The PLANETARY REPORT

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Back to the Moon

From The Editor

Why go back to the Moon? That question lacks a simple, direct answer. In this issue of *The Planetary Report*, various authors approach the question from different directions, arriving at different answers. All their answers may be correct, for no single reason can justify the expense, complexity, and focused effort that must be sustained for decades if humans are to return to the Moon to stay.

The Vision for Space Exploration (VSE) set out by President George W. Bush is now funneling most of NASA's energy and resources toward the Moon. The agency's priorities are to finish the International Space Station, to build rockets to replace the space shuttle and take astronauts to the Moon, and to construct a lunar base. Mars remains a distant goal for human explorers, waiting for the groundwork first to be laid through work on the Moon.

Scientific exploration has taken a back seat in NASA because the modest budget increases the space agency expected, and that were stated in the original VSE, have not materialized. To return to the Moon on the VSE timetable, something has to be cut. In large part, science is what has absorbed the cuts—hence The Planetary Society's Save Our Science! campaign.

The choices are hard. To make wise ones, we must understand the issues. In these pages, we grapple with the lunar question and hope we advance some little way toward resolving it.

—*Charlene M. Anderson*

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On the Cover:

The Moon—its surface is cold, stark, dry, and lifeless. Yet, since the dawn of recorded history, humans have treated Earth's companion as an entity with power to affect life on Earth. From the beginning, our luminous satellite has inspired myths, stories, songs, poetry, art, and romance. Now the spacefaring nations of Earth are looking at the Moon as our stepping-stone to the future, a place to prepare for our explorations of Mars and worlds beyond.
Photo: StockTrek, Getty Images

Background:

It's been nearly 40 years since people first walked on the lunar surface. Still, no other image has surpassed this one's power to remind us of the great things human beings can accomplish. On July 20, 1969, *Apollo 11* astronaut Buzz Aldrin left this bootprint on the surface of the Moon. Photo: NASA

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Contents

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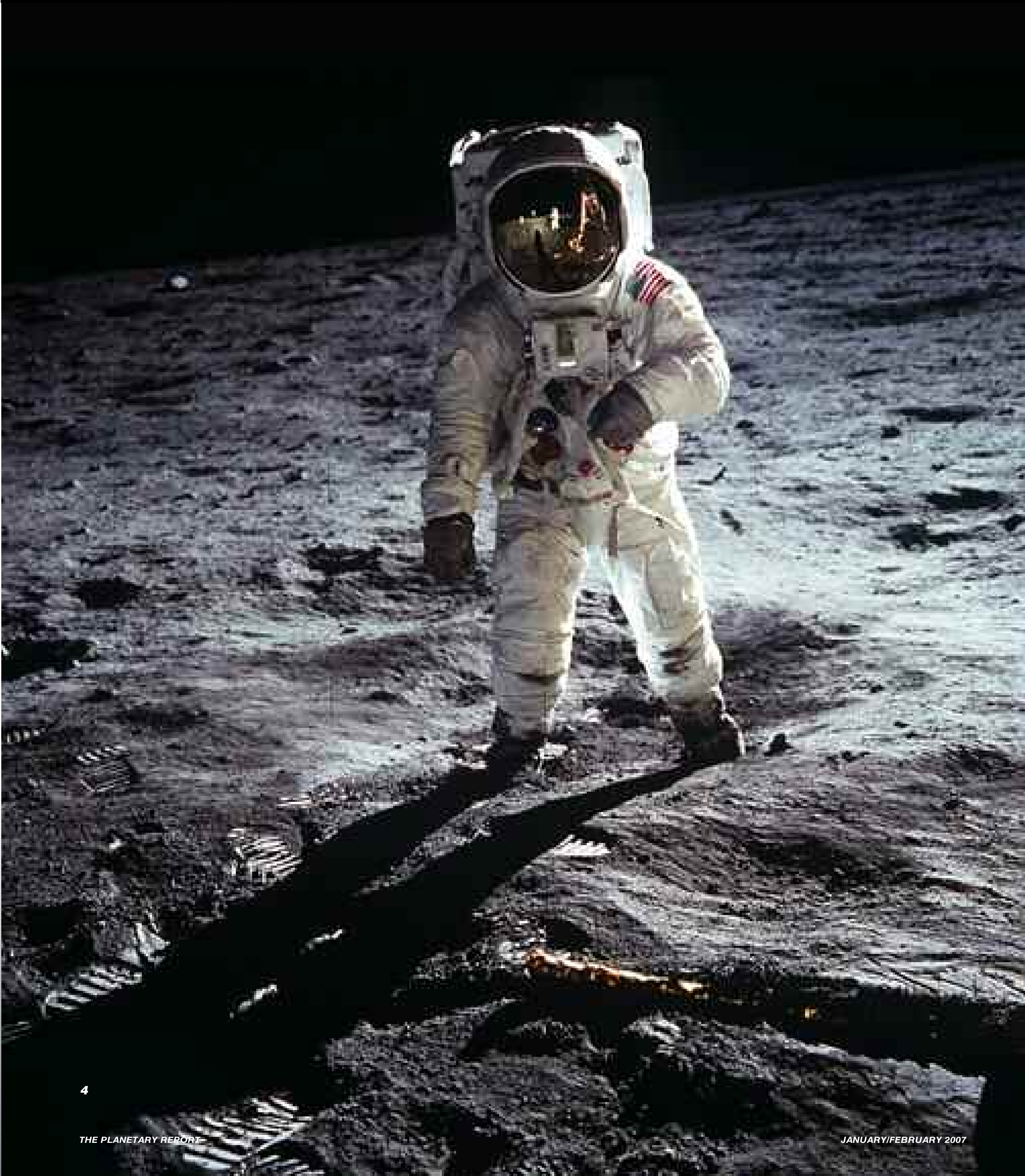
WHY RETURN TO



THE MOON?

BY BUZZ ALDRIN

A broad base of permanent support is needed for the slow expansion of human explorers into space. Farside Observatory is a 10-meter radiotelescope observatory and habitat (HAB) on the Moon's far side. To the left of the observatory is a small nuclear generator, and solar panels extend from the base of the dish. *Illustration: Bill Wright*

With the United States setting the goal of returning humans to the Moon by 2017, we are at long last on track for the rebirth of crewed space exploration. Space exploration is not an endless circling of Earth; it is going to other worlds. But why return to the Moon? Haven't we been there, done that?

Hardly. There is still much to learn from the Moon, resources to utilize, and unlimited economies to launch. An observatory on the back side of the Moon would be a giant leap for astronomy, but there is a far more important reason to return. As when youths leave home for college, the Moon can become a schooling place, a steppingstone to the boundless horizons of human destiny.

We return to the Moon to practice living off the extraterrestrial land and to test not only engineering systems but also political and social prerequisites. With the experience gained from research stations on the Moon, people from Earth will one day walk the ancient river valleys of Mars, dive the ice seas of Europa, climb the Great Wall of Miranda, and cross the far edge of the solar system.

The continued exploration of the solar system is a challenge that can unite nations, inspire youth, advance science, and ultimately end our confinement to one fragile planet.

The familiar photo that Neil Armstrong snapped of me as I stood on the surface of the Moon has become a popular icon, not because the Moon itself was some kind of culmination but because it suggests the open-ended future that awaits humanity, poised on the threshold of space. Beyond robotics and Earth-serving space stations lies the infinite journey.

We covered the globe in the old millennium and will inhabit the solar system in the new. Escaping dependence on one vulnerable world, we will found new cultures and new species of awareness, spreading consciousness into the cosmos.

But a lasting human presence in space won't result from sudden leaps like *Apollo*; it must move outward on a broad base of permanent support. This will require the cooperation not only of nations but also of the public and private sectors. Any permanent presence on the Moon should extend beyond government and NASA. Private industry and quasi-private consortia can help pay the costs of expansion and share in the benefits.

It is hard to know which industries will initially find such investments worthwhile. One showing immediate promise is space tourism—the one industry in which private investments in space are now being made.

I have championed access to space for tourists, not only in the hope that more people can share the adventure of which I was privileged to be a part but also in the belief that public and private interests, working side by side, will benefit from a more affordable space infrastructure.

This gold replica of an olive branch, less than 15 centimeters (about 6 inches) in length, was placed on the Moon's surface by Neil Armstrong. The gesture represented a wish for peace for all humankind. *Image: NASA*

Four decades ago, the Cold War was the catalyst for a two-nation race to the Moon. Today, with the Vision for Space Exploration in America, Aurora in Europe, GLOBE and *Soyuz* in Russia, *SELENE* in Japan, *Chang'E* and *Shenzhou* in China, *Chandrayaan* in India, and the efforts of private entrepreneurs everywhere, we will fulfill the promise of the plaque Neil and I left on the Moon 37 years ago.

In the 21st century, we will truly go "in peace for all mankind."

On July 20, 1969, Apollo 11 *astronaut Buzz Aldrin became one of the first humans to walk on the Moon. Since that day, Aldrin has remained at the forefront of efforts to ensure a continued leading role for the United States in human space exploration. He founded a rocket design company, Starcraft Boosters, Inc., and the ShareSpace Foundation, a nonprofit organization devoted to opening the doors to space tourism for all people.*

Buzz Aldrin walks on the Moon near the leg of the Apollo 11 *lunar module* Eagle *on July 20, 1969.* *Image: NASA*

LUNAR MYSTERIES

Above: The Moon's ancient, and relatively undisturbed, cratered surface was once thought by many to hold the answers to questions about the birth of our solar system. Closer scrutiny by the Apollo *missions, however, revealed our satellite to be an oddball with a history all its own.*

The large crater at the center of this image is Hipparchus. It is 138 kilometers (86 miles) in diameter, and its edges have been softened by time and subsequent impacts. This oblique view was captured by Apollo 16 *in April 1972.* Image: NASA

Right: A growing body of indirect evidence supports the popular theory that the Moon formed from material splashed off the early Earth by a cataclysmic impact with another body. This loose material formed a ring in orbit around our infant planet and eventually coalesced into our lone satellite. Illustration: Kees Veenenbos

In many respects, our Moon is the best-studied body other than Earth, yet it is the destination for spacecraft launched or proposed by India, China, Japan, and the United States. If we have already learned so much, what do we expect to gain by going back?

