Face to Face

NASA's new rover Curiosity will take Mars exploration to an entirely new level.

Emily Lakdawalla

I can only see the eyes of the engineer who hands me booties to cover my shoes, and a paper face mask and hair net for my head. Next comes a white coverall and a second set of cloth boots. After donning a hood and vinyl gloves, I'm covered from head to foot in sterile white cloth, with only my eyes visible. All of this gear is not to protect me, it's to protect Mars, and a spacecraft that's being sent to explore it.

Next I'm guided into an airlock where a hundred little blowers blast me with air, whisking away any dust that may have stuck to my coverall. I leave the airlock and walk through tall double doors into a giant clean room at NASA's Jet Propulsion Laboratory. There it is: Curiosity, NASA's next Mars rover, attended by more white-suited engineers. My first thought — really, everyone's reaction when they first lay eyes on it — is "Wow, this thing is *huge!*"

MAT KAPLAN

HUGE ROVER Author Emily Lakdawalla poses in front of Curiosity during her visit to the Jet Propulsion Laboratory on April 4, 2011. Like everyone who sees the rover for the first time, she was immediately struck by its large size. Her "bunny suit" protects delicate spacecraft components from dust and other earthly contaminants.

with a Giant

CURIOSITY ON MARS NASA's new rover will usher in a new phase of Mars exploration. Spirit and Opportunity proved that liquid water once flowed on the planet's surface; Curiosity will take the next step by investigating whether those wet environments were hospitable for life as we know it.

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Left: **This photo shows from left to right, full-scale models of Spirit (or Opportunity), Sojourner, and Curiosity. Amazingly, the instrument package at the end of Curiosity's robotic arm is almost as large as Sojourner, which rolled across Ares Valles for 83 Mars days (sols) in 1997. *Right*: Clara Ma, a 12-year-old from Lenexa, Kansas, submitted the winning name "Curiosity" in a contest that inspired more than 9,000 entries from students aged 5 to 18. Clara is seen here visiting JPL's Mars Yard on June 8, 2009.**

Curiosity's body plan is similar to its predecessors Spirit and Opportunity, but whereas those two were golf-cart scale, Curiosity is an automobile. The six enormous wheels connect to the body through a suspension system made of black pipes as thick as my arm. That body is a fat white box, its metal skin held on with rows of rivets like those on an aircraft. I'm barely tall enough to see over the rover's back, and I have to crane my neck to look up at the top of its camera mast.

Curiosity won't win any beauty contests. But seeing it looming so large before me gives me newfound respect; this pile of parts has come together into a businesslike machine, constructed for heavy duty. It's nearly ready to trek up dusty red hills, take spectacular images, and drill into Martian rocks. Its mission is to move our study of Mars beyond the search for water, toward the search for life.

Piecing Together Mars's Story

Curiosity will cap a tremendously successful program of Mars exploration that has unfolded over the past 15 years. Every orbiter and rover launched since 1996 has been sent to answer the same basic questions, and each successful mission has contributed a piece to the puzzle. How long ago was liquid water present on Mars's surface? How much was there, and how long did it last? Where did it come from, and where did it go? And did it persist long enough for life to develop?

In 1997 NASA's Mars Global Surveyor mapped the global mineral patterns for the first time. This orbiter didn't find the carbonates that geologists had hoped would be the telltale signs of ancient oceans, but it spotted an unusual concentration of gray, crystalline hematite in Meridiani Planum. On Earth, gray hematite usually forms near hot springs, where volcanic activity heats groundwater. Four years later, Mars Odyssey peered beneath Mars's dust, discovering abundant hydrogen all over Mars, in vast deposits of ice lurking just below the surface. Mars's missing water was everywhere, just hidden from optical cameras.

