The PLANETARY REPORT

Volume XII Number 5 September/October 1992

Raising the Flag

A Tribute to Tom Paine

A Publication of
THE PLANETARY SOCIETY

The Planetary Report (ISSN 0736-3680) is published six times yearly at the editorial offices of The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106, (818) 793-5100. It is available to members of The Planetary Society. Annual dues in the US or Canada are $25 US dollars or $30 Canadian. Dues outside the US or Canada are $35 (US).

Editor, CHARLENE M. ANDERSON
Technical Editor, JAMES D. BURKE
Assistant Editor, DONNA ESCANDON STEVENS
Copy Editor, GLORIA JOYCE
Production Editor, MITCHELL BIRD
Art Director, BARBARA S. SMITH

In Canada, Second Class Mail Registration Number 9567

***COVER: Raising the flag on Mars is a scene from the future imagined by artist Carter Emmart, who painted this as a tribute to Tom Paine. Tom created the Mars flag as an award to the person or organization that he felt had contributed most to advancing the human exploration of Mars. In 1987 it was won by The Planetary Society. One of Tom's last requests was that the Society take over the awarding of the Mars flag. We are now organizing the Thomas O. Paine Memorial Award program. Details will be given in a later issue of* The Planetary Report.**

FROM THE EDITOR

After the graveside services for Tom Paine, high on a bluff above the Pacific Ocean, the gathered friends broke up into small groups and began to drift away. A few people walked to the edge of the bluff and gazed down at the sea. There a pod of pilot whales was swimming by—pilot whales, named for their habit of swimming alongside ships, seeming to guide them in and out of harbor. The metaphor was hard to miss. We had just buried an old Navy man, and it seemed as if the whales had come to guide his spirit out on its last journey.

It's difficult to resist such sentimental musings when remembering Tom Paine, who led NASA during its moment of supreme triumph—the first landing of humans on the Moon. For people of my generation, too young to work on *Apollo*, Tom Paine was the leader of a band of heroes who had conquered for humanity that emblem of the unattainable.

I was fortunate that I came to know my hero in his capacity as a Director of The Planetary Society. He was an inspirational leader who will be sorely missed by the other Directors, the staff and the members of The Planetary Society.

To help us say good-bye, we have put together this special issue of *The Planetary Report.* Our theme is Mars, for it was Tom Paine's greatest dream that someday humans would walk on the Red Planet as they had on the Moon.

In this issue you'll also find our annual catalog, bound into the center for your holiday shopping convenience. Please remove it and keep it for future reference.

—Charlene M. Anderson

A Note About the Illustrations

Although several spacecraft have explored Mars, none returned a good image of the complete disk of the Red Planet. The United States Geological Survey in Flagstaff, Arizona, undertook to fill that void. From detailed images returned by the *Viking* orbiters, they built four full hemispheric views using computer techniques. We reproduce them on pages 8, 12, 16 and 20 to introduce the essays on the future of Mars.

Members' Dialogue

As administrators of a membership organization, The Planetary Society's Directors and staff care about and are influenced by our members' opinions, suggestions and ideas about the future of the space program and of our Society. We encourage members to write us and create a dialogue on topics such as a space station, a lunar outpost, the exploration of Mars and the search for extraterrestrial life.

Send your letters to: Members' Dialogue, The Planetary Society, 65 N. Catalina Avenue, Pasadena, CA 91106.

Considering the constant discussions in Congress about the high cost of maintaining the space shuttle and using it to build the proposed space station, I am curious about whether an alternative and, it seems to me, more cost-effective system of delivering payloads and astronauts into space has ever been considered.

What I mean is a much smaller, cheaper version of the shuttle—one whose sole purpose is to transport personnel into Earth orbit. The job of lofting satellites, probes and spce station components would be left to a diverse fleet of unmanned rockets. In this way, any experiments designed to determine the effect of space travel on human physiology could be accomplished using a smaller shuttle not designed to carry multiton payloads. Likewise, any satellite or probe not requiring direct human assistance could be deployed without the expense and risk involved in sending people into orbit. Moreover, in cases like the construction of the space station, where direct human intervention is required, it would be possible to send the raw material into orbit on unmanned rockets and later send the human technicians to assemble it. This way materials could first be put into orbit cheaply on unmanned rockets and then be assembled during a single human mission. This would allow NASA to accomplish its goals with less risk to humans and with less money.

While I believe that a permanent human presence in space should be a goal of this country, I do not believe that human life should be risked unnecessarily. When we factor in the enormous cost of sending humans into space and the fact that this cost is threatening the very existence of many important space science projects, it seems that a more cost-effective system should have been considered. Has it?

—JAMES FIORDALISI, *St. Louis, Missouri*

This question goes right to the heart of the debate over the raison d'être *of the space shuttle. In the 1970s and early 1980s, the idea was promulgated that a reusable human-piloted launch vehicle would be cost-effective as the nation's* sole *launch vehicle. This proved to be tragically erroneous. There has now been a shift in thinking to the use of automated launch vehicles for cargo, as you suggest, and to reduce dependency on human-piloted launches—except, of course, to send humans into space. There is now no development under way for a next-generation shuttle—although a smaller system called the National Aerospace Plane (NASP) has been proposed. Whether it will be cost-effective is still being debated.*

—Louis D. Friedman, Executive Director

As you know, changes happen in this part of the world, so now I live in another country. Yugoslavia doesn't exist anymore, now I live in Slovenia. I hope that this madness will stop at last and that people will spend money on research and education rather than on stupid fighting.

If you can do anything, tell your congressman to put money on your programs (Mars, etc.) rather than on weapons.

—MARICA STARESINIC, *Ljubljana, Slovenia*

News Briefs from the March/April issue of *The Planetary Report* contains some errors. You report that "chlorine monoxide is a free radical that separates itself from chlorofluorocarbons and destroys the ozone layer." Chlorine monoxide (Cl_2O) is not a free radical. A free radical is a molecule that has an unpaired valence electron. Perhaps you meant chlorine dioxide (ClO_2), which is a free radical. Chlorine monoxide does not separate itself from chlorofluorocarbons and is not destroying the ozone layer.

—P. JAN CANNON, *Tecumseh, Oklahoma*

NEWS BRIEFS

On July 10, the European Space Agency's (ESA) *Giotto* probe passed comet Grigg-Skjellerup within 300 kilometers (about 190 miles) at a distance of 214 million kilometers (about 130 million miles) from Earth. This was an even closer approach than *Giotto*'s encounter with comet Halley in 1986. Of the original 11 instruments, 7 were successfully reactivated on July 9. The spacecraft's signal was routed from NASA's Deep Space Network station near Madrid to the European Space Operations Center in Darmstadt, Germany.

After its Halley encounter, the probe was put into hibernation before being redirected toward Grigg-Skjellerup in July 1990.

—from the European Space Agency

Richard Goldstein, a radar specialist from the Jet Propulsion Laboratory, and his colleagues at JPL, the Johnson Space Center and Cornell University have found a way to track space debris with Puerto Rico's Arecibo radio telescope. The researchers used Arecibo's main antenna, which is 305 meters in diameter, as a radar transmitter, and a smaller antenna about 10 kilometers away as a receiver, pointing both antennas at the same spot above Earth. The receiver clearly picked up radio waves echoing off space garbage as small as 5 millimeters long, which is like detecting a thumbtack in San Francisco when you're standing in Los Angeles.

—from *Discover*

Engineers from Stanford University have teamed with Russian space exploration experts to define an international human mission to Mars that would cost about $70 billion—a bargain compared to NASA's estimates for a United States-only mission. *Energia*, the Russian heavy launch vehicle, is an essential part of the low-budget plan. Significant contributions from ESA and Japan are included in the plan, which envisions sending six astronauts to Mars for a 500-day stay in 2009. The study's conclusions will be presented at NASA Ames Research Center and Johnson Space Center, then circulated throughout NASA.

The Stanford group chose to rely on readily available space technology. "The Stanford approach is 'let's not put any giant, undeveloped technology issues between us and a mission,' " said Christopher P. McKay, a research scientist in NASA's Solar System Exploration Office.

—from *Aviation Week and Space Technology*

The Last of the Corsairs:
The Life of Thomas O. Paine

by Carl Sagan, Bruce C. Murray, Louis D. Friedman and Charlene M. Anderson

Photograph: Michael Pizzuto

Tom Paine was a dreamer, an adventurer, a scientist and a leader. He charted a course to Mars and believed in his heart that humans would make the journey. When he died, on May 4, 1992, the people of Earth had not yet mustered the will or the resources to follow this course. Still, many of us who knew him share his conviction that humans will one day walk on the Red Planet and make it their home.

Tom Paine knew how to get to Mars. He knew what it would be like to do it. He had served on submarines in the Pacific theater during World War II, so he knew how to live in close confinement with other people during extended periods of extreme danger. He led NASA when humans first set foot on another world, so he knew the complex technical and organizational demands of space travel to other worlds. He had advised United States presidents on the future in space; he had thought long and hard about what interplanetary voyages are possible and desirable.

Tom Paine was a pillar of The Planetary Society, serving as a member of the Board of Directors since 1986. He brought to us the experience of a remarkable life and the enthusiasm of a person who has seen the future and reveled in it. One role of a Director is to inspire and lead the members of the organization in pursuit of their goals. In this role he excelled.

When Tom Paine died, The Planetary Society and, indeed, the people of Earth lost a set of experiences, vision and just plain know-how that may well be irreplaceable. He left behind plans on how to get to Mars, most completely presented in *Pioneering the Space Frontier*, the report to Congress of the National Commission on Space, which he chaired. When humans finally fly to Mars, they will be fulfilling the vision of Tom Paine.

★ ★ ★

He was born into a Navy family, so seafaring—and, later, spacefaring—came naturally to him. His father was Commodore George T. Paine, USN; his mother was Ada Louise Otten. Tom was born November 9, 1921, in Berkeley, California. Commodore Paine was a naval architect specializing in destroyer and submarine construction, so Tom's childhood was spent prowling around navy yards.

On December 8, 1941, the day after Pearl Harbor, Tom enlisted in the US Navy. Told to report for duty after graduation the next June, he completed his undergraduate work at Brown University, earning a bachelor's degree in engineering. Then, after undergoing "90-day wonder" training at Annapolis, he volunteered for submarine service and was posted to the southwestern Pacific. He made seven combat patrols in the USS *Pompon*, from the South China Sea to the Sea of Okhotsk.

Many commentators have made the connection between long submarine voyages and long voyages to the planets. Tom had firsthand knowledge of what confinement, forced intimacy and shared danger could do to people. He also knew what it was like to face an alien environment alone. He earned his deep-sea diver's rating and walked muddy harbor bottoms in canvas rig, hard hat and lead shoes.

