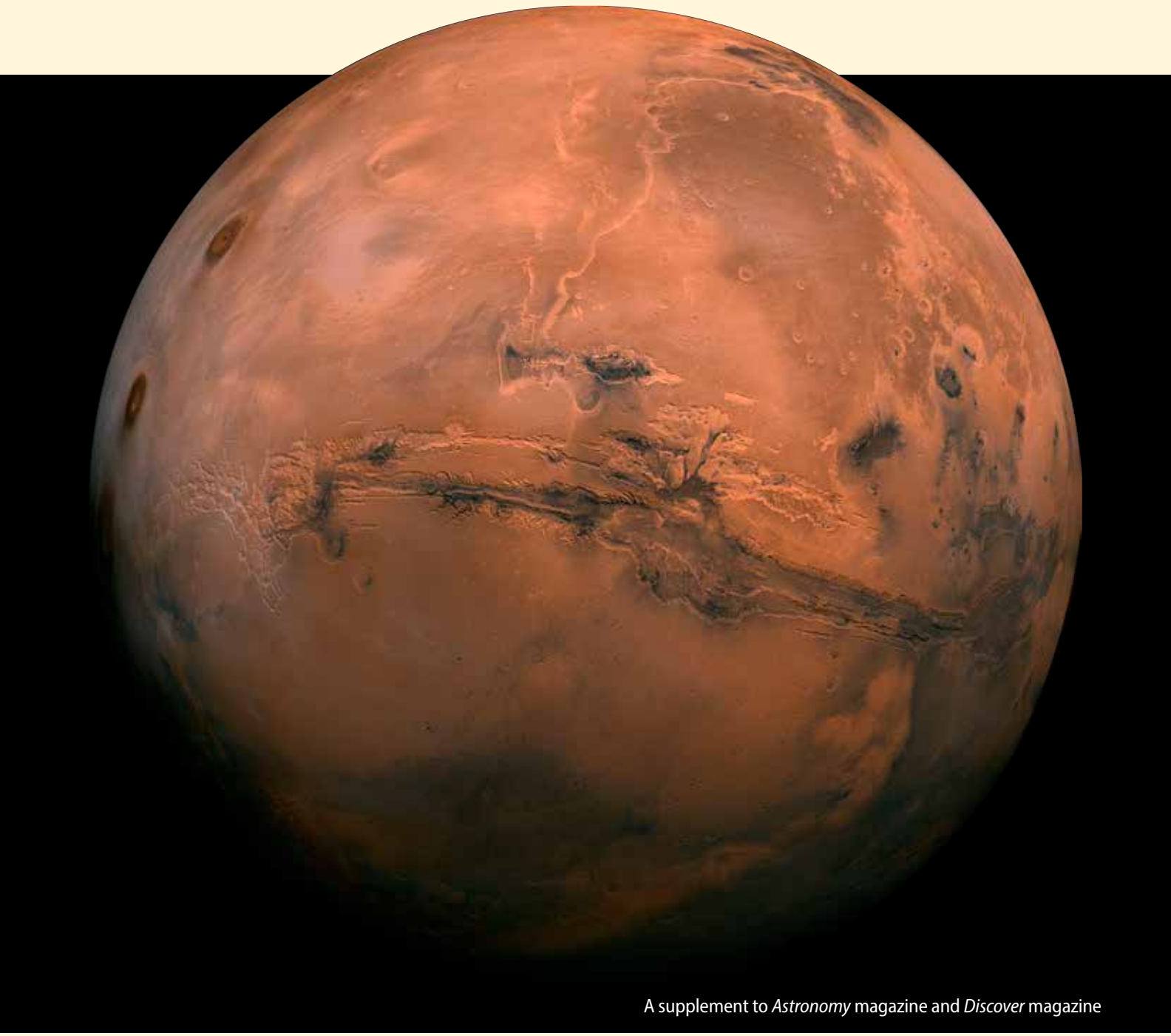
Astronomy magazine

MARS AT OPPOSITION

The Red Planet appears its largest since 2005. Catch up on the latest science and observing tips.



A supplement to *Astronomy* magazine and *Discover* magazine

NASA/JPL-CALTECH

A fresh look

Seven spacecraft — two on the ground and five circling above — continue to scour the Red Planet for signs of ancient water and conditions conducive to life.

by Jim Bell

Mars— the latest international hotspot. Although that designation might seem a bit far-fetched, it seems less so if you consider the seven spacecraft now operating at the Red Planet and the five more being readied to go as scientific tourists. Robotic emissaries from Earth have occupied Mars continuously since 1997, and the missions currently active date back to 2001. This is the busiest, most fruitful, and most exciting time in the history of Mars exploration. The armada of spacecraft delivers a steady stream of data to planetary scientists that has led to important discoveries but also raised intriguing new mysteries.