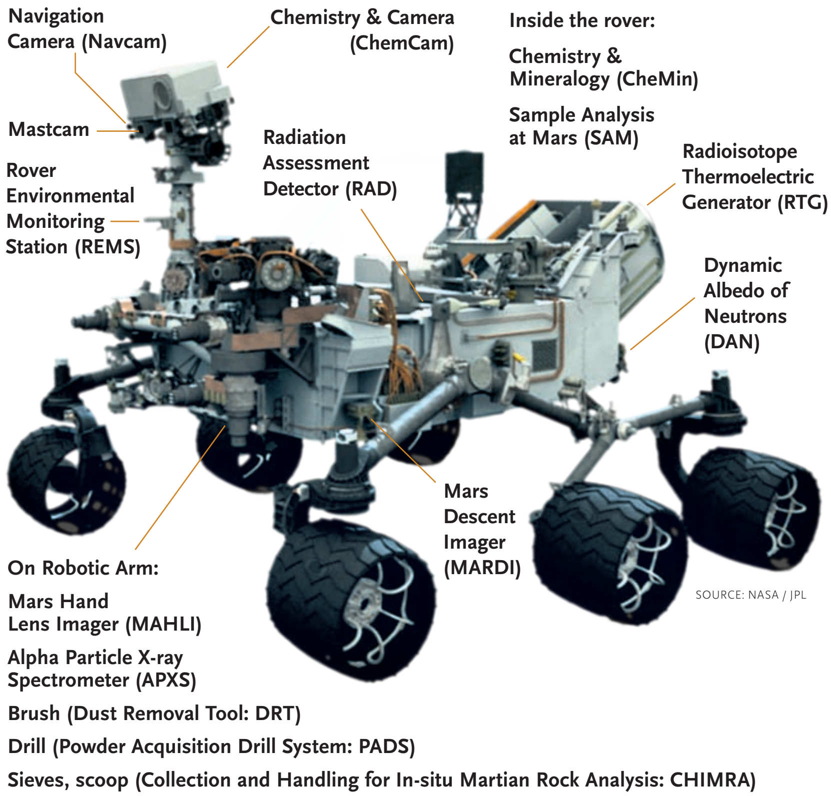
Then NASA sent two rovers to "ground truth" the orbital finds. Spirit landed in Gusev Crater, which must have been a lake, at least briefly, when water gushed through a deep channel that emptied into the crater floor. Opportunity landed in the middle of Meridiani Planum to investigate the hematite signal. The rovers succeeded beyond everyone's hopes, proving that liquid water once played an important role on Mars. Opportunity found sandstones and evaporites that had been saturated by very salty, highly acidic water. Spirit found a fossil fumarole, where silica-rich water percolated near a volcanically heated vent, and it discovered sulfate salts that may have been deposited much more recently.

On May 25, 2008, Phoenix landed in Mars's frozen north. This stationary lander ground-truthed the Odyssey evidence for near-surface ice, finding a hidden water-ice table just centimeters below the surface (*S&T:* October 2008, page 22).

Over the past several years, spectral data from the European Space Agency's Mars Express orbiter and NASA's Mars Reconnaissance Orbiter (MRO) have revealed from space, at last, tiny exposures of rock containing minerals that must have formed in water: clays, carbonates, sulfates, and salts, among others (*S&T:* July 2009, page 22). These deposits are ancient and very deeply buried; they are only revealed through rare, small windows where the overlying volcanic rock and windblown sediments have been eroded away.

The combined work of four orbiters, two rovers, and a polar lander has given scientists a new understanding of Mars's geologic history, and the role that water played in it. A long time ago, while it still retained its infant heat, Mars was quite wet, at least underground. This early, wet era can be read from clays found at the bases of deeply incised canyon walls, such as those of Mawrth Vallis. Then the internal heat from Mars's formation waned and produced a last, violent burst of volcanic activity. Volcanoes spewed out gas as well as rock, water vapor, and more noxious gases that combined in the atmosphere to create acid rain. Mars's global chemistry changed. It no longer made clays; instead, sulfate minerals precipitated out of acid waters, forming deposits such as those at Meridiani.

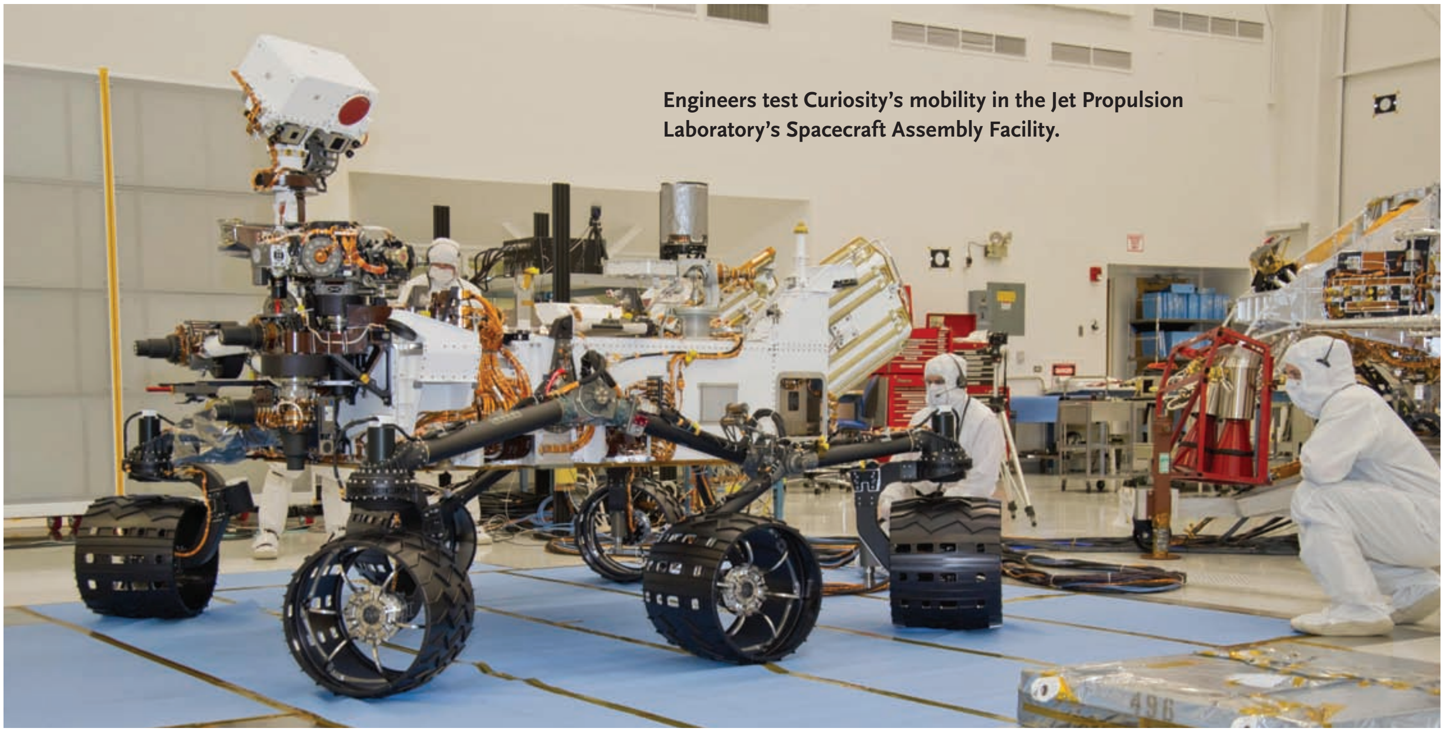
Last came the longest, quietest era of Mars's history, the cold, mostly dry, oxidizing environment we see today. Periodically, as the orientation of Mars's spin axis varies from perfectly upright to nearly sideways, summers may get warm enough to allow thin films of water to coat soil grains and facilitate reactions with atmospheric molecules to form new minerals, sulfates, and oxides. Though it's possible that Martian microbes exist in tiny underground refugia, the watery environments of the sulfate or clay eras offered better prospects for life. Curiosity will take the logical next step in the Mars program by going up to sulfate- and clay-rich rocks and figuring out whether Mars was a habitable place when they formed.