I will offer an answer different from many of those you usually hear. I don't think that the answer lies simply in learning more (in the sense that one can always draw a better map or make more precise measurements). You can always say that about studying any planet, including our own. I am also skeptical about arguments that emphasize the use of the Moon as a platform for astronomical observations or that advocate lunar resources (helium-3 in the soils or putative water ice at the poles). These arguments and associated goals might or might not have merit but scarcely justify a mammoth effort.

I argue instead that we really don't understand the Moon very well, and that it is a body the understanding of which features prominently in our attempts to figure out what took place when the planets formed. My advocacy for Moon exploration involves nothing requiring human efforts (astronauts), but if we have other reasons for a manned program, possibly nonscientific, then such a purely scientific exploration could take place in conjunction with it. Regardless of one's view of the manned program, further exploration of the Moon is warranted.

What We Know (or Think We Know)

Back before the *Apollo* program, our Moon was thought by some to be the "Rosetta Stone" for our solar system. In contrast to Earth, whose shifting tectonic plates and whose ocean and atmosphere efficiently eliminated most of the record of its earliest history, the Moon has an ancient surface. Perhaps we could read this surface, much as Egyptologists read hieroglyphics, and tell the story of our origins.

As so often happens in planetary exploration, our expectations were wrong. The *Apollo* program and subsequent research revealed that our Moon is an oddball. It has a history that is unique to that body and testament to a remarkably energetic beginning for a body so small.

The Moon is the only body (other than Earth) for which we have rocks of known provenance, brought to Earth by the *Apollo* astronauts. We have meteorites from Mars and even some from the Moon, but all these rocks have an uncertain provenance. The Soviet soil samples from the Moon were far less useful than the whole rocks returned by *Apollo*, although even the soil samples reveal a complex history because of the broken-up nature of the lunar surface, the result of impacts.

The widely accepted view of the origin of our Moon is that it was born of a giant impact in which a body about the size of Mars hit the forming Earth some 4.50 or 4.55 billion years ago. After that impact, material splashed out to form a disk, and from that orbiting disk, the Moon formed quickly. The newly formed Moon raised a tidal bulge in the solid Earth and in Earth's oceans. Because

Left: Japan's Lunar-A *spacecraft is designed to image the lunar surface, monitor Moonquakes, measure the Moon's near-surface thermal properties, and study its core and interior structure. Originally scheduled to lift off in 2004,* Lunar-A *was rescheduled to launch in 2010. However, as we went to press, the Japanese announced that the mission might be canceled.*
Illustration: Japan Aerospace Exploration Agency (JAXA)

Earth rotates faster on its axis than does the Moon (then and now), this bulge is carried ahead of the line joining the two bodies. The gravitational attraction of the Moon to this bulge causes Earth's spin to decrease and the Moon's orbit to increase. The Moon later moved away from a close-in orbit (roughly three Earth radii) to its now distant location some 60 Earth radii away.

This story is backed up by all sorts of data: the composition of the Moon, the dating of ancient rocks from the Moon, and the angular momentum (a measure of total spin) of the Earth-Moon system.

What We Want to Know

What's wrong with the standard story of the Moon that we need more exploration to fix the story? And anyway, why should we worry about the details of how our Moon came to be? Part of the answer lies in something that often happens in science: we have a story that is widely accepted, but it is a story that is actually incomplete and poorly tested. To some extent, the so-called giant impact origin of the Moon has gained acceptance through the failure of alternatives rather than through its evident correctness.

The kind of information that we most need, which concerns the global structure and history of the body, requires seismology—the science that has done most for interpreting the inside of our Earth. Seismology relies on the fact that sound waves travel at a speed that depends on the properties of the materials. Moreover, abrupt changes in rock properties cause the waves to be reflected and refracted, just as a lens or surface can change the way that light propagates. By detecting the waves that arrive at a seismometer after a quake, one can learn about what's inside a body of rock.

The *Apollo* missions included a rudimentary seismic experiment from which we learned a bit about the lunar interior, as well as the important fact that the Moon is seismically active. The seismology experiments established the presence of seismic activity (Moonquakes); however, those experiments were insufficient for determining internal structure.

A good seismological determination will be more difficult for the Moon than for Earth. On Earth, the main variation of material behavior is in the radial direction outward from Earth's core (all materials at a given pressure or depth have similar properties), and this variation is large because of the wide range of pressure inside our planet. In the Moon, by contrast, this variation with radius is small because the Moon is small and has much lower pressures. As a consequence, the variations of seismic properties by region (that is, latitude and longi-

Seismology has revealed more information about the inner workings of our Earth than any other branch of science, and it will be vital in interpreting the Moon's interior. Apollo*'s simple seismic experiments revealed that our Moon is seismically active, but we really need an array of seismometers on the Moon's surface to determine its internal structure. This partial view of* Apollo 16*'s Lunar Surface Experiment shows the Passive Seismic Experiment in the foreground, with the Central Station at rear.* *Image: NASA*

tude) are likely to be as large as those by radius.

Seismological studies are harder to accomplish than are current plans to use remote orbital sensing. Orbiters can provide very precise gravity and magnetic field data as well as very good spectral data, which can contribute to knowledge about the minerals and elements at the surface. The Japanese mission *Lunar-A*, originally scheduled for launch in 2004 and now bumped to 2010, has a planned seismic experiment that would begin to tell us about the nature of the lunar interior.

Advances in understanding of the Moon will come from the combined analysis of seismology, better understanding of gravity and topography, and correlation of this information with what is learned about the Moon's chemistry. This means that we need both kinds of missions currently planned, orbital and ground-based. In addition, we need missions that place an array of seismometers on the Moon, probably at least six.

Getting to Know Our Nearest Neighbor

The known clues to lunar origin are dynamical and chemical, but to interpret both the initial state of the Moon and the way it has changed over time, we need to understand its internal structure. Earth contains clues to its origin in its current internal structure (for example, the high temperature of Earth's core), but the Moon likely has preserved more information about its early history in the way it is (or is not) layered at different depths.

The Moon clearly has a lower-density crust, and we suspect it has a small iron-rich core, but the variation of minerals in between is poorly known. The Moon is sometimes portrayed as geologically dead, and in one sense, this characterization is correct: the surface morphology is largely unaltered over long periods and is predominantly shaped by ancient impact craters. The Moon is not dead, however, in the sense of being cold inside.

Even the absence of change at the surface recently has been challenged. In a paper in the November 9, 2006 issue of *Nature*, Brown University's Peter Schultz and colleagues presented evidence that gas is escaping from the lunar interior. The interior must be hot because of the presence of radioactive elements, and it is even quite likely that the Moon has a small iron-rich core, part of which is liquid. By bouncing laser signals off the Moon, scientists measured the variation in lunar pole position, which suggested a response to forces somewhat like the effect of a clutch in an automobile. It seems that the "clutch fluid" in this case is the lunar core; the liquid allows the core to rotate differently from the rest of the Moon. That difference in rotation is what causes the pole position to shift.

By studying the Moon, we are not merely trying to under-

What is Helium-3?

Helium has been implanted in the upper lunar regolith by the solar wind. Most of it is helium-4; that is, it has two protons, which define it as helium, and two neutrons, with a total nuclear mass of four (protons and neutrons have similar mass, and the total of protons and neutrons is the nuclear mass). Helium-4 is the same stuff that fills balloons and is a product of the decay of heavy radioactive elements such as uranium and thorium, as well as nuclear fusion in the Sun.

The solar wind also has implanted tiny quantities of the less abundant, but stable, helium-3, which has two protons and one neutron. Helium-3 is a potential fuel for future power-generating fusion reactors on Earth—a fuel that has several advantages over its alternative (tritium, also known as hydrogen-3, which has three protons and no neutrons) because it allows easier containment and produces very little radioactivity.

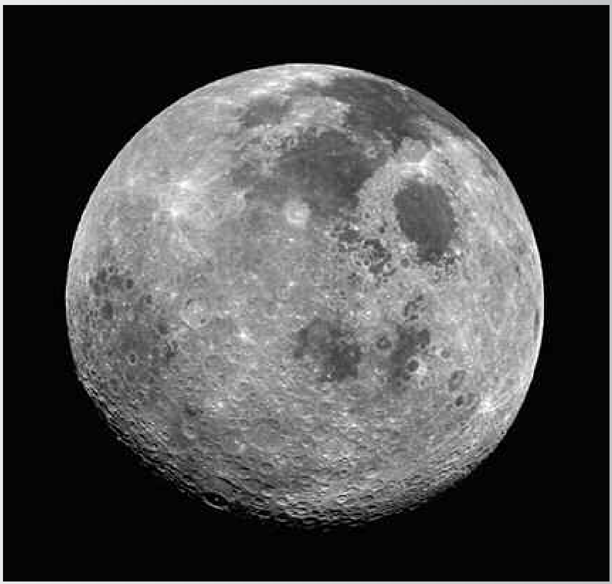
There is very, very little helium-3 on Earth, which has led some scientists to strongly advocate helium-3 as a significant lunar resource. Despite the high potential value of lunar helium-3, others have questioned the economic viability of extracting it. Extraction would require gigantic mining operations because of the very tiny percentage of helium-3 in regolith (less than 10 nanograms per gram), and heating large quantities of regolith to extract the helium-3 would be a difficult and expensive endeavor. *—DS*

Origin of the Moon

Look at the surface of the Moon, and you'll see dark regions (the mare) and relatively lighter colored regions (the highlands). These less-dark parts are also the most heavily cratered, the result of bodies hitting the surface of the Moon over geologic time.