As it was for many men of his generation, World War II was one of the best remembered times of Tom's life, despite the terror and the horror. He was full of tales of his sea adventures. One of his favorites was about how he served as executive officer on a *Japanese* submarine.

After Japan surrendered, Americans took control of Sasebo Harbor, home port to the *I-400*, then the largest submarine in the world. The *I-400* had another distinction: It was equipped as a submersible aircraft carrier and on its deck was a large hangar for bombers. The Americans were naturally anxious to study the Japanese technology. Three prize crews were dispatched to sail the *I-400* and two sister ships to Pearl Harbor. Tom served as "XO" on the *I-400*.

Sailing a captured enemy vessel without blueprints or instructions was not easy work. The American crew had to improvise, salvaging any spare parts or supplies they happened to find in the warehouses and caves around the Sasebo navy yard. Tom's crew found much more than they needed. Soon, Tom recalled, the former bomber hangar was filled with rifles and bayonets, Japanese uniform buttons and rating badges, rubber stamps and even a sampan. The crew then set out to wheel and deal their way across the Pacific to Pearl Harbor. The *I-400* became, in Tom's words, "history's first underwater interisland trader."

When the war ended, Tom was one of the few American servicemen in no hurry to get back home. In Perth, Australia, he had met Barbara Helen Taunton Pearse of the Women's Auxiliary Australian Air Force. After some maneuvering, he got her into the United States, married her and cut their wedding cake with a Japanese sword.

World War II had brought Tom together with two of the great passions of his life: Barbara and submarines. Tom left the Navy, earning a PhD in metallurgy from Stanford University and going to work for the General Electric Company. But he maintained his interest in submarine warfare his whole life. In 1944, while he was still assigned to the USS *Pompon*, Barbara had given Tom a book on submarines called *Stand by to Surface* by Richard Baxter. This book began a collection that grew to over 3,000 volumes. Tom kept up his work on submarines right up to his last day of consciousness, adding to his *Submarine Registry and Bibliography*, which he hoped would someday become an on-line, cross-indexed data base open to all interested researchers.

The last thing Tom wrote was a collection of memories entitled "Unforgettable Images From the World War II Pacific Submarine War." He wrote of seeing such things as Sunken Battleship Row in Pearl Harbor, and Japan's Inland Sea "looking like a lovely old Hiroshige print—except for the remains of sunken Japanese battleships littering the beaches of the little pine-covered islands, and dry docks full of minisubs under construction." He closed with the words of George Grider, his skipper on the *Pompon:* "We were the last of the corsairs!"

★ ★ ★

Tom joined General Electric in 1949 and worked for the company for 25 years. He became manager of GE Tempo, a company think tank located in Santa Barbara, California. Tom described Tempo's functioning to a *New York Times Magazine* writer in 1969:

"We didn't offer ourselves as management consultants. We concentrated on areas I thought were important—rural development abroad, urban rehabilitation here, communications, transportation. What we'd say was, 'We've been spending a lot of time looking at the world of the future, and we think we can tell you a lot of valuable things about the problems you'll be facing 10 or 15 or 25 years from now.'"

Tom's formula paid off for General Electric, and his success at Tempo attracted the attention of Johnson administration staffers, who in 1968 were looking for a deputy administrator for NASA.

John Kennedy had in 1961 given the American space agency the task of landing a man on the Moon and returning him safely to Earth before the decade was out. With the American public and Congress staunchly behind the effort, and willing to provide the money to do it, NASA was on the verge of attempting to send three men to orbit the Moon in 1968. But all was not roses at NASA. The *Apollo 1* fire had killed three astronauts and shaken the country's faith in the agency. The Vietnam war had diverted attention and money from the Space Race. NASA's top management was fighting to keep the program on track and adequately funded.

While he was in Washington, DC, on other business, Tom was asked to stop by NASA and talk about the job of deputy administrator. He was not yet fluent in bureaucratese and at first thought the job title indicated some sort of assistant office manager position. But he had some time to kill and decided to go. In January 1968, he got the job.

There was little time for on-the-job training. A few months later, with NASA Administrator James Webb out of the country, Tom was called upon to decide whether to send *Apollo 8* to circle the Moon. He listened to *Apollo* project leaders discuss all sides of the question; then, with customary boldness, Tom gave the approval for humanity's first voyage to another world. He called his boss in Vienna to give him the news.

Shortly thereafter, in October 1968, James Webb resigned and Tom became acting administrator of NASA. Then the November general election saw the victory of the Republican candidate, and Tom found himself a lonely Democrat in the Nixon administration. Tom's managerial style had won him a lot of supporters, who lobbied for his permanent appointment. The new administration came around, and in March 1969 Tom was officially confirmed in the job he had already been doing for many months.

Tom was at NASA's helm at the most glorious moment in its history: On July 20, 1969, Neil Armstrong and Buzz Aldrin of *Apollo 11* became the first humans to walk on the Moon.

It was typical of Tom that, even before that moment of supreme triumph, he was looking beyond to future challenges. A few months earlier, after the flight of *Apollo 10*, Tom had proclaimed Mars to be the true destination of human spacefarers. It was a belief he was never to relinquish.

Tom planned to build an economical shuttle system for space travel, an Earth-orbiting space base and an orbiting lunar station; he also planned a mission of humans to Mars by the mid-1980s. He went far beyond his predecessors in planning for the future, and impatiently dismissed those who refused to commit themselves to an expansive future in space. He demanded imagination and courage.

Tom understood that the general public finds it harder to identify with spacefaring robots than with humans, yet he vigorously supported the robotic missions of science. During his watch at NASA, Tom approved plans for the most ambitious planetary mission ever launched: *Viking* to Mars. He also laid the groundwork for the Grand Tour of the outer planets, a mission in scaled-back form that would become known as *Voyager*.

Tom led NASA through some difficult years. It was a time of supreme achievement, culminating in the *Apollo* landings, but it was also a time of self-doubt and criticism, when it became difficult to reconcile the achievements of science and technology with the failures of society and government.

In fighting the perennial budget battle in Congress, Tom addressed the problem of social inequalities. He wrote: "We recognize the many important needs and urgent problems we face here on Earth. America's space achievements in the 1960s have rightly raised hopes that this country and all mankind can do more to overcome pressing problems of society. The space program should inspire bolder solutions and suggest new approaches."

Unfortunately, the confident nation that had in 1961 challenged itself to go to the Moon, and met that challenge just eight years later, had changed. Vietnam, civil unrest and social tensions were foremost in people's minds. The Space Race had been won, the Soviet Union had been bested, the point had been made, and many saw little sense in continuing the adventure.

Despite the shift in the wind, Tom continued to speak confidently of Mars. He fought hard to preserve NASA's budget and its goals. Still, the force of the retreating tide was too much for him to control. The planned lunar landings beyond *Apollo 17* were canceled. Plans for an orbiting space base went no further than the three-person *Skylab*. A human Mars mission was put on hold indefinitely.

On July 28, 1970, barely a year after the triumph of *Apollo 11*, Tom resigned as head of NASA. The official reason was that General Electric had made him an offer too good to refuse. Other reported reasons were the decline of NASA, the grind of defending the agency to Congress and the administration, and the desire to earn enough money to support four children through school and college.

With Tom gone, NASA changed direction. He was replaced by James Fletcher, who led the agency to the development of the Space Transportation System, the shuttle we have today. This was not a program that excited Tom. He once called the shuttle a "space truck with a mission no more glamorous than carting a load of toothpicks to Topeka."

One of the most lasting legacies of Tom's time at NASA was not accomplished until 1975 with the *Apollo–Soyuz* test project. He had initiated this project, in which astronauts in an *Apollo* spacecraft would dock with cosmonauts in a *Soyuz* spacecraft to test the feasibility of joint missions. Tom had long believed that humanity could do far more exploring if the spacefaring nations worked together. Even in the nationalistic afterglow of *Apollo 11*, he lamented that we would have been able to accomplish much more if the Soviet Union had worked with us. In his dreams of Mars, he saw the two nations traveling together, and he continued to work toward that dream until the end of his life.

It is possible to summarize Tom's time at NASA with one of his favorite sayings, attributed to Daniel Burnham, who drew up the plans for rebuilding Chicago after the great fire: "Make no little plans; they have no magic to stir men's blood."

☆ ☆ ☆

After leaving NASA, Tom returned to General Electric as vice president and group executive of the Power Generation Group and senior vice president for science and technology. In 1976 he went to the Northrop Corporation, where he became president, chief operating officer and a director. He retired from Northrop in 1982.

In 1985, President Reagan appointed Tom chairman of the National Commission on Space. In the 15 years since Tom had left NASA, it had become painfully obvious that the US space program was adrift. Congress had created the commission to chart a course into the next century.

If they wanted a leader with vision, Tom was the man to supply it. The Paine commission, as it came to be known, presented the president and Congress with *Pioneering the Space Frontier*, which set out an ambitious series of goals. But the timing was a little off. The report was completed soon after the *Challenger* disaster, when the nation's attention was diverted.

Despite the lukewarm response to the Paine commission report, Tom refused to let go of his vision. He liked to present it in what he called a "one-sentence" overview. It was a pretty long sentence. It reads:

"NASA must develop six challenging new technology bases and program elements:

"1. A *Highway to Space*, using economical joint NASA–USAF [US Air Force] heavy-lift launch vehicles to provide regular, low-cost access to Earth orbit for passengers and massive cargo;

"2. *Orbital Spaceports*, evolved from international Space Station 'Freedom,' circling the Earth, Moon and Mars, to support remote human operations and the assembly, storage, repair, refueling, checkout, launch and recovery of robotic and piloted spacecraft;

"3. A *Bridge Between Worlds* to open regular transport to the Moon, and to extend spaceflight to Mars (perhaps using automated electric propulsion/aerobraking cargo carriers, and heavily shielded international passenger ships, with artificial gravity, cycling in permanent orbits between Earth and Mars);

"4. *Prospecting and Resource Utilization Systems* to map and characterize the resources of the inner solar system, and to develop robotic processes for 'living off the land' using indigenous materials on other worlds;

"5. *Closed-Ecology Biospheres* to recycle air and water and provide food and organic products within Earth-like habitats on other worlds; and

"6. *Lunar and Martian Bases* to furnish advanced life-support, power supply, robotic systems, construction facilities, workshops, laboratories, transportation and exploration infrastructure for sustained international operations on the Moon and Mars."

Tom's bold vision remained in demand in Washington. In 1990 he was appointed to the Advisory Committee on the Future of the US Space Program (the Augustine committee) to suggest better ways for NASA to conduct its business. In 1991, he was appointed to the US Space Policy Advisory Board to guide yet another administration through space.

