feet) long

Weight: 1,062 kilograms (2,341 pounds) total at launch, consisting of 174-kilogram (384-pound) rover, 365-kilogram (805-pound) lander, 198-kilogram (436-pound) backshell and parachute, 90-kilogram (198-pound) heat shield and 183-kilogram (403-pound) cruise stage, plus 52 kilograms (115 pounds) of propellant

Power: Solar panel and lithium-ion battery system providing 140 watts on Mars surface

Science instruments: Panoramic cameras, miniature thermal emission spectrometer, Mössbauer spectrometer, alpha particle X-ray spectrometer, microscopic imager, rock abrasion tool, magnet arrays

Spirit Mission

Launch vehicle: Delta II 7925

Launch: June 10, 2003, from Cape Canaveral Air Force Station, Fla.

Earth-Mars distance at launch: 103 million kilometers (64 million miles)

Mars landing: Jan. 4, 2004, at about 2:30 p.m. local Mars time (signal received at Earth 8:35 p.m. PST Jan. 3)

Landing site: Gusev Crater, possible former lake in giant impact crater

Earth-Mars distance on landing day: 170.2 million kilometers (105.7 million miles)

One-way speed-of-light time Mars-to-Earth on landing day: 9.46 minutes

Total distance traveled Earth to Mars (approximate): 487 million kilometers (303 million miles)

Near-surface atmospheric temperature at landing site: -100 C (-148 F) to 0 C (32 F)

Primary mission: 90 Mars days, or "sols" (equivalent to 92 Earth days)

Opportunity Mission

Launch vehicle: Delta II 7925H (larger solid-fuel boosters than 7925)

Launch: July 7, 2003, from Cape Canaveral Air Force Station, Fla.

Earth-Mars distance at launch: 78 million kilometers (48 million miles)

Mars landing: Jan. 25, 2004, at about 1:15 p.m. local Mars time (signal received at Earth 9:05 p.m. PST Jan. 24)

Landing site: Meridiani Planum, where mineral deposits suggest wet past

Earth-Mars distance on landing day: 198.7 million kilometers (123.5 million miles)

One-way speed-of-light time Mars-to-Earth on landing day: 11 minutes

Total distance traveled Earth to Mars (approximate): 456 million kilometers (283 million miles)

Near-surface atmospheric temperature at landing site: -100 C (-148 F) to 0 C (32 F)

Primary mission: 90 Mars days, or "sols" (equivalent to 92 Earth days)

Program

Cost: Approximately \$820 million total, consisting approximately of \$645 million spacecraft development and science instruments; \$100 million launch; \$75 million mission operations and science processing

Mars at a Glance

General

- ❑ One of five planets known to ancients; Mars was Roman god of war, agriculture and the state
- ❑ Yellowish brown to reddish color; occasionally the third brightest object in the night sky after the Moon and Venus

Physical Characteristics

- ❑ Average diameter 6,780 kilometers (4,212 miles); about half the size of Earth, but twice the size of Earth's Moon
- ❑ Same land area as Earth, reminiscent of a rocky desert
- ❑ Mass 1/10th of Earth's; gravity only 38 percent as strong as Earth's
- ❑ Density 3.9 times greater than water (compared to Earth's 5.5 times greater than water)
- ❑ No planet-wide magnetic field detected; only localized ancient remnant fields in various regions

Orbit

- ❑ Fourth planet from the Sun, the next beyond Earth
- ❑ About 1.5 times farther from the Sun than Earth is
- ❑ Orbit elliptical; distance from Sun varies from a minimum of 206.7 million kilometers (128.4 million miles) to a maximum of 249.2 million kilometers (154.8 million miles); average distance from the Sun 227.7 million kilometers (141.5 million miles)
- ❑ Revolves around Sun once every 687 Earth days
- ❑ Rotation period (length of day) 24 hours, 39 min, 35 sec (1.027 Earth days)
- ❑ Poles tilted 25 degrees, creating seasons similar to Earth's

Environment

- ❑ Atmosphere composed chiefly of carbon dioxide (95.3%), nitrogen (2.7%) and argon (1.6%)
- ❑ Surface atmospheric pressure less than 1/100th that of Earth's average
- ❑ Surface winds up to 80 miles per hour (40 meters per second)
- ❑ Local, regional and global dust storms; also whirlwinds called dust devils
- ❑ Surface temperature averages -53 C (-64 F); varies from -128 C (-199 F) during polar night to 27 C (80 F) at equator during midday at closest point in orbit to Sun

Features

- ❑ Highest point is Olympus Mons, a huge shield volcano about 26 kilometers (16 miles) high and 600 kilometers (370 miles) across; has about the same area as Arizona
- ❑ Canyon system of Valles Marineris is largest and deepest known in solar system; extends more than 4,000 kilometers (2,500 miles) and has 5 to 10 kilometers (3 to 6 miles) relief from floors to tops of surrounding plateaus
- ❑ "Canals" observed by Giovanni Schiaparelli and Percival Lowell about 100 years ago were a visual illusion in which dark areas appeared connected by lines. The Mariner 9 and Viking missions of the 1970s, however, established that Mars has channels possibly cut by ancient rivers

Moons

- ❑ Two irregularly shaped moons, each only a few kilometers wide
- ❑ Larger moon named Phobos ("fear"); smaller is Deimos ("terror"), named for attributes personified in Greek mythology as sons of the god of war

Historical Mars Missions

Mission, Country, Launch Date, Purpose, Results

[Unnamed], USSR, 10/10/60, Mars flyby, did not reach Earth orbit
[Unnamed], USSR, 10/14/60, Mars flyby, did not reach Earth orbit
[Unnamed], USSR, 10/24/62, Mars flyby, achieved Earth orbit only
Mars 1, USSR, 11/1/62, Mars flyby, radio failed at 106 million km (65.9 million miles)
[Unnamed], USSR, 11/4/62, Mars flyby, achieved Earth orbit only
Mariner 3, U.S., 11/5/64, Mars flyby, shroud failed to jettison
Mariner 4, U.S., 11/28/64, first successful Mars flyby 7/14/65, returned 21 photos
Zond 2, USSR, 11/30/64, Mars flyby, passed Mars but radio failed, returned no planetary data
Mariner 6, U.S., 2/24/69, Mars flyby 7/31/69, returned 75 photos
Mariner 7, U.S., 3/27/69, Mars flyby 8/5/69, returned 126 photos
Mariner 8, U.S., 5/8/71, Mars orbiter, failed during launch
Kosmos 419, USSR, 5/10/71, Mars lander, achieved Earth orbit only
Mars 2, USSR, 5/19/71, Mars orbiter/lander arrived 11/27/71, no useful data, lander burned up due to steep entry
Mars 3, USSR, 5/28/71, Mars orbiter/lander, arrived 12/3/71, lander operated on surface for 20 seconds before failing
Mariner 9, U.S., 5/30/71, Mars orbiter, in orbit 11/13/71 to 10/27/72, returned 7,329 photos
Mars 4, USSR, 7/21/73, failed Mars orbiter, flew past Mars 2/10/74
Mars 5, USSR, 7/25/73, Mars orbiter, arrived 2/12/74, lasted a few days
Mars 6, USSR, 8/5/73, Mars flyby module and lander, arrived 3/12/74, lander failed due to fast impact
Mars 7, USSR, 8/9/73, Mars flyby module and lander, arrived 3/9/74, lander missed the planet
Viking 1, U.S., 8/20/75, Mars orbiter/lander, orbit 6/19/76-1980, lander 7/20/76-1982
Viking 2, U.S., 9/9/75, Mars orbiter/lander, orbit 8/7/76-1987, lander 9/3/76-1980; combined, the Viking orbiters and landers returned 50,000+ photos
Phobos 1, USSR, 7/7/88, Mars/Phobos orbiter/lander, lost 8/88 en route to Mars
Phobos 2, USSR, 7/12/88, Mars/Phobos orbiter/lander, lost 3/89 near Phobos
Mars Observer, U.S., 9/25/92, lost just before Mars arrival 8/21/93
Mars Global Surveyor, U.S., 11/7/96, Mars orbiter, arrived 9/12/97, high-detail mapping through 1/00, now conducting second extended mission through fall 2004
Mars 96, Russia, 11/16/96, orbiter and landers, launch vehicle failed
Mars Pathfinder, U.S., 12/4/96, Mars lander and rover, landed 7/4/97, last transmission 9/27/97
Nozomi, Japan, 7/4/98, Mars orbiter, currently in orbit around the Sun; Mars arrival delayed to 12/13/03 due to propulsion problem
Mars Climate Orbiter, U.S., 12/11/98, lost upon arrival 9/23/99
Mars Polar Lander/Deep Space 2, U.S., 1/3/99, lander and soil probes, lost on arrival 12/3/99
Mars Odyssey, U.S., 3/7/01, Mars orbiter, arrived 10/24/01, currently conducting prime mission studying global composition, ground ice, thermal imaging
Mars Express/Beagle 2, European Space Agency, 6/2/03, Mars orbiter/lander, due to enter orbit 12/25/03, landing 12/25/03 (evening of 12/24/03 in U.S. time zones)

Mars: The Water Trail

Thirty-eight years ago, on the eve of the first spacecraft flyby of Mars, everything we knew about the Red Planet was based on what sparse details could be gleaned by peering at it from telescopes on Earth. Since the early 1900s, popular culture had been enlivened by the notion of a habitable neighboring world crisscrossed by canals and, possibly, inhabited by advanced lifeforms that might have built them -- whether friendly or not. Astronomers were highly skeptical about the canals, which looked more dubious the closer they looked. About the only hard information they had on Mars was that they could see it had seasons with ice caps that waxed and waned, along with seasonally changing surface markings. By breaking down the light from Mars into colors, they learned that its atmosphere was thin and dominated by an unbreathable gas known as carbon dioxide.

The past four decades have completely revolutionized that view. First, hopes of a lush, Earth-like world were deflated when Mariner 4's flyby in 1965 revealed large impact craters, not unlike those on Earth's barren, lifeless Moon. Those holding out for martians were further discouraged when NASA's two Viking landers were sent to the surface in 1976 equipped with a suite of chemistry experiments that turned up no conclusive sign of biological activity. Mars as we came to know it was cold, nearly airless and bombarded by hostile radiation from both the Sun and from deep space.

But along the way since then, new possibilities of a more hospitable martian past have emerged. Mars is a much more complex body than Earth's Moon. Scientists scrutinizing pictures from the Viking orbiters have detected potential signs of an ancient coastline that may have marked the edges of a long-lost sea. Today's Mars Global Surveyor and Mars Odyssey orbiters have revealed many features that strongly appear to have been shaped by running water that has since disappeared, perhaps buried as layers of ice just under the planet's surface.

Although it appears unlikely that complex organisms similar to Earth's could have existed in any recent time on Mars' comparatively hostile surface, scientists are intrigued by the possibility that life in some form, perhaps very simple microbes, may have gained a foothold in ancient times when Mars may have been warmer and wetter. It is not unthinkable that life in some form could persist today in underground springs warmed by heat vents around smoldering volcanoes, or even beneath the thick ice caps. To investigate those possibilities, scientists must start by learning more about the history of water on Mars -- how much there was and when, in what form it existed, and how long it lasted.

One of the most promising ways to answer those questions is to look at the diverse clues that water has left on Mars. Besides the water-carved landforms visible for decades from orbiting spacecraft, many details of the story of water on the Red Planet are locked up in the rocks littered across its surface. Rocks are made up of building

blocks known as minerals, each of which tells the story of how it came to be a part of a any given rock. Some types of minerals, for example, are known to form on Earth only submerged underwater, while others are profoundly altered when hot water runs through them, leaving behind residues. Up until now, it has been very difficult to get to know the minerals in martian rocks because we have not had the tools to unravel their mineralogies. By understanding Mars' rocks in a more complete manner, scientists can gain a better view into the history of liquid water on the planet. Like their predecessor mission, Mars Pathfinder, the Mars Exploration Rovers will pursue this goal by placing robotic geologists on the planet's surface -- ideally suited to "reading the rocks" to understand the still mysterious history of water, and even of life-friendly ancient environments.