Because the Moon lacks efficient erosion, heavily cratered regions are the most ancient parts of the Moon's surface. Most of these impact craters were not formed back when the Moon formed, about 4.55 billion years ago, but rocks that *Apollo* astronauts brought back to Earth show us that these heavily cratered regions of the Moon include rocks that date from the earliest period of lunar history. We also know from their chemistry that they most likely formed through a process of freezing from a thick magma ocean, a molten rock layer that originally was many hundreds of kilometers thick.

The impact origin of the Moon gained favor in the 1980s, partly because it provided the prospect of explaining such a hot initial state for the Moon, but also because it made dynamical sense: the angular momentum of the Earth-Moon system (a measure of the spin of Earth about its axis and the same sense of motion of the Moon about Earth) is indeed explainable by a glancing impact on Earth of a body the approximate mass of Mars. Such impacts are thought to be a natural (not rare) consequence of the way large planets such as Earth are assembled. Moreover, computer calculations of such an impact showed that roughly the right amount of material (one-tenth of a Mars mass or so) would be put into Earth orbit and be available for coalescing into what is now the Moon.



The Moon's heavily cratered, lighter colored highlands are the most ancient parts of its surface. These regions include rocks whose chemistry indicates that they most likely froze out of a thick magma "ocean," and their composition dates them from the earliest period of lunar history.

The crew of* Apollo 17 *took this photo of the full Moon in December 1972, on their way home to Earth. The dark spots—or lunar mare—visible here include Serentatis, Tranquillitatis, Nectaris, Foecunditatis, and Crisium. *Image: NASA*

There is no direct physical evidence of this giant impact, nor would one expect any. Most or all of the material left behind on Earth and available to make the Moon was melted or vaporized during the giant impact.

There is, nonetheless, a growing body of indirect evidence for the model in the observed properties of Earth and the Moon. Much of this evidence is in the isotopic makeup of Earth and the Moon (the abundances of various nuclei of the same chemistry and atomic number but different nuclear mass). This is a major focus of geochemists.

Several alternatives to the impact origin have been proposed. One could imagine making the Moon elsewhere and then capturing it (which might be possible provided that the Moon encounters sufficient friction during a close flyby of Earth). Or one could imagine building the Moon in Earth orbit over a long period, just as in the currently favored ideas about how the large moons of Jupiter were built around that planet. One could even revive the fission hypothesis in which the Moon broke away from a very rapidly spinning Earth (though this would require more spin than we can actually account for now). All these alternatives have very major and extensively studied shortcomings. This is, however, not the same as saying that we know for sure that the giant impact happened—it simply seems more likely than rival hypotheses. *—DS*

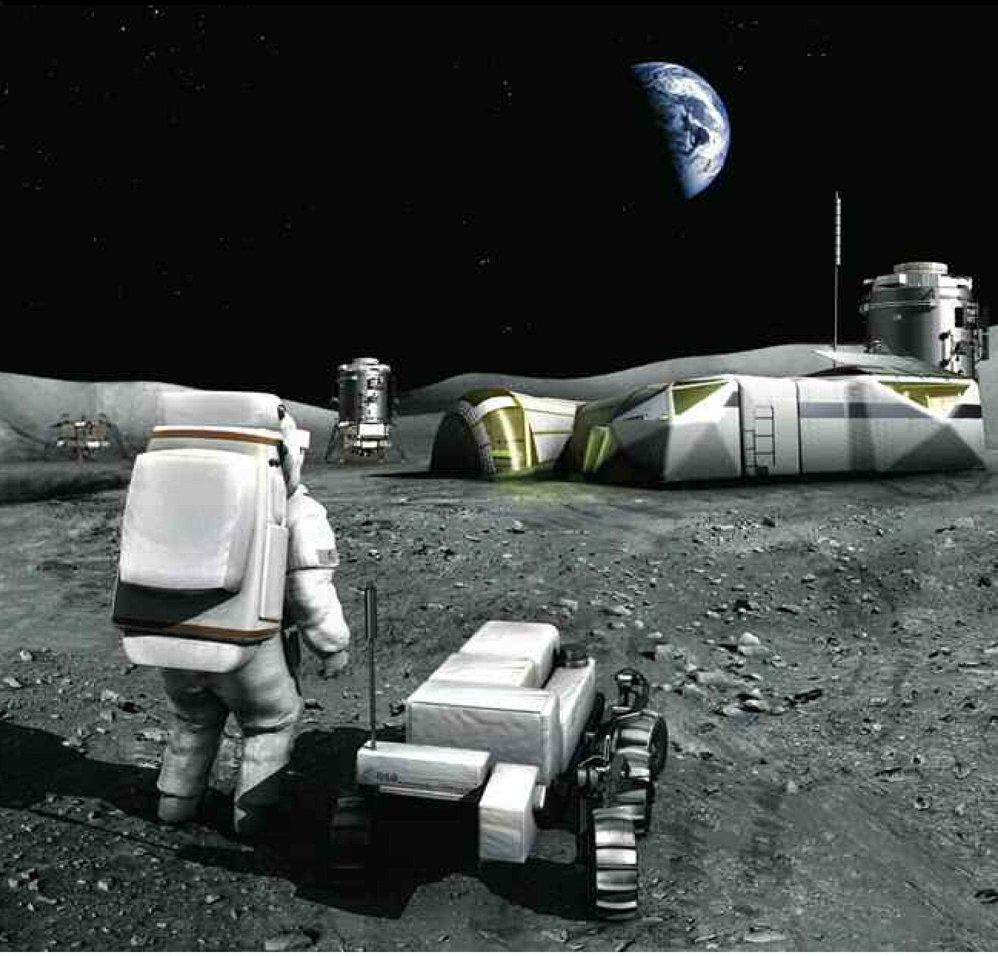
stand an "oddball"; we are investigating the outcome of a process—giant impacts—that we believe is a natural part of the accumulation process of planets. In our current view of how Earth formed, it is likely that the planet suffered very large impacts by bodies about the mass of Mars. Not all such impacts will make a moon, but the impact that formed the Moon likely left a legacy in the evolution of Earth.

The Moon has long fascinated us, but we would be wise not to lose that fascination as we turn our eyes to the exciting new discoveries of bodies out to and beyond Pluto and copious planets around other stars. In the words of Ralph Kramden (played by Jackie Gleason in the old TV show *The Honeymooners*), "to the Moon!"

Dave Stevenson is the George Van Osdol Professor of Planetary Science at the California Institute of Technology.

DESTINATION MOON:

BY LOUIS D. FRIEDMAN



Above: Japan's **SELENE** *(SELenological and ENgineering Explorer) will launch in late 2007 or early 2008. The most ambitious lunar mission since* **Apollo** *will study the Moon's origin and composition, as well as examining the possibilities for future human use and exploration.* Illustration: JAXA

Left: A revived interest in returning to the Moon has spread throughout the spacefaring nations of the world, and never before have so many countries focused their sights on Earth's satellite at one time. The Planetary Society has proposed the International Lunar Decade to help these nations coordinate their plans and share the results with the rest of the world. We also want to create opportunities for not-yet-spacefaring nations to participate.

The U.S. Vision for Space Exploration has, as one of its goals, a human return to the Moon by the year 2020. Europe's Aurora program has set a similar goal, as this illustration of an Aurora Moon base shows. Illustration: ESA/AOS Medialab

This year, we will mark the 50th anniversary of spaceflight, the October 4, 1957 launch of *Sputnik 1*. In the first 15 years of the Space Age, 95 spacecraft and 24 men reached the Moon. Since 1972, however, no humans and only four spacecraft have visited our nearest off-Earth destination.

Now, the Moon is again becoming a target for explorers from Earth. This year, China and Japan are planning to send orbiters; next year, India and the United States will do the same. These four spacefaring nations, as well as a reviving Russia, have even grander ambitions for future missions to the Moon, including the return of human explorers, as laid out in the U.S. Vision for Space Exploration.

National ambitions alone are not driving this revived interest in the Moon. Private interests are also investigating potential lunar missions. One group is working on an International Lunar Observatory that would be privately developed but used by government-funded researchers. Several years ago, at least three companies initiated private ventures for commercial purposes, but none made it to the launch stage. The Moon is still a tempting target for entrepreneurs. We'll wait and see what happens.

As it was for the United States and the Soviet Union in the 1960s, reaching the Moon is a symbol of achievement and a demonstration of national technological prowess. It is an ambitious next step beyond Earth for both current and emerging spacefaring nations.

A Destination for Robots and for Humans

The U.S. Vision for Space Exploration sets the goal to "extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations." With the Aurora program, Europe has set a similar goal, and both Russia and Japan have offered "road maps" for sending humans to the Moon as a step toward walking on Mars.

China's developing human spaceflight program and India's intended one are not ready to plan human missions to the Moon, but their robotic lunar missions represent their first steps beyond low Earth orbit into the solar system. Italy is considering sending its own orbiter, and Russia is developing *Lunar Glob*, an orbiter carrying multiple small landers.