The ground truth

Two rovers — Opportunity and Curiosity — continue to return sensational scientific information from the surface. Opportunity, which landed in January 2004 and celebrated its 4,000th martian day, or sol (one sol equals about 1.03 Earth days), in April 2015, surpassed the 26.219-mile (42.195 kilometers) distance of a marathon a month earlier. The rover's science team, working on the planet's surface virtually through the robot, is now exploring the eroded rim of an ancient impact crater called Endeavour.

NASA orbiters previously had detected evidence for clay minerals on the rim of this 14-mile-wide (22km) crater. Opportunity has sampled those clays and found abundant evidence for mineral-filled veins containing gypsum. Both substances provide further proof that groundwater and perhaps even surface water once existed on this part of Mars. The clays, in particular, suggest that some of this water could have been comparable to fresh water on Earth rather than the mildly acidic water inferred from Opportunity's earlier discoveries at Eagle, Endurance, and Victoria craters.

Even though Curiosity is the new kid on the block, having landed in August 2012, it surpassed its 1,000th sol in late May 2015. The sophisticated rover is now exploring the lower slopes of Mount Sharp, the looming 3-mile-high (5km) mountain of layered sedimentary rocks inside Gale Crater that drew the rover team to this landing site. Mount Sharp's layers record important parts of Mars' early warmer and wetter history. Curiosity's mission is to decipher that record in detail, layer by layer if need be, to learn as much as possible about the Red Planet's potential past habitability.

Like its predecessors, Opportunity and Spirit (which ceased transmissions in March 2010), Curiosity has found and continues to find ample evidence that both surface and groundwater once flowed on Mars. Recently revealed signs of that water include swarms of mineral-rich veins created when moving groundwater deposited materials that filled fractures in rocks. Other fresh discoveries of ancient water involve the detection of the iron-oxide mineral hematite,

at MARS

NASA's Curiosity rover poses for a selfie on Mount Sharp in January 2015. This vista combines dozens of images captured by a camera that sits at the end of the rover's robotic arm. (Ground controllers positioned the arm so it would be out of the mosaic's frames.) The rim of Gale Crater appears at the top right of this image, and the peak of Mount Sharp is at the top left. NASA/JPL-CALTECH/MSSS

NASA's Opportunity rover captured this panorama from the rim of Endeavour Crater in January 2015. The clay materials Opportunity has found at Endeavour imply that groundwater once existed in this area. NASA/JPL-CALTECH/CORNELL UNIVERSITY/ARIZONA STATE UNIVERSITY

Curiosity continues to explore the layered rocks on Mount Sharp's lower slopes. In September 2014, the rover drilled its first hole on the mountain to collect samples for onboard analysis. The hole measures 0.63 inch (1.6 centimeters) across and 2.6 inches (6.7cm) deep. NASA/JPL-CALTECH/MSSS

Curiosity discovered these two-toned mineral veins on the lower slopes of Mount Sharp in March 2015. They apparently formed when water flowed through fractured rock and deposited minerals in the cracks. The veins appear as a network of ridges, each of which measures up to 2.5 inches (6 centimeters) thick and half that in width. NASA/JPL-CALTECH/MSSS

NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA

The Mars Reconnaissance Orbiter captured Curiosity and its tracks as it trekked through layered deposits in April 2014. The rover (arrow) appears blue in this image's exaggerated color.

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formed when water alters basaltic volcanic rock, and jarosite, an iron- and sulfur-bearing mineral that can arise when volcanic rock interacts with mildly acidic water.

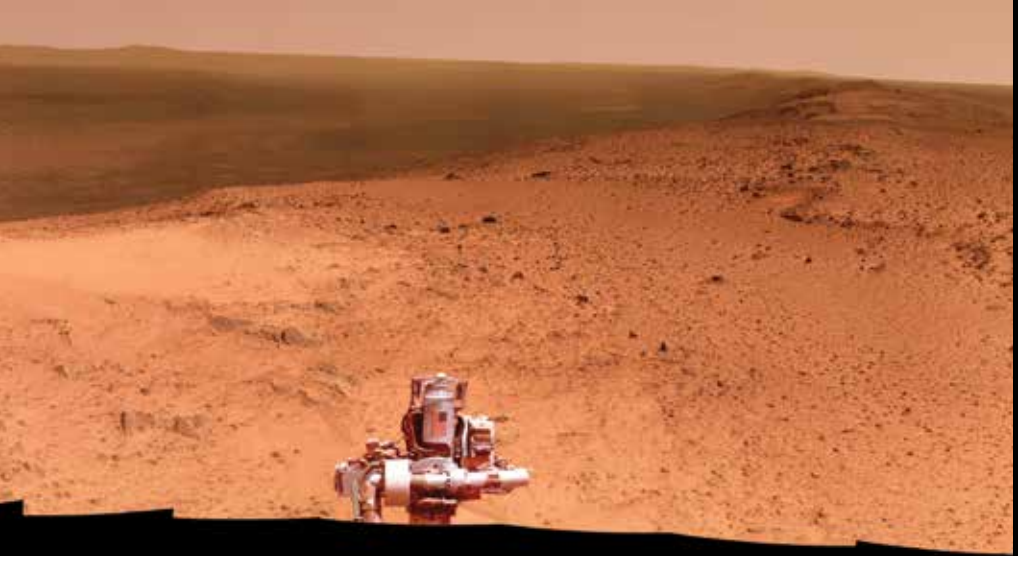
These kinds of mineral discoveries coupled with spectacular images of finely layered sandstones and mudstones (fine-grained sedimentary rocks that typically form in water's presence) are beginning to paint a clearer picture of Mount Sharp. Scientists now suspect it is an enormous accumulation of sediments deposited in an ancient lake that periodically filled Gale Crater early in the planet's warmer and wetter history. It's an exciting hypothesis, but Curiosity needs to do a lot more climbing and sampling of additional layers to fully test it and tease out more details of the habitability of that possible ancient lake.