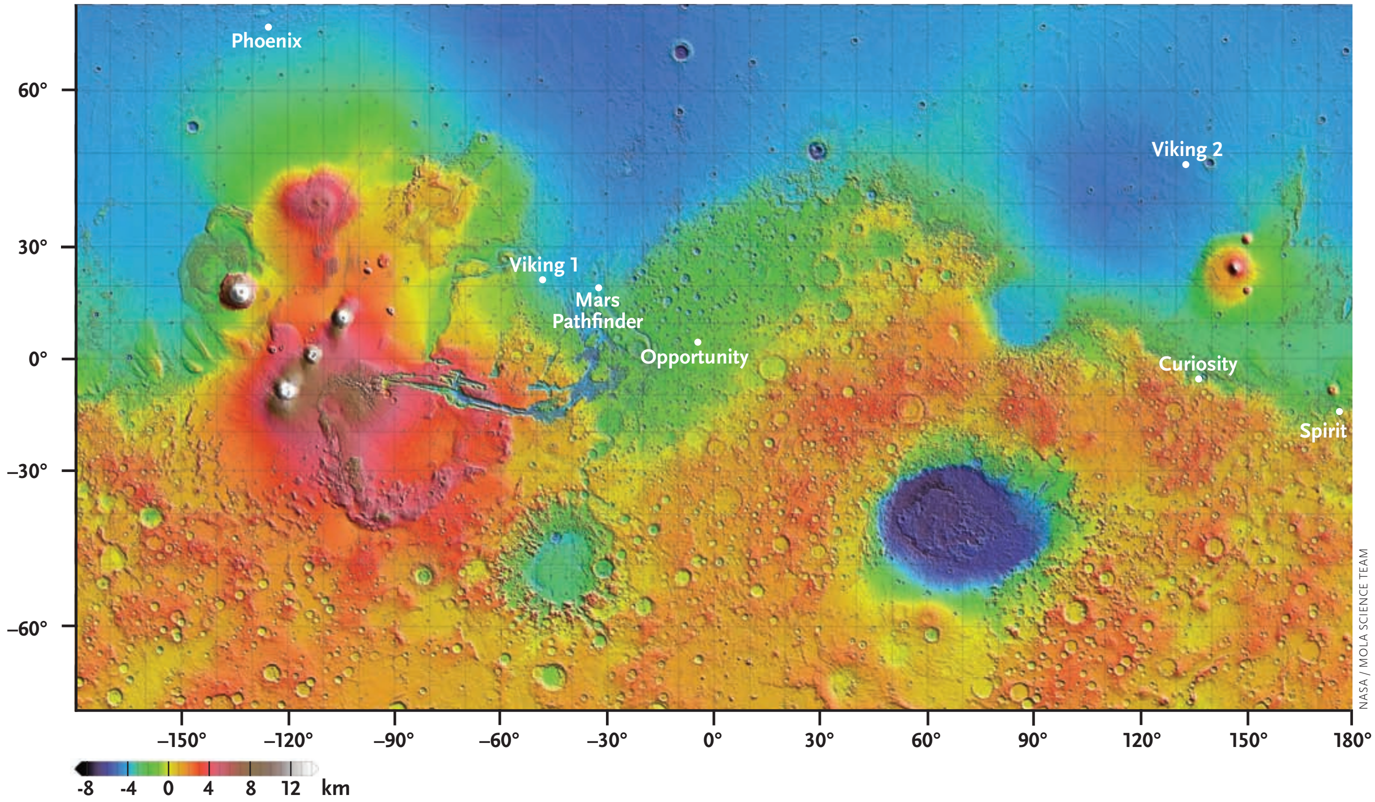
SOURCE: NASA / JPL

Habitable, Not Inhabited

Curiosity isn't designed to detect life, living or dead. Finding fossils even in Earth's 3-billion-year-old rocks is like looking for a needle in a haystack. Looking for life and not finding it on Mars, which is what happened with the


Engineers test Curiosity's mobility in the Jet Propulsion Laboratory's Spacecraft Assembly Facility.

NASA / JPL-CALTECH



THE TARGET Curiosity will land in Gale Crater, located just 4.6° south of the equator and right on the boundary between Mars's flat, low-lying northern hemisphere and heavily cratered southern highlands. The laser altimeter aboard NASA's Mars Global Surveyor orbiter provided the data for this topographical map.

Viking landers, won't tell you for certain whether or not Mars ever harbored life. Instead, Curiosity is designed to study ancient rocks in order to determine what the environment was like when they formed, and whether the ingredients for life — water, a source of energy, and organic materials — were present, and for how long.

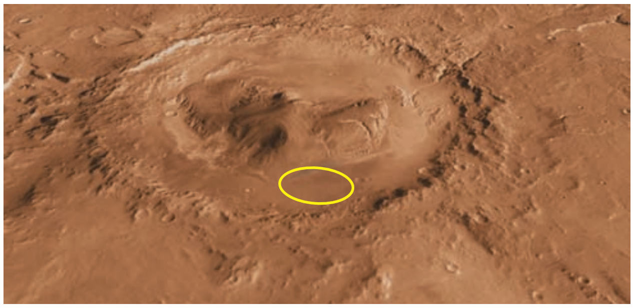
Thanks to the thorough orbital mapping, Curiosity is guaranteed to find rocks that formed in the presence of water. Finding and measuring organic materials will be harder. The problem is that water, a necessary ingredient for life as we know it, is also a powerful agent for destroying evidence of life's existence. If an organism is entombed in water-rich sediment, its complex organic compounds of carbon, oxygen, hydrogen, and sulfur