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Tom's ambitions for The Planetary Society were as big as his vision for NASA. In June 1991, he set before his fellow Directors his view of the Society's future:

- "Planetary Society editorial policy, publications and testimony should encourage the United States, Soviet republics, Europe and Japan to lead international space exploration and advance the technologies needed to build an evolutionary spaceflight infrastructure.
- "Planetary Society aspirations should include: by 2005 a prototype base on the Moon transmitting video bulletins to our members on Earth, by 2015 Martian men and women demonstrating how to live off the land from the foot of Olympus Mons, and by the 50th anniversary of Mike's epic voyage [fellow Director Mike Collins was an *Apollo 11* astronaut] a Video Planetfest that links asteroid explorers to our members on three worlds.
- "Planetary Society programs should attract widespread support for international space exploration, inspiring young people around the world to prepare for exciting careers in space sciences, engineering, exobiology and extraterrestrial operations.
- "The Planetary Society should vigorously promote the universal goal of a New Age of Exploration in which the human intellect expands terrestrial life throughout the solar system.
- "Planetary Society activities, plus unforeseeable breakthroughs in fields like biological engineering and terraforming, should stimulate interest in the role of intelligence in the cosmos, and the determination that our descendants will reach the stars."

After his years in industry and government, Tom seemed to appreciate the freedom of action provided by a membership-supported group like The Planetary Society. He reveled in our ability to undertake projects with space agencies anywhere in the world, and in the resulting expeditions to drag the SNAKE guide-rope through the Mojave Desert and to send the Mars Rover up Death Valley hills. "Our bold, independent freedom of action," and our difference from other institutions, reminded him of a song from his submarining youth, sung to the tune of "The Old Gray Mare":

Oh, we don't have to march like the Infantry,
Ride like the Cavalry,
Shoot like Artillery,
Oh, we don't have to fly over Germany,
We are the old Nyvee!
And *we are The Planetary Societee!*

Tom Paine will be impossible to replace.

☆ ☆ ☆

Tom Paine was buried on a bluff overlooking the ocean in Santa Barbara, California. Those attending the funeral included longtime friends, leaders of the *Apollo* program, an *Apollo 11* astronaut, colleagues from industry, Planetary Society Directors and staff, and representatives of a new generation who, inspired by Tom's vision, hope to lead humanity to Mars. David Thompson, the young president and CEO of Orbital Sciences Corporation, read a selection from "Ulysses" by Alfred, Lord Tennyson, over Tom's grave.

Come, my friends,
'Tis not too late to seek a newer world.
Push off, and sitting well in order smite
The sounding furrows; for my purpose holds
To sail beyond the sunset, and the baths
Of all the western stars, until I die.
It may be that the gulfs will wash us down:
It may be we shall touch the Happy Isles,
And see the great Achilles, whom we knew.
Though much is taken, much abides; and though
We are not now that strength which in old days
Moved earth and heaven; that which we are, we are;
One equal temper of heroic hearts,
Made weak by time and fate, but strong in will
To strive, to seek, to find, and not to yield.

To Settle the Red Planet: A Decade-by-Decade Look at Martian History, 1990 to 2090

by Thomas O. Paine

The Schiaparelli hemisphere of Mars. Image: United States Geological Survey

The future of humankind will be decided by the race between two competing human drives, one to unleash military power to compete for planet Earth's finite resources, the other to cooperate to provide access to unlimited extraterrestrial resources. The outcome of this fateful competition will be determined in the near future. I believe that rational statesmen will choose peace and the extension of humanity to other worlds.

The prospects for peace and prosperity will make the settlement of another world—specifically, Mars—technically feasible, affordable and desirable. Driving forces will motivate humans to settle Mars, and its conquest, undertaken by a vigorous international program, will provide a unifying force that reaches out to all people on Earth. In this paper, I propose a schedule for the colonization of Mars, an adventure that can eliminate limits to humanity's aspirations and open our way to the stars.

International Cooperation for Peace and Prosperity

> The Stone Age may return on the gleaming wings of science.
> —*Winston Churchill*

Since World War II, nuclear weapons have increased in number and destructive power by more than a factor of a thousand, and at least seven nations already have them. Their awesome power effectively deterred the nuclear superpowers from escalating warfare. In the new geopolitical environment of the 1990s, the threat of nuclear holocaust is diminishing. With good luck and responsible statesmanship, there appears to be a good chance that nonproliferation treaties and international inspection can avert nuclear war.

If major conflicts can be avoided, can we then achieve global technical and economic progress on a scale that would make sustained martian investment feasible?

To answer this question, we need to imagine what will happen to the world economy. There are many alternative scenarios, but since exponential technological advances initiate revolutionary social change—though basic human nature changes very little—I've selected as most likely Herman Kahn's "guarded optimism" scenario. This sees the steady economic growth of the past 200 years continuing as the industrial revolution spreads.

An increasing percentage of humanity will possess advanced technologies, growing capital resources, trained scientists and engineers, and future-oriented leaders. This combination will encourage many nations to participate in pioneering the space frontier. Although there are many uncertainties, I believe that productivity and living standards will continue to advance. Strengthened international trade and environmental institutions will be required to guide wise economic growth, but five fundamental factors suggest favorable prospects for international cooperation in the 21st century:

- Forty-five years of Cold War ending without a nuclear Armageddon.
- The decline of military expenditures, freeing capital so it may be used to update the world's industrial, agricultural, communication and transportation infrastructure.
- Accelerating technical progress that will improve public health and education, and spur further widespread productivity gains.
- Demonstrated growth of national economies in well-managed, global-market-oriented nations.
- Increasing capabilities of effective international organizations like Intelsat, the worldwide satellite communications consortium, to bring nations together in high-tech enterprises.

It therefore appears likely that the substantial economic, human and technical resources required for the settlement of Mars in the 21st century will be broadly available.

This brings us to a basic question: Will Mars settlement be affordable? I estimate that the US space budget required would be about twice NASA's $20 billion annual expenditure in the *Apollo* lunar landing era. With a comparable sum spent by other technically oriented nations, Earth's investment in Mars would average around $80 billion (in 1992 dollars) per year—about the annual output of the Ford Motor Company. Assuming that the expenditure level will rise gradually over the century, this would represent a cumulative total investment in Mars settlement of about $5 trillion.

I believe that this price tag is not unreasonable. If the annual gross world product (GWP) in this period rises from today's $20 trillion to $100 trillion in 2085, this $5 trillion investment in Mars would represent less than a tenth of a percent of the cumulative GWP over the century. A prospering Earth can readily afford major investment in the extension of terrestrial life to Mars. Will it wish to do so?

Driving Forces for the Settlement of Mars

> Men need the mystery and romance of new horizons almost as badly as they need food and shelter. In the difficult years ahead, we should remember that the Snows of Olympus lie silently beneath the stars, waiting for our grandchildren.
> —*Arthur C. Clarke*

Once Europeans mastered deep-sea navigation, settlements were rapidly established on other continents, attracting pioneers having diverse motivations. Men and women endured great hardships crossing stormy seas in sailing vessels, opening the American West in Conestoga wagons, impelled both by dissatisfaction with conditions behind them and by visions of a better life ahead. Hazardous 6-to-9-month trips were undertaken as a matter of course.

In the 21st century, when space navigation and closed-ecology life-support technologies have been mastered, Mars will be settled for a similarly wide range of reasons, including these:

- Economic development—long-term investment in a new growth economy, using extraterrestrial materials and energy to carry out the development of the inner solar system.
- Limitless growth potential—access to virgin continents with vast untapped resources, opening an endless frontier

that eliminates Malthusian limits to human aspirations.

• National pride and leadership—the desire of farsighted citizens to participate in history's greatest high-tech human venture.

• Religious, ideological and humanistic values—the desire to preserve life and to transmit deeply treasured beliefs and heritages to posterity.

• Martian descendants—opportunities for the transplanting and growth of genes, families, races and ethnic groups on a new world.

• A fresh start—the attraction of working toward a future for humankind free of the old world's diseases, ignorance, fears and prejudices.

• Technical pilgrim's haven—the chance to build frontier societies that place a high value on scientific vision, technical competence, individual responsibility and cooperative enterprise.

• High-productivity systems driver—initial labor costs on Mars a hundred times those on Earth will stimulate the development of robotic systems with a productivity a hundred times that of terrestrial factories.

• Research and exploration—an R&D base ideally located for astronomy, planetary research, spaceflight development and the exploration of the asteroids and outer solar system.

• Prototype extraterrestrial community—a lifeless planet with rich resources (including water and carbon) for engineering of self-replicating robotic mining, agriculture, industry and closed-ecology life-support systems that future generations will employ throughout our solar system—and, eventually, on an expanding frontier of planets circling other stars.

I am convinced that these driving forces will appeal to many individuals and national leaders, attracting more volunteers than can be initially accommodated. How, then, is the exploration and settlement of Mars likely to proceed over the next hundred years?

A Timeline for Martian Exploration and Settlement

> Only a miraculous insight could have enabled the scientists of the eighteenth century to foresee the birth of electrical engineering in the nineteenth. It would have required a revelation of equal inspiration for a scientist of the nineteenth century to foresee the nuclear power plants of the twentieth. No doubt, the twenty-first century will hold equal surprises, and more of them. But not everything will be a surprise. It seems certain that the twenty-first century will be the century of scientific and commercial activities in outer space, of manned interplanetary flight and the beginnings of the establishment of permanent human footholds outside the mother planet Earth.
>
> —*Wernher von Braun*

Let's begin by summarizing the technical foundation, laid down over the years from 1957 to 1992, on which the Mars venture will be built:

• Large rocket engines and heavy-lift launch vehicles (HLLVs) for getting to low Earth orbit (LEO), the space shuttle for making round-trips to LEO, European and Chinese commercial launchers, and Russian *Energia* HLLVs and automated LEO resupply freighters.

• Upper stages propelling spacecraft from LEO into interstellar space, with advanced R&D [Research and Development] on alternative propulsion systems, from electric ion thrusters to thermal nuclear stages.

• Global tracking networks and tracking and data relay satellites capable of communicating with spacecraft beyond Neptune and Pluto.

• Human orbital flights of many months' duration in *Salyut*, *Mir* and *Skylab* space stations that demonstrate adaptation to weightlessness by humans adequate for the long round-trip to Mars.

• Life science advances, including closed-ecology life-support experiments by NASA, Biosphere II and Russian laboratories.

• Robotic reconnaissance of the solar system from Mercury to Neptune.

• Earth observation satellite systems studying oceans, land masses, ice fields, the atmosphere, and their complex interactions.

• Reconnaissance satellite systems capable of monitoring Earth in support of arms control and peacekeeping treaties.

• Orbiting astrophysical observatories scanning the universe across the spectrum from radio through gamma rays.

• Six human lunar expeditions that demonstrated, more than 20 years ago, surface exploration with self-contained space suits, electric vehicles, automated lunar orbit rendezvous, and other systems and techniques usable on Mars.