Myths and Reality

Mars caught public fancy in the late 1870s, when Italian astronomer Giovanni Schiaparelli reported using a telescope to observe "canali," or channels, on Mars. A possible mistranslation of this word as "canals" may have fired the imagination of Percival Lowell, an American businessman with an interest in astronomy. Lowell founded an observatory in Arizona, where his observations of the Red Planet convinced him that the canals were dug by intelligent beings -- a view that he energetically promoted for many years.

By the turn of the last century, popular songs envisioned sending messages between worlds by way of huge signal mirrors. On the dark side, H.G. Wells' 1898 novel "The War of the Worlds" portrayed an invasion of Earth by technologically superior Martians desperate for water. In the early 1900s novelist Edgar Rice Burroughs, known for the "Tarzan" series, also entertained young readers with tales of adventures among the exotic inhabitants of Mars, which he called Barsoom.

Fact began to turn against such imaginings when the first robotic spacecraft were sent to Mars in the 1960s. Pictures from the 1965 flyby of Mariner 4 and the 1969 flybys of Mariner 6 and 7 showed a desolate world, pocked with impact craters similar to those seen on Earth's Moon. Mariner 9 arrived in 1971 to orbit Mars for the first time, but showed up just as an enormous dust storm was engulfing the entire planet. When the storm died down, Mariner 9 revealed a world that, while partly crater-pocked like Earth's Moon, was much more geologically complex, complete with gigantic canyons, volcanoes, dune fields and polar ice caps. This first wave of Mars exploration culminated in the Viking mission, which sent two orbiters and two landers to the planet in 1975. The landers included a suite of experiments that conducted chemical tests in direct search of life. Most scientists interpreted the results of these tests as negative, deflating hopes of identifying another world on where life might be or have been widespread. However, Viking left a huge legacy of information about Mars that fed a hungry science community for two decades.

The science community had many other reasons for being interested in Mars, apart

from the direct search for life; the next mission on the drawing boards concentrated on a study of the planet's geology and climate using advanced orbital reconnaissance. Over the next 20 years, however, new findings in laboratories on Earth came to change the way that scientists thought about life and Mars.

One was the 1996 announcement by a team from Stanford University and NASA's Johnson Space Center that a meteorite believed to have originated on Mars contained what might be the fossils of ancient bacteria. This rock and other likely Mars meteorites discovered on several continents on Earth are believed to have been blasted off the Red Planet by asteroid or comet impacts. They are presently believed to have come from Mars because of gases trapped in them that unmistakably match the composition of Mars' atmosphere as measured by the Viking landers. Many scientists questioned the conclusions of the team announcing the discovery of possible life in one martian meteorite, but if nothing else the mere presence of organic compounds in the meteorites increases the odds of life forming at an earlier time on a far wetter Mars.

Another development that shaped scientists' thinking was spectacular new findings on how and where life thrives on Earth. The fundamental requirements for life as we know it today are liquid water, organic compounds and an energy source for synthesizing complex organic molecules. Beyond these basics, we do not yet understand the environmental and chemical evolution that leads to the origin of terrestrial life. But in recent years, it has become increasingly clear that life can thrive in settings much different -- and more harsh -- from a tropical soup rich in organic nutrients.

In the 1980s and 1990s, biologists found that microbial life has an amazing flexibility for surviving in extreme environments -- niches that by turn are extraordinarily hot, or cold, or dry, or under immense pressures -- that would be completely inhospitable to humans or complex animals. Some scientists even concluded that life may have begun on Earth in heat vents far under the ocean's surface.

This in turn had its effect on how scientists thought about Mars. Martian life might not be so widespread that it would be readily found at the foot of a lander spacecraft, but it may have thrived billions of years ago in an underground thermal spring or other hospitable environment. Or it might still exist in some form in niches below the currently frigid, dry, windswept surface, perhaps entombed in ice or in liquid water aquifers.

After years of studying pictures from the Viking orbiters, scientists gradually came to conclude that many features they saw suggested that Mars may have been warm and wet in an earlier era. And two currently operating orbiters -- Mars Global Surveyor and Mars Odyssey -- are giving scientists yet new insights into the planet. Global Surveyor's camera detected possible evidence for recent liquid water in a large number of settings, while Odyssey's camera system has found large amounts of ice mixed in with Mars surface materials at high latitudes, as well as potential evidence of ancient snowpacks.

The Three Ages of Mars

Based on what they have learned from spacecraft missions, scientists view Mars as the "in-between" planet of the inner solar system. Small rocky planets such as Mercury and Earth's Moon apparently did not have enough internal heat to power volcanoes or to drive the motion of tectonic plates, so their crusts grew cold and static relatively soon after they formed when the solar system condensed into planets about 4.6 billion years ago. Devoid of atmospheres, they are riddled with craters that are relics of impacts during a period of bombardment when the inner planets were sweeping up remnants of small rocky bodies that failed to "make it as planets" in the solar system's early times.

Earth and Venus, by contrast, are larger planets with substantial internal heat sources and significant atmospheres. Earth's surface is continually reshaped by tectonic plates sliding under and against each other and materials spouting forth from active volcanoes where plates are ripped apart. Both Earth and Venus have been paved over so recently that both lack any discernible record of cratering from the era of bombardment in the early solar system.

Mars appears to stand between those sets of worlds, on the basis of current yet evolving knowledge. Like Earth and Venus, it possesses a myriad of volcanoes, although they probably did not remain active as long as counterparts on Earth and Venus. On Earth, a single "hot spot" or plume might form a chain of middling-sized islands such as the Hawaiian Islands as a tectonic plate slowly slides over it. On Mars there are apparently no such tectonic plates, at least as far as we know today, so when volcanoes formed in place they had the time to become much more enormous than the rapidly moving volcanoes on Earth. Overall Mars appears to be neither as dead as Mercury and our Moon, nor as active as Earth and Venus. As one scientist quips, "Mars is a warm corpse if not a fire-breathing dragon." Thanks to the ongoing observations by the Global Surveyor and Odyssey orbiters, however, this view of Mars is still evolving.

Mars almost resembles two different worlds that have been glued together. From latitudes around the equator to the south are ancient highlands pockmarked with craters from the solar system's early era, yet riddled with channels that attest to the flow of water. The northern third of the planet, however, overall is sunken and much smoother at kilometer (mile) scales. There is as yet no general agreement on how the northern plains got to be that way. At one end of the spectrum is the theory that it is the floor of an ancient sea; at the other, the notion that it is merely the end product of innumerable lava flows. New theories are emerging thanks to the discoveries of Mars Odyssey, and some scientists believe a giant ice sheet may be buried under much of the relatively smooth northern plains. Many scientists suspect that some unusual internal process not yet fully understood may have caused the northern plains to sink to relatively low elevations in relation to the southern uplands.

Scientists today view Mars as having had three broad ages, each named for a geographic area that typifies it:

- The **Noachian Era** is the name given to the time spanning perhaps the first billion years of Mars' existence after the planet was formed 4.6 billion years ago. In this era, scientists suspect that Mars was quite active with periods of warm and wet environment, erupting volcanoes and some degree of tectonic activity. The planet may have had a thicker atmosphere to support running water, and it may have rained and snowed.
- In the **Hesperian Era**, which lasted for about the next 500 million to 1.5 billion years, geologic activity was slowing down and near-surface water perhaps was freezing to form surface and buried ice masses. Plunging temperatures probably caused water pooled underground to erupt when heated by impacts in catastrophic floods that surged across vast stretches of the surface -- floods so powerful that they unleashed the force of thousands of Mississippi Rivers. Eventually, water became locked up as permafrost or subsurface ice, or was partially lost into outer space.
- The **Amazonian Era** is the current age that began around 2 billion to 3 billion years ago. The planet is now a dry, desiccating environment with only a modest atmosphere in relation to Earth. In fact, the atmosphere is so thin that water can exist only as a solid or a gas, not as a liquid.

Apart from that broad outline, there is lively debate and disagreement on the details of Mars' history. How wet was the planet, and how long ago? What eventually happened to all of the water? That is all a story that is still being written.

In addition to studying the planet from above with orbiting spacecraft, NASA's Mars Exploration Program is putting robotic geologists on the surface in the form of instrumented rovers. Both of the landing sites selected for the Mars Exploration Rovers show evidence of water activity in their past. The rovers Spirit and Opportunity will look at rocks to understand the types of minerals that they are made of, and hence the environments in which they formed. This, in turn, will offer clues about the environment in which the rocks formed. Some types of rocks, for example, might be of types that form in running water, whereas others might be typical of the sediments that form on the beds of lakes.

Even if we ultimately learn that Mars never harbored life as we know it here on Earth, scientific exploration of the Red Planet can assist in understanding the history and evolution of life on our own home world. Much if not all of the evidence for the origin of life here on Earth has been obliterated by the incredible pace of weathering and global tectonics that have operated over billions of years. Mars, by comparison, is a composite world with some regions that may have histories similar to Earth's crust, while oth-

Where We've Been and Where We're Going

Building on scientific discoveries and lessons learned from past and ongoing missions, NASA's Mars Exploration Program will establish a sustained observational presence both around and on the surface of Mars in coming years. This will include orbiters that view the planet from above and act as telecommunications relays; surface-based mobile laboratories; robots that probe below the planet's surface; and, ultimately, missions that return soil and rock samples to Earth. With international cooperation, the long-term program will be guided by compelling questions that scientists are interested in answering about Mars, developing technologies to make missions possible within available resources. The program's strategy is to seek to uncover profound new insights into Mars' past environments, the history of its rocks and interior, the many roles and abundances of water and, quite possibly, evidence of past and present life.

The following are the most recently completed, ongoing and near-term future Mars missions of exploration in the NASA program:

❑ **Mars Pathfinder** (December 1996 - March 1998): The first completed mission in NASA's Discovery Program of low-cost, rapidly developed planetary missions with highly focused scientific goals, Mars Pathfinder far exceeded its expectations and outlived its primary design life. This lander, which released its Sojourner rover at the martian surface, returned 2.3 billion bits of information, including more than 17,000 images and more than 15 chemical analyses of rocks and soil and extensive data on winds and other types of weather. Investigations carried out by instruments on both the lander and the rover suggest that, in its past, Mars was warm and wet, with liquid water on its surface and a thicker atmosphere. The lander and rover functioned far beyond their planned lifetimes (30 days for the lander and 7 days for the rover), but eventually, after about three months on the martian surface, depletion of the lander's battery and a drop in the lander's operating temperature are thought to have ended the mission.

❑ **Mars Global Surveyor** (November 1996 - present): During its primary mapping mission from March 1999 through January 2001, NASA's Mars Global Surveyor collected more information than any other previous Mars mission. Today the orbiter continues to gather data in a second extended mission. As of May 1, 2003, it has completed more than 20,000 orbits of Mars and returned more than 137,000 images, 671 million laser-altimeter shots and 151 million spectrometer measurements. Some of the mission's most significant findings include: evidence of possibly recent liquid water at the martian surface; evidence for layering of rocks that points to widespread ponds or lakes in the planet's early history; topographic evidence that most of the southern hemisphere is higher in elevation than most of the northern hemisphere, so that any downhill flow of water and sediments would have tended to be northward; identification of gray hematite, a mineral suggesting a wet environment when it was formed; and extensive evidence for the role of dust in reshaping the recent martian environment. Global Surveyor provided valuable details for evaluating the risks and attractions of potential landing sites for the Mars Exploration Rover missions, and it will serve as a communications relay for the rovers as they descend to land on Mars and afterwards.

❑ **Mars Climate Orbiter and Mars Polar Lander** (1998-99): These spacecraft were both lost upon Mars arrival.