are destroyed, oxidized to inorganic chemicals such as carbon dioxide. These substances may, in turn, be incorporated into the rock as a carbonate mineral, leaving no sign of its former chemical richness. That's why fossils are so rare on Earth.

Organic compounds in meteoroids are falling to Mars's surface even now, riding within carbonaceous chondrites. They are possibly providing the raw materials for current life (if it exists), but these organics may not last long. One of Phoenix's startling discoveries was the potent oxidizer *perchlorate* in the Martian soil. To search for organics, Viking had to bake the sample; if there was perchlorate in the Martian soil, the heat could have split apart any organics into tiny inorganic compounds.

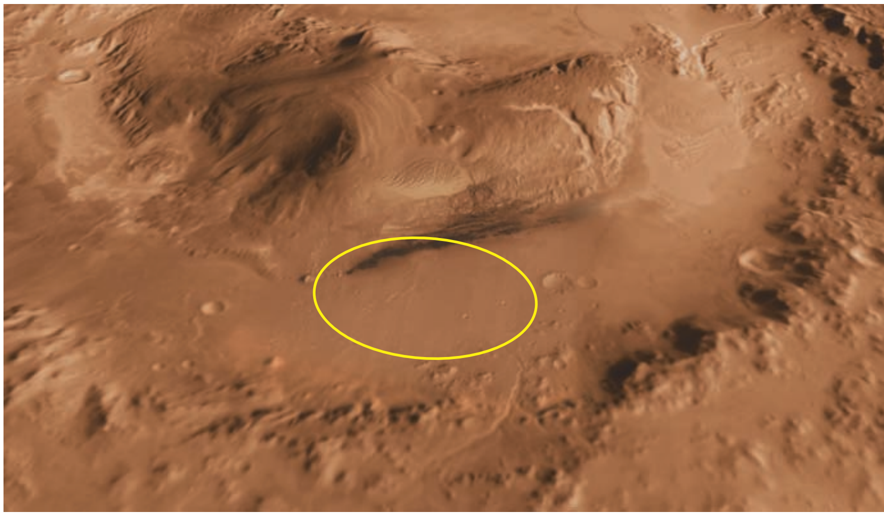
Curiosity can look for organics without wetting its samples. So in order to understand a place and time on Mars where life had any chance of starting, Curiosity will be sent to explore Gale Crater — a landing site that was carefully selected to contain ancient, water-lain sediments that formed in the unusual sort of environment where organic materials have a chance of being preserved. The 154-kilometer-wide (96 miles) crater is near Mars's equator and on the "dichotomy boundary" that separates the northern lowlands from the southern highlands. Gale has long intrigued Mars scientists because of its central mound, a 5-km-high stack of intricately layered rocks. Mars Express and MRO have found signs of both sulfates and clays at different levels within this mound.