This is our heritage. What lies ahead as we build on our 35 years of spaceflight experience to pioneer the space frontier?

1990 to 2000

NASA's new management decides that industry knows how to build space systems and university teams know how to conduct space research. New contracting procedures are therefore instituted that give aerospace firms and academia new freedom and responsibility to carry out faster-paced programs at lower cost.

New launch vehicles and spacecraft are being deployed on accelerated schedules. Space station *Freedom* is canceled in favor of a later HLLV-launched station designed to support the Space Exploration Initiative. The result is a new orbital maintenance and operations center, with life science laboratories; spacecraft maintenance, checkout, refueling and launch capabilities; an experimental space construction test-bed; tether experiments; and other capabilities oriented to the 21st century.

2000 to 2010

Humanity returns to the Moon 30 years after *Apollo* to establish permanent international lunar bases. Aerospace planes and human-rated HLLVs are in initial operation, greatly lowering the cost and risk of transporting men and women between Earth and LEO. The shuttle fleet is retired after another tragic accident. Proposed martian habitats and workshops are being tested on the Moon. A crash program has been instituted to send prospector probes with penetrators to [the martian moons] Phobos, Deimos and the martian surface. Prototype systems under development and test include low-cost electric orbit transfer vehicles using large electric ion thrusters and aerobraking, closed-ecology life-support habitations, robotic mining and industrial systems, and rotating artificial gravity spacecraft.

A human-rated space transportation system is extended to geosynchronous Earth orbit (GEO) and the Moon; human-tended orbiting bases constructed in LEO are deployed to GEO and lunar orbit using economical electric ion propulsion. Martian rovers with automated sample-return capability are helping to select the most promising sites for resource development.

2010 to 2020

The first US-led international Mars expedition shoves off from an Earth-orbital base to rendezvous with Phobos and Deimos and check out predeployed surface habitats. The first humans then land on Mars to activate bases and initiate exploration. Prototype extraterrestrial communities based on robotic resource development begin operation. A new international space agency is organized to manage extraterrestrial operations.

2020 to 2030

The first automated nuclear electric generating station goes on line to power martian bases. Its energy is used to separate hydrogen and oxygen from permafrost to fuel surface transport and surface-to-orbit shuttles. Economical electric ion thrusters are providing propulsion for robotic freighters delivering heavy cargoes from Earth and to emplace the first multipurpose space base in low Mars orbit. This facility serves as Mars Mission Control Center, orbital laboratory, transportation node, space maintenance base and refueling station. Automated aerobraking freighters are using nuclear generators for power; these one-way transports deliver structural materials and automated power equipment for use on Mars. Simultaneous global holidays on Earth and Mars mark the birth of the first martian baby.

2030 to 2040

The population of the Moon now numbers several thousand, and the first extraterrestrial children are thriving. Closed-cycle lunar communities are increasingly supported by robotic mining, metallurgy, ceramic processing, factory production and agriculture using indigenous resources, but hydrogen and carbon are still costly imports. Martian research bases are experimenting with resource development and construction techniques adapted to martian conditions. The bases are operated by several hundred men and women scientists, engineers and technicians who have volunteered for seven-year tours of duty.

2040 to 2050

Technologically, this decade is advanced as far beyond the year 1992 as the 1940s are behind it. Closed-ecology prototype communities now support 10,000 Lunarians, but more advanced life-support systems using indigenous resources are being emplaced on Mars. By 2045 there are 1,000 people on Mars completing installation of martian infrastructure, with emphasis on lunar-demonstrated robotic agricultural and industrial facilities to reduce dependence on costly shipments from Earth.

2050 to 2060

Because optical data communication between planets is so much cheaper than the transport of mass, robotic factories on Mars with direct links to their twin factories on Earth are achieving an effective "teleportation." Equipment like hydrogen-and-oxygen-fueled vehicles with artificial intelligence guidance can be produced on Earth and simultaneously duplicated on Mars, and vice versa. By 2055, this system of teleportation via robotic factory software, in which bits are transmitted instead of objects, is creating a wealth of opportunities for trade between the planets. The human population of Mars has grown to 5,000 through immigration and the encouragement of multiple births. Robotic martian factories are working 24 hours and 37 minutes a day, 686 days a year, to turn out more robotic martian factories.

2060 to 2070

The population of Mars is passing 10,000 humans and 100,000 equivalent robots. Mars–Earth trade is moving toward a balanced exchange, and joint scientific research programs are under way. The space programs of Earth and Mars are cooperatively exploring the asteroids and the giant outer planets with their resource-rich moons; materials that are scarce on Mars and Earth's Moon are being sought on low-gravity worlds to reduce dependence on terrestrial resources. Mars–Earth astronomical interferometers have pinpointed the location of 11 other civilizations in the galaxy, but all are too distant to permit communication within a lifetime. The industrial policy of Mars is to reduce dependence on imported goods from Earth and attain self-sufficiency at the earliest possible date. On Earth, fusion power is hailed as the space propulsion drive of the future.

2070 to 2080

As robotic mining, manufacture and construction extend martian community facilities, immigration from Earth is stepped up and the human population of Mars nears 50,000. Trade with Earth is now nearing balance, with artistic products, engineering designs, scientific research results and other software products predominating. Specialized high-value goods continue to be imported and exported, and tourism is becoming an important source of foreign exchange for the martian economy. On Mars, matter–antimatter drives are hailed as the space propulsion drive of the future.

2080 to 2090

The vigorous young Mars settlements contain 100,000 people and close to 1 million equivalent robots. Martian immigration policy is promoting a rich gene pool from every continent on Earth, while biological laboratories, zoos, gene libraries, museums, art galleries, and book and image libraries house extensive collections of terrestrial life. Although a lively trade is under way, the continuation of life on Mars no longer depends upon imports from Earth; the same is true of the Moon. Martians, Lunarians and Earthlings are now evolving independently on three resource-rich worlds.

Genetically engineered bacteria are under test to initiate the terraforming of Venus and Mars. Young Martians are pressing for additional settlements beyond the asteroid belt, and in response promising sites on Triton, Titan and other moons of Uranus, Saturn and Jupiter are being surveyed. Joint Mars–Earth–Moon research on matter–antimatter and photon propulsion to drive spacecraft at speeds approaching 10 percent of the speed of light shows promise of opening the challenging "stellar frontier." And, finally, long-range plans call for launching robotic probes to temperate planets circling nearby stars before the end of the century. ❑

Exploring the Limits:
Humanity's Future in Space

by Bruce C. Murray

The Valles Marineris hemisphere of Mars. Image: United States Geological Survey

Thirty years ago, a small band of intrepid young Jet Propulsion Laboratory engineers and university scientists set out to do what seemed impossible. They committed themselves to design, build and launch the first ever picture-snapping probe to Mars. Only a pitifully underpowered rocket was available; *Sputnik* had blasted open the Space Age five years earlier, but America still lagged way behind in rocket power. To cap the JPL challenge, they had just two years to transform their ideas into reliable hardware for the unprecedented eight-month celestial voyage.

As a junior scientist helping to design the robot's diminutive television eye, I simply blocked out the great likelihood that our untried spacecraft would fail en route—even if it survived the hazards of the launch. We all were obsessed with the opportunity to see for the first time the fantasy world of Mars—if the Soviets, who had been trying since October 10, 1960, didn't get there before us. Win, lose or draw, we all felt part of the future, terribly lucky to be on the cutting edge of history.

And we did beat the odds—and the Soviet Union. On July 15, 1965, the 575-pound *Mariner 4* whispered back a few tiny television images from that alien world. Everyone hoped Mars would be another Earth. People from the news media camped noisily outside JPL's gates while we struggled to make sense of the faint signals. Then, finally, there it was. Not the poetic abode of Ray Bradbury's Martians, but an ancient, uninhabited surface, stranger than any fiction.

Fuzzy or not, those first Mars pictures were big news. First, President Lyndon Johnson, and then the Senate and the House, got special showings. I happened to be the one who presented the pictures to the Senate Space Committee. Senator Stennis was in the chair. I went through my little song and dance, enthusiastically interpreting the faint Mars features. Afterward, he said, "Son, Ah didn't unduhstand a woud you said, but it was great!" For him, it was great because America had done the impossible, and in a competitive international posture.

Now, in 1992, we are three and a half decades into the Space Age. We absently note the 500th anniversary of Columbus' first voyage. Our civil space program is demoralized, bogged down and ruinously expensive. We aren't pushing the limits any more. We aren't *going* anywhere.

NASA hit its low point in mid-1991. It started a full-blown space station project, to be a symbol of American "leadership in space" in the year 2000. We have before us now the prospect of space station *Freedom*, a hugely expensive dreadnought circling Earth. An uncertain America now tries to redefine the frontier of space as convenient low Earth orbit. In our youth as a spacefaring nation, however, we changed forever human expectations.

America made the effort and took the risk to be first at Mars with robots and first to the Moon with astronauts. How did we end up in such a mediocre state after such an exciting beginning? Because we didn't follow Tom Paine's vision. He had seen us reach the Moon in only eight years. He dreamed, with reason, that we could land a person on Mars within 20 years. But, instead of chasing dreams, NASA settled for limited objectives and expensive programs—content to circle round and round our own planet.

Nations and individuals have always explored for gold, glory or curiosity. Five hundred years ago, colonization of new lands and acquisition of raw materials were dominant motivations for exploration. Two hundred and fifty years ago, the focus began to shift to mysterious peoples in exotic, remote locales. Tahiti, Australia, central Africa and Prester John—all these were the romantic unknown. Then on to the geographic limits of Earth—the Northwest Passage, the North Pole and, finally, the South Pole. Starting in 1957, underutilized ships and airplanes left over from World War II opened up Antarctica to sustained scientific exploration. For the first time, curiosity and binding international agreements guided major national exploration. Antarctica is a hopeful glimpse of the next century from this one dominated by ethnic and national egocentrism.

Away from the silent ice of Antarctica, Cold War rules prevailed. National glory powered the leap into space. Scientists' curiosity and careers, organized into Big Science, fashioned a compliant partner. Space travel by humans and robots became the supreme symbol of technological achievement. The USSR spawned startling successes early—*Sputnik*, *Lunik 3*, Gagarin. John Kennedy responded in 1961 by challenging the Soviets to a technological race only we could win—men on the Moon by the end of the decade. Over a billion people throughout the world watched Neil Armstrong's first step onto the austere lunar surface on July 20, 1969.