❑ **Mars Odyssey** (April 2001 - present): This orbiter's prime mapping mission began in March 2002. Its suite of gamma-ray spectrometer instruments has provided strong evidence for large quantities of frozen water mixed into the top layer of soil in the 20 percent of the planet near its north and south poles. By one estimate -- likely an underestimate -- the amount of water ice near the surface, if melted, would be enough water to fill Lake Michigan twice. Odyssey's infrared

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camera system has also provided detailed maps of minerals in rocks and soils. A layer of olivine-rich rock in one canyon near Mars' equator suggests that site has been dry for a long time, since olivine is easily weathered by liquid water. Nighttime infrared imaging by Odyssey's camera system provides information about how quickly or slowly surface features cool off after sunset, which gives an indication of where the surface is rocky and where it is dusty. Odyssey's observations have helped evaluate potential landing sites for the Mars Exploration Rovers. When the rovers reach Mars, radio relay via Odyssey will be one way they will return data to Earth.

❑ **Mars Reconnaissance Orbiter (2005):** This mission is being developed to provide detailed information about thousands of sites on Mars, connecting the big-picture perspective of an orbiter with a level of local detail that has previously come only from landing a spacecraft on the surface. The spacecraft's telescopic camera will reveal martian landscapes in resolution fine enough to show rocks the size of a desk. Maps of surface minerals will be produced in unprecedented detail for thousands of potential future landing sites. Scientists will search in particular for types of minerals that form in wet environments. A radar instrument on the orbiter will probe hundreds of meters (or yards) below Mars' surface for layers of frozen or melted water, and other types of geologic layers. Another instrument will document atmospheric processes changing with Mars' seasons, and study how water vapor enters, moves within and leaves the atmosphere.

❑ **Phoenix Mars Scout (2007):** This mission will send a spacecraft to land in an ice-rich region of northern Mars, scoop up soil to analyze at the landing site, and radio home evidence about the history of martian water and the possibility of past or current life. NASA chose Phoenix in August 2003 to be the first flight in the Mars Scout program of competitively selected missions. Phoenix will land in May 2008 on arctic ground where Mars Odyssey has found abundant ice near the surface. A stereo color camera and a weather station will study the surrounding environment while other instruments check excavated soil samples for water, organic chemicals and conditions that could indicate whether the site was ever hospitable to life. Microscopes will reveal features as small as 1/1,000th the width of a human hair. The mission will use many components of a spacecraft originally built for a 2001 Mars lander mission, which was kept in storage after that mission was cancelled. NASA plans to select a second Mars Scout from a future round of proposals to fly in 2011.

❑ **Mars Science Laboratory (2009):** Following the high-resolution study of the planet by the Mars Reconnaissance Orbiter in search for the highest-priority sites on Mars, the program calls for a precision lander to one of those sites in search for habitable environments and the basic building blocks of life. Baseline as being nuclear-powered, the mission will also take advantage of advances in entry, descent and landing technologies to enable it to access about three-fourths of Mars. It will have the capability to move on the surface for a full martian year or longer, and across distances an order of magnitude larger than the Mars Exploration Rovers.

❑ **Mars Telecommunications Orbiter (2009):** This mission will be the first interplanetary spacecraft whose primary mission is to provide communications services to other missions. It will fly in a higher orbit than any previous Mars orbiter missions. It will dramatically increase the amount of data that surface missions such as the Mars Science Laboratory can send to Earth. It will operate in two radio bands and carry an optical communications terminal to demonstrate use of a laser beam for interplanetary communications.

The present decade represents the most intense scientific exploration of a neighboring world since the Apollo era, focusing on the search for ancient and modern habitats through the history of water. The next decade will witness the transition from "following the water" to a "search for building blocks of life" -- in other words, following the carbon. Alternate pathways of exploration have been defined by the science community to be responsive to the unknown and unpredictable discoveries of this decade; they include intensive analysis by robotic craft at Mars, and analysis of Mars samples in Earth laboratories designed to provide definitive evidence of biological building blocks. Scout missions will continue to augment and complement the program in innovative ways to fill identified science measurement gaps.

ers serve as a frozen gallery of the solar system's early days.

Thus, even if life never developed on Mars -- something that we cannot answer today -- scientific exploration of the planet may yield critical information unobtainable by any other means about the pre-biotic chemistry that led to life on Earth. Mars as a fossil graveyard of the chemical conditions that fostered life on Earth is an intriguing possibility.

Science Investigations

The Mars Exploration Rover mission seeks to determine the history of climate and water at sites on Mars where conditions may once have been favorable to life. Each rover is equipped with a suite of science instruments that will be used to read the geologic record at each site, to investigate what role water played there, and to determine how suitable the conditions would have been for life.

Science Objectives

Based on priorities of the overall Mars Exploration Program, the following science objectives were developed for Spirit and Opportunity:

- Search for and characterize a diversity of rocks and soils that hold clues to past water activity (water-bearing minerals and minerals deposited by precipitation, evaporation, sedimentary cementation, or hydrothermal activity).
- Investigate landing sites, selected on the basis of orbital remote sensing, that have a high probability of containing physical and/or chemical evidence of the action of liquid water.
- Determine the spatial distribution and composition of minerals, rocks and soils surrounding the landing sites.
- Determine the nature of local surface geologic processes from surface morphology and chemistry.
- Calibrate and validate orbital remote-sensing data and assess the amount and scale of heterogeneity at each landing site.
- For iron-containing minerals, identify and quantify relative amounts of specific mineral types that contain water or hydroxyls, or are indicators of formation by an aqueous process, such as iron-bearing carbonates.
- Characterize the mineral assemblages and textures of different types of rocks and soils and put them in geologic context.
- Extract clues from the geologic investigation, related to the environmental conditions when liquid water was present and assess whether those environments were conducive for life.

Science Instruments

The package of science instruments on the rovers is collectively known as the Athena science payload. Led by Dr. Steven Squyres, professor of astronomy at Cornell University, Ithaca, N.Y., the Athena package was originally proposed to fly under different Mars lander and rover mission concepts before being finalized as the science payload for the Mars Exploration Rovers.

The package consists of two instruments designed to survey the landing site, as well as three other instruments on an arm designed for closeup study of rocks. Also on the arm is a tool that can scrape away the outer layers of rocks. Those instruments are supplemented by magnets and calibration targets that will enable other studies.

The two instruments that will survey the general site are:

□ **Panoramic Camera** will view the surface using two high-resolution color stereo cameras to complement the rover's navigation cameras. Delivering panoramas of the martian surface with unprecedented detail, the instrument's narrow-angle optics provide angular resolution more than three times higher than that of the Mars Pathfinder cameras. The camera's images will help scientists decide what rocks and soils to analyze in detail, and will provide information on surface features, the distribution and shape of nearby rocks, and the presence of features carved by ancient waterways. The camera's two eyes sit 30 centimeters (12 inches) apart, about 1.5 meters (5 feet) above ground level on the rover's mast. The instrument carries 14 different types of filters, allowing not only full-color images but also spectral analysis of minerals and the atmosphere. Each exposure of each eye produces a digital image 1,028 pixels wide by 1,028 pixels wide. Full-circle panoramas will be mosaics about 24 frames wide and four frames high, for a combined image full of fine detail even if enlarged to the size of a giant movie screen.

□ The **Mini-Thermal Emission Spectrometer** is an instrument that sees infrared radiation emitted by objects. By measuring the brightness of that emission in 167 different "colors" of infrared for each point it views, this spectrometer will determine from afar the mineral composition of martian surface features and allow scientists to select specific rocks and soils to investigate in detail. Observing in the infrared allows scientists to see through dust that coats many rocks, allowing the instrument to recognize carbonates, silicates, organic molecules and minerals formed in water. Infrared data will also help scientists assess the capacity of rocks and soils to hold heat over the wide temperature range of a martian day. Besides studying rocks, the instrument will be pointed upward to make the first-ever high-resolution temperature profiles through the martian atmosphere's boundary layer. The data from the instrument will be complement that obtained by the thermal emission spectrometer on the Mars Global Surveyor orbiter. Most of the instrument rides inside the

rover. The rover's camera mast doubles as a periscope for this spectrometer, and a scanning mirror assembly high on the mast reflects infrared light down through the mast to the spectrometer.

The instruments on the rover arm are:

□ The **Microscopic Imager** is a combination of a microscope and a camera. It will produce extreme closeup black-and-white views (at a scale of hundreds of microns) of rocks and soils examined by other instruments on the rover arm, providing context for the interpretation of data about minerals and elements. The imager will help characterize sedimentary rocks that formed in water, and thus will help scientists understand past watery environments on Mars. This instrument will also yield information on the small-scale features of rocks formed by volcanic and impact activity as well as tiny veins of minerals like the carbonates that may contain microfossils in the famous Mars meteorite, ALH84001. The shape and size of particles in the martian soil can also be determined by the instrument, which provides valuable clues about how the soil formed.

□ Because many of the most important minerals on Mars contain iron, the **Mössbauer Spectrometer** is designed to determine with high accuracy the composition and abundance of iron-bearing minerals that are difficult to detect by other means. Identification of iron-bearing minerals will yield information about early martian environmental conditions. The spectrometer is also capable of examining the magnetic properties of surface materials and identifying minerals formed in hot, watery environments that could preserve fossil evidence of martian life. The instrument uses two pieces of radioactive cobalt-57, each about the size of a pencil eraser, as radiation sources. The instrument is provided by Germany.

□ The **Alpha Particle X-Ray Spectrometer** will accurately determine the elements that make up rocks and soils. This information will be used to complement and constrain the analysis of minerals provided by the other science instruments. Through the use of alpha particles and X-rays, the instrument will determine a sample's abundances of all major rock-forming elements except hydrogen. Analyzing the elemental make-up of martian surface materials will provide scientists with information about crustal formation, weathering processes and water activity on Mars. The instrument uses small amounts of curium-244 for generating radiation. It is provided by Germany.

□ The arm-mounted instruments will be aided by a **Rock Abrasion Tool** that will act as the rover's equivalent of a geologist's rock hammer. Positioned against a rock by the rover's instrument arm, the tool uses a grinding wheel to remove dust and weathered rock, exposing fresh rock underneath. The tool will expose an area 4.5 centimeters (2 inches) in diameter, and grind down to a

depth of as much as 5 millimeters (0.2 inch).

In addition, the rovers are equipped with the following that work in conjunction with science instruments:

□ Each rover has three sets of **Magnet Arrays** that will collect airborne dust for analysis by the science instruments. Mars is a dusty place, and some of that dust is highly magnetic. Magnetic minerals carried in dust grains may be freeze-dried remnants of the planet's watery past. A periodic examination of these particles and their patterns of accumulation on magnets of varying strength can reveal clues about their mineralogy and the planet's geologic history. One set of magnets will be carried by the rock abrasion tool. As it grinds into martian rocks, scientists will have the opportunity to study the properties of dust from these outer rock surfaces. A second set of two magnets is mounted on the front of the rover for the purpose of gathering airborne dust. These magnets will be reachable for analysis by the Mössbauer and alpha particle X-ray spectrometers. A third magnet is mounted on the top of the rover deck in view of the panoramic camera. This magnet is strong enough to deflect the paths of wind-carried, magnetic dust. The magnet arrays are provided by Denmark.

□ **Calibration Targets** are reference points that will help scientists fine-tune observations not only from imagers but also other science instruments. The Mössbauer spectrometer, for example, uses as a calibration target a thin slab of rock rich in magnetite. The alpha particle X-ray spectrometer uses a calibration target on the interior surfaces of doors designed to protect its sensor head from martian dust. The miniature thermal emission spectrometer has both an internal target located in the mast assembly as well as an external target on the rover's deck.