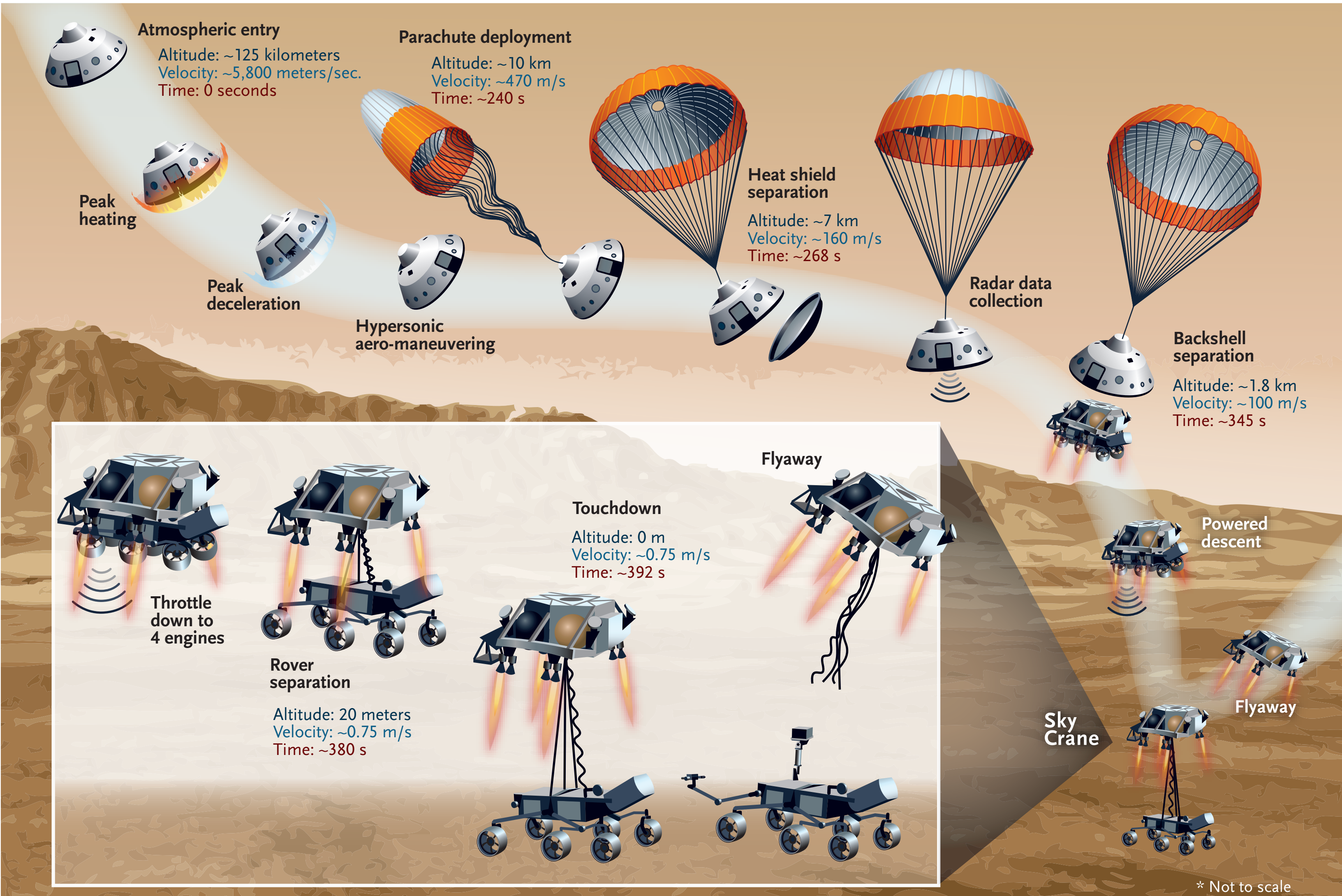
Delays and Overruns

Mars Science Laboratory, as Curiosity was originally called, was selected for flight in 2004. Transforming Curiosity from blueprint to reality required numerous revisions to both software and hardware. Development of the avionics proved to be extremely difficult for such a complex vehicle with so many redundant systems, and the original 2009 launch schedule left insufficient time for testing. The new sample-acquisition and handling systems were also redesigned several times. Originally planned as a rock corer and crusher, the acquisition system had to be changed to a rock-powdering drill. In fact,



GALE CRATER After years of discussion, NASA selected a small target region inside the Connecticut-sized Gale Crater. Orbital observations of the base of the 5-km-high central mound revealed layers of sulfates and clays that likely required water to form. Powered by heat from the radioactive decay of 4.8 kg of plutonium dioxide, Curiosity has a good chance of surviving long enough to venture outside its 20×25-km landing ellipse. North is at bottom.