> *Win, lose or draw, we all felt part of the future, terribly lucky to be on the cutting edge of history.*

Televised images of United States astronauts driving electric cars across rocky lunar plains were still fresh in the nation's memory in 1972. NASA and JPL then sought approval to boldly go where no one had gone before. They proposed to send smart robots to the very edge of the solar system. *Mariner Jupiter/Saturn* was to be a lineal descendant of *Mariner 4*, but dramatically enhanced to fly through Jupiter's radiation belts and on to Saturn. Best of all, if JPL could get this complex beast designed, built, tested and on the launchpad by August 1977, *MJS* could exploit a very rare celestial alignment and ride free all the way out to Uranus and Neptune.

MJS was renamed *Voyager*. The twin spacecraft broadcast back a spectacular reconnaissance of Jupiter and Saturn in 1979, 1980 and 1981. And *Voyager 2* did catch that rare celestial alignment. In January 1986, nearly 2 billion miles from Earth, *Voyager 2* returned stunning close-up pictures of the enigmatic, tiny, icy moon of Uranus called Miranda. Miranda was discovered only in 1948! Finally, in August 1989, as if to counterpoint the collapse of the Soviet empire, *Voyager 2* raced past planet Neptune, the outermost world of our solar system. It arrived there barely three decades after the launching of *Sputnik* and less than three centuries after the invention of the telescope. *Voyager* was an extraordinary electronic zoom lens linked via mass communication to the eyes and brains—and curiosity—of billions of people on Earth.

Voyagers 1 and *2*, and their smaller precursors *Pioneers 10* and *11*, obediently continue to radio their findings from

In our youth as a spacefaring nation, we changed forever human expectations.

the very edge of our solar system back to an immensely changed America. Truly, their signals are a faint, distant echo of John Kennedy's May 1961 *Apollo* speech, a last hurrah for that fantastic burst of American technological capacity in the service of human imagination—and Cold War competition.

That thirty-year-old, crew-cut enthusiast who helped with the first Mars camera is now a sixty-year-old, graying advocate for international cooperation in space. The Cold War has ended. America is no longer the cultural, political and economic force that it was following World War II. Indeed, the Era of Empires is over, be they Spanish, Portuguese, British, French, German, Soviet or American.

We shouldn't think something is fundamentally wrong if the frenzied tempo of the sixties or the naive projections of the seventies and eighties don't fit the demanding new era of the nineties. A downsizing of space efforts to "cheaper, smaller, quicker" is proper. If *Mariner 4* could go from a gleam in engineers' eyes to reality in two years, why can't we once again do things quickly and, therefore, more cheaply?

Fortunately, NASA now has a new administrator, Dan Goldin. He is starting to steer the agency in a new direction, toward high achievement we can afford. However, profound conflict lies ahead, as the new fiscal reality forces wrenching choices between new exploration and high achievement in space, and the continuation of the costly and bureaucratic programs inherited from the 1970s and the 1980s.

What do we have to look forward to now? Is the excitement of exploration gone for our times? I don't think so. I'm hopeful that my children will one day gaze upon the first close-up images of Pluto, of the unexplored half of Mercury and of the tarry surface of Saturn's cloud-enshrouded moon Titan. Perhaps they will even see Venus' surface through the robotic eyes of some novel submersible, periodically diving through the scalding hot envelope of carbon dioxide gas surrounding that planet, exploring briefly and promptly ascending. And surely the fascinating landscape of Mars will become more familiar to everyone as robotic rovers, probably from several nations, crawl about its vast surface, looking, touching, feeling, tasting.

Indeed, Mars tugs at our imaginations just as the Moon did at the beginning of the Space Age. Mars will inevitably be the next place to go after the Moon. As Tom Paine argued way back in 1969, the journey is technically feasible for humans.

Exciting milestones await us along the grand human journey to Mars. It has been 20 years since the US and the USSR agreed to the *Apollo–Soyuz* mission (another fruit of Tom Paine's imagination). Now the new space agreement just signed between Russia and the US opens the door for practical joint biomedical tests. The proven and versatile Russian space station *Mir* is the best zero gravity laboratory available. Astronauts and cosmonauts on board *Mir*, supported by the broad US capability in biomedical research, can together search for effective means to combat the debilitating effects of weightlessness in preparation for the year-long flight to Mars.

And robotic spacecraft will blaze a path in space for humans once again. More than a dozen robotic scouts paved the way for the first human visitors to the Moon. Mars is a much larger, more complex body. Its first human explorers will need even more robotic precursors. That need can best be met by pooling the considerable robotic capabilities of the US and Russia, aided by Europe and Japan. Indeed, the international exploration of Mars should be a major unifying theme of post–Cold War space activity. What counts is making the journey in good company, not racing to prove our national "manhood." What counts is journeying to Mars, not arriving there by some arbitrary date.

To be sure, adventurous societies will also send adventurous individuals rocketing to asteroids, to comets and perhaps to the icy moons around Saturn. However, Mars probably is the only place where humans will *stay*. It offers the only potentially habitable surface in the solar system besides Earth. Oxygen, carbon, nitrogen and hydrogen, the critical elements for life, are all available on Mars' harsh but survivable surface. Probably, a small outpost will operate there during the next century. There might even be, by the end of the 21st century, a permanent base similar to the one the US has operated at the South Pole for many decades, where aircraft transport all supplies and personnel. I hope that Mars base will be international, representing planet Earth. That would be a grand escalation of the 20th century Antarctic experience into the 21st century. Wouldn't it be wonderful for Tom Paine's Mars flag (see cover) to be *the* flag waving against the red martian sky?

Beyond that, there are speculations about terraforming—artificially changing a planet's surface and atmosphere to make it habitable for humans. However, humanity's problem for the next century on its home planet is that Earth's atmosphere and surface are changing to make the planet *less* habitable. We are reverse terraforming Earth. The overriding challenge of the next century will be to bring humanity and Earth's biosphere into a sustainable balance. Assisting in that great task through remote sensing will be a priority task for space endeavors. Thus, for me, worrying now about how to modify another planet is not very timely. Centuries will pass before the necessary environmental knowledge is likely to be available. Even then, the moral issue will inevitably arise, "If we have failed to protect our own world, what gives us the right to screw up another one?" Terraforming, if it is in human destiny at all, must be a long, long way down the road.

Where, then, will future bursts of energy lead restless *Homo sapiens*? Has *Voyager* put humanity on the pathway to the stars? I don't think so. We live in amazing times and have come to accept mind-bending changes as the hallmark of our present and future. The sustained success of such films as *Star Trek*, *2001*, *Star Wars*, *Alien*, *Close Encounters of the Third Kind* and *E.T.* testifies to the widespread popular acceptance of the concept of interstellar travel. But the stars are very, very far apart. Our nearest stellar neighbor is so distant that its light is more than four years old by the time it reaches us. For humans to travel there would be a one-way journey requiring many generations. Who would want to be locked up, to live, breed and die, in a giant sealed space cannister? Unless there are wormholes and parallel universes or some surprises in physics, star travel by humans is simply not going to happen on any human time scale.

How then will humankind probe stellar environments? Will microminiaturized *Voyagers* one day streak deep into the galaxy? Even for robots, the stars are very far apart. If an automated probe is to send back results, say 30 years after launch—a considerable length of time to expect contemporary societies to wait for results—that spaceship must reach a speed at least one-fifth that of light itself. At such a speed, collision with but a tiny grain of interstellar dust becomes a miniature atomic explosion. And there also must be a superpropellant. Even the wildest rocket concepts produced by today's visionaries cannot make real star travel practical. Human ingenuity in the future may, even so, discover ways to extend our robotic reach to touch the envelopes of a few nearby stellar neighbors, but not much farther, I think.

However, physical limits to going out in space don't mean there isn't a way to keep exploring. We will continue to probe the cosmos ever more deeply and more finely through telescopes on the ground, in Earth orbit and on the Moon. Most important, we are already beginning to listen for *artificial* radio signals from other star systems. By far the most interesting thing we could seek in outer space is evidence of alien intelligence—proof that we are not alone. It is hard for me and many other scientists to accept the proposition that intelligent life started only on this single planet orbiting the rather undistinguished star we call "Sun." There are millions of comparable locales in our galaxy. Scientists are listening for radio signals from alien beacons right now. The elegant and relatively inexpensive effort sponsored by The Planetary Society has been listening for five years. It will be joined by a comprehensive new NASA effort in October, although there have been renewed congressional threats to the project's funds. And there is other promising work going on, both in the United States and elsewhere.

Such imaginative searches could bear fruit at any moment, if something out there is trying *very hard* to communicate with *us* by radio. Over the next century, Earth's efforts to detect transmissions from planets about other stars can grow enormously more effective and complete by exploiting all the new sensor and computational technologies that are likely to become available.

By AD 2092, Earth should be technically capable of detecting alien beaconing in general, not just those radio signals being "spoon-fed" to this particular stellar location. I will be disappointed (in spirit!) if signals of extraterrestrial origin are not detected by then. My great-grandchildren should have observational proof that a communicating galactic network exists—and they should begin to wonder if it accepts new members. They can be justifiably puzzled if the cosmos still seems devoid of signals after systematic attempts to detect beacons.

Most important, our species is growing up. Our descendants will have to adapt to genuine limits to physical exploration. Perhaps, over the next several centuries, aggressive and expansive *Homo sapiens* will finally evolve a benign, sustainable equilibrium with its surroundings after so many millennia of relentless geographic and demographic expansion. Indeed, our distant descendants may look back upon our times of reckless growth and destabilizing technological change as the adolescence of the species. I don't think we humans are doomed to the eternal hellfire of technologically generated instability, forever to be half-savage, pistol in hand, never able to overcome fully our animal origins. Our descendants will exhibit a true planetary consciousness as one people, with diverse genes and cultures, living relatively harmoniously on one planet, sharing dreams.

> *What counts is journeying to Mars, not arriving there by some arbitrary date.*

Few may remember the 1000th anniversary of Columbus' voyage in AD 2492. By then, the emotional, intellectual and moral potential of *Homo* may be bursting forth, having been obscured only for an interlude by the sound and fury of electricity, rockets and splitting atoms in the hand of adolescent *Homo sapiens*. Our task is to be good ancestors so our distant descendants can grow up and find their place in the galactic community.

Bruce Murray is Vice President of The Planetary Society and a professor of planetary science and geology at the California Institute of Technology.

This essay is adapted from an article being published in the October 1992 issue of Discover.

A World for the Winning: The Exploration and Terraforming of Mars

by Robert M. Zubrin and Christopher P. McKay

The Cerberus hemisphere of Mars. Image: United States Geological Survey

Witness this new-made World, another Heav'n
From Heaven Gate not farr, founded in view
On the clear Hyaline, the Glassie Sea;
Of amplitude almost immense, with Starr's
Numerous, and every Starr perhaps a World
Of destined habitation.