An International Effort

Over the next decade, it could get crowded up there, with orbiters, landers, and rovers from four, five, or six countries cruising around. Russia and the United States may be nearing launch of humans. The public may be riding along on some of these spacecraft through virtual reality and a lunar Internet.

But then what? We know the Moon is a stepping-stone into the solar system, but what can we do there to enable us to take the next step—to Mars?

An International Lunar Decade

With so many nations, and perhaps private interests, going to the Moon, coordinating all these endeavors will be a daunting challenge. If exploration is to continue beyond Earth orbit, we must avoid wasteful duplication of efforts and pursuit of large projects with dubious benefits (other than employment).

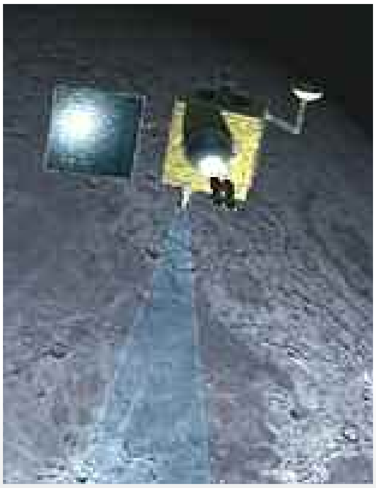
This is why The Planetary Society has proposed the International Lunar Decade. It would provide a means to involve the spacefaring nations in coordinating their plans and sharing the results worldwide as well as creating opportunities for not-yet-spacefaring countries to participate.

The International Lunar Decade would launch this year with the first of the new missions. It would end when humans return to the Moon—by 2017, we hope, but at least by 2020. (We will allow an international decade to last a little more than 10 years, but not too much longer.)

The International Lunar Decade has now been endorsed by the International Lunar Exploration Working Group and COSPAR (the International Council of Scientific Unions' Committee on Space Research), and we are bringing it to the International Astronautical Federation and UN Committee on Peaceful Uses of Outer Space for additional endorsement. In addition, the Society is working with all space agencies conducting lunar missions to provide additional support.

Louis D. Friedman is executive director of The Planetary Society.

China's Chang'E-1 *orbiter, scheduled to launch this spring, is the first element of a three-part program that extends to 2020.* *Illustration: China National Space Administration*



Chandrayaan-1, *India's first lunar mission, will seek to understand the Moon's history, map its surface, and increase India's technical and scientific abilities.* *Illustration: Indian Space Research Organizationn*

With Lunar Reconnaissance Orbiter, *the United States will perform its first systematic mapping survey of the Moon since the late 1960s.* *Illustration: NASA*

Explore More

Download a PDF of the paper *The International Lunar Decade—A Vision for Human Spaceflight* at ***planetary.org/about/executive_director/intl_lunar_decade_proposal.pdf***

Hear Louis Friedman discuss the International Lunar Decade on Planetary Radio at ***planetary.org/radio/show/00000194/***

The Saturn V rocket carrying Apollo 17*—the last mission carrying people to the Moon—sits ready for launch on the evening of December 7, 1972.* *Photo: NASA*

To Mars By Way

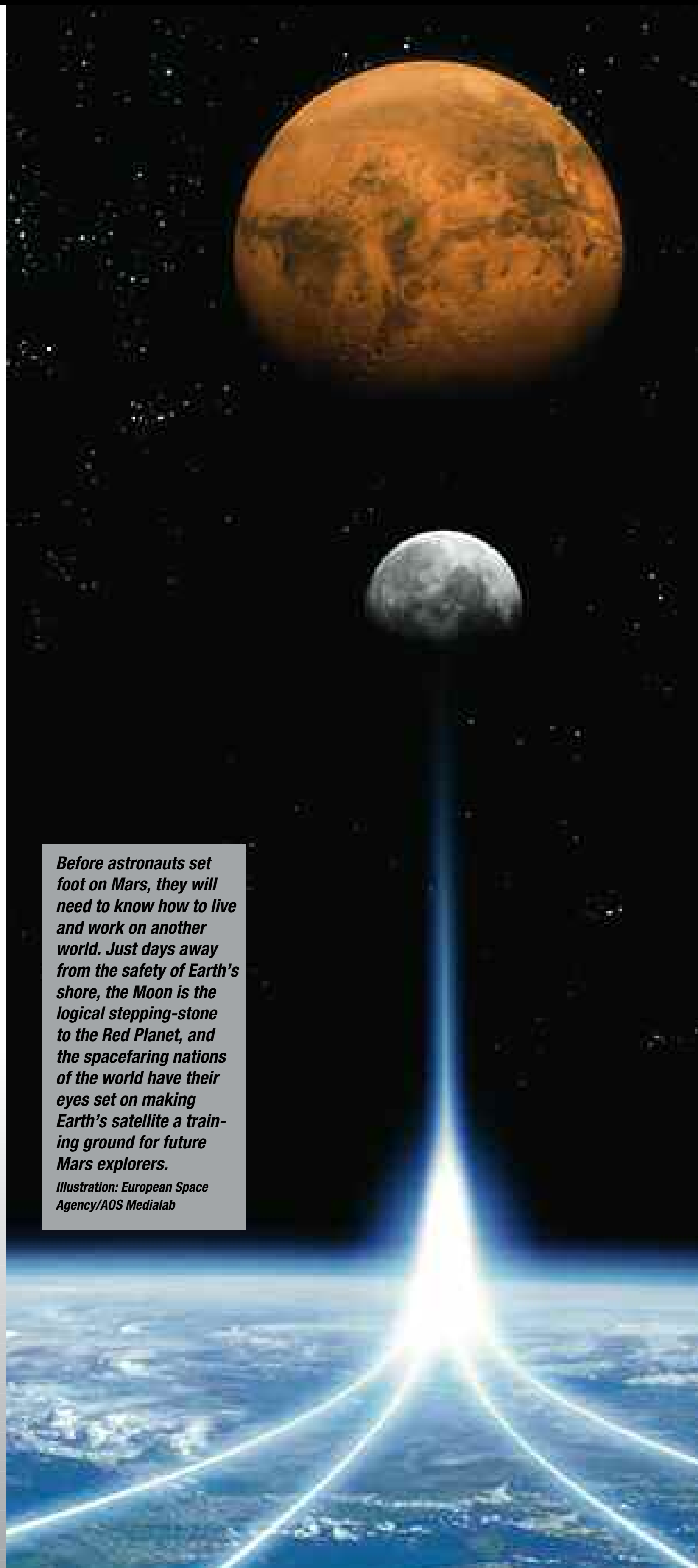
My goal is to explore Mars on foot: to search for microscopic aliens—dead or alive—and determine if Mars can be a home for life—Martian or terrestrial—sometime in the future. This, however, will not be NASA's next step into the solar system. The administration's Vision for Space Exploration (VSE) would first send humans back to the Moon to practice and hone their techniques and technologies for living off Earth. Those of us for whom Mars is the ultimate goal must now focus on developing the capability to reach Mars by using the Moon as the stepping-stone. This one small step on the way to Mars could give us one giant leap in the capability to live on, work on, and explore other worlds.

By following the VSE, humans will return to the Moon by the end of the next decade. NASA and its aerospace contractors are focused on building the rockets and crew vehicles to get astronauts there, and they are designing this hardware so it can be used to reach farther destinations in the solar system. Recently, NASA unveiled its architecture for the new Moon program, with this explicit goal: "Exploration Preparation: Test technologies, systems, flight operations, and exploration techniques to reduce the risks and increase the productivity of future missions to Mars and beyond."

Along with many others, I think Mars is the most compelling destination for human exploration. On that planet, we can search for evidence of life and determine if it is related to our own type of life or if it represents a second genesis. We can learn if it is possible for humans to live and work on Mars, and if we can make that planet a long-term home for terrestrial life. It is important, then, to ensure that the new Moon program really does pave the way for humans to reach Mars.

A Place to Call Home

It will not be easy to send humans to Mars and bring them back. The most profound challenge is the distance between the planets, compounded by the fact that launch periods occur only every two years. The most significant advantage Mars offers is its atmosphere, which contains many of the key life-support consumables that human explorers will need. In these two key respects, Mars is the opposite of the nearby Moon, which we can reach at almost any time and which has no usable atmosphere.

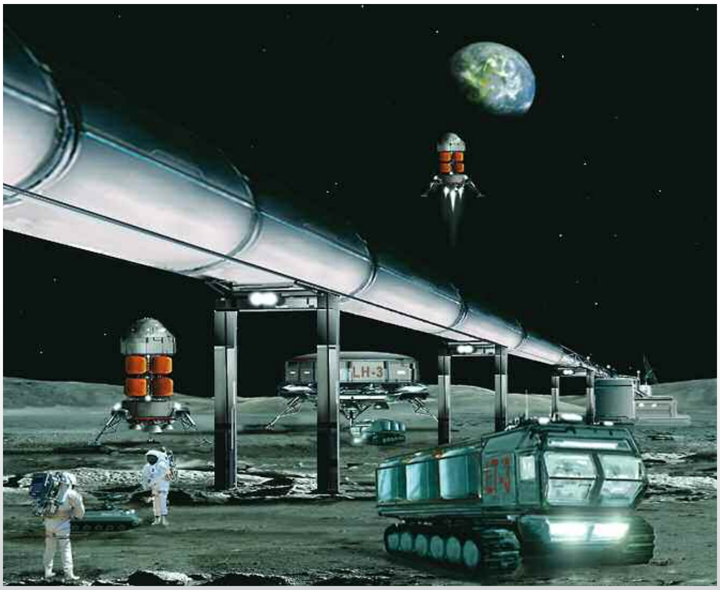


Before astronauts set foot on Mars, they will need to know how to live and work on another world. Just days away from the safety of Earth's shore, the Moon is the logical stepping-stone to the Red Planet, and the spacefaring nations of the world have their eyes set on making Earth's satellite a training ground for future Mars explorers.
Illustration: European Space Agency/AOS Medialab

In August 2006, NASA announced that its proposed Crew Exploration Vehicle will be named Orion*. This craft will carry human explorers back to the Moon and then later to Mars. NASA plans* Orion*'s first flight to the Moon to take place no later than 2010.* *Illustration: NASA/John Frassanito and Associates*

With those differences in mind, we must direct the design and operations of the Moon program carefully to make sure they advance Mars exploration. To do this, we must first figure out what we need for the Mars program.