HOLD YOUR BREATH! Due to its 900-kg (2,000-pound) weight, Curiosity is too heavy to land on Mars using prior methods. Engineers devised Sky Crane, an entirely new way to put a heavy science package on the surface of Mars. If successful, it could pave the way for more ambitious future missions. Sky Crane has been exhaustively tested, and engineers are confident it will work. Watch an animation of the landing sequence at http://youtu.be/E37Ss9Tm36c.

S&T: LEAH TISCIONE / SOURCE: NASA / JPL-CALTECH

Selected Mars Rovers and Landers Compared

Mars landers	Mass (kg)	Number of science instruments*	Average energy used per sol	Mission goal	Mission duration
Viking lander	576	8	1,600 watt-hours (RTG)	Conduct a detailed scientific investigation of Mars, including a search for life.	Lander 1: 2,245 sols Lander 2: 1,281 sols
Sojourner	10.6	1	100 w-hr (solar array)	Demonstrate technology, and determine the elemental abundances in surface rocks.	83 sols / 104-meter traverse
Spirit/Opportunity	185	5	900 w-hr (solar array)	Determine the history of climate and water at sites where conditions may once have been favorable to life.	Spirit: 2,210 sols / 7,730-meter traverse, Opportunity: 2,700+ sols and 33,500+ meter traverse and counting
Curiosity	900	10	2,400 w-hr (RTG)	Explore and quantitatively assess Mars as a potential habitat for life, past or present.	Nominal: 687 sols / 20,000-meter traverse (and possibly longer)

*Instrument totals do not include cameras used for engineering purposes such as hazard avoidance, nor do they include instrument positioning tools such as camera masts, robotic arms, or sampling equipment.

modifications to the sample-handling systems were still being made as the rover was undergoing final testing in early 2011, in response to the experiences of Mars Phoenix.

Phoenix showed that experts had failed to accurately predict how Martian soil would behave. The stuff clumped and clogged the hoppers and sieves that were supposed to funnel samples to Phoenix's analytical instruments. Curiosity's sample-handling mechanisms have been tested for Phoenix-like clumpy soil, so they'll be ready to deal with it on Mars.

But it was a different problem that finally broke the 2009 launch schedule. The mission team had planned to develop a new technology of dry-lubricated motors with titanium parts that would enable the rover to drive at low temperatures, without spending precious power to heat the motors first, permitting more activity in colder weather. Those efforts failed, and they had to go back to the tried-and-true wet-lubricated steel motors. This change occurred so late in Curiosity's development — just a year before the intended launch — that there was insufficient time to build and test the performance of all of the 32 motors necessary to operate Curiosity's arm and wheels (and the duplicates needed for the test rover on Earth). It didn't make the October 2009 launch opportunity. And when you miss the bus to Mars, you have to wait 26 months for the next one. The upcoming launch window runs from November 25th to December 18th.

The challenges, redesigns, and delays cost a lot of money. A brief NASA interest in belt-tightening in 2007 removed some of the rover's science capabilities, including a zoom function on its main cameras, but it failed to deflate the ballooning price. Originally estimated to cost around $1 billion, the mission may wind up costing taxpayers as much as $2.5 billion.

Sky Crane

Pathfinder, Spirit, and Opportunity all bounced down within folded landers that were enveloped by a cocoon of airbags. But with a weight more than twice that of Spirit and Opportunity combined, Curiosity is far too heavy for that approach. There is no way to launch Curiosity to Mars inside a lander big enough to protect it; and even the most durable airbags would shred under the force of its impact. Instead, Curiosity needs to decelerate under the power of retrorockets, but somehow end up separate from its rocket stage, ready to roll, without the benefit of a protective lander.

JPL engineers devised a solution termed "sky crane." A heat shield and parachute will slow Curiosity's descent. It will jettison its heat shield, and then, at an altitude of 1,500 meters (4,900 feet), it will separate from its parachute, leaving the rover attached to the bottom of a descent stage that will fire eight rockets to bring the rover to a hover. Then comes sky crane: the descent stage will deploy cables to lower the rover gently toward the ground as its wheels and legs deploy, until the wheels rest safely on the surface. Curiosity will cut the tethers to its

SKY CRANE The mother ship will use retrorockets to hover like a helicopter about 20 meters above the surface. It will gently lower Curiosity to the ground on cables.

NASA / JPL-CALTECH

A Mission Worth the Price

The general shape of Curiosity's traverse from landing site to steeper terrain will be mapped out far in advance, thanks to MRO's complete coverage of the Gale Crater landing site with aerial photos and topographic maps. Scientists can identify rock targets of interest from space, if they're more than half a meter or so across.

From the moment of the landing between August 6 and August 20, 2012, Gale's central mountain will dominate Curiosity's southern horizon. As it approaches the mound's toe, it will encounter the most ancient rocks, which contain the clays. As Curiosity climbs, it will also be traveling forward through Martian time, into sulfate minerals. Thus the mission's scientists will be reading Mars's watery history in the order in which it happened. Curiosity will examine its environment with an unprecedentedly powerful (not to mention large) assemblage of instruments and tools.