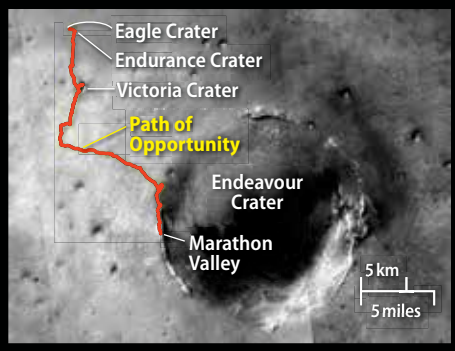
Curiosity's measurements of the martian atmosphere have been no less thrilling. A detailed search for methane early in the mission came up essentially blank, but in late 2013 the rover observed a tenfold spike in the abundance of this gas followed by a quick return to near-zero levels. Are there localized sources of this simple organic compound on Mars, perhaps a byproduct of geological processes such as a reaction between water and subsurface rock? Or could it be from some subsurface biological process? Although the latter seems unlikely, mission scientists don't want to discount any possibilities until they perform additional measurements and analyses.

The view from above

In the meantime, five active probes — three from NASA, one from the European Space Agency (ESA), and one from the Indian Space Research Organization (ISRO) — are plying the orbital seas above Mars. Using a variety of sophisticated instruments, these spacecraft are scouting the planet's geology, mineralogy, and atmospheric composition as well as searching for landing sites for future rovers and surface probes.

The most venerable of this quintet, and indeed the longest-operating spacecraft ever to explore the Red Planet, is NASA's Mars Odyssey. Since arriving in polar orbit in 2001, Mars Odyssey has circled the world nearly 60,000 times. In the process, it has discovered water ice in the south polar cap, found evidence that melting snow carved some geologically recent gullies, and helped find landing sites for Spirit and Opportunity.





NASA/JPL-CALTECH/MSSS/NMMNHS; *ASTRONOMY*: KELLIE JAEGER

On March 24, 2015, Opportunity completed its first marathon when it passed the 26.219-mile (42.195 kilometers) mark on Mars' surface. The journey took more than 11 years and carried the rover from its landing site in Eagle Crater to the rim of Endeavour Crater.

It also has built up an impressive collection of chemical and mineral maps of the surface that have helped scientists understand the distribution of ground ice as well as new details about the planet's geology and mineralogy. Thanks to the mission's longevity, the Mars Odyssey team recently was able to complete a global set of infrared geologic maps at a resolution of around 330 feet (100 meters) per pixel. These are the highest-resolution maps of surface properties yet created for Mars and are helping researchers differentiate bedrock from sediments and dust-covered surfaces.

The second-oldest orbiter is ESA's Mars Express, which went into an elliptical orbit around the planet in late 2003. The spacecraft's instruments have been mapping the geology (in 3-D), mineralogy, and atmospheric chemistry of Mars during each close pass ever since. They have discovered minerals that can form only in the presence of water, vast amounts of water ice beneath the martian surface, and lava flows that might be only a few million years old. The High Resolution Stereo Camera continues to crank out spectacular topographic maps of volcanoes, craters, and canyons across the planet. The 3-D images are helping scientists understand the details of past geologic processes and adding key information to the search for future landing sites.