—John Milton, *Paradise Lost*

Should the nations of Earth send human explorers to Mars? The Red Planet has fascinated humankind for centuries as a possible home for life or even an extraterrestrial civilization. While the sobering discoveries of the Space Age have dissolved the fantasyland of canals, beautiful princesses and green-skinned warriors, they have revealed in its place an equally amazing world. Towering mountains and enormous canyons, triple the size of their terrestrial counterparts, mark its surface. It is scarred by mysterious dry river and lake beds, hinting that billions of years ago it may have been home to a native martian biosphere.

The discovery on Mars of fossils or evidence of contemporary martian life would be epochal, since it would prove that the evolution of nonliving matter toward life is not unique to Earth. This would imply that the universe we inhabit is filled with living things. And if Mars was once a home for life, might it not be made so again? Finding the truth in such matters is worth more than a little effort.

We believe that the human exploration of Mars in the near future is technically feasible at reasonable cost, and that it is necessary if the mystery of life on Mars, past or future, is to be resolved.

Means and Ends

Of course, it is always possible to plan an exploratory mission on such a grandiose scale as to be unaffordable, and it is always possible to settle on a technique that drives matters in such a direction. For example, in the 19th century the British Navy sent dozens of expeditions, at great expense, to explore the Canadian Arctic in search of a Northwest Passage. Flotillas of steam-powered warships loaded with coal and supplies would battle forward against the ice packs for several years at a time. Then shortages would force an about-face, with little to show for the effort. At the same time, however, small teams of explorers working for fur-trapping interests were traveling freely over the Arctic by dogsled. Feeding themselves and their dog teams on native game, they traveled light, and at insignificant expense they accomplished far more in the way of exploration than did the naval fleets.

Many concepts have been advanced for human Mars missions analogous to the ponderous Royal Navy approach to Arctic exploration. Grand ships would be used to haul all the supplies and propellant needed for the entire mission. Because such ships are too large to be launched in one piece, construction in orbit is required, as is long-term storage of cryogenic propellant. Large orbiting facilities are needed for both operations, and the cost of the whole project goes out of sight.

However, as in the case of Arctic exploration, there is a different way a Mars mission can be approached—a "dogsled" way, if you will, by making use of the resources available in the environment to be explored.

A proposed plan called Mars Direct approaches a Mars mission in this spirit. No large interplanetary spaceships are used, and thus no orbiting space bases are needed to construct and service them. Instead, the astronauts in their habitat are sent directly to Mars by the upper stage of the same booster rocket that lifted them to Earth orbit, in just the same way the *Apollo* missions and all robotic interplanetary probes have been flown.

While granting the attractiveness of such a scheme, conventional wisdom would deem it infeasible, since the mass of propellant and supplies needed for a human Mars mission and subsequent return is much too large to be launched in such a way. Conventional wisdom would be right, except for one thing: If done in a clever way, most of the propellant and supplies needed for the mission do not have to be launched from Earth at all. They can be found on Mars.

The approach removes the human Mars mission from the realm of mega-fantasy.

Here's how the Mars Direct plan works. At an early launch opportunity, for example 1999, a single heavy-lift booster (with a capability equal to that of the *Saturn V* used during the *Apollo* program or that of an updated Russian *Energia*) is launched from Cape Canaveral and uses its upper stage to throw a 40-metric-ton payload onto a trajectory to Mars. Arriving at Mars eight months later, it uses friction between its aeroshield and the planet's atmosphere to brake itself into orbit, then lands with the help of a parachute.

This first payload is the Earth Return Vehicle (ERV), and it flies out to Mars with its two methane-and-oxygen-driven rocket propulsion stages unfueled. Also on board are 6 tons of liquid hydrogen cargo, a 100-kilowatt nuclear reactor mounted in the back of a methane-and-oxygen-driven light truck, a small set of compressors, an automated chemical-processing unit, and a few small scientific rovers.

As soon as landing is accomplished, the truck is telerobotically driven a few hundred meters away from the site, and the reactor is deployed to provide power to the compressors and the chemical processing unit. The hydrogen (H_2) brought from Earth can be quickly reacted with the martian atmosphere, which is 95 percent carbon dioxide gas (CO_2), producing methane (CH_4) and water (H_2O). This procedure eliminates the need for long-term storage of cryogenic hydrogen on the planet's surface. The methane is liquefied and stored; the water is electrolyzed to produce oxygen, which is stored, and hydrogen, which is cycled into the system to generate more methane.

Ultimately, these two reactions (methanation and water electrolysis) produce 24 tons of methane and 48 tons of oxygen, to be used as propellant. Since this is not enough oxygen to burn the methane at its optimal mixture ratio, an additional 36 tons of oxygen is produced via direct dissociation of martian carbon dioxide.

The entire process takes 10 months, at the conclusion of which 108 tons of methane–oxygen propellant will have been generated. This represents a leverage of 18:1 of martian propellant produced compared to the hydrogen brought from Earth. Ninety-six tons of the propellant will be used to fuel the ERV, leaving 12 tons available to support the use of high-powered, chemically fueled, long-range ground vehicles. Large stockpiles of oxygen can also be produced, both for breathing and for turning into water by combination with hydrogen brought from Earth later. Since water is 89 percent oxygen (by weight), and since foodstuffs are mostly water, this greatly reduces the amount of life-support consumables that need to be hauled from Earth.

Was there, is there, can there be life on Mars?

With the initial propellant production completed on Mars, two more boosters lift off from the Cape in 2001 and throw their 40-ton payloads toward Mars. One of the payloads is a fuel factory/ERV just like the one launched in 1999; the other is a habitation module containing a crew of four, a mixture of whole food and dehydrated provisions sufficient for a three-year journey, and a ground vehicle fueled by methane–oxygen. On the way out to Mars, artificial gravity can be provided for the crew by extending a tether between the habitat and the burnt-out booster upper stage, and spinning the assembly.

Upon arrival, the craft carrying the crew drops the tether, aerobrakes, and then lands at the 1999 landing site, where a fully fueled ERV and a beaconed landing site await it. With the help of the beacon, the crew should be able to land right on the spot; but if the landing is off course by tens or even hundreds of miles, the crew can still achieve the surface rendezvous by driving over in the ground vehicle. If it is off by thousands of miles, the second ERV provides a backup.

However, if the landing at site number one goes as planned, the second ERV will land several hundred miles away to start making propellant for the 2003 mission, which in turn will fly out with an additional ERV to open up Mars landing site number three.

Thus, every other year, two heavy-lift boosters are launched, one to land a crew, and the other to prepare a site for the next mission, giving an average launch rate of just one booster per year in a continuing program of Mars exploration. This is only about 10 percent of the US launch capability and is clearly affordable. In effect, this dogsled approach removes the human Mars mission from the realm of mega-fantasy and reduces it to a task comparable in difficulty to launching the *Apollo* missions to the Moon.

Each crew will stay on the surface for 1.5 years, taking advantage of the mobility afforded by their high-powered, chemically driven vehicle to explore a great deal of terrain. With a 12-ton fuel stockpile, they have the capability for over 14,000 miles of traverse before they leave.

Since no one has been left in orbit, the entire crew will have available to them the natural gravity and the protection against cosmic rays and solar radiation afforded by the martian environment. There will be no need for the quick return to Earth that plagues conventional Mars mission plans based upon orbiting mother-ships with small landing parties.

At the end of their stay, the crew will return to Earth directly from the martian surface in the ERV. As the series of missions progresses, a string of small bases is left behind on the martian surface, opening up broad stretches of territory to human cognizance.

Why Humans Are Needed

Why send humans to Mars? The answer lies in what Mars may once have been: a habitable world. Today, Mars is a cold, dry world where humans need space suits to survive. But there is considerable evidence that early Mars was a gentler place. The dry river and lake beds suggest that Mars once had copious amounts of liquid water, and the gigantic but now extinct volcanoes tell us that Mars was more active geologically as well.

Early in Mars' history, it was much more similar to early Earth than it is today—or than Earth is now. One event that we do know occurred somewhere on the volcanically active, water-rich early Earth was the origin of life. The seed that generated all life on Earth originated sometime in the first few hundred million years of Earth's 4.6-billion-year history. During that time, Mars also enjoyed a warm, moist climate. What happened to Mars? Why did it lose its habitable climate, and where did the waters of Mars go?

These questions are at the heart of some of the most fundamental issues in planetary science. Understanding the climate of Mars and how it changed could be vital for humanity as we strive to protect the climate of our own habitable planet. More fundamental to our view of humanity's place in the universe, however, is the question of life. Was there, is there, can there be life on Mars?

This question reverberates through the history of human observation of the Red Planet. Finding evidence of life on Mars, however humble or long-extinct, would tell us that life on Earth is not freak chance. Rather, it would confirm our speculations that life is a highly probable natural phenomenon of energy-rich, liquid-water environments. We could then predict that elsewhere in the galaxy there could be other Earths and other Mars' with liquid water, and with life.

The search for evidence of life on Mars will not be a simple task; it is not easy to find evidence of prehistoric life here on Earth. It is difficult to locate fossils, and it is often hard to understand the unusual settings that preserved them. Unusual they must be, since the vast majority of lifeforms do not become fossilized.

On Earth, the only way we know of to conduct such a search is with scientists trained not only in classrooms but in the field. While robotic probes operating from orbit or from dispersed landing sites can provide preliminary data, they are incapable of conducting the type of exploration needed on Mars. In the final analysis, trained field scientists working on the planet's surface for many years will be necessary to do the job.

To thoroughly investigate Mars or even study one geologic feature comprehensively will require field trips to many different sites. For example, to determine the timing and cause of the fluvial erosion features at the end of the giant canyon Valles Marineris may well require the exploration of sites along the entire valley system—a distance of several thousand kilometers. This, again, ultimately can most effectively be done by an on-site human geologist endowed with substantial surface mobility.

The Once and Future World

If Mars was a habitable planet billions of years ago, could it be restored to habitability? Could the atmosphere and hydrosphere be brought out of cold storage and put in place? Such is the vision behind terraforming, a concept that is gaining increasing attention as we realize that humans are capable of changing environments on planetary scales—as we are already doing on Earth. Terraforming literally means making a planet Earth-like, in the sense that the planet is able to support life. In our solar system, only Mars has the potential to be terraformed using present technology.

Mars today has everything needed to support life: water, carbon and oxygen (as carbon dioxide), and nitrogen (N_2). Its gravity, rotation rate and axial tilt are close enough to those of Earth, and it is not too far from the Sun to be made habitable.

In fact, computational studies involving climate models suggest that we could make Mars habitable using foreseeable technology. While Mars' carbon dioxide atmosphere has only about 1 percent the pressure of Earth's at sea level, there probably are reserves of carbon dioxide within the soil sufficient to thicken the atmosphere to the point where its pressure would be about 30 percent that of Earth's. The way to get this gas to emerge is to heat the planet. Each martian year, the planet warms and cools as it cycles between its nearest and farthest positions from the Sun. This causes the atmospheric pressure to vary seasonally by plus or minus 20 percent compared to its average value.