The panoramic camera's calibration target is, by far, the most unique the rover carries. It is in the shape of a **Sundial** and is mounted on the rover deck. The camera will take pictures of the sundial many times during the mission so that scientists can make adjustments to the images they receive from Mars. They will use the colored blocks in the corners of the sundial to calibrate the color in images of the Martian landscape. Pictures of the shadows that are cast by the sundial's center post will allow scientists to properly adjust the brightness of each camera image. Children provided artwork for the sides of the base of the sundial.

Supplemental Instruments

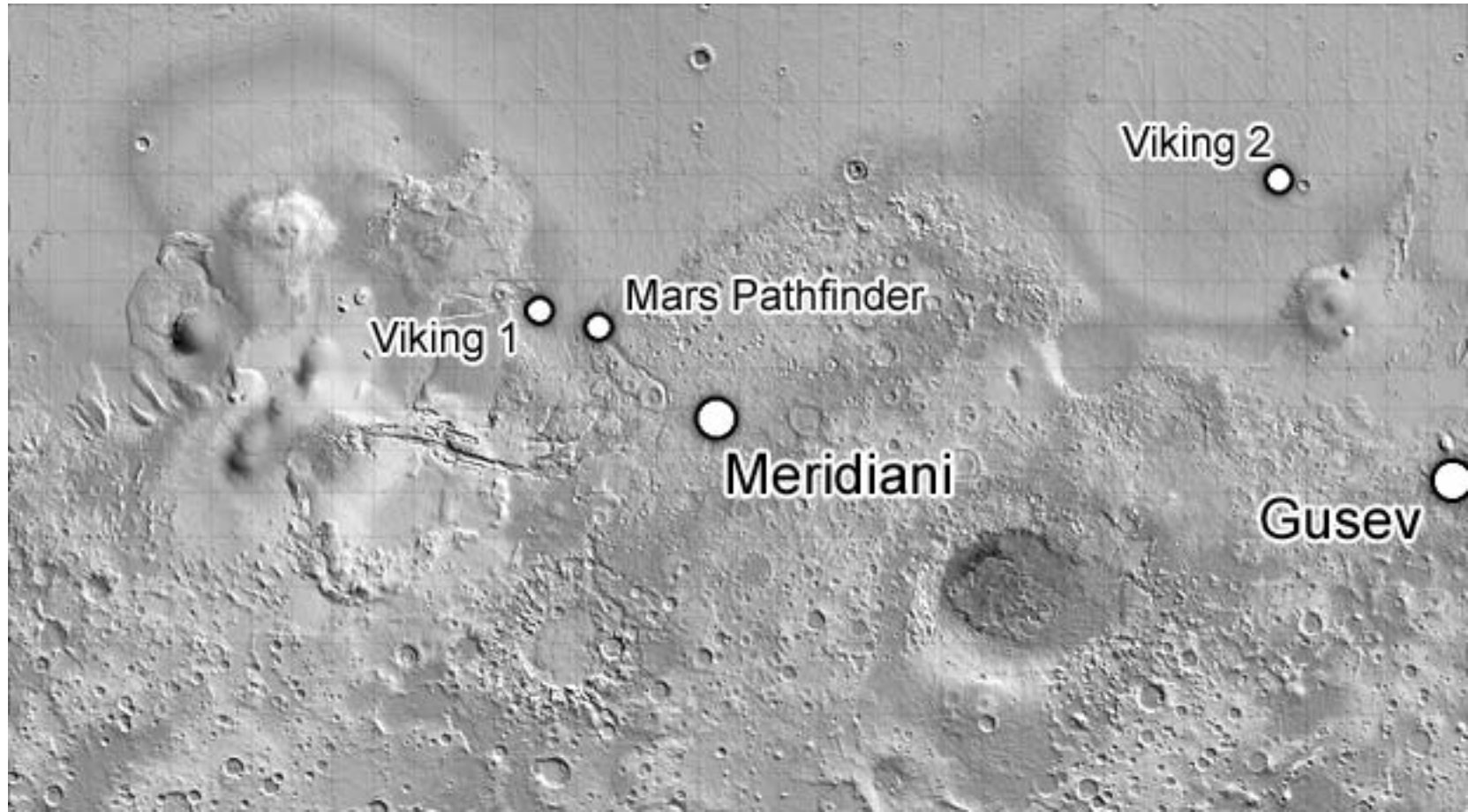
Each rover also has other tools that, while primarily designed for engineering use in the operation of the rover, can also provide information about the geology of the landing region:

□ **Hazard-Identification Cameras** ride low on the front and rear of the rover. The cameras are in stereo pairs at each location in order to produce three-dimensional information about the terrain before or behind the rover. Each hazard-identification camera provides a fisheye wide-angle view about 120 degrees across. They are sensitive to visible light and yield black-and-white pictures. Onboard navigation software can analyze the images from these cameras to identify obstacles and avoid them. The front pair of hazard identification cameras provides position information to help movement of the rover's arm and placement of arm-mounted tools on target rocks.

□ The **Navigation Camera** is another stereo pair of black-and-white cameras. Like the panoramic camera, it sits on top of the mast and can rotate and tilt. Unlike the panoramic camera, it shoots wider-angle images (about 45 degrees across, compared with about 16 degrees across for the panoramic camera) and it does not have changeable filters to produce color images. Because of its wider field of view, the navigation camera's images can give a quick full-circle view of the surroundings at each new location that the rover reaches, requiring less data-transmission time than would a full-circle set of panoramic camera images. Engineers and scientists will use those images in planning where to send the rover and where to use the science instruments for more detailed examinations.

□ Each spacecraft has one more camera on the underside of the lander as a key component in what is called the **Descent Image Motion Estimation Subsystem**. The main purpose of this camera is to aid in safe landing by providing information about how fast the spacecraft is moving horizontally in the final half-minute of its descent. It will take a total of three black-and-white images it takes from altitudes of up to about 2.4 kilometers (1.5 miles) above ground, which may also provide scientists with a broader geological context about the landing site.

□ **Wheels** of the rover, in addition to providing mobility, may be used to dig shallow trenches to evaluate soil properties and expose fresh soil to be examined.



Landing sites

Landing Sites

Selection of landing sites for the two Mars Exploration Rovers required more than two years of intensive study. More than 100 scientists and engineers participated in evaluating sites both on the basis of favorable criteria for safe landings and on the prospects for outstanding science opportunities after the rovers reach the ground.

To qualify for consideration, candidate sites had to be near Mars' equator, not too rugged, not too rocky, not too dusty, and low enough in elevation so the spacecraft would pass through enough atmosphere to slow down sufficiently. In all, 155 potential sites met the initial safety constraints. Detailed observations by two active orbital spacecraft, Mars Global Surveyor and Mars Odyssey, provided an unprecedented amount of information for evaluating finalist candidate sites.

The pair that made the final cut satisfied all the safety criteria; they also show powerful evidence of past liquid water, but in two very different ways.

Spirit to Gusev

The first Mars Exploration Rover, Spirit, is flying to Gusev Crater, a bowl bigger than Connecticut that appears to have held a lake long ago. Scientists will use the robot's instruments to seek and analyze geological evidence about past environmental conditions in the crater. If sedimentary rocks lie on the surface, they may yield telltale clues to whether the crater ever did hold a wet environment that might have been suitable for sustaining life.

An asteroid or comet impact perhaps as much as 4 billion years ago dug Gusev Crater. Many smaller, younger impact craters pock Gusev's 150-kilometer-diameter (95-mile) floor. One of the largest branching valleys on Mars, likely carved by flowing water more than 2 billion years ago, leads directly into Gusev Crater through a breach in the crater's southern rim. Gusev sits at 15 degrees latitude south of Mars' equator at longitude 184.7 degrees west, in a transition zone between the ancient highlands on the southern part of the planet and smoother plains to the north. The valley, called Ma'adim Vallis, snakes northward Nile-like about 900 kilometers (550 miles) from the highlands to Gusev. In places, it gapes more than 25 kilometers (16 miles) wide and 2 kilometers (1.2 miles) deep.

Water flowing down the valley would have pooled in Gusev Crater, dropping sediments there before exiting through a gap in the crater's northern rim. Comparable crater lakes, such as Lake Bosumtwi in Ghana, exist on Earth. Gusev's lake, if indeed it did exist, is now gone. But the floor of Gusev Crater may hold water-laid sediments that preserve records of the lake environment, of the sediments' highlands origins and of the sediments' river trip.

As a potential complication, sedimentary layers may lie buried under later deposits from volcanic eruptions or wind-blown dust. If so, the best chances for finding sedimentary rocks may be in material thrown outward when younger craters were excavated by impacts that punched through the covering layers.

The targeted landing area for Spirit is an ellipse about 78 kilometers (48 miles) long and 10.4 kilometers (6.5 miles) wide near the center of Gusev Crater. Several small craters in and near the ellipse have likely stirred up rocks from underneath the top veneer of Gusev's flat floor. Whether they have dug deep enough to expose lake-related material if volcanic overburden is deep remains to be seen.

A Mars Exploration Rover is well equipped to pursue clues to Gusev's past environment. The panoramic camera and miniature thermal emission spectrometer will scan the scene for an initial survey of the surroundings after landing. Decisions about where to drive Spirit and how to use its other tools will depend on what that survey shows, such as whether any sedimentary rocks appear to be accessible. As the rover drives to new locations during its planned three months of Mars surface operations, a succession of further panoramic surveys will multiply the number of candidate rocks to consider for up-close examination.

If Spirit can find and approach sedimentary samples, several physical traits that the panoramic camera and the microscopic imager could reveal might testify about the long-ago environment. The rock abrasion tool could provide the cameras with fresh, unweathered surfaces to examine. The types of traits scientists may be checking for include:

- ❑ **Grain size.** Larger particles can settle out of water even when the water is moving. Smaller ones form sediments where water is still. The size of the particles that are consolidated into a sedimentary is a major clue about the conditions that existed when the sediments accumulated.
- ❑ **Grain uniformity.** A sedimentary rock with an assortment of grain sizes suggests jumbling by dynamic conditions such as a mudslide or a variable current. Uniformity of grain size suggests more stable conditions over time.
- ❑ **Grain angularity.** The shapes of grains in a sedimentary rock may be sharply angular or may be more rounded. Round grains tell a geologist that they may have worn off their edges by tumbling in a river for a long distance from where they started.
- ❑ **Cross-bedding.** Some sedimentary rocks have evenly stacked, horizontal layering; others have some layers at an angle to the stack. This second pattern, called cross-bedding, can result from an episode of migrating sand waves or ripples creating cyclical patterns of sediments that build up, then partially erode away, then rebuild.

❑ **Fine layering.** On Earth, some sedimentary rocks show annual layers that result from seasonal changes in the environment, like the growth rings of trees. Layers resulting from faster deposition in one season alternate with layers resulting from slower deposition the rest of the year. Scientists will be watching for anything similar in Mars rocks.

Spirit's miniature thermal emission spectrometer, alpha particle X-ray spectrometer and Mössbauer spectrometer could provide a different set of clues about Gusev Crater's past. These three instruments analyze the composition of rocks and soils. Scientists may use them to look for evidence such as:

❑ **Weathering.** Interaction with water can alter the chemical composition of rock-forming material. The water's temperature affects those changes. Information from the spectrometers could thus provide evidence about the wetness and temperature of the past environment, two key factors in whether that environment was hospitable to life.

❑ **Evaporites.** Some minerals are formed when dissolved salts get left behind as water evaporates. Finding and identifying any "evaporite" minerals at Gusev would suggest that the crater once held a salty, shallow lake.

❑ **Carbonates.** Carbonate minerals, such as limestone, can form from chemical reactions that pull carbon dioxide out of the atmosphere into bodies of water. If Spirit's spectrometers identify carbonate rocks, images from the rover's cameras could yield clues about how long the environment stayed wet and whether water was in the form of hot springs.