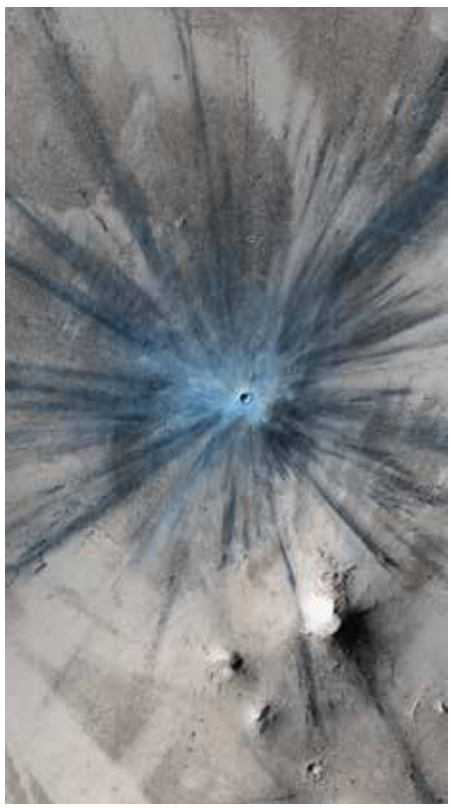
The Mars Reconnaissance Orbiter (MRO) ranks as NASA's most prolific Mars orbiter yet. Since it arrived in its circular polar orbit in 2006, the spacecraft has returned more than 30 terabytes of data — more than all other Mars missions combined. MRO captures the sharpest details from orbit and has helped planetary scientists map Mars' mineralogy and subsurface structure. The probe has found buried glaciers and the clay-rich minerals that led Curiosity's science team to Gale Crater.

The mission's Context Camera has imaged more than 90 percent of the martian surface at a resolution of about 20 feet (6m) per pixel. An even higher-resolution camera, the High Resolution Imaging Science Experiment, helps scientists study intricate details in small gullies apparently created by seeping water, identify fresh impact craters formed within the past decade, and even spot alien spacecraft parts on the surface — most recently, the likely wreckage from the 2003 crash of ESA's Beagle-2 lander.

The new arrivals

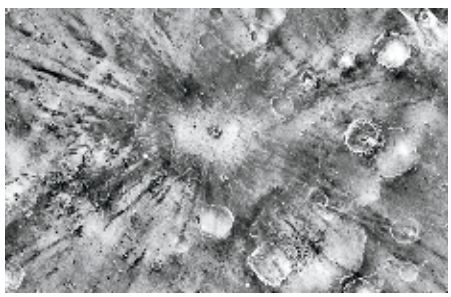
Two rookies recently joined these three veteran orbiters. ISRO's Mars Orbiter Mission (MOM), also called Mangalyaan, is India's first interplanetary mission. And when it entered Mars orbit in September 2014, that nation became the first to achieve success at the Red Planet on its first try. MOM's primary purpose is to test basic spacecraft and instrument capabilities as well as ISRO's ability to journey to Mars and operate successfully from orbit there. But in the process of demonstrating these technologies and skills, the spacecraft has captured some stunning color photos of the martian surface and atmosphere from its highly elliptical orbit.

NASA's newest artificial martian satellite arrived two days before MOM. The space agency designed the Mars Atmosphere and Volatile EvolutioN (MAVEN) orbiter specifically to study the Red Planet's atmosphere and especially the way it interacts with the stream of high-energy particles emitted by the Sun known as the solar wind. One of the mission's main goals is to test the hypothesis that the solar wind slowly eroded ancient Mars' thicker and warmer atmosphere, perhaps after the planet's core solidified and its early magnetic field disappeared. Mars once had a



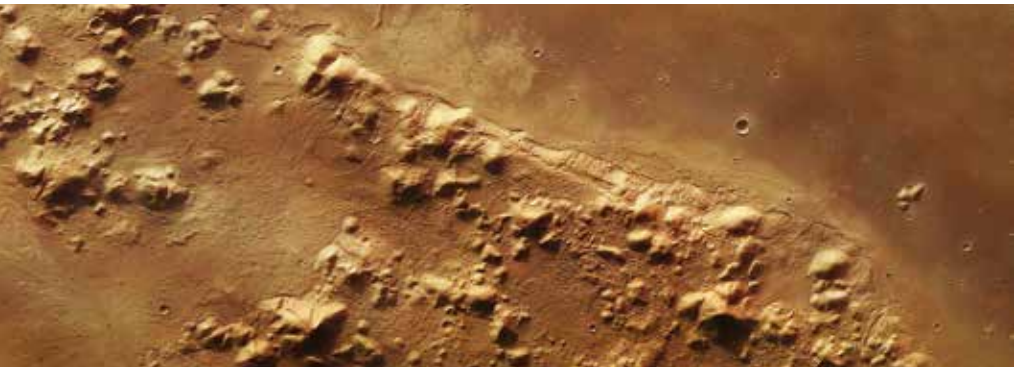
NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA

NASA's Mars Reconnaissance Orbiter captured this impact crater, which formed in the past five years. This enhanced-color close-up reveals the 100-foot-wide (30 meters) scar and debris that spreads up to 9 miles (15 kilometers) away.



NASA/JPL-CALTECH/ARIZONA STATE UNIVERSITY

Scientists working with Mars Odyssey data recently created the highest-resolution global map of martian surface properties, in which warm areas appear bright and cool regions dark. This tiny section highlights the 4.3-mile-wide (6.9 kilometers) impact crater Gratteri.