We will almost certainly need a central base on Mars. Because of the relative motions of Earth and Mars around the Sun, missions to Mars will be separated by about two years, and sojourns on Mars will have to be this long—or even longer. Between these intermittent launch windows, the Mars expedition will have to be self-sufficient, unlike crews on the Moon, which are always just a few days away. We'll need tons of equipment, backup tools, spare parts, and redundant facilities on Mars, and this large inventory will be housed at the central base.



To learn to live and work autonomously on another world, we'll need a long-term base on the Moon. This nuclear-powered processing plant is extracting water from lunar regolith. The large pipeline structure is an aqueduct that transports water to the main lunar base, and the crawler in the foreground carries water to other outlying installations. Orion *and plant operators' living quarters are visible in the background.* *Illustration: Bill Wright*

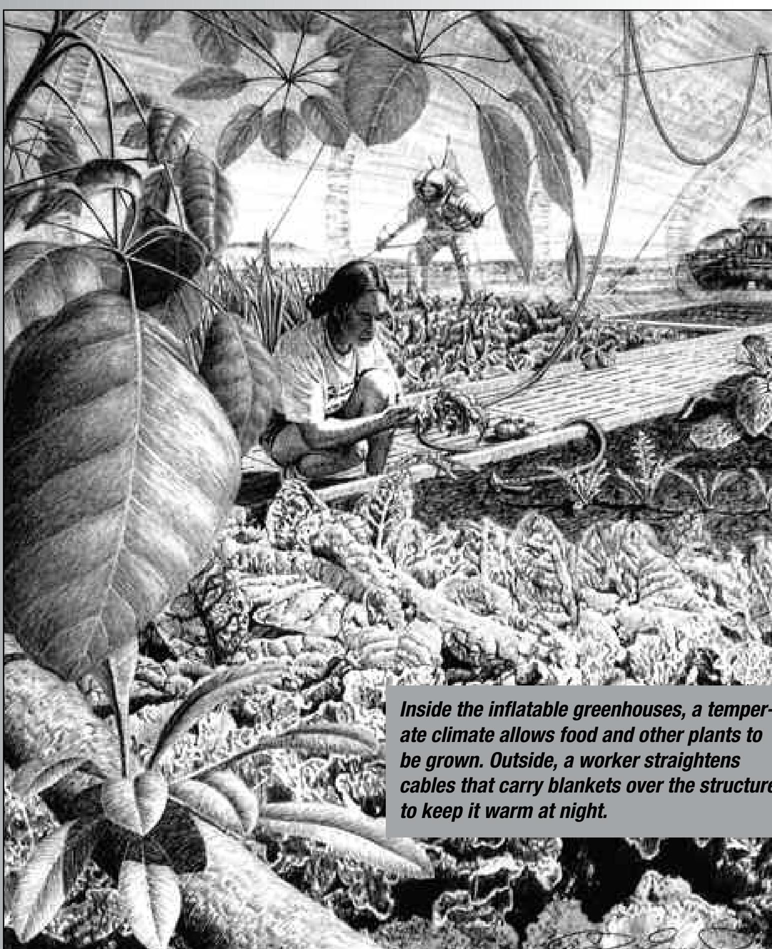
The experience on the Moon will be different. The *Apollo* missions carried everything they needed with them, and we could continue to explore the Moon this way. If we are going to use the Moon program to pave the way to Mars exploration, however, we need to test a base on the Moon, learning what it takes to live and work autonomously on another world for years at a time. The Moon program cannot rely solely on self-contained missions. The current NASA architecture calls for a long-term base on the Moon for precisely this reason.

On Mars, incurably curious scientists will want to explore the entire globe, so they will want some form of transport to take them from the central base to distant locales, where they can spend days in the field. On the Moon, the capability could be achieved with *Apollo*-style missions launched from Earth. To plan for Mars, however, we need to design the lunar base so it can be a hub for expeditions to anywhere on the Moon. This has important implications for the complexity and technical capabilities that the base must possess. If the only goal were scientific exploration of our little Moon, this would not be required, but it is essential if the Moon base is to be the engineering model for the Mars base.

Because human explorers will need to stay on Mars for at least two years, a centralized, self-sufficient base will be necessary. The concept for this early base consists of two identical habitats (HABS)—redundant systems in case of emergency or equipment failures. Each HAB has an attached, inflatable greenhouse, airlocks, and rock sample racks accessible by robot arms, and a small airlock for hands-on examination. In a nearby crater, a small nuclear generator provides initial electrical energy.

These astronauts are building a solar-electric "farm" in a Sun-facing crater slope. A steady supply of energy is key to establishing a foothold on the Red Planet.

Illustrations: Carter Emmart



Inside the inflatable greenhouses, a temperate climate allows food and other plants to be grown. Outside, a worker straightens cables that carry blankets over the structure to keep it warm at night.

Becoming Self-Sufficient

Because Mars is so far away and missions will take so long, explorers must be able to produce air, water, and even food and fuel on Mars. If all supplies are carried from Earth, explorations will be severely limited. Four important technologies are necessary to reach this level of self-sufficiency: in situ resource utilization, recycling life-support systems, plant growth systems, and power systems. All can be developed on the Moon in ways that make them relevant to Mars.

The atmosphere on Mars makes human exploration seem achievable. It is present everywhere and contains carbon dioxide, nitrogen, and water vapor. The Moon has no corresponding assets. Designs exist for getting oxygen—and possibly water—from the lunar soil, but this has little relevance for taking oxygen and water from the Martian atmosphere. On Mars, we will have to learn how to use the available resources.

On the other hand, the technology we develop for recycling life-support resources on the Moon can apply directly to Mars. Physical and biological systems that recycle waste materials, used water, and air into useful resources can be tested on the Moon. Any systems that work in the 1/6 gravity of the Moon likely also will work in the 1/3 gravity of Mars. In this technology area, more than any other, there may be complete commonality between the Moon and Mars.

A key part of any biologically based recycling system is certain to be plants, which take in carbon dioxide, a waste product of human respiration, and release oxygen, which is needed for human metabolism. Of course, plants are also a crucial resource for human nutrition. Greenhouses on the Moon can be test beds for greenhouses on Mars.

A reliable power source will be essential for running the equipment needed for survival on Mars for years. For both the Moon and Mars, the options are nuclear and solar power. On either body, nuclear power stations would probably be very similar, so the lunar experience would transfer easily to Mars. For safety and environmental reasons, however, solar power may be preferable. A Martian day is 24.5 hours long, very similar to Earth's, but Martian dust storms greatly diminish available sunlight and can last for months. A day on the Moon lasts 28 days on Earth; because the Moon is locked with one side always facing Earth, it completes one rotation for each orbit around the planet. Because of the difference in length of day and reliability of available sunlight, solar power systems developed for the Moon cannot transfer directly to Mars, but they may work with only moderate design adjustments.

Long-term missions on Mars will severely test the functioning of mission components—both humans and machines. The human crew will have to work together in isolated and confined environments for years, always within the glare of public attention. Every upset or interpersonal fracas will be front-page news. The crew will risk becoming the ultimate reality show—without

Flowers for the Moon and Mars

"There has never been a flower on Mars," she said, "but we will learn to grow them."
—from *A Rose for Ecclesiastes*, by Roger Zelazny

I particularly like one example of using the Moon to support Mars exploration: send a plant growth module to the Moon. A human base on Mars will need plants as part of the biological recycling system and for food production. Plants can also serve as soothing decoration or even companions as we learn to live on other worlds.

To learn how to grow plants on Mars, we can start with a simple plant growth payload on a robotic mission. (See "Flowers for Mars" in the September/October 2001 issue of *The Planetary Report*.) Performing such a mission first on the Moon makes good sense for a number of reasons. The Moon and Mars share the central problem of low gravity. Sensing which way gravity is pulling tells plants to grow in the opposite direction—toward the light, if they are underground. High doses of cosmic radiation hit the Moon as well as Mars, and these can damage cells in both plants and animals. In fact, both of these factors are more severe on the Moon, so we expect that plant growth systems that work on the Moon will also work on Mars.

***It is extremely important to protect Mars from Earthly contaminants. Researchers at Johnson Space Center are experimenting with producing germ-free plants, such as the lettuce (left), tomatoes (center), and citrus (right) grown in lunar soil returned by* Apollo 15.** *Photo: NASA*

A key difference between growing plants on the Moon and on Mars is the requirement for planetary protection—that is, a series of protocols to ensure that terrestrial organisms do not contaminate other worlds and vice versa. There are no concerns about the Moon, which has no means to support life unless we provide it, but there are significant concerns about contaminating Mars. If we can fly a plant mission to the Moon and demonstrate that it does not contaminate the surrounding area and is in full compliance with planetary protection protocols, that will make it easier to send such a mission to Mars. *—CPM*

the option to vote anyone off the island. Mission success will demand considerable training and crew coherence. The Moon base can provide a testing ground for how to provide this training to ensure that coherence.