Spirit might not find any water-related rocks at all as it explores the landing-site region. Even if a lake once covered the Gusev floor, later deposits, such as ash from a volcanic area north of Gusev, could have thoroughly buried sedimentary evidence of the lake. Spirit's examination of the surface geology might still provide new insights about Mars' history, such as the nature of ancient volcanic activity.

The geographical coordinates for the center of Spirit's landing ellipse target are 14.59 degrees south latitude and 175.3 degrees east longitude.

Gusev Crater was named in 1976 for Russian astronomer Matvei Gusev, who lived from 1826 to 1866. Ma'adim Vallis takes its name from the Hebrew word for Mars.

Opportunity to Meridiani

The second Mars Exploration Rover, Opportunity, is targeted for Meridiani Planum, a smooth plain near the equator halfway around the planet from Gusev Crater. Intense scientific interest in the site results not from the shape of the terrain, as at Gusev, but

from an unusual mineral deposit found by a Mars-orbiting spacecraft.

Scientists using an instrument called the thermal emission spectrometer on NASA's Mars Global Surveyor have discovered that Meridiani Planum is rich in gray hematite, a type of iron oxide mineral. On Earth, gray hematite usually -- but not always -- forms in association with liquid water. Some environmental conditions that can produce gray hematite, such as a lake or hot springs, could be quite hospitable to life. Others, such as hot lava, would not.

The gray hematite covers an estimated 15 to 20 percent of the surface in the vicinity of the planned landing site. It appears as a dark cap layer atop a brighter layer that is exposed at many places within the ellipse-shaped landing target.

With the tools on Opportunity, scientists hope to determine which type of hematite-forming environment existed at Meridiani. Each of several possible past environments might leave geological clues to distinguish it from the others. For example:

- ❑ Gray hematite can form in oxygenated water in an iron-rich lake or ocean. If Opportunity finds evidence of sedimentary layering in rocks associated with a Meridiani hematite outcropping, that would support such a scenario possibly hospitable to life.
- ❑ As it percolates through the ground, iron-rich water heated by underground volcanism can deposit veins of gray hematite. This type of "hydrothermal" environment could offer microbes a favorable habitat. It would likely leave behind other types of telltale minerals that Opportunity's instruments could identify, such as carbonates.
- ❑ Weathering in the presence of very small amounts of liquid water can create a veneer of gray hematite on rocks bearing other types of iron oxide. Scientists using the rock abrasion tool and two spectrometers on the rover's arm may determine whether the hematite at Meridiani fits this pattern.
- ❑ Gray hematite can result from direct oxidation of hot, iron-rich lava. This process requires no liquid water and would not indicate a past environment hospitable to life. If Opportunity finds only volcanic rocks at Meridiani, that would support this scenario.

The geographical coordinates for the center of Opportunity's landing target are 1.98 degrees south latitude and 5.94 degrees west longitude. The targeted landing area is an ellipse about 85 kilometers (53 miles) long and 11 kilometers (6.8 miles) wide.

The site is within a large region that has been known as Meridiani since the earliest days of telescopic study of Mars because it lies near the planet's arbitrarily designated prime meridian, or line of zero longitude. "Planum" means plains, and the name fits:

Meridiani Planum is one of the smoothest, flattest places on Mars.

Gusev Crater and Meridian Planum do have something in common. At both sites, scientists expect surprises. Mars has held surprises for every successful mission sent there so far. The types of observations and target rocks described here may well bear little resemblance to what end up being the Mars Exploration Rover mission's chief discoveries.

Mission Overview

NASA's Mars Exploration Rover Project will deliver two mobile laboratories to the surface of Mars for robotic geological fieldwork, including the examination of rocks and soils that may reveal a history of past water activity.

Sequences of launch, cruise and arrival operations are dispatching each rover to a different area of the planet three weeks apart to explore those areas for about three months each.

The twin rovers, Spirit and Opportunity, can recognize and maneuver around small obstacles on their way to target rocks selected by scientists from images sent by the rovers. They will conduct unprecedented studies of Mars geology, such as the first microscopic observations of rock samples. They will provide "ground truth" characterization of the landing vicinities that will help to calibrate observations from instruments that view the planet from above on Mars orbiters.

NASA selected the sites to be explored, Gusev Crater and Meridiani Planum, from 155 potential locations as the two offering the best combination of safe landing potential and scientific appeal in assessing whether liquid water on Mars has ever made environments conducive to life.

While the rovers and the instruments they carry are the centerpieces of the project, each rover mission also depends on the performance of other components: the launch vehicle; a cruise stage; a system for entering Mars' atmosphere, descending through it and landing; a versatile system for deep-space communications; Earth facilities for data processing; and an international team of engineers, scientists and others.

Launch

The two rover spacecraft were lofted on three-stage Delta II rockets from Florida's Cape Canaveral Air Station. Spirit was launched on June 10, 2003, from Canaveral's Space Launch Complex 17A on a version of the Delta II known as model 7925. Opportunity's launch on July 7, 2003, from Launch Complex 17B used a newer, slightly more powerful version called model 7925H; the H identifies the vehicle as a heavy lifter.

Interplanetary Cruise and Approach to Mars

Following launch, each spacecraft has spent several months en route to Mars. During this cruise and the approach to Mars, each spacecraft has been attached to a cruise stage that will be jettisoned in the final minutes of the flight. Solar panels on the cruise stage provide electricity for the spacecraft in flight.

Flight teams at NASA's Jet Propulsion Laboratory, Pasadena, Calif., have prepared and commanded trajectory correction maneuvers, instrument checkouts and other activities while the twin spacecraft have been speeding toward Mars. The trajectory corrections are carefully calculated firings of thrusters located on the cruise stage to make planned adjustments to the spacecraft's flight path. Each rover spacecraft is scheduled to perform four or five maneuvers, with an optional final maneuver on arrival day if needed to tweak landing targeting.

The trajectory correction maneuvers are as follows:

- ❑ Spirit: June 20, Aug. 1, Nov. 14 and Dec. 27, 2003; Jan. 1, 2004; optional final maneuver on Jan. 3, 2004.

- ❑ Opportunity: July 18 and Sept. 8, 2003; Jan. 17 and Jan. 22, 2004; optional final maneuver on Jan. 24, 2004.

Like NASA's Mars Odyssey orbital mission, the Mars Exploration Rover project is supplementing two traditional tracking schemes with a relatively new triangulation method to improve navigational precision. One of the traditional methods is ranging, which measures the distance to the spacecraft by timing precisely how long it takes for a radio signal to travel to the spacecraft and back. The other is Doppler, which measures the spacecraft's speed relative to Earth by the amount of shift in the pitch of a radio signal from the craft.

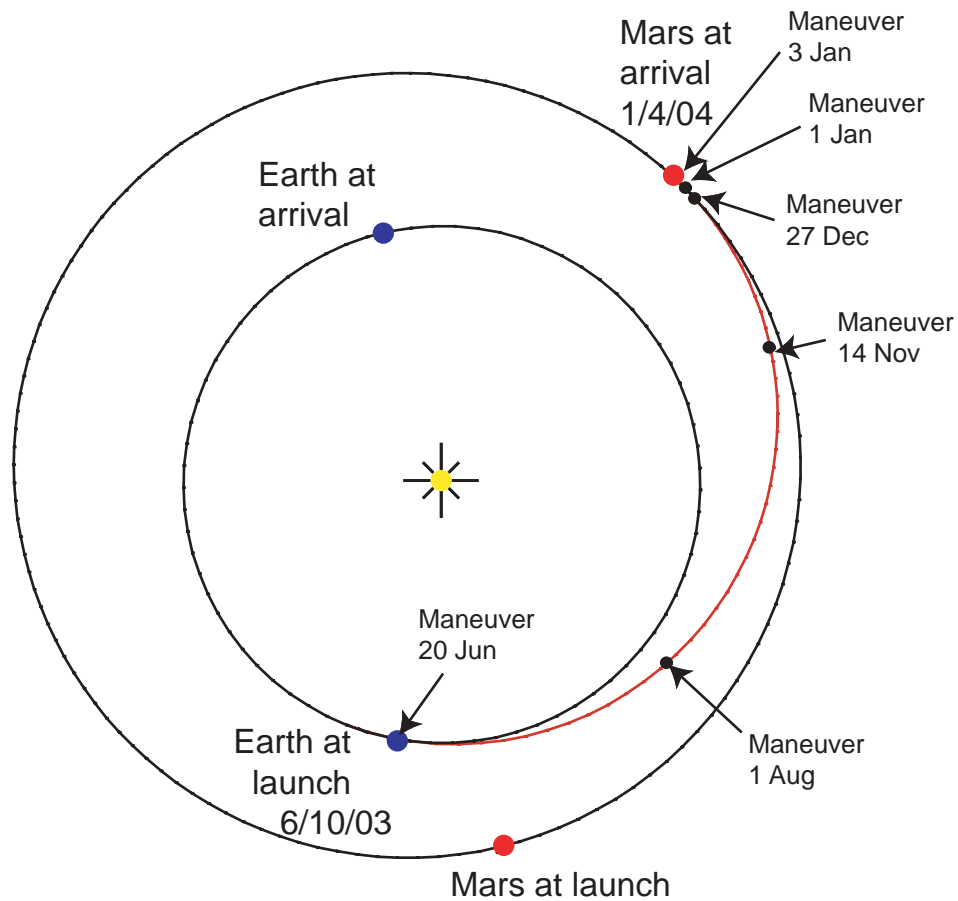
The newer method, called delta differential one-way range measurement, adds information about the location of the spacecraft in directions perpendicular to the line of sight. Pairs of antennas at Deep Space Network sites on two different continents simultaneously receive signals from the spacecraft, then use the same antennas to observe natural radio waves from a known celestial reference point, such as a quasar. Successful use of this triangulation method is expected to shave several kilometers or miles off the amount of uncertainty in delivering the rovers to their targeted landing sites.

The months in which Spirit and Opportunity have been traveling from Earth to Mars have also provided time for testing critical procedures, equipment and software in preparation for arrival.

Entry, Descent and Landing

The Mars Exploration Rovers will use the same airbag-cushioned landing scheme that successfully delivered Mars Pathfinder to the Red Planet in 1997.

About 84 minutes before entering Mars' atmosphere, each rover spacecraft will begin a 14-minute partial rotation to orient its heat shield forward. From that point until the rover deploys its own solar panels after landing, five batteries mounted on the lander

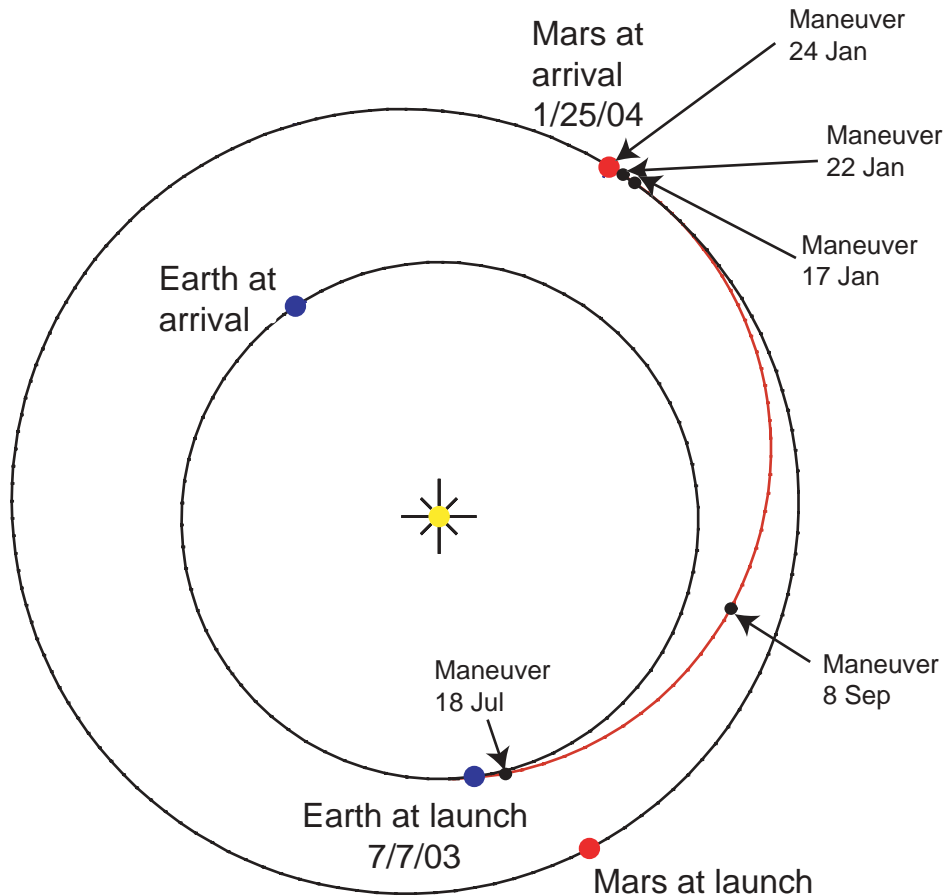


Spirit trajectory

will power the spacecraft.