The European Space Agency's Mars Express satellite captured this complex region of isolated hills and ridges in the southernmost section of Phlegra Montes in the planet's northern hemisphere. The probe's High Resolution Stereo Camera snapped this scene in October 2014 at a resolution of about 50 feet (15 meters) per pixel. ESA/DLR/FU BERLIN

strong magnetic field, a discovery made by NASA's earlier Mars Global Surveyor mission, but no longer does. Will MAVEN find that this is why Mars evolved into the cold, dry world it is today?

Early science results from MAVEN include the surprising discoveries of an auroral glow lower in the atmosphere than scientists expected and a dust layer much higher in the atmosphere than expected. Some researchers have suggested that the absence of a shielding magnetic field could allow the solar wind to penetrate deeper before it initiates the aurora. The origin of the high-altitude dust remains a mystery, however. Is it dust from Mars lofted upward by strong atmospheric currents? Or could it be dust raining down from the martian moons, Phobos or Deimos, or from streams of cometary dust? Scientists plan to test these and other hypotheses with additional MAVEN observations perhaps augmented by other orbiters.

Comet encounter

MAVEN and the other active spacecraft had front-row seats to one of 2014's most exciting astronomical events — October's close encounter between Mars and Comet Siding Spring (C/2013 A1). Although the comet's icy nucleus would miss the planet by approximately 87,000 miles (140,000km), astronomers predicted that its extended envelope would pass right over Mars and intermingle with its atmosphere.

Cometary impacts and near-misses happen rarely, but they can teach us a lot about planetary atmospheres and comets themselves. Scientists remember vividly when Comet Shoemaker-Levy 9 collided with Jupiter in 1994, a dramatic celestial fireworks show that provided new information about the giant planet's cloud layers as well as the nature of high-speed impacts. Indeed, researchers studying the February 2013 meteor explosion over Chelyabinsk, Russia, analyzed the event using computer models developed partially from the Shoemaker-Levy 9 impact. Would Siding Spring deliver a similar show, or a show at all? No one was sure how the comet, which originated in the distant Oort Cloud, would behave.

MAVEN had perhaps the best view, and its science team commanded the spacecraft to observe the comet both before and after its Mars encounter. Although the probe's highly sensitive ultraviolet instruments are optimized to study the planet's upper atmosphere and aurorae, scientists often use these same kinds of tools to study comets.

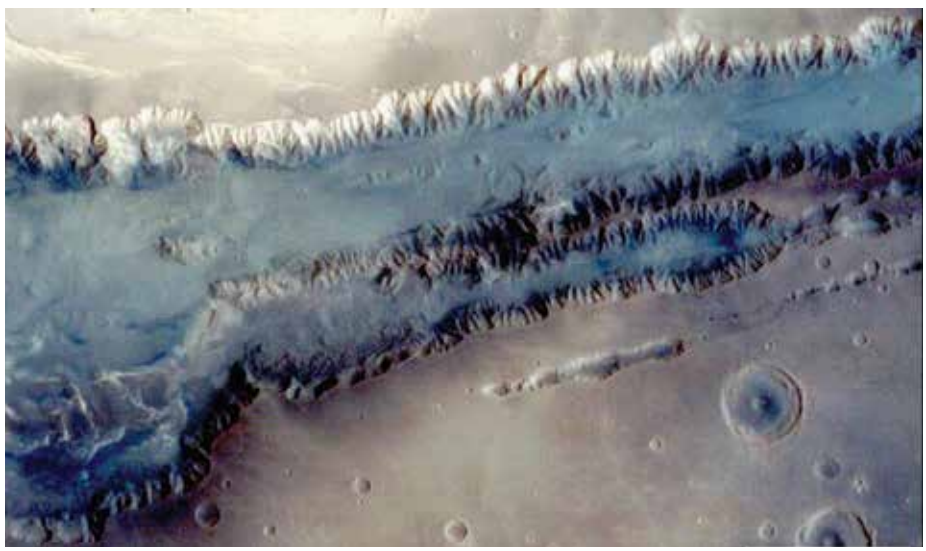
There was some danger in making these observations, however. High-speed impacts by even tiny chunks of ice or dust ejected by the comet could cause a catastrophic failure of spacecraft components. To minimize the risk, mission managers manipulated MAVEN's orbit to "hide" the spacecraft behind Mars during the comet's closest approach. Better safe than sorry, especially since MAVEN had arrived at Mars just a month earlier. As the comet swooped past the Red Planet, controllers of the other Mars orbiters similarly protected their probes.

The spacecraft delivered a treasure-trove of information about Siding Spring. MAVEN, MRO, and Mars Express all detected strong increases in the number of electrically charged atoms in Mars' upper atmosphere. These ions formed as the comet's dust and gas slammed into the planet, stripping the atoms of electrons. MAVEN's ultraviolet instruments captured the bright glow from the comet's magnesium and iron ions, for example, and then the probe sampled these and other ions as it circled back around the planet. These observations were the first direct measurements scientists had ever made of ionized material from an Oort Cloud comet in a planetary atmosphere.