We cannot, of course, move Mars to a warmer orbit. However, if factories were set up on Mars to produce greenhouse gases such as chlorofluorocarbons at about the same rate they are currently being produced on Earth (a production rate that would require an electric power capacity about equal to that of Chicago), the planet would warm enough to release large amounts of carbon dioxide from the soil. This carbon dioxide would add massively to the greenhouse effect being created by the chlorofluorocarbon gases, and speed the warming process. (These CFCs will be especially formulated so that they won't stop Mars from developing a thick ozone layer.)

As the planet's temperature rises, the water frozen into the soil as permafrost would begin to melt, and it would flow out into the dry riverbeds of Mars. Water vapor is also a very effective greenhouse gas, and thus the reappearance of liquid water on the martian surface would add to the avalanche of self-accelerating effects warming Mars. Over several decades, Mars could be transformed from its current dry and frozen state into a warm and moist planet capable of supporting life.

Humans could not breathe the air of the transformed Mars, but they would no longer need space suits to survive there. Instead they could travel freely in the open wearing ordinary clothes and a simple scuba-type breathing gear. However, because the outside atmospheric pressure will have been raised to human-tolerable levels, it will be possible to build domelike, inflatable tents containing breathable air. On the other hand, plants could thrive in the carbon dioxide–rich outside environment, and spread rapidly across the planet's surface. Over the course of centuries, these plants would introduce oxygen into Mars' atmosphere. Eventually the day would come when the domed tents would no longer be necessary.

Terrestrial life could go forth and multiply into realms of diversity unimagined.

Such is the potential indicated by current theory. But only human explorers operating on Mars can learn enough about the planet and its resources to transform such a dream into reality. Yet the game certainly is worth the candle, for what is at stake is an entire world. Mars could become a second home for life, all life—not only humans and other terrestrial plants and animals but a plenitude of new species. New worlds invite new forms, and in the novel habitats that a terraformed Mars would provide, terrestrial life could go forth and multiply into realms of diversity unimagined, a wondrous heritage for the generations of the future.

Robert M. Zubrin is a senior engineer at Martin Marietta Astronautics in Denver, working on the design of advanced space missions. Christopher P. McKay is a planetary scientist at NASA Ames Research Center, interested in the origin of life and the exploration of Mars.

Dreams Are Maps: Exploration and Human Purpose

by Carl Sagan

The Syrtis Major hemisphere of Mars. Image: United States Geological Survey

I know where I was when the Space Age began. In early October 1957, I was a graduate student at the University of Chicago, working toward a doctorate in planetary astronomy. The previous year, when Mars was the closest it ever gets to Earth, I had been at the McDonald Observatory in Texas, peering through the telescope and trying to understand something of what our neighboring world is like. But there had been dust storms on both planets, and Mars was 40 million miles away. When you're stuck on the surface of Earth, those other worlds, however tantalizing, are inaccessible.

I was sure that someday spaceflight would be possible. I knew something about the American rocket pioneer, Robert Goddard, and V-2 rockets, Project Vanguard and even Soviet pronouncements earlier in the 1950s about their ultimate intentions to explore the planets. But despite all that, *Sputnik 1* caught me by surprise. I hadn't imagined that the Soviets would beat the United States to Earth orbit, and I was startled by the large payload (which, US commentators claimed, must have been reported with a misplaced decimal point). Here the satellite was, beeping away, effortlessly circling the Earth every 90 minutes, and my heart soared—because it meant that we would be going to the planets in my lifetime. The dreams of visionary engineers and writers—Konstantin Tsiolkovsky, Goddard, Wernher von Braun, H.G. Wells, Edgar Rice Burroughs—were about to be fulfilled.

Sputnik 1, in 1957, was the first artifact of the human species to orbit Earth. *Mariner 2*, in 1962, was the first spacecraft to explore another planet, Venus. These two achievements—one Soviet, the other American—mark a new age of exploration, a new direction for our species: the extension of the human presence to other worlds.

We have always been explorers. It is part of our nature. Since we first evolved a million years or so ago in Africa, we have wandered and explored our way across the planet. There are now humans on every continent—from pole to pole, from Mount Everest to the Dead Sea—on the ocean bottoms and in residence 200 miles up in the sky.

The first large-scale migration from the Old World to the New happened during the last ice age, around 11,500 years ago, when the growing polar ice caps shallowed the oceans and made it possible to walk on dry land from Siberia to Alaska. A thousand years later, we were in Tierra del Fuego, the southern tip of South America. Long before Columbus, people from Borneo settled Madagascar, off the African coast; Indonesians in outrigger canoes explored the western Pacific; and a great fleet of oceangoing junks from Ming Dynasty China crisscrossed the Indian Ocean, established a base in Zanzibar, rounded the southern tip of Africa and entered the Atlantic Ocean. In the 18th and 19th centuries, American and Russian explorers, traders and settlers were racing west and east across two vast continents to the Pacific. This exploratory urge has clear survival value. It is not restricted to any one nation or ethnic group. It is an endowment that the human species holds in common.

At just the time when Earth has become almost entirely explored, other worlds beckon. The nations that have pioneered this new age of exploration are the former Soviet Union and the US—motivated nationalistically, of course, but serving as well as the vanguard of our species in space. Their combined achievements (see box, pages 22-23) are the stuff of legend. We humans have sent robots, then animals and then ourselves above the blue skies of Earth into the black interplanetary void. The footprints of 12 of us are scattered across the lunar surface, where they will last a million years. We have flown by some 60 new worlds, many of them discovered in the process. Our ships have set gently down on scorching Venus and chilly Mars, returning images of their surfaces and searching for life. Once above our blanket of air, we have turned our telescopes into the depths of space and back on our small planet to see it as one interconnected and interdependent whole. We have launched artificial moons and artificial planets, and we have sent four spacecraft on their way to the stars.

From the standpoint of a century ago, these accomplishments are breathtaking. From a longer perspective, they are mythic. If we manage to avoid self-destruction, so that there *are* future historians, our time will be remembered in part because this was when we first set sail for other worlds. In the long run, as we straighten things out down here, there will be more of us up there. There will be robot emissaries and human outposts throughout the solar system. We will become a multiplanet species.

We have always been explorers. It is part of our nature.

We are not motivated by gold or spices or slaves or a passion to convert the heathen to the One True Faith, as were the European explorers of the 15th and 16th centuries. Our goals include exploration, science and technology, education, national prestige and a recognition that the future is calling. There is a very practical reason as well: We can take better care of Earth (and its inhabitants) by studying it from space and by comparing it with other worlds.

But whatever our reasons, we are on our way. We advance by fits and starts; there are detours and failures of nerve. In the long run, though, it's getting cheaper and easier to go into space, and there is progressively more for us to do there.

Only a handful of nations have access to space at the moment, but their number is increasing. France and China are now lifting commercial payloads for a profit. Japan

Our time will be remembered because this was when we first set sail for other worlds.

and the European Space Agency, in 1986, mustered their first, extremely successful missions into interplanetary space. There will be other spacefaring nations in the next few decades. Others may lose their determination and their vision, as did Portugal, which trailblazed the great sailing-ship voyages of discovery and then gradually sank into obscurity.

With the competitive impetus of the Cold War over, the Soviet Union having disintegrated and the US facing grave fiscal and other domestic problems, it is conceivable that those nations that pioneered the early exploration of space will not be engaged in the enterprise when its real fruits begin to be harvested. But this need not be the case, and with a real dedication to international cooperation—trimming costs and pooling resources—I believe that the human species will be fully able to continue its exploring.

It has been my good fortune to have participated, from the beginning, in this new age of exploration; to have worked with those glistening *Mariners*, *Apollos*, *Pioneers*, *Vikings* and *Voyagers* in their journeys between the worlds, a technology that harmed no one, that even America's adversaries admired and respected; to have played some part in the preliminary reconnaissance of the solar system in which we live. I feel the same joy today in these exploratory triumphs that I did when *Sputnik 1* first circumnavigated Earth, when our expectations of what technology could do for us were nearly boundless.

But since that time, something has soured. The anticipation of progress has been supplanted by a foreboding of technological ruin. I look into my children's eyes and ask myself what kind of future we are preparing for them. We have offered them visions of a future in which—unable to

Notable Space Achievements

Soviet Union

First artificial satellite to orbit Earth (*Sputnik 1*, 1957)

First animal in space (*Sputnik 2*, 1957)

First spacecraft to escape from Earth's gravity (*Luna 1*, 1959)

First artificial planet of the Sun (*Luna 1*, 1959)

First spacecraft to impact another world (*Luna 2*, 1959)

First spacecraft to photograph the far side of the Moon (*Luna 3*, 1959)

First human in space (*Vostok 1*, 1961)

First human to orbit Earth (*Vostok 1*, 1961)

First spacecraft to fly by other planets (*Venera 1*, 1961; *Mars 1*, 1962)

First woman in space (*Vostok 6*, 1963)

First multiperson space mission (*Voskhod 1*, 1964)

First space "walk" (*Voskhod 2*, 1965)

First entry into the atmosphere of another planet (*Venera 3*, 1966)

First successful soft landing on another world (*Luna 9*, 1966)

First spacecraft to orbit another world (*Luna 10*, 1966)

First robot mission to return a sample from another world (*Luna 16*, 1970)

First roving vehicle on another world (*Luna 17*, 1970)

First soft landing on another planet (*Mars 3*, 1971)

First scientifically successful landing on another planet (*Venera 8*, 1972)

First orbital radar mapping of another world (*Venera 15*, 1983)

First balloon payload to another planet (*Vega 1*, 1985)

First cometary encounter (*Vega 1*, 1986)

First permanently inhabited space station (*Mir*, 1986)

Longest duration spaceflight—two cosmonauts, 366 days (*Mir*, 1988–1989)


VENUS


MOON


EARTH

read, to think, to invent, to compete, to make things work, to anticipate events—our nation sinks into lethargy and economic decay; in which ignorance and greed conspire to destroy the air, the water, the soil and the climate; in which, with over 50,000 nuclear warheads still in existence, we permit a nuclear holocaust. The visions we present to our children shape the future. It *matters* what those visions are. Often they become self-fulfilling prophecies. Dreams are maps.

I do not think it irresponsible to portray even the direst futures; if we are to avoid them, we must understand that they are possible. But where are the alternatives? Where are the dreams that motivate and inspire? Where are the visions of hopeful futures, of times when technology is a tool for human well-being and not a gun on hair trigger pointed at our heads? Our children long for realistic maps of a future they (and we) can be proud of. Where are the cartographers of human purpose?