A Stage for Science

Mars is a world of huge potential for science exploration. The challenges of the search for evidence of past life will absorb the best and the brightest of the science community for years to come. If evidence for life is found, we will begin the quest to understand the nature of that Martian life and its relationship, if any, to life on Earth. At the same time, we will investigate the possibility of restoring Mars to habitable condition and determine if the planet can be a home for future life. It will take decades of exploration to answer this question. In this respect, the Moon is of no relevance at all.

The best way to prepare humans to investigate the astrobiological aspects of Mars is with robotic trailblazers. We started in the 1970s with the *Viking* landers, continued with *Pathfinder* in the 1990s, and now have *Spirit* and *Opportunity* resolutely poking into hidden nooks and crannies searching for signs that Mars once possessed life-supporting liquid water. *Mars Global Surveyor* returned data that suggest liquid water may still exist there today, and *Mars Express*, *Mars Odyssey*, and *Mars Reconnaissance Orbiter* are hard at work as well. A fleet of American and European robots are slated to follow, and the combined data returned will be a feast for astrobiologists for years to come. If we hope to answer the questions of life on Mars—past, present, and future—we have to make sure that these missions continue even while we build a Moon base.

So, it's possible—there are many ways to design a program of human lunar exploration so it does indeed pave the way for humans to explore Mars. I have focused here on concrete technical questions and challenges involved in human factors. But there are more subtle—and possibly even more important—ways in which a vigorous program of human exploration of the Moon leads to Mars: by once more making the exploration of other worlds the focus of space programs, by motivating and training the next generation of space explorers in field science, and by making other worlds destinations that future scientists can dream about walking on and digging into.

Christopher P. McKay, guest editor of this issue of The Planetary Report*, is a planetary scientist with the Space Science Division of NASA Ames and a member of The Planetary Society's Board of Directors.*

McMurdo Station, on Antarctica's Ross Island, as seen from Observation Hill.
Photo: Gaelen Marsden, http://en.wikipedia.org/wiki/McMurdo_Station.jpg

To the Moon by Way of Antarctica

The exploration of Antarctica is probably the best historical analog for those thinking about how to send human explorers to the Moon. The largely frozen continent is the only major landmass that was not populated by prehistoric peoples, and even today, we can travel to and survive in the Antarctic only with the advantages of modern technology.

Antarctic bases are nationally supported programs maintained for international prestige and competition. By treaty, all activities at these bases must be for scientific exploration and coordinated by international committees. For example, McMurdo Station is the central hub for U.S. activities on "The Ice" (as Antarctica is called by regular visitors; the Moon might come to be called "The Rock"). It was established in December 1956 as part of the International Geophysical Year (which also triggered the launch of *Sputnik*) and has continuously operated since then. During the austral summer (November–February), there are typically 1,000 people at the station; the winter population numbers 100 or fewer.

Although the U.S. Antarctic bases have operated constantly for more than 50 years, people serve there for only few months to a year. Because it is readily accessible, there is no need for settlement. This is a probable mode of operation for an initial research station on the Moon.

In many ways, travel to and from a Moon base may be easier and more predictable than travel to and from the Antarctic. Depending on weather, it takes 3 to 10 days to get to McMurdo from the continental United States. There is virtually no access during the winter months. In contrast, travel to the Moon takes about three days and is not restricted to particular times of year. Crews might go to and from the Moon on a regularly scheduled basis.

The U.S. Antarctic program is operated by the National Science Foundation, which combines science and logistical support functions in one office. This results in a smooth, unified approach to planning and decision making. NASA separated the office responsible for the science of lunar and Mars exploration from the office that will build the infrastructure on these locations. The Antarctic model suggests that a better approach would be to create a unified Lunar and Mars Exploration Directorate combining science with the robotic and human exploration tools to achieve that science.

After more than 50 years of sustained study, there is no indication that the Antarctic continent has lost its scientific interest. The Moon is as interesting as Antarctica, so it is unlikely that in 50 years we will conclude that the Moon no longer warrants scientific exploration.

We should plan for the long term on the Moon. To maintain a base for several years, the cost must shrink over time to a funding level that can be sustained as NASA turns its focus to the Mars program. In Antarctica, costs have been reduced by gradually transferring operations to private contractors. Once a U.S. government and military operation, the U.S. Antarctic program is now largely operated by civilian organizations selected through competitive bidding. The Moon base must follow this pattern to be affordable as a long-term program.

Following in the footsteps of explorers of the once-forbidding Antarctic have come tourists. Cruise lines, travel agencies, and even nonprofit groups such as The Planetary Society regularly schedule trips to this literal end of the Earth. Tourism appears to be the activity that follows scientific exploration by national agencies, and now start-up companies have begun selling tickets to ride into space. After a lunar base is established, we may see people lining up to take trips to the Moon.
—*CPM*

World Watch

Special Report by Lori Garver

Washington, D.C.—The U.S. elections of November 2006 gave control of both houses of Congress to the Democrats. Democrats have taken the chairs of the congressional committees overseeing NASA's budget, and although space policy is set by the presidential administration, the purse strings are controlled by Congress.

Historically, Congress has not made dramatic changes in NASA spending or policy. Given the current number of critical space issues, however, even slight shifts in policy and budgets could have significant implications for programs The Planetary Society advocates.

We will see several new players in Congress who have not worked extensively on space issues in the past. Speaker of the House of Representatives Nancy Pelosi (D-CA) has never served on key NASA committees. A look at her voting record shows consistent votes to cut the NASA budget. House Majority Leader Steny Hoyer (D-MD) is a NASA supporter and will be looked to as the key NASA supporter in the 110th Congress.

Senate Majority Leader Harry Reid (D-NV) has a mixed voting record when it comes to civil space issues. As majority leader, he will most likely defer to the senators with key interests in space and science.

NASA supporters' biggest concern is the new chair of the House Appropriations Committee, David Obey (D-WI), who replaces NASA supporter Jerry Lewis (R-CA). During his tenure in Congress, Congressman Obey has led efforts to cancel the International Space Station and cut NASA's budget. As Appropriations Committee chair, Obey is one of the most powerful members of the new Congress.

Congressman Obey will likely present the greatest challenge to NASA's exploration programs. He has frequently referred to the Moon and Mars programs as "luxuries" and noted that the United States should be directing funding to health care and education programs instead. He has referred to fellow members of Congress who support the Vision for Space Exploration as suffering from "Mars Fever." He is more supportive of NASA science programs, however, and has decried the $600 million cut to the fiscal year (FY) 2007 science account.

With Congressman Obey in charge of the Appropriations Committee, any increases to NASA's budget will have to come from the White House. He is unlikely to support the supplemental appropriations that Senator Barbara Mikulski (D-MD) is trying to pass for FY 2007, and he is likely to be skeptical of adding funds for human spaceflight and other exploration programs.

NASA's Appropriations Subcommittee on Science, State, Justice and Commerce is chaired by Alan Mollohan (D-WV). Congressman Mollohan is a supporter of NASA and has spoken on the House floor in favor of increasing NASA's budget.

The House Authorizing Committee has also seen changes. Congressman Bart Gordon (D-TN) chairs the Science Committee, and Congressman Mark Udall (D-CO) takes the reins of the Space Subcommittee. Democrats on the Authorizing Committee are expected to provide additional oversight of NASA and increase the number of hearings. Congressman Gordon will seek a balanced NASA portfolio with increases in science and aeronautics. Congressman Udall may also look to increasing science and aeronautics, perhaps at the expense of the Vision for Space Exploration, but he is not likely to oppose exploration beyond low Earth orbit.

Fewer changes for NASA are expected from the new Senate leadership. Senator Robert Byrd (D-WV) replaces Thad Cochran (R-MS) as chair of the Appropriations Committee. The full Senate Appropriations Committee probably will continue to leave NASA issues to the subcommittee. NASA supporter Senator Mikulski returns to chair the NASA Appropriations Subcommittee for Commerce, Justice and Science.

Both the NASA Goddard Space Flight Center and the Johns Hopkins University Applied Physics Laboratory are in Senator Mikulski's district, and she has been one of the space program's most stalwart proponents for more than a decade. She is the prime sponsor of an amendment to increase NASA funding by $1 billion for 2007. Senator Richard Shelby (R-AL), the ranking minority member of the subcommittee, has also been a great supporter of NASA.

Senate budget authorizers traditionally take a much less prominent role in NASA issues than do their House counterparts. Senator Daniel Inouye (D-HI) chairs the Commerce, Science and Transportation Committee, taking over from Senator Ted Stevens (R-AK), and we expect Senator Inouye to continue to support the agency.

Senator Bill Nelson (D-FL), who has the Kennedy Space Center in his district, chairs the Science and Space Subcommittee. His views tend to mirror those of his Republican counterpart, Senator Kay Bailey Hutchison (R-TX), whose district is home to the Johnson Space Center.

The Planetary Society is working with leaders in both parties to increase support for space exploration and science programs. We urge you to contact your own representative to express your support for space exploration.

Lori Garver is The Planetary Society's Washington representative.

We Make It **Happen!**

by Bruce Betts

Planetary Society Members Are Going to the Moon

Apropos of this special lunar issue, I'm happy to tell you that all Planetary Society members—OK, actually your names—will be heading to the Moon on board the Japanese *SELENE* spacecraft. All of our members' names, etched in foil, will be included aboard the spacecraft as part of our Wish Upon the Moon project, which has been carried out in conjunction with The Planetary Society of Japan and the Japan Aerospace Exploration Agency (JAXA). The message from Earth will also include wishes that people submitted over the web.