Comet Siding Spring also must have produced an impressive meteor shower. Unfortunately, the cameras on Opportunity and Curiosity were built to image the daytime surface and not the nighttime sky. Their relatively short exposures didn't capture any meteors and rendered the comet as little more than a fuzzy blob.

Future exploration

Six national space agencies have now launched more than 40 missions to Mars since the first attempt in 1960. Only about half of these proved even partially successful, attesting to the difficulty in exploring the Red Planet. Despite the challenges, however, humans continue to send robotic



Although India designed its Mars Orbiter Mission only to demonstrate technology, the spacecraft has returned some stunning images since arriving in September 2014. This one shows part of Valles Marineris, a canyon system that spans 2,500 miles (4,000 kilometers) and digs 4.5 miles (7km) deep. ISRO

NASA's Mars Atmosphere and Volatile Evolution spacecraft discovered a martian aurora three months after it arrived in September 2014. This artist's concept shows the probe's ultraviolet imager capturing the glow. NASA/UNIVERSITY OF COLORADO

The martian armada targeted Comet Siding Spring (C/2013 A1) in October 2014. In this artist's concept, NASA's three orbiters watch as comet material crashes into the atmosphere and ionizes atoms from the deep-space visitor. NASA/JPL-CALTECH

The dark reddish lines angling to the upper left in this Mars Reconnaissance Orbiter image are active flows extending downhill from Hale Crater's central peaks. Scientists think the flows might be caused by seeping water. NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA

emissaries and even have started thinking about plans for the first crewed missions, perhaps as soon as the 2030s.

Indeed, several missions in the works have direct connections to the eventual human exploration of Mars. In 2016, NASA will launch Insight, a lander based on the successful design of the 2008 Phoenix spacecraft. Insight will deploy a sensitive seismometer and heat-flow probe to search for signs of seismic or geothermal activity. Is Mars geologically dead or still active? Insight is designed to find out during its two-year primary mission, which will start in late 2016.

Also in late 2016, ESA, in cooperation with the Russian space agency, Roscosmos, will deploy the ExoMars Trace Gas Orbiter. This spacecraft will study methane and other minor atmospheric gases that might provide clues to the planet's geologic and possible biologic evolution. As part of the mission, the orbiter will deploy an entry, descent, and landing demonstration module called Schiaparelli. ESA expects Schiaparelli to prove the agency's ability to make a controlled landing on Mars' surface. If it survives touchdown, the spacecraft will conduct a science mission lasting two to eight sols designed to study the landing site's atmospheric conditions.

ESA will attempt its first Mars rover, once again in cooperation with Roscosmos, with ExoMars. Currently scheduled for a 2018 launch, the rover will use cameras, spectrometers (which analyze elemental composition), radar, and a drill to study the geological history of a past watery environment on Mars.

Understanding the detailed nature of the martian environment is also at the forefront of NASA's plans for its next Mars rover, tentatively called Mars 2020 after the year of its planned launch. To save money, some 80 to 90 percent of the rover will be constructed from spare parts from Curiosity. NASA envisions Mars 2020 as a first step in a longer-term set of missions designed to bring samples back from Mars. The rover will feature high-resolution cameras, spectrometers, and drilling/coring systems that will allow it to physically sample a variety of surface materials and cache them for potential transport to Earth on future missions.

Many planetary scientists believe that the next major leap in Mars exploration, and a critical step toward eventual human exploration of the Red Planet, will be to bring these carefully selected samples of soils and rocks to Earth for detailed geochemical and biological analysis. Are there chemical compounds in the soils that could degrade space-suit seals or other systems needed for life support? Is martian dust toxic to the human respiratory system in some unanticipated way? Can explorers extract resources such as oxygen and water from common Mars surface materials?

The future of Mars exploration looks as promising as the present. Future rovers may employ a small helicopter to scout ahead, finding features of interest and allowing ground controllers to plot the best driving routes. NASA/JPL-CALTECH

A primary goal of the Mars 2020 mission is to collect samples that can begin to answer such questions. Engineers are currently working on ways to cache these samples and decide the best way to return them to our planet.

I believe the human fascination with Mars stems in part from the fact that the deeper we look at it, the more we see parallels with our own world's past. Early in its history, Mars was much more Earth-like than it is today. It was warmer and wetter — at least in places. Heat from the Sun, geothermal sources, and impacts provided abundant energy, and the rain of asteroid and comet impacts that pelted Mars and the rest of the planets provided a steady supply of organic molecules.

Water, energy, and organic molecules are the key ingredients needed for life as we know it. Past and present missions have helped us discover that Mars was indeed a habitable world long ago. Upcoming missions, including the first human explorers in the not-too-distant future, will be working to up the ante, trying to find out if Mars was — or still is — not just habitable, but inhabited.