The planned sequence of events for entering the atmosphere, descending and landing is essentially the same for each of the two rover missions, though the operation will take several seconds more for Spirit because its landing target is at a slightly lower elevation than Opportunity's. On both spacecraft, 15 minutes before atmospheric entry, the protective aeroshell encasing the lander and rover will separate from the cruise stage, whose role will at that point be finished. Each cruise stage will ultimately impact Mars.

Each spacecraft will hit the top of the atmosphere, about 128 kilometers (80 miles) above Mars' surface, at a flight path angle of about 11.5 degrees and a velocity of about 5.4 kilometers per second (12,000 miles per hour). Although Mars has a much thinner atmosphere than Earth does, the friction of traveling through it will heat and slow the spacecraft dramatically. The surface of the heat shield is expected to reach a temperature of 1,447 C (2,637 F). By 4 minutes after atmospheric entry, speed will



Opportunity trajectory

have decreased to about 430 meters per second (960 miles per hour). At that point, about 8.5 kilometers (5.3 miles) above the ground, the spacecraft will deploy its parachute.

Within 2 minutes, the spacecraft will be bouncing on the surface, but those minutes will be packed with challenging events crucial to the mission's success.

Twenty seconds after parachute deployment, the spacecraft will jettison the bottom half of its protective shell, the heat shield, exposing the lander inside. Ten seconds later, the backshell, still attached to the parachute, will begin lowering the lander on a tether-like bridle about 20 meters (66 feet) long. Spooling out the bridle to full length will take 6 seconds. Almost immediately, a radar system on the lander will begin sending pulses toward the ground to measure its altitude. Radar will detect the ground when the craft is about 2.4 kilometers (1.5 miles) above the surface, approximately 35 seconds before landing.

The Mars Exploration Rover design has two new tools, absent on Mars Pathfinder, to avoid excessive horizontal speed during ground impact in case of strong winds near the surface. One is a downward-looking camera mounted on the lander. Once the radar has sensed the surface, this camera will take three pictures of the ground about 4 seconds apart and automatically analyze them to estimate the spacecraft's horizontal velocity. The other innovation is a set of three small transverse rockets mounted on the backshell that can be fired in any combination to reduce horizontal velocity or counteract effects of side-to-side swinging under the parachute and bridle.

Eight seconds before touchdown, gas generators will inflate the lander's airbags. Two seconds later, the three main deceleration rockets on the backshell -- and, if needed, one or two of the transverse rockets -- will ignite. After 3 more seconds, when the lander should be about 10 to 15 meters (33 to 49 feet) above ground and have zero vertical velocity, its bridle will be cut, releasing it from the backshell and parachute. The airbag-protected lander will then be in free fall for a few seconds as it drops toward the ground.

The first bounce may take the airbag-protected lander back up to 15 meters (49 feet) or more above the ground. Bouncing and rolling could last several minutes. By comparison, the airbag-cushioned Mars Pathfinder bounced about 15 times, as high as 15 meters (49 feet), before coming to a rest 2-1/2 minutes later about a kilometer (0.6 mile) from its point of initial impact.

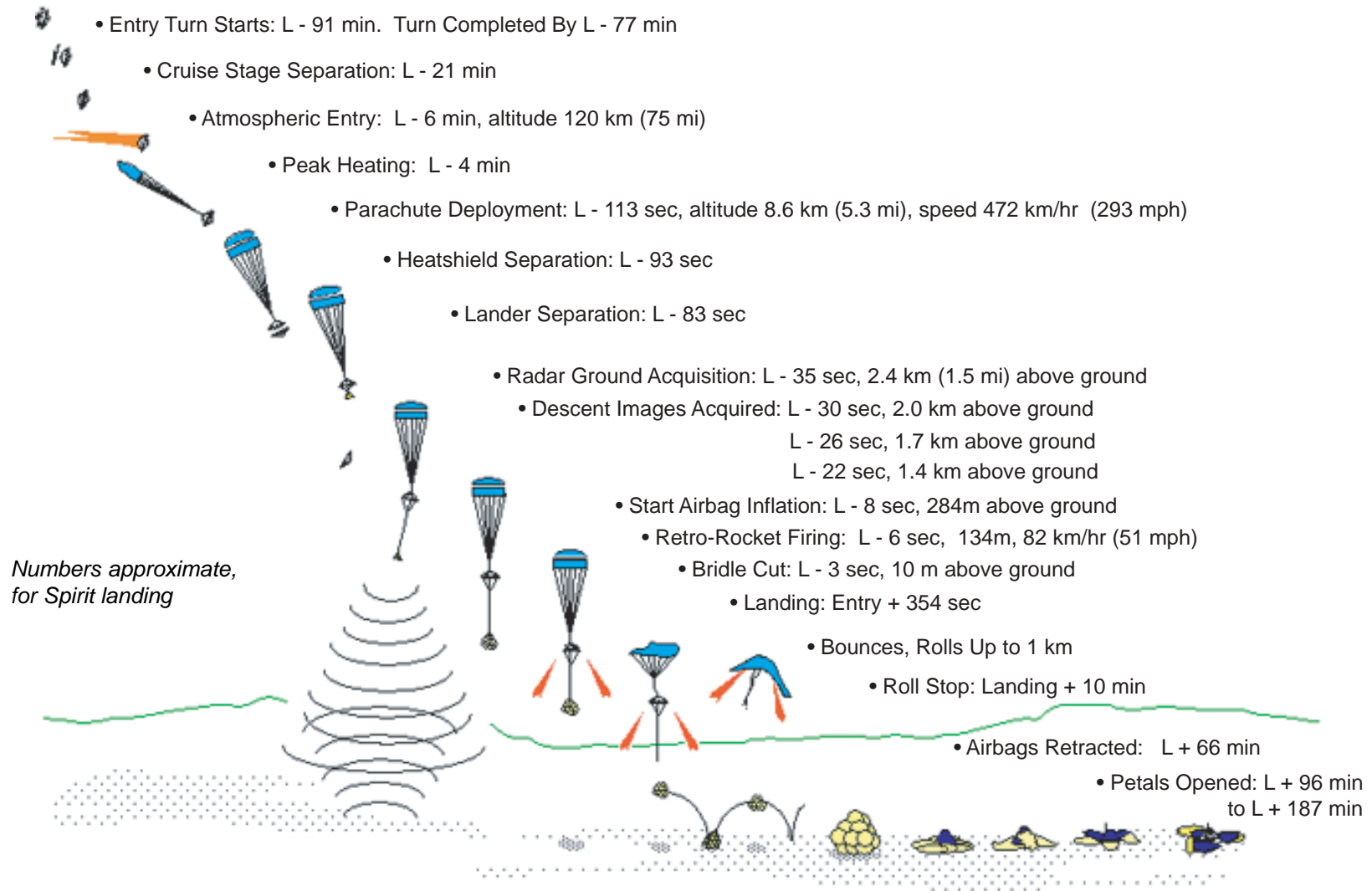
Twelve minutes after landing, motors will begin retracting the airbags, a process likely to take about an hour. Then the lander petals will open. No matter which of the four petals is on the bottom when the folded-up lander stops rolling, the petal-opening action will set all four face up, with the rover's base petal in the center. Opening of the petals is expected to take about 20 minutes if the spacecraft has rolled to a stop with its base petal down, about 35 minutes if one of the three side petals is down, or more than an hour if the rolling ended with the lander nose-down.

Mars Surface Operations

Opening of the four-sided lander will uncover the rover tucked snugly inside. Each rover's first action will be to unfold its solar-array panels. Then, still in a crouch, it will take images of the immediate surroundings with four hazard-identification cameras mounted below the plane of the solar panels.

Since the rovers rely on sunlight to generate electrical power, their operations on the surface will run on a schedule timed to the length of the martian day. A martian day, or "sol," lasts 24 hours, 39 minutes and 35 seconds.

Each rover will need to spend a week or more completing a series of engineering and scientific tasks before moving off its lander.



Entry, descent and landing

Pre-programmed actions before the first martian sunset -- about four hours after landing for each rover -- include taking stereo wide-angle pictures with the hazard-identification cameras on the front and back of the rover, raising the camera mast and beginning to take navigation camera images in each direction around the rover. If time permits, the higher resolution panoramic camera may also take images that first day on the surface. After the first-day images are transmitted to Earth, possibly on the following day, they will help engineers begin to plan the safest route for the rover's later departure from the lander.

The rover will also use the panoramic camera to locate the Sun in the sky, allowing it to calculate its orientation and point its high-gain antenna toward Earth.

Each rover goes through several stages in rising from its crouching position to stand at its full height while still on the lander base petal. First it unfolds its front wheel assembly. Then a lift mechanism raises the rover so its suspension rockers can drop and latch into deployed position. The rover is lowered back down for a check that the suspension system supports its weight. Rear wheels extend. Middle wheels descend. Connecting cables are cut. The flight team sends a "go" command for each step only after thorough checks of the preceding step, so standup requires a number of days.

Once the rover is at its full height atop the lander platform, it will take a 360-degree high-resolution, stereo, color panorama with its panoramic camera and a matching 360-degree panorama with its miniature thermal emission spectrometer before moving off the lander. Scientists will rely heavily on those images to decide which rocks and soils the rover should go examine.

Unlike Mars Pathfinder, when each Mars Exploration Rover rolls off its lander, the lander's role in the mission will have ended. A new chapter in Mars exploration will begin.

In the next few sols after roll-off, the rover will finish checking and calibrating its science instruments and move to whichever nearby rock or patch of soil the science team has selected as the first target by analyzing the panoramic and infrared images taken earlier. The rover will examine each target up close, then begin moving on the following sol toward its next target. Its maximum travel in one day will likely be about 20 meters (approximately 65 feet), possibly less if the landing region is rough or more if the region is quite smooth. The rover will cover less than the maximum on most travel days as it maneuvers itself to avoid hazards on the way.

To coordinate their work with the rovers, flight team engineers and scientists operating the rovers from NASA's Jet Propulsion Laboratory in Pasadena, Calif., will be living on a martian schedule, too. The nearly 40-minute difference from Earth's day length means that, by about two weeks after the rovers land on Mars, team members' wake-up times and meal times will have shifted by about 9 hours. After the second rover reaches Mars, its team will be working on a different martian schedule than the first rover's team because the two chosen landing sites are about halfway around Mars

from each other. When it's noon at Meridiani, it's midnight at Gusev. Each rover will typically transmit each sol's accumulation of data in the martian afternoon. The flight team will analyze that data, refine plans for the next sol's rover activity, and send updated commands to the rover the next martian morning.

Each rover has a prime-mission goal of operating for at least 90 martian sols (92 Earth days) after landing, though environmental conditions such as dust storms could cut the mission shorter.