SELENE, which stands for SELenological and ENgineering Explorer, will launch in the summer of 2007. It consists of three separate spacecraft: a main spacecraft orbiter and two small relay satellites. The relay satellites will permit the spacecraft to map the gravity field on the far side of the Moon by relaying radio transmissions from that region to Earth in real time. Instruments on the main spacecraft will measure elemental and mineral distribution, surface structure, and the lunar environment. You can find out more about *SELENE* and Wish Upon the Moon at *planetary.org/selene*.

A Flock of Lunar Missions

As discussed elsewhere in this issue, many spacecraft are headed to the Moon in the next few years. Recently, I attended a meeting hosted by the science team of the *Lunar Reconnaissance Orbiter* (*LRO*), NASA's 2008 orbiter. There was much discussion of not only science, education, and outreach but also exactly the types of things we have been pushing for in recent years, which involve coordination of the many international missions. Representatives of several of those missions attended the meeting, and we received positive feedback about our concept of an International Lunar Decade (see Lou Friedman's article on page 10) as an organizing construct. We also collaborated on outreach opportunities with many of the missions. At this point, we have formal roles with *SELENE* and with the Chinese *Chang'E* mission (to be launched in April 2007), and we are pur-

What's **Up?**

In the Sky

There will be a total lunar eclipse on March 3–4, which will be visible in entirety from Europe, Africa, and western Asia. Those in eastern Asia will see part of it as the Moon sets, and in the eastern Americas, part of it will be visible as the Moon rises. A partial solar eclipse will be visible on March 19 from eastern Asia and northern Alaska. See *sunearth.gsfc.nasa.gov/eclipse* for eclipse information.

Saturn rises around sunset in the east and is high overhead in the middle of the night. Venus is very bright and low in the west after sunset. Jupiter is very bright in the predawn eastern sky, with Mars dimmer and redder below it.

Random Space Fact

Earth reaches perihelion, its closest point to the Sun, in January (emphasizing—especially for Northern Hemisphere people—that this isn't a dominant factor in our weather, because Earth's orbit is nearly circular).

Trivia Contest

Our September/October contest winner is Paul Bruckman of Sointula, British Columbia. Congratulations!

The Question was: How many of *Apollo 15*'s parachutes worked properly during Earth re-entry?

The Answer: Two of three. One failed, but two were sufficient for a safe splashdown.

Try to win a free year's Planetary Society membership and a Planetary Radio T-shirt by answering this question:

How many different astronauts lived on* Skylab*?

E-mail your answer to *planetaryreport@planetary.org* or mail your answer to *The Planetary Report*, 65 North Catalina Avenue, Pasadena, CA 91106. Make sure you include the answer and your name, mailing address, and e-mail address (if you have one).

Submissions must be received by April 1, 2007. The winner will be chosen by a random drawing from among all the correct entries received.

For a weekly dose of "What's Up?" complete with humor, a weekly trivia contest, and a range of significant space and science fiction guests, listen to Planetary Radio at *planetary.org/radio.*

suing involvement opportunities with them all.

We have also advocated a concept for future exploration called Planetary Outposts, for which the first step we proposed was an International Lunar Waystation. This would be a location on the Moon about which standards would be agreed upon so various international missions could contribute. The goal of the Waystation would be to systematically emplace robotic assets, then later follow those robots with human explorers who would use the robotic infrastructure. All of this would be done with an eye toward an eventual Mars base.

A few years ago, we disseminated a paper discussing what first steps would be needed for this type of activity. We outlined issues that need to be addressed in any lunar exploration strategy so as to increase science and exploration return and to maximize efficiency. At the *LRO*-hosted meeting, many of the important issues we called out were being discussed, such as creating a common coordinate system for the Moon and common calibration sites (some of which could lead to landing sites). These types of issues are not glamorous, but they are important if we are to facilitate coordination between missions. Other critical topics we identified, such as better gravity mapping—key not only to science but also to issues such as accurate landing on the lunar surface—will be better addressed by planned missions such as *SELENE*. No matter what the lunar future holds, these matters will be vitally important in facilitating the most efficient science and exploration possible.

Bruce Betts is director of projects at The Planetary Society.

Members' Dialogue

Short-Term Concerns

I am responding to your notice about membership renewal with a check and best wishes to The Planetary Society. Your help in saving vital robotic missions like the one on its way to Pluto is greatly appreciated—as well as your help in keeping the *Voyager* and Hubble projects going. But I remain troubled about the Society's emphasis on human space exploration "with the ultimate goal of seeing human explorers on Mars."

Your membership letter cites Society Cofounder Carl Sagan's goals and priorities, but in Sagan's 1994 book *Pale Blue Dot*, he expresses some reservations about human space travel to Mars and beyond. On page 244, he says: "The ancient explorers would have understood the call of Mars. But mere scientific exploration does not require a human presence. We can always send smart robots. They are far cheaper, they don't talk back, you can send them to much more dangerous locales, and, with some chance of mission failure always before us, no lives are put at risk."

In the book, Sagan did discuss longer-term reasons for humans to venture into space, including the survival of our species, but in the shorter term, there are many concerns, including possible human contamination of alien life. The robotic program to such exciting places as Jupiter's moon Europa is lagging. Continued budget cuts are likely. The shuttle, the space station, and related human flight efforts will drain off more scarce financial resources, with relatively little scientific return. And there are always serious risks to those who fly the missions.

I hope The Planetary Society considers these and many other such factors that favor a vibrant, well-planned robotic program for quite a while. I can stay energized for weeks just thinking about all the benefits from the *Voyager* program.

—EARL FINKLER,
Barrow, Alaska

Public Involvement

Carl Sagan wanted to involve Planetary Society Members in missions to other worlds. The Society has demonstrated to the leaders of our country that large numbers of people believe in the exploration of space.

Probably, one result from this was that the public was actually invited to suggest where to aim the *Mars Global Surveyor*. For two years, I made suggestions and received many pictures back from Mars. It was one of the most exciting ventures I've ever attempted. It was like a football fan being able to run a few plays in the Super Bowl.

The best of my images, and the images of other amateurs, can be viewed on my website: *paws.flcc.edu/~secoskjj/*

—JIM SECOSKY,
Manchester, New York

Titan

Knight *Cassini*'s vow
your riddling shroud
methane ethane
clouds rain snow
secret seas to be won
what you allow
intrepid probes know
cove cliff rill
what secrets spill
so far from Sun.

—LAURIE A. CARLSON,
Natick, Massachusetts

Please send your letters to
Members' Dialogue
The Planetary Society
65 North Catalina Avenue
Pasadena, CA 91106-2301
or e-mail: *tps.des@planetary.org*

Questions and Answers

Some Martian craters, such as Victoria, do not have a raised rim but are fairly level with the surrounding terrain. Factors such as age, erosion, and in-fill contribute to a crater's appearance. The Mars rover Opportunity *imaged this promontory called Cape St. Mary from Cape Verde, the next point over along Victoria's deeply scalloped rim.*
Image: NASA/JPL-Caltech/Cornell University

It seems that some Martian craters don't have a noticeable uplifted rim around the edges; instead, the rims seem to be level with the surrounding plane—like Victoria crater. Do scientists have a possible explanation for this?
—Mike Martinez
Hudson, Wisconsin

More and more evidence is pointing to complex geologic processes operating in "recent" geologic time (the last 100 million years or so) to modify Martian topography. We are used to this idea on Earth; holes and ponds may fill in, and very few impact craters survive from ancient eras. But scientists are only slowly coming to accept this for Mars.

In the case of crater rims, we can speculate on a number of processes. Dry crater rims are piles of loose, fragmental material. Depending on the material in the impact target area (such as a sea of sand), the rim may contain only fine particles. In many areas, winds may simply blow away much of the rim, as well as depositing sand dunes in the interior, which would act to fill in the crater.

At middle to upper latitudes on Mars, cycles of change in axial tilt cause significant climate change on time scales of about 10 million years, triggering ice to condense on dust particles. As the ice sublimes away, a dusty mantle many meters thick builds up, as discovered in particular by Jack Mustard and his colleagues at Brown University. This mantle drapes over surface features and tends to smooth them out. In other areas, an impact crater may form in ice-rich material, then simply flatten out as the ice flows slowly, like a glacier, to fill in the hole.

The situation at Victoria crater is more complicated because the area is filled in with sediments laid by water and wind. There is some evidence that the region was once a lake bed. The sediments there are much weaker and more crumbly than the familiar basaltic rocks at other sites. The high number of hematite "blueberry" concretions now on the surface indicates that several meters of blueberry-containing sediments have eroded or blown away, leaving the denser, heavier hematite spherules behind.

Original crater rims on Mars may have been composed of plate-like slabs of rock (from the sediment layers below) and loose, fine sedimentary dust and gravel. The processes of erosion and in-fill have modified the topography and flattened the rims of ancient craters. Thus, the present form of a crater depends mostly on its age and amount of erosion and in-fill.
—WILLIAM K. HARTMANN,
Planetary Science Institute, Tucson

If a metal asteroid five kilometers (three miles) in diameter coming straight in at average speed were to hit Earth, where would the "best" impact point be to kill the fewest people?
—Pete Newman
Westlake Village, California

The bad news is that if a five-kilometer metal asteroid were to hit Earth at about 20 kilometers (12 miles) per second—the average impact velocity for near-Earth objects (NEOs)—the "best" impact point for it, in terms of the least damage to life, would be moot. In all likelihood, the result would be the end of humanity and the end of civilization, regardless of the impact point.

Scientists believe the object that created the Chicxulub crater in the Yucatán was about 12 kilometers (7 miles) in diameter, about a factor of 10 greater in volume. However, assuming the Chicxulub impactor was a stony object (the most common), its likely bulk density would have been about one-fourth that of your proposed impactor. The energy of your impact therefore would still be about one-third that of the Chicxulub mass extinction event—that is, the equivalent of 30 million megatons of TNT.