Observe MARS at its best

The brightness of our celestial neighbor will have you seeing red through your scope this spring. **by Michael E. Bakich**

This Hubble Space Telescope image of Mars, taken June 26, 2001, remains one of the best ever. At the time, the Red Planet was 43 million miles (68 million kilometers) from Earth.
NASA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

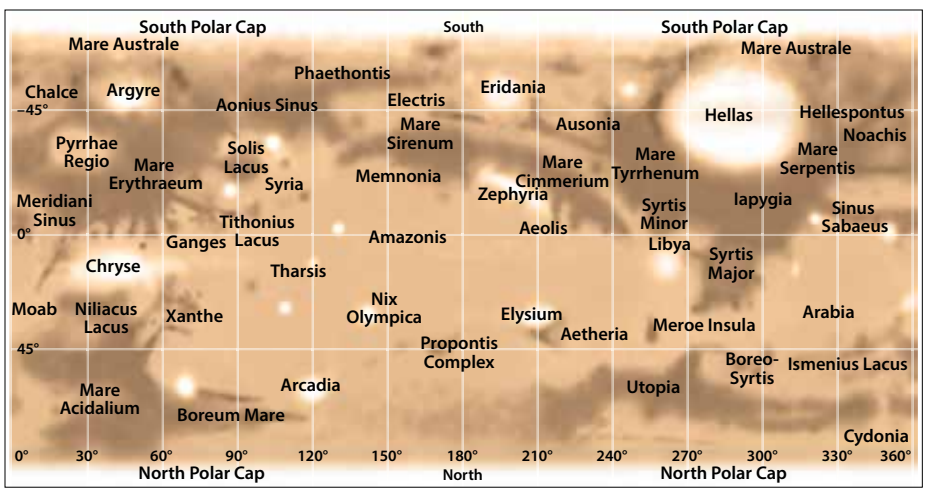
IN THE 1980s, A FRIEND described observing Mars to me as "two long years of waiting for four to six weeks of panicked activity," referring to Mars' closest approach to Earth every 26 months. How true that statement was. But equipment is better now, so you don't have to wait for the Red Planet to reach its largest size. If you have a 4-inch or larger scope and steady air above your observing site, you will see details on the martian disk. Start looking on the next clear night, and then every clear night after that. Because before you know it, this apparition of Mars will be history.

The numbers game

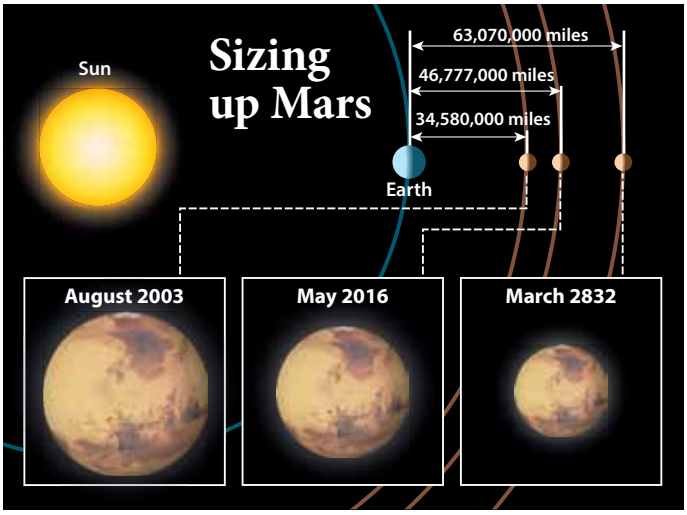
Amateur astronomers concentrate on observing Mars near its opposition. At this point in its orbit, Mars rises in the east as the Sun sets, making it visible in our sky all night. Some oppositions are more favorable than others because Mars lies closer to the Sun (and therefore to Earth). The 2016 martian opposition occurs at 11h17m UT (7:17 A.M. EDT) May 22.

The point of closest approach between Mars and Earth occurs eight days after opposition. At 21h34m UT (5:34 P.M. EDT) May 30, Mars lies 0.5 astronomical unit, or 46,777,000 miles (75,280,000km), from Earth. Closest approach marks the date when Mars' diameter is greatest — 18.6". This size is nearly 7" smaller than when the Red Planet was at its closest point in recent history in August 2003, but it's larger than it has been at any opposition since 2005.

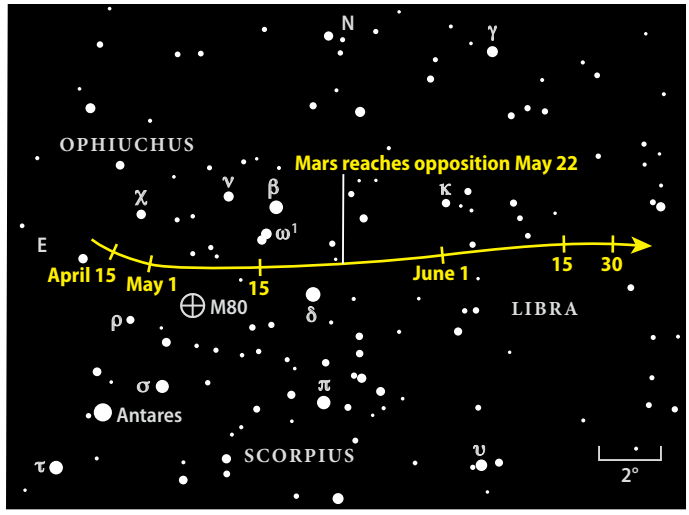
The date of opposition also is when Mars appears brightest. This year, the planet shines at magnitude –2.1. In lay terms, Mars will dazzle us at some 20 times brighter than the nearby 1st-magnitude red supergiant Antares (Alpha [α] Scorpii). Curiously, the word *Antares* means "rival of Mars." This refers to the similar color of the two objects, but only at certain times. When the planet is as brilliant as it will be this month, its hue is closer to orange-white than red.