As the rover drives, it will image its surroundings with its color Mastcams and also remotely analyze rock compositions with ChemCam. Once the team has identified an interesting rock from orbit or with Curiosity's remote sensors, the rover will be commanded to approach it, placing it within reach of its robotic arm. If imaging with its MAHLI microscopic imager and elemental analysis with its APXS spectrometer indicate that the rock is worth sampling, the rover will bore into it with its percussive powdering drill.

Transferring a sample from inside a rock to inside the rover will be an arduous, tedious ordeal, especially in the mission's early days, before operators have built confidence in their methods through experience. Pulverized rock powder must be augured up the drill and transferred through a tube into a set of chambers and sieves called CHIMRA. Gravity will guide the rock powder through and out of CHIMRA's mazelike chambers, as the rover performs a series of moves to reorient the turret that its engineers refer to jokingly as "rover tai chi." These maneuvers will parcel out the drilled material into samples of the desired volume, with the preferred grain size, to deliver to two inlet ports on the rover's body that lead to its analytical instruments.

NASA / JPL-CALTECH

PARACHUTE TEST In April 2009 engineers tested the rover's parachute in the world's largest wind tunnel, at NASA's Ames Research Center. The parachute is nearly 16 meters (52 feet) across. Most of the fabric is nylon.

Curiosity's huge size is a product mostly of the requirement that it haul around CheMin and SAM, two complex instruments of a type that are commonly used in geological laboratories on Earth but that have never before been sent to another planet. CheMin will yield the first definitive identifications of the mineral and elemental abundances of sampled rocks and soils. Mineralogy can only be inferred from Spirit and Opportunity's measurements; CheMin can measure mineral composition directly.

SAM focuses on the molecular and elemental chemistry of elements such as carbon, oxygen, nitrogen, sulfur, and hydrogen that are present in Mars's atmosphere and within the planet's rocks and soil. If Curiosity finds organic materials, SAM will make that discovery. SAM can also sniff the atmosphere for methane (CH_4) to see if concentrations and isotopic ratios change over time. Curiosity scientists have no expectation for finding evidence of

Listen to a BONUS AUDIO INTERVIEW

To listen to an audio interview with Curiosity Deputy Project Scientist Joy Crisp, visit SkyandTelescope.com/Curiosity.

mother ship, and the descent stage will pitch at an angle and fly away from the rover as far as its remaining fuel will take it, crashing hundreds of meters away.

This Rube-Goldberg-like autonomous sequence frightens many people, but its development gave engineers relatively few headaches. The landing technology was essentially ready for action for the originally planned October 2009 launch.

With its guided descent, the spacecraft can steer as it passes through the atmosphere to stay closer to its planned trajectory. That produces significantly less uncertainty about where it will touch down. Navigators define a "landing ellipse" as an area within which the craft is about 99% likely to touch down. Spirit and Opportunity had landing ellipses of about 80×20 km, mostly due to uncertainty in the variable density of Mars's atmosphere on landing day. That uncertainty sharply limited the options for those rovers' landing sites to very flat regions. But Curiosity's landing ellipse is only 20×25 km, and that might be narrowed further during flight. The ellipse fits comfortably inside a flat area on the northern floor of Gale Crater, between the crater wall and the central 5-km-high mound. Curiosity is designed to drive far enough to exit its landing ellipse. So once Curiosity has landed safely and completed its commissioning, it will drive southward, making tracks for the enticing layered mound.

life on Mars, but if SAM finds methane gas, the team will be very interested to compare concentration and isotopic measurements with those on Earth, where most atmospheric methane has a biological origin.