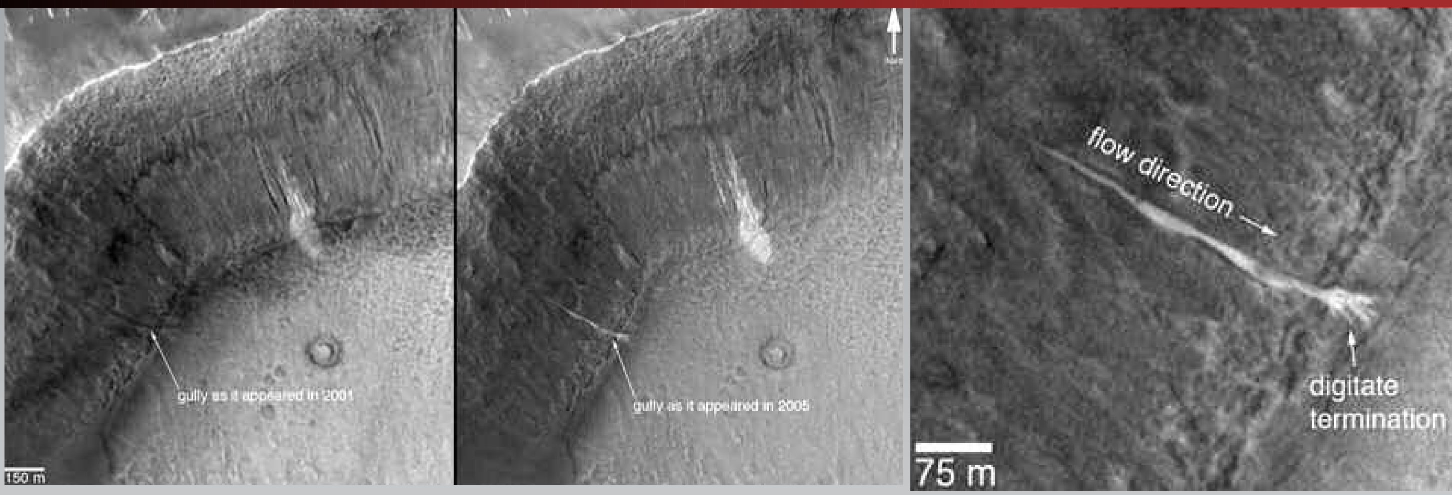
The good news is that such an object is extremely unlikely to exist in the NEO community, and perhaps in the main asteroid group as well. Far more dangerous to us are the many NEOs with diameters of 1 kilometer (0.6 mile) and smaller. The total population of those that can do damage if they impact Earth's surface exceeds 500,000! Fortunately, we are discovering them at an increasing rate (giving us early warning), we have the technology to deflect some of them now, and (if we get to work) we could have a comprehensive deflection capability in a decade or two. We are also beginning work now to develop an NEO deflection treaty for the United Nations, so that when an NEO confronts us, there will be a decision system in place to respond in a timely manner.

Regarding a smaller impactor and where it would have to hit for minimal damage, about all that can be said is that for NEOs under about 200 meters, hitting in the ocean would be best (luckily, Earth's surface is about 70 percent ocean). If the impactor were larger than that, however, the tsunami damage would begin to rival that from a land impact. Ironically, once these putative impactors get up toward 400 meters, the tsunami damage (according to sparse economic modeling) would slightly exceed the damage were the same object to impact on land.

That being said, the best place for an impact to occur on land is somewhere far away from me! If it can hit in Siberia, or the mid-Sahara, or some other sparsely inhabited spot, so much the better.

—RUSTY SCHWEICKART,
B612 Foundation

Factinos



Recent* Mars Global Surveyor *images of gullies in two Martian craters show evidence that liquid water may be emerging from below the surface. This series of an unnamed crater in Mars' Terra Sirenum region shows (at left) the gully as it appeared in December 2001. The image at center, taken in April 2005, shows a bright deposit in the same gully. Above is a closer view of the deposit, taken in August 2005. The newly deposited material covers the entire gully floor and, on the downward end, breaks off into five fingerlike channels.

Images: NASA/JPL/Malin Space Science Systems

Liquid water may still flow in brief spurts on the surface of Mars (see images above). Pictures of gullies returned by the now-defunct *Mars Global Surveyor* (*MGS*) reveal bright new deposits that suggest liquid water carried sediment through them sometime during the last seven years. The spacecraft's Mars Orbiter Camera (MOC) imaged the new deposits in 2004 and 2005.

"The shapes of these deposits are what you would expect to see if the material were carried by flowing water," said MOC Principal Investigator Michael Malin. "They have fingerlike branches at the downhill end and are easily diverted around small obstacles." Malin is lead author of a report about the findings, which appeared in the December 8, 2006 issue of *Science*.

Researchers think water could remain liquid long enough after reaching Mars' surface to carry debris downslope before freezing in the planet's thin atmosphere and cold temperatures. The two fresh deposits are each several hundred meters long.

Tens of thousands of gullies on slopes and inside craters and depressions on Mars have been imaged by *MGS*. To look for changes that might indicate current flows of water, Malin's camera team repeatedly imaged hundreds of the sites.

The two sites, inside craters in the Terra Sirenum and Centauri Montes regions of southern Mars, are the first (after earlier imaging of the same gullies) to reveal newly deposited material that appears to have been carried by fluids.

"These fresh deposits suggest that at some places and times on present-day Mars, liquid water is emerging from beneath the ground and briefly flowing down the slopes," Malin said. "This possibility raises questions about how the water would stay melted below ground, how widespread it might be, and whether there's a below-ground wet habitat conducive to life. Future missions may provide the answers."

—from the Jet Propulsion Laboratory

Society News

Travel with The Planetary Society

Alaska Aurora Borealis Expedition

March 15–21, 2007

Join us as we explore the great beauty of Alaska in winter and see the famed Aurora Borealis (northern lights), the greatest light show on Earth!

Look for wildlife on a Resurrection Bay boat trip, then travel from Anchorage to Fairbanks by train, passing 20,320-foot Denali (Mt. McKinley), the highest peak in North America!

See the Ice Festival in Fairbanks, and watch the Aurora Borealis dance across the night sky! The cost for this adventure is $2,495* plus air.

Discover Antarctica!

November 16–29, 2007

Come discover the absolute splendor of the world's most magnificent wilderness, traveling on board M/V *Ushuaia* (formerly the NOAA scientific vessel *Malcolm Baldrige*).

See a profusion of wildlife, glaciers that plunge to the sea, and stunning mountain peaks. Enjoy traveling with other Planetary Society members as you learn how Antarctica holds many answers to Earth's past climate.

Explore in zodiacs and marvel at the penguins, humpback whales, and sheer beauty of it all!

All this adventure is priced from $4,995* plus air.

*Prices based on twin share plus air.

For more information on either of these trips, contact Betchart Expeditions by phone at (408) 252-4910 or e-mail at *deborah@betchartexpeditions.com*.

Plan to Celebrate with Us!

Coming Soon: A Gala Celebration of 50 Years of Exploring Space

October 2007 marks the 50th year since the launch of *Sputnik*—and 50 years of space exploration and discovery. The Society will celebrate throughout the year with symposia, lectures, contests, and more.

These festivities will culminate in a gala celebration at which we will "pass the torch" to the next generation and the next 50 years.

Continue to watch *The Planetary Report*, our website at *planetary.org*, and your mailbox as we unveil our plans for festivities around the world.

Thank you for being part of our space age!

—Andrea Carroll,
Director of Development

Special Members-Only Discount!

Autographed copies of Sally Ride's newly revised book, *The Mystery of Mars*

Sally Ride Science is pleased to offer members of The Planetary Society copies of the newly revised *The Mystery of Mars*, signed by Sally Ride, for $18.75, a savings of 25%.

In *The Mystery of Mars*, pioneering astronaut Sally Ride and noted science writer Tam O'Shaughnessy draw on results from the most recent missions to Mars to present a comprehensive overview of Earth's nearest planetary neighbor.

With its thin atmosphere, rocky canyons, extinct volcanoes, and icy polar regions, Mars has many things in common with Earth. It's possible that water once flowed over its surface and that life may have begun there. Comparing the two planets' evolution, geology, and geography, the authors explain what we know about Mars today—and what we hope to learn about Mars in the future, including whether primitive life does exist somewhere beneath its barren surface.

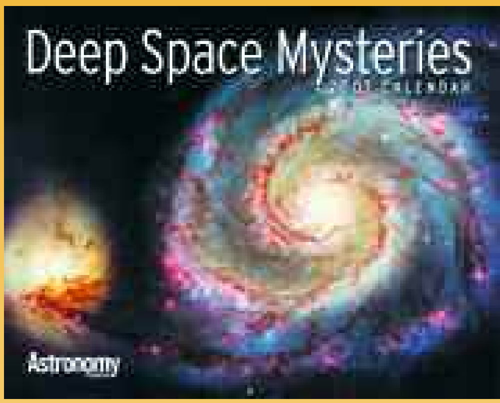
With lavish color photographs, this engaging and accessible introduction to the Red Planet is the ideal guide to a new age of Mars research.

To redeem your Planetary Society discount, visit *planetary.org/special/sallyride.html*, or if you prefer to order by phone, call (800) 561-5161 and give your special Planetary Society code: **tps01**.

Don't miss out on this special offer!

—Jennifer Vaughn,
Director of Publications

Welcome a New Year of Exploration!



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