Continuing, cooperative planetary exploration cannot solve all our problems. It is merely one component of a solution. But it is practical, readily understood, cost-effective, peaceful and stirring. Like Tom Paine, I believe it is our responsibility to create a future worthy of our children, to fulfill the promise made decades ago by *Sputnik 1* and *Mariner 2*, to open up the universe to those intrepid explorers from planet Earth.

The visions we present to our children shape the future. It matters what those visions are.

Carl Sagan, the David Duncan Professor of Astronomy and Space Sciences and Director of the Laboratory for Planetary Studies at Cornell University, is a recipient of the Explorers Club 75th Anniversary Award "for achievements in furthering the spirit of exploration."

United States

First scientific discovery in space—Van Allen radiation belt (*Explorer 1*, 1958)

First television images of Earth from space (*Explorer 6*, 1959)

First scientific discovery in interplanetary space—direct observation of the solar wind (*Mariner 2*, 1962)

First scientifically successful planetary mission (*Mariner 2* to Venus, 1962)

First observatory in space (Orbiting Solar Observatory 1, 1962)

First humans to orbit another world (*Apollo 8*, 1968)

First humans to land on another world (*Apollo 11*, 1969)

First samples returned to Earth from another world (*Apollo 11*, 1969)

First human-operated roving vehicle on another world (*Apollo 15*, 1971)

First spacecraft to orbit another planet (*Mariner 9*, 1971)

First dual-planet mission—to Venus and Mercury (*Mariner 10*, 1974)

First successful Mars landing; first spacecraft to search for life on another planet (*Viking 1*, 1976)

First flybys of Mercury (*Mariner 10*, 1974), Jupiter (*Pioneer 10*, 1973), Saturn (*Pioneer 11*, 1979), Uranus (*Voyager 2*, 1986) and Neptune (*Voyager 2*, 1989)

Discovery of the ring of Jupiter and the volcanoes of its moon Io; first close-up study of Jupiter and its moons (*Voyager 1*, 1979)

First close-up study of Saturn, its rings and moons (*Voyagers 1* and *2*, 1980–1981)

First reusable spacecraft with human crew (*Columbia*, 1981)

First satellite to be retrieved, repaired and redeployed in space (Solar Maximum Mission, 1980–1984)

First spacecraft to achieve escape velocity from the solar system—accelerated by close encounters with Jupiter (*Pioneers 10* and *11*, 1973 and 1974; *Voyagers 1* and *2*, 1979)


MERCURY

Images: JPL/NASA


JUPITER


SATURN

A TALK WITH

Daniel Goldin

Daniel Goldin has recently taken the helm of NASA, following the departure of Admiral Richard Truly earlier this year. He has taken over a troubled agency, one criticized from both without and within for an inability to fulfill the expectations of a nation that remembers the achievements of the *Apollo* years. In July, Planetary Society Executive Director Louis Friedman interviewed Mr. Goldin on his plans for turning NASA around.

The Planetary Report: What are your objectives for NASA and the United States space program, in a 3-year time frame, and in a 10-year time frame?

Daniel Goldin: I will make my answer generic because NASA hasn't finished its vision statement, so everything I'm saying is bounded by the fact that I want to work with the NASA employees in developing a shared vision, and we're in the middle of it. I don't want to take a firm position, because I feel it would be unfair to the process.

TPR: What are you trying to get out of that process?

Goldin: I'd like NASA to come up with a vision that's bold, that reaches far enough that it causes us to develop advanced technologies that will benefit not just the space program, but American society. And that it will stimulate the human mind with the exciting things that it does to unlock the secrets in the solar system and the universe, and in the understanding of our planet. That is the thing I am expecting out of this.

Most important, NASA is the future of America. This is one of the major reasons I took this job on, Lou. See that headline, "Ridden With Debt, US Companies Cut Funds for Research"? America is in trouble. We've become so focused on our day-to-day activities that we've lost sight of an obligation to our children for the future. NASA is the key to the technological climb of America, and we can't let that flame go out as we deal with present practicalities. The purpose of this vision is to ensure that NASA makes that commitment.

In the next three years, I'd like NASA to be an example of outstanding management recognized worldwide for its innovation and effectiveness. First, in making major technological advances, and second, and most important, in producing the technologies for our space and aeronautical systems.

TPR: In 10 years?

Goldin: In 10 years, NASA is going to be well on its way toward the exploration of the solar system. It will be executing the vision developed in 1992–1993. NASA will be traveling on a path that's clear. It will be making significant discoveries about the universe. We will have had wonderful data back from the planets and asteroids, and we will have begun receiving robust data back from missions to Earth. The aeronautics industry in America will have benefited from a revitalized partnership with NASA, and the bottom line will be robustness in the American aviation business.

TPR: Do you agree with the Augustine committee's conclusion that space science should be NASA's number one priority?

Goldin: The committee said science is the first priority. I think science, exploration and technology development are the goals of NASA, and to separate them and say this is a priority, and that is a priority, is something I don't necessarily agree with.

What I do agree with is, given that NASA performs scientific exploration and technology development, that it should not be investing the lion's share of its budget in infrastructure. We spent the last 20 years developing infrastructure and getting ready to spend another 10 years developing infrastructure. And it's not that we didn't do science, exploration or technology development, but the emphasis has been on infrastructure. You can only go so long developing infrastructure. I think what Augustine was saying is not that science is first but that you have to perform your mission at some point and not just continuously invest in infrastructure.

TPR: Do you have plans for changes in NASA?

Goldin: NASA's a very good organization filled with good people, but, like any organization that's been in existence more than 30 years, at some point it builds up tradition and bureaucracy. Every decade or so, you have to look back and say, "Let's go back and get young again."

In 1964 we sent an orbiter to the Moon in 27 months and 3 days. We didn't know what we didn't know, we just went off and did it. Now we've become so conservative that we're losing the bubble. In reaching out and doing bold things, going to the planets and the stars, you develop an incredible technological capability. From that investment, you give multiple products back to society. But, I'm a little concerned that we've drifted away. I don't see a revolution at NASA, I see evolution at NASA, a rebirth, if you will, of the organization.

TPR: You have talked about balance between the human flight program and the robotic. What does *balance* mean?

Goldin: Let me define what *imbalance* is. Imbalance is when the lion's share of the budget is associated with human spaceflight and the infrastructure that goes with it, to the point where it begins to quench the ability to do the robotic missions in a timely and intrepid fashion. You want to make sure that doesn't happen. You want to make sure that we have an aggressive robotic mission, and that we have an efficiently run, exciting human mission that has great science return. When I talk about balance, it's not just the balance of robotic and human. It's balance within the human space program—we must have deep scientific content, not just infrastructure, transportation of humans and excitement.

TPR: The Planetary Society, as you know, has taken a position that the current space station plan is unrealistic because it is so demanding on shuttle launches and susceptible to cost overruns, and might actually delay the day when the nation could be ready for human exploration of the solar system. Do you think this is an undue worry?

GOLDIN: I view The Planetary Society as a loyal supporter of the space program, and I think the Society has every right to ask a question like that. I believe the Society should demand from NASA efficiency in its execution of its programs and a commitment not to allow the space station program to run out of control to where it consumes the total NASA budget. That would be absolutely unacceptable, and that's one of the reasons I have asked for an in-depth review of all our programs,

NASA is the key to the technological climb of America, and we can't let that flame go out.

including the space station.

In a way, I'm responding to The Planetary Society and the many other people who have asked that question. When its members [of Congress] stood on the floor of Congress, before the 1991 space station vote, I didn't hear people who were upset with the space program. They were expressing concern, just like The Planetary Society. NASA has an obligation to deliver on its commitments, and that's what we intend to do.

TPR: The president's Space Exploration Initiative—SEI—hasn't garnered much political or popular support. Why?

GOLDIN: Space station *Freedom* is the first step in the Space Exploration Initiative. You cannot venture out to the Moon and Mars without understanding how humans can live and operate in space for long periods. That is the main purpose of space station *Freedom*. It would be unconscionable to rush to perform a long interplanetary mission before we knew the measures to take to safeguard every bodily function. We have to know how to perform space medicine. It's not just the zero gravity. How do you maintain the health of human beings for long periods in a hostile environment? What happens if someone goes into cardiac arrest or has a serious disease?

So, the space station is not just a bunch of aluminum, steel and plastic and some communications systems up in space, it is a major research laboratory with a hundred different instruments.

Now we are planning to go back to the Moon to stay and on to Mars. We're looking at a number of precursor missions, which I hope will begin in 1994, perhaps with a lunar polar orbiter. There is always a temptation to say "Let's move on." We have a limited budget at NASA. Fourteen billion dollars is a lot of money, but given the present financial situation of the United States, with the debts we have, with the tremendous social needs and the need to rebuild [the country's] infrastructure, it's unrealistic for NASA to go to the Congress and say, "Let's start something else."

Focus is the word. Let's focus on the space station. Let's work on the precursor missions. Let's get the critical technology going to retire some of the risk, and then move on. I think that the Congress is not unsupportive of the president and the space program. It's just a prudent business approach to say, "Let's take things one step at a time."

The president's schedule, to go on to Mars in roughly 30 years, is realistic. Time is a precious commodity; you can only make withdrawals on it. If you use time wisely, and you think things through, it doesn't have to cost a lot of money. But if you squander time, and you rush into something without planning, you spend a fortune.

TPR: Do you think there is a rationale for human exploration to Mars?

GOLDIN: It is human destiny to break the chain that binds us to Earth and go out into space. Space is the next frontier, just as 500 years ago the ocean was the frontier. The minute we stop exploring the frontier is the minute we die as a society.

Earth is a planet with finite resources. When I was born in 1940, there were roughly 2 billion people on this planet, and now as we speak there are 5.5 billion. I hope to live to be 100, and by that time there will be close to 10 billion people on this

The minute we stop exploring the frontier is the minute we die as a society.

planet. Don't we want to offer future generations the hope of new worlds, unexplored? Who knows what we're going to find on asteroids, on the Moon, on Mars, and ultimately at the outer bounds of the solar system? My successors centuries and millennia from now will be able to think about travel to planets in our distant solar system. So, it's a beginning.

TPR: Should there be an SEI program right now?

GOLDIN: Without a doubt. As we reach for the Moon and Mars, it will catalyze incredible technological development. We need it—in our electronics industries, automobiles, and now even aviation. America had been at the forefront. Where are the cutting-edge developments going to come from, unless we become bold?

I saw a survey where some 65 percent of the American public thinks the NASA budget is from $200 billion to $300 billion a year. The fact is, the NASA budget is $14 billion a year. It is 1 percent of the federal budget. It is a quarter of a percent of the gross national product. It's an investment that returns dividends that are beyond belief.

If we could take the whole NASA budget, Lou, and throw it into the $1.4 trillion federal budget, it would not make a dent in improving people's lives today. But let