Mars' distance from the Sun varies much more than Earth's does, and Mars will have passed the closest point to the Sun in its 23-month elliptical orbit about 5 months before the rovers arrive. The distance between Mars and the Sun will therefore increase by about 7 percent between mid-January and mid-April 2004, resulting in two principal consequences for how long the rovers can keep working. The rovers land at the end of summer in Mars' southern hemisphere, and with the onset of autumn the decreasing intensity of solar radiation reaching their solar panels will lessen the amount of electrical power produced. Also, colder nights will increase the need for electrically powered heating to keep the batteries warm enough to work. On top of those factors, a less predictable but possibly most important element limiting the rovers' lifetime will be the accumulation of dust on their solar panels.

Communications

Like all of NASA's interplanetary missions, the Mars Exploration Rover project will rely on the agency's Deep Space Network to track and communicate with both spacecraft. During the critical minutes of arrival at Mars, Spirit and Opportunity will transmit essential spacecraft-status information throughout their atmospheric entry, descent and landing. On the surface of Mars, the rovers will be capable of communicating either directly with Earth or through Mars orbiters acting as relays. The distance between Earth and Mars will increase by about 65 percent between mid-January and mid-April 2004, reducing the rate at which data can be transmitted across space.

The Deep Space Network, which will be 40 years old on December 24, 2003, transmits and receives radio signals through large dish antennas at three sites spaced approximately one-third of the way around the world from each other. This configuration ensures that spacecraft remain in view of one antenna complex or another as Earth rotates. The antenna complexes are at Goldstone in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. Each complex is equipped with one antenna 70 meters (230 feet) in diameter, at least two antennas 34 meters (112 feet) in diameter, and smaller antennas. All three complexes communicate directly with the control hub at NASA's Jet Propulsion Laboratory, Pasadena, Calif. The network served more than 25 spacecraft in 2002.

The network has been preparing to deal with an extraordinary level of demand for interplanetary communications in late 2003 and early 2004. Several missions besides

Spirit and Opportunity will be conducting critical events. Among others, the European Space Agency's Mars Express will enter Mars orbit after dropping the Beagle 2 lander to the surface; Japan's Nozomi orbiter will be arriving at Mars; NASA's Stardust spacecraft will fly by a comet; and NASA's Cassini spacecraft will be nearing its mid-2004 arrival at Saturn. The Deep Space Network has upgraded the capabilities of its antennas at all three complexes and added a new 34-meter antenna at the Madrid complex. That new antenna alone adds about 70 hours of spacecraft-tracking time per week during the periods when Mars is in view of Madrid.

During each Mars Exploration Rover mission's early cruise phase, a low-gain antenna mounted on the cruise stage provided the communications link with Earth. A low-gain antenna does not need to be pointed as precisely as a higher-gain antenna. During early cruise it would have been difficult to keep an antenna pointed at Earth and the solar panels oriented toward the Sun, due to the Sun-Earth angle at that stage of the mission. Later in the cruise toward Mars, the angle between the Sun and Earth shrank, making it possible for the spacecraft to switch to a more directional medium-gain antenna, also mounted on the cruise stage.

Data transmission is most difficult during the critical sequence of atmospheric entry, descent and landing activities, but communication from the spacecraft is required during this period in order to diagnose any potential problems that may occur.

Minutes before the spacecraft turns to point its heat shield forward in preparation for entering Mars' atmosphere, the cruise stage's low-gain antenna will take over again, which will reduce the data transmission rate to 10 bits per second, less than 2 percent of the mid-gain antenna's rate. Through this antenna and later through other low-gain antennas on the backshell, lander and rover, transmissions during the next hour or more will consist of simple signal tones coded to indicate the accomplishment of critical activities. For example, a change in tone might tell controllers when the spacecraft has successfully jettisoned its cruise stage about 15 minutes before hitting the atmosphere. During the descent through the atmosphere, about 36 ten-second signal tones will be transmitted. The signal-to-noise ratio for these tones is very low, especially as the spacecraft gets deeper into Mars' atmosphere. Some or all could be undetectable on Earth or require lengthy processing before they can be identified.

Before its first night on the surface of Mars, each rover may deploy its high-gain antenna for use the following martian morning. Once a high-gain link is established, the rover may be able to communicate directly with Earth at transmission rates greater than 11,000 bits per second.

About a minute before each lander drops to the martian surface, another important communication method -- relay through Mars orbiter spacecraft -- will begin to be used. An antenna mounted on each lander will transmit status information to the orbiting Mars Global Surveyor from the time the descending lander emerges from the backshell until ground impact. If that antenna survives the first bounce, it will continue to relay

information for a few minutes as the lander bounces and rolls to a stop. The orbit of Mars Global Surveyor will be adjusted in preceding weeks to place it over the landing vicinity during those crucial minutes to receive the transmissions. The orbiter will later transmit the data to Earth. This first relay link is designed to provide information for later reconstruction of the events during the spacecraft's descent and landing, not to provide immediate play-by-play notice as they happen.

Throughout each rover's surface mission, a rover-mounted antenna will be able to communicate with Mars Global Surveyor and Mars Odyssey for several minutes once or twice per sol while each of the two orbiters pass overhead via a UHF link at 128,000 bits per second. Plans call for using direct-to-Earth communications for transmissions critical to mission success, but about half the total data returned from the rovers could be relayed via the orbiters. One engineering goal for the project is to demonstrate relay capability at least once with the European Space Agency's Mars Express orbiter, which is due to begin circling Mars in December 2003.

Planetary Protection Requirements

In the study of whether Mars has had environments conducive to life, precautions are taken against introducing microbes from Earth. The United States is a signatory to an international treaty that stipulates that exploration must be conducted in a manner that avoids harmful contamination of celestial bodies.

The primary strategy for preventing contamination of Mars with Earth organisms is to be sure that the hardware intended to reach the planet is clean. Each Mars Exploration Rover spacecraft complied with requirements to carry a total of no more than 300,000 bacterial spores on any surface from which the spores could get into the martian environment. Technicians assembling the spacecraft and preparing them for launch frequently cleaned surfaces by wiping them with an alcohol solution. The planetary protection team carefully sampled the surfaces and performed microbiology tests to demonstrate that each spacecraft meets requirements for biological cleanliness. Components tolerant of high temperature, such as the parachute and thermal blanket, were heated to 110 C (230 F) or hotter to kill microbes. The core box of each rover, containing the main computer and other key electronics, is sealed and vented through high-efficiency filters that keep any microbes inside. Some smaller electronics compartments are also isolated in this manner.

Another type of precaution is to be sure that other hardware doesn't go to Mars accidentally. When the Delta launch vehicle's third stage separated from the spacecraft, the two objects were traveling on nearly identical trajectories. To prevent the possibility of the third stage hitting Mars, that shared course was deliberately set so that the spacecraft would miss Mars if not for its first trajectory correction maneuver, about 10 days later.

Spacecraft

Each of the two Mars Exploration Rover spacecraft resembles a nested set of Russian dolls. The rover will travel to Mars tucked inside a folded-up lander wrapped in airbags. The lander in turn will be encased in a protective aeroshell. Finally, a disc-shaped cruise stage is attached to the aeroshell on one side and to the Delta II launch vehicle on the other.

Cruise stage

The cruise stage provides capabilities needed during the seven-month passage to Mars but not later in the mission, such as a propulsion system for trajectory correction maneuvers. Approximately 2.6 meters (8.5 feet) in diameter and 1.6 meters (5.2 feet) tall, the disc-shaped cruise stage is outfitted with solar panels and antennas on one face, and with fuel tanks and the aeroshell on the other. Around the rim sit thrusters, a star scanner and a Sun sensor.

The propulsion system uses hydrazine propellant stored in two titanium tanks. Since the entire spacecraft spins at about 2 rotations per minute, fuel in the tanks is pushed outward toward outlets and through fuel lines to two clusters of thrusters. Each cluster has four thrusters pointing in different directions.

The star scanner and Sun sensor help the spacecraft determine its orientation. Since the rover's solar arrays are tucked away inside the aeroshell for the trip, the cruise stage needs its own for electrical energy. The arrays could generate more than 600 watts when the spacecraft was about as far from the Sun as Earth is, and generate about half that much as it nears Mars.

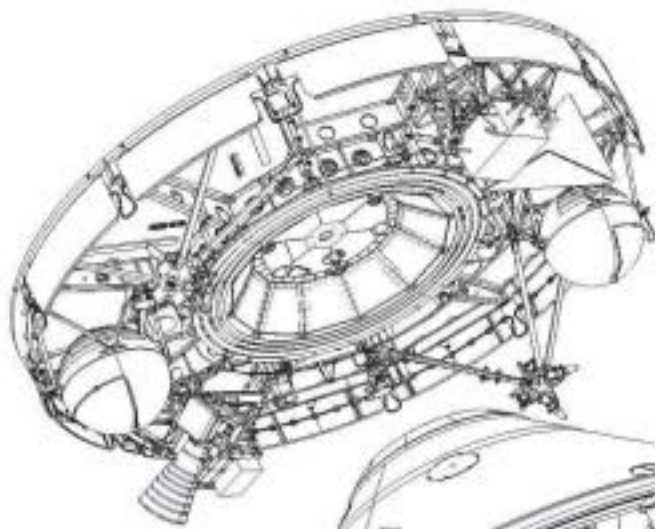
The cruise stage also carries a system for carrying excess heat away from the rover's computer with a pumped freon loop and rim-mounted radiators.

Entry, Descent and Landing System

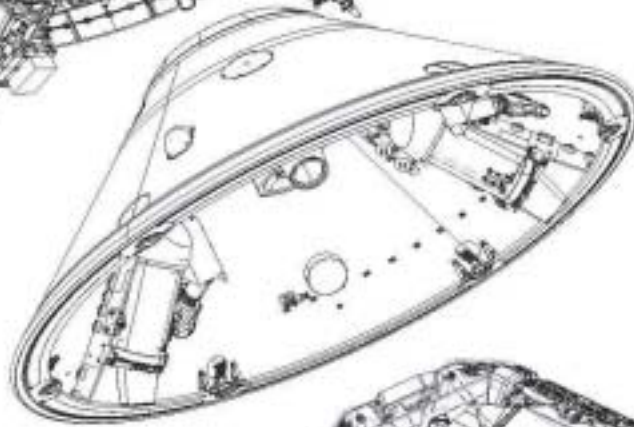
The system for getting each rover safely through Mars' atmosphere and onto the surface relies on an aeroshell, a parachute and airbags. The aeroshell has two parts: a heat shield that faces forward and a backshell. Both are based on designs used successfully by NASA's Viking Mars landers in 1976 and Mars Pathfinder in 1997.

The parachute is attached to the backshell and opens to about 15 meters (49 feet) in diameter. The parachute design was tested under simulated martian conditions in a large wind tunnel at NASA's Ames Research Center near Sunnyvale, Calif.

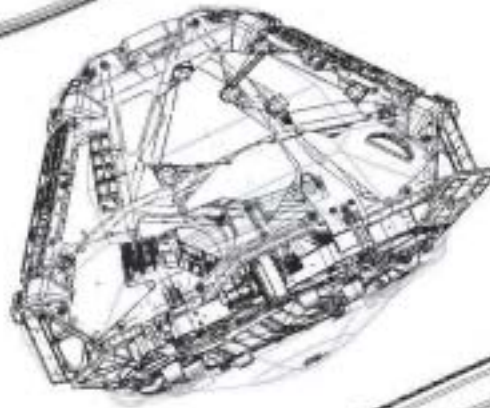
The backshell carries a deceleration meter used to determine the right moment for deploying the parachute. Solid-fuel rockets mounted on the underside of the shell



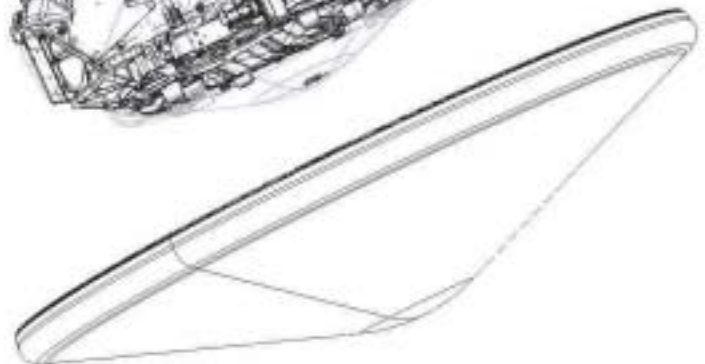
Cruise stage



Back shell



Rover and
lander



Heat shield

Flight system

reduce vertical velocity and any excessive horizontal velocity just before landing.