A martian day is 37.4 minutes longer than ours, meaning it rotates slightly slower. So if you observe Mars at the same time each night, its markings will shift westward 9.1° per night. Therefore, in a little more than five weeks, Mars slowly rotates backward one full turn. *ASTRONOMY*: ROEN KELLY



Although smaller than in 2003, Mars in 2016 will appear much larger than during its worst opposition, more than 800 years from now. *ASTRONOMY:* ROEN KELLY



This chart shows Mars' motion through the stars from mid-April through June when the planet passes through Libra. *ASTRONOMY:* RICHARD TALCOTT AND ROEN KELLY

Now for the bad news: Mars lies in the constellation Scorpius for its opposition and Libra for its closest approach. The planet crosses into the Scales on May 28 and stays there until it once again enters Scorpius on August 2.

The southerly locations of these two star patterns mean Mars won't appear high in the sky for Northern Hemisphere observers. In fact, the planet's declination at opposition will be –21°39'. For an observer at 40° north latitude, Mars will climb a scant 28° above the southern horizon. (Because celestial objects rise in the east and set in the west, they reach their highest point when they're directly south.)

This low altitude is significant because the thickest, most distorting part of Earth's atmosphere lies near the horizon. As you look at objects higher in the sky, less atmosphere lies between your eyes and the object. So, having two-thirds of the sky above the planet will make observing Mars this year an adventure for Northern Hemisphere observers.

Have a look

Beginners often ask which telescope is best for observing Mars. The answer is simple: the biggest. The larger your scope, the more detail it can resolve in a celestial object. But a good view of the Red Planet depends more on the quality of your sky than on the size of your scope.

One thing working against us is that Mars is a small object — nowhere as big as most star clusters, nebulae, or galaxies — so it requires high magnification for details to be visible. This means if the air above your observing site is unsteady, you won't be able to use high power.

This image, taken October 23, 2014, shows Mars (below center) passing by the Lagoon (M8) and Trifid (M20) nebulae in Sagittarius. DEREK DEMETER

On the positive side, Mars is bright this year. That means light pollution is irrelevant. In fact, some ambient light actually is welcome when you observe the Red Planet. A white light off to your side (not directly in your field of view) and lighting up your surroundings will cause your daytime vision — which is superior to your night vision in both resolution and color sensitivity — to kick in.

Because of the Red Planet's smaller size, thin atmosphere, and lack of erosion, surface features there tend to be more pronounced than Earth's.

With a 4-inch telescope, you can observe the larger albedo features. These include Syrtis Major, the Hellas basin, Solis Lacus, and the North Polar Ice Cap, which will be tilted 12° toward Earth. Don't confuse Hellas with the polar cap. Hellas is a round, bright feature — an impact basin with lots of light-colored dust and sometimes fog or clouds. When seen near the limb (the planet's edge), Hellas can look like a polar cap. In all cases, compare your view with the map at the bottom of p. 58.

When "cloudy" is good

Through a 6-inch or larger scope, you can observe several types of clouds in Mars' atmosphere. One type is discrete clouds, which stick to one area as the planet rotates. Most discrete clouds are in Mars' northern hemisphere during spring and summer. A blue filter works best on them.

Orographic clouds are discrete clouds made of water ice. They form when wind passes over the peaks of martian mountains and volcanoes. High-altitude orographic clouds look best through a blue or violet filter. A green filter works best on low-altitude orographic clouds.

Finally, you can observe morning and evening clouds. These bright patches of fog form at sunrise or sunset. Don't confuse such a sighting with ground frost. Morning clouds disappear in a few hours. Frost may last all day. Evening clouds are generally larger, and there are more of them. They grow as the martian night approaches.

Head outside now

The best time to observe Mars is tonight. Take advantage of the planet's size and brightness, and don't worry that it's so low in the sky. Head out to a science center or observatory, contact your local astronomy club, or point your scope at the Red Planet, and take a good, long look.

Michael E. Bakich *is a senior editor of* Astronomy. *He will be conducting a massive public viewing party for the 2017 total solar eclipse at Rosecrans Memorial Airport in St. Joseph, Missouri. See www.fpsci.com for details.*