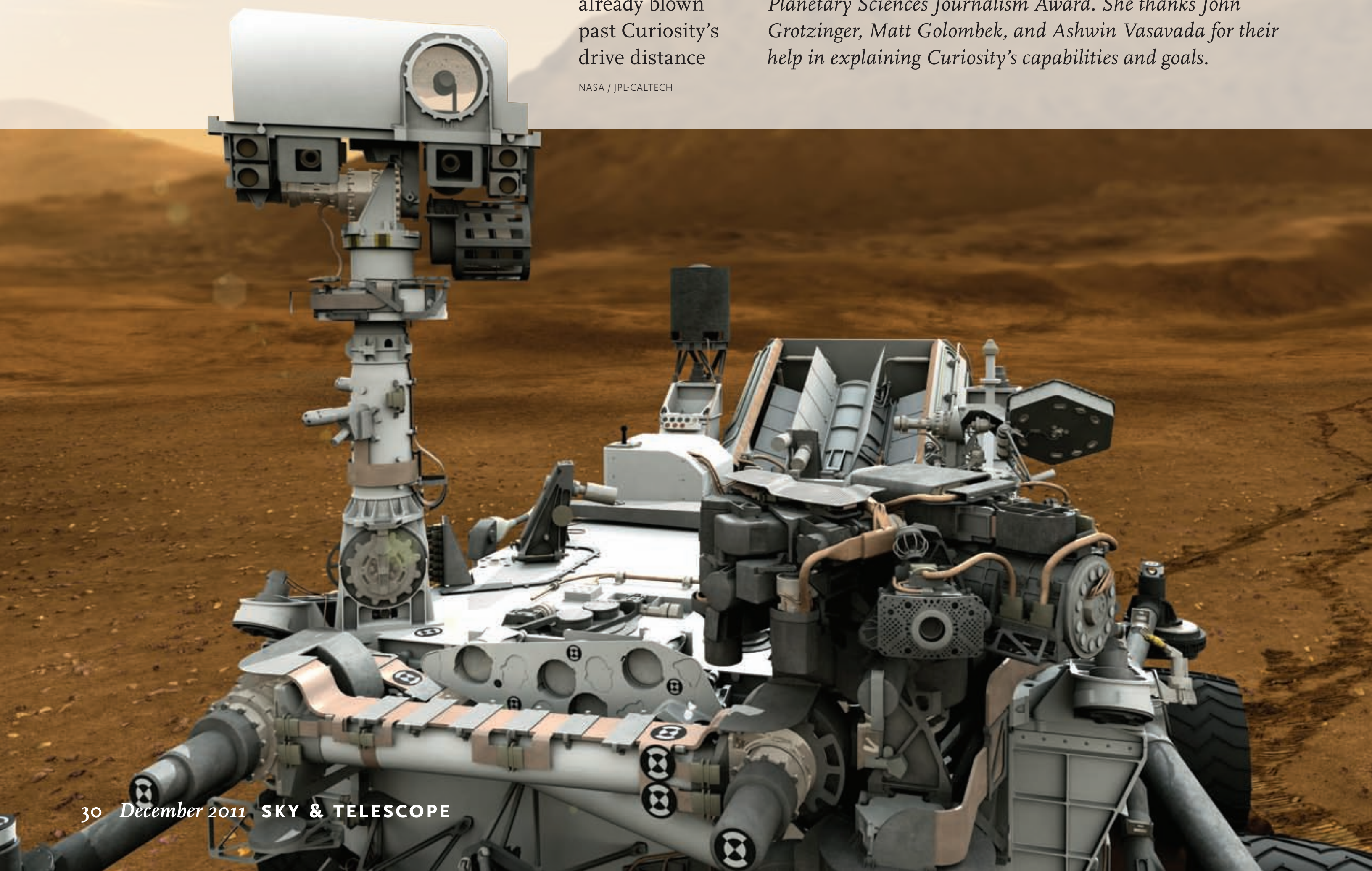
The mission has established flexible targets of between 15 and 50 samples over 8 to 20 km of driving during the primary mission, planned to last one Mars year (687 Earth days). Less driving would leave time for more samples, and vice versa. If the rover survives the primary mission in good health, there will be plenty more Martian history to explore.

Spirit and Opportunity's bat-wing solar panels give them grace and symmetry. But Curiosity is nuclear powered. The housing for its radioisotope thermoelectric generator (RTG) protrudes awkwardly from the rover's posterior, where it can safely radiate surplus heat. The RTG can theoretically provide sufficient power to operate the rover for at least 14 Earth years, although the decay of its plutonium will decrease its performance over time. Both SAM and CheMin have reusable sample chambers designed for more than 70 analyses, so an extended mission will be highly productive.

Despite its ambitious goals, Curiosity has a tough act to follow in Spirit and Opportunity. With an odometer reading of 33.5 km at press time, Opportunity has already blown past Curiosity's drive distance goal. And Opportunity may even reach those elusive clay minerals as it explores Endeavour Crater, perhaps even before Curiosity lands on Mars. Beating Curiosity to clays is not an official goal for Opportunity, but its close-knit team of scientists and engineers has imbued that rover with a plucky personality and are rooting for its success. Spirit inspired similar love but also exasperation, surviving tortuous struggles to climb mountains, only to suffer mechanical breakdowns at the most dramatic possible moments.

Will the ungainly Curiosity rover inspire the same kind of devotion? It's unclear yet what its personality will be. After I'd listened to one of the engineers proudly describe Curiosity's capabilities for awhile, I asked whether his peers referred to Curiosity as "it," or as "she." He answered that not many colleagues anthropomorphize the rover or refer to it as female (as is traditional for spacecraft). But he predicted that the situation would begin to change now that the rover is being readied for launch. As it's tested and flown, operators will find Curiosity to have its own unique set of quirks. "It doesn't have a soul yet," he said. "But it will." ✦

S&T contributing editor and Planetary Society blogger ***Emily Lakdawalla*** *is the 2011 recipient of the Jonathan Eberhart Planetary Sciences Journalism Award. She thanks John Grotzinger, Matt Golombek, and Ashwin Vasavada for their help in explaining Curiosity's capabilities and goals.*



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