The airbags, based on Pathfinder's design, cushion the impact of the lander on the surface. Each of the four faces of the folded-up lander is equipped with an envelope of six airbags stitched together. Explosive gas generators rapidly inflate the airbags to a pressure of about 6900 Pascal (one pound per square inch). Each airbag has double bladders to support impact pressure and, to protect the bladders from sharp rocks, six layers of a special cloth woven from polymer fiber that is five times stronger than steel. The fiber material, Vectran, is used in the strings of archery bows and tennis racquets.

Lander

The lander, besides deploying the airbags, can set the rover right-side-up, if necessary, and provides an adjustable platform from which the rover can roll onto Mars' surface. It also carries a radar altimeter used for timing some descent events, as well as two antennas.

The lander's basic structure is four triangular petals made of graphite-epoxy composite material. Three petals are each attached with a hinge to an edge of the central base petal. The rover stays fastened to the base petal during the flight and landing. When folded up, the lander's petals form a tetrahedral box around the stowed rover. Any of the petals could end up on the bottom when the airbag-cushioned bundle rolls to a stop after landing. Electric motors at the hinges have enough torque to push the lander open, righting the rover, if it lands on one of the side petals.

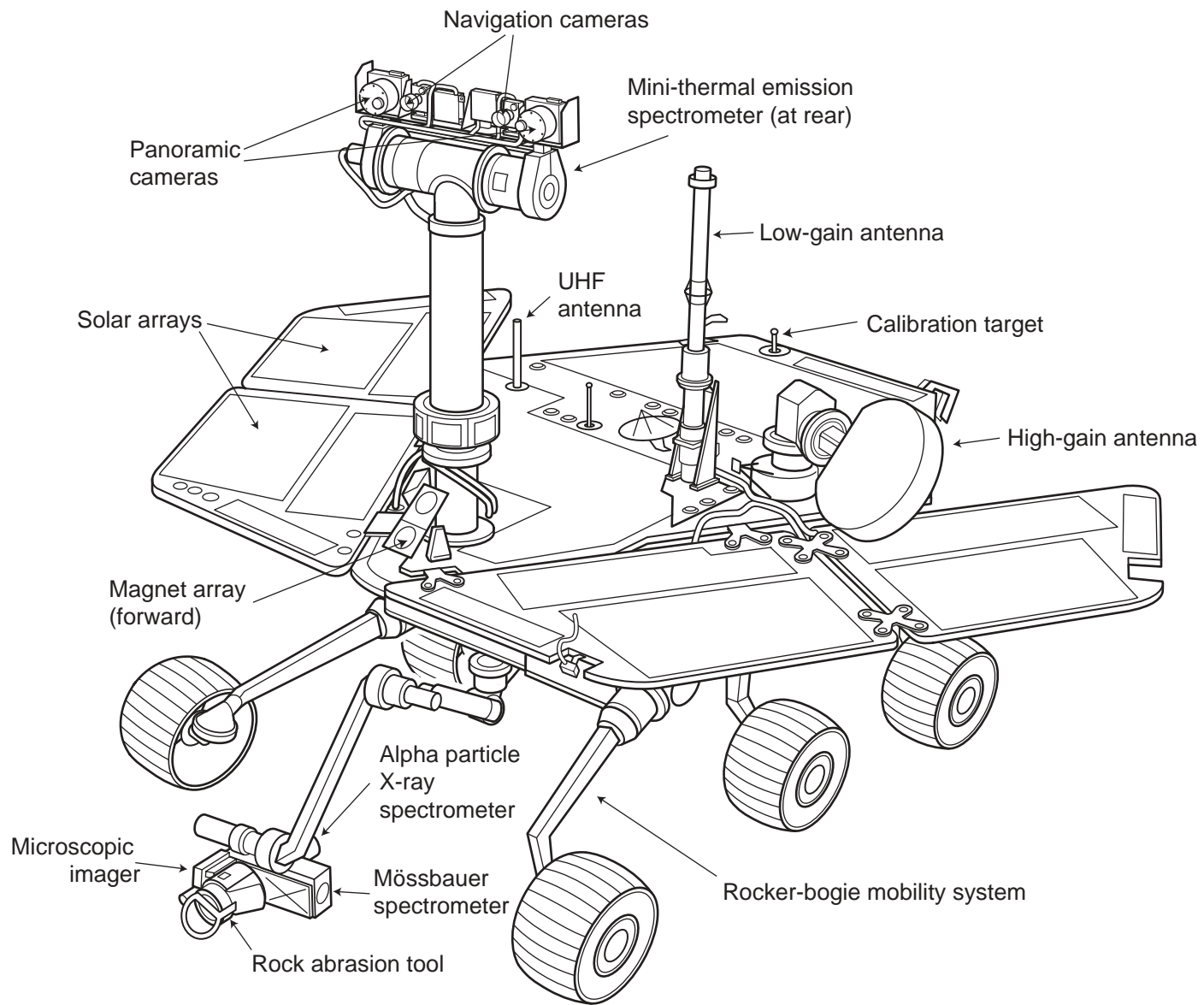
Other motors retract the deflated airbags. An apron made out of the same type of tough fabric as the airbags stretches over ribs and cables connected to the petals, providing a surface that the rover can drive over to get off the lander. The side petals can also be adjusted up or down from the plane of the base petal to accommodate uneven terrain and improve the rover's path for driving off of the lander.

Nearly 4 million people have a special connection to the Mars Exploration Rover project by having their names recorded on each mission's lander. Each of the two landers carries a digital versatile disc, or DVD, containing millions of names of people around the world collected during a "Send Your Name to Mars" campaign, which ended in November 2002.

Rover

At the heart of each Mars Exploration Rover spacecraft is its rover. This is the mobile geological laboratory that will study the landing site and travel to examine selected rocks up close.

The Mars Exploration Rovers differ in many ways from their only predecessor, Mars Pathfinder's Sojourner rover. Sojourner was about 65 centimeters (2 feet) long and



Mars Exploration Rover

weighed 10 kilograms (22 pounds). Each Mars Exploration Rover is 1.6 meter (5.2 feet) long and weighs 174 kilograms (384 pounds). Sojourner traveled a total distance equal to the length of about one football field during its 12 weeks of activity on Mars. Each Mars Exploration Rover is expected to travel six to 10 times that distance during its three-month prime mission. Pathfinder's lander, not Sojourner, housed that mission's main telecommunications, camera and computer functions. The Mars Exploration Rovers carry equipment for those functions onboard and do not interact with their landers any further once they roll off.

On each Mars Exploration Rover, the core structure is made of composite honeycomb material insulated with a high-tech material called aerogel. This core body, called the warm electronics box, is topped with a triangular surface called the rover equipment deck. The deck is populated with three antennas, a camera mast and a panel of solar cells. Additional solar panels are connected by hinges to the edges of the triangle. The solar panels fold up to fit inside the lander for the trip to Mars, and deploy to form a total area of 1.3 square meters (14 square feet) of three-layer photovoltaic cells. Each layer is of different materials: gallium indium phosphorus, gallium arsenide and germanium. The array can produce nearly 900 watt-hours of energy per martian day, or sol. However, by the end of the 90-sol mission, the energy generating capability is reduced to about 600 watt-hours per sol because of accumulating dust and the change in season. The solar array repeatedly recharges two lithium-ion batteries inside the warm electronics box.

Doing sport utility vehicles one better, each rover is equipped with six-wheel drive. A rocker-bogie suspension system, which bends at its joints rather than using any springs, allows rolling over rocks bigger than the wheel diameter of 26 centimeters (10 inches). The distribution of mass on the vehicle is arranged so that the center of mass is near the pivot point of the rocker-bogie system. That enables the rover to tolerate a tilt of up to 45 degrees in any direction without overturning, although onboard computers are programmed to prevent tilts of more than 30 degrees. Independent steering of the front and rear wheels allows the rover to turn in place or drive in gradual arcs.

The rover has navigation software and hazard-avoiding capabilities it can use to make its own way toward a destination identified to it in a daily set of commands. It can move at up to 5 centimeters (2 inches) per second on flat hard ground, but under automated control with hazard avoidance, it travels at an average speed about one-fifth of that.

Two stereo pairs of hazard-identification cameras are mounted below the deck, one pair at the front of the rover and the other at the rear. Besides supporting automated navigation, the one on the front also provides imaging of what the rover's arm is doing. Two other stereo camera pairs sit high on a mast rising from the deck: the panoramic camera included as one of the science instruments, and a wider-angle, lower-resolution navigation camera pair. The mast also doubles as a periscope for another one of the science instruments, the miniature thermal emission spectrometer.

The rest of the science instruments are at the end of an arm, called the "instrument deployment device," which tucks under the front of the rover while the vehicle is traveling. The arm extends forward when the rover is in position to examine a particular rock or patch of soil.

Batteries and other components that are not designed to survive cold martian nights reside in the warm electronics box. Nighttime temperatures may fall as low as minus 105 C (minus 157 F). The batteries need to be kept above minus 20 C (minus 4 F) for when they are supplying power, and above 0 C (32 F) when being recharged. Heat inside the warm electronics box comes from a combination of electrical heaters, eight radioisotope heater units and heat given off by electronics components.

Each radioisotope heater unit produces about one watt of heat and contains about 2.7 grams (0.1 ounce) of plutonium dioxide as a pellet about the size and shape of the eraser on the end of a standard pencil. Each pellet is encapsulated in a metal cladding of platinum-rhodium alloy and surrounded by multiple layers of carbon-graphite composite material, making the complete unit about the size and shape of a C-cell battery. This design of multiple protective layers has been tested extensively, and the heater units are expected to contain their plutonium dioxide under a wide range of launch and orbital-reentry accident conditions. Other spacecraft, including Mars Pathfinder's Sojourner rover, have used radioisotope heater units to keep electronic systems warm and working.

The computer in each Mars Exploration Rover runs with a 32-bit Rad 6000 microprocessor, a radiation-hardened version of the PowerPC chip used in some models of Macintosh computers, operating at a speed of 20 million instructions per second. Onboard memory includes 128 megabytes of random access memory, augmented by 256 megabytes of flash memory and smaller amounts of other non-volatile memory, which allows the system to retain data even without power.

Program/Project Management

The Mars Exploration Rover Project is managed by the Jet Propulsion Laboratory, Pasadena, Calif., for NASA's Office of Space Science, Washington, D.C. At NASA Headquarters, Dr. Edward Weiler is associate administrator for space science, Orlando Figueroa is Mars program director, Dr. Jim Garvin is the lead scientist for the Mars Exploration Program, David Lavery is Mars Exploration Rover program executive and Dr. Catherine Weitz is Mars Exploration Rover program scientist.

At the Jet Propulsion Laboratory, Dr. Firouz Naderi is the Mars program manager, Dr. Dan McCleese is Mars chief scientist, Peter Theisinger is Mars Exploration Rover project manager and Dr. Joy Crisp is Mars Exploration Rover project scientist.

At Cornell University, Ithaca, N.Y., Dr. Steve Squyres is principal investigator for Mars Exploration Rover's Athena suite of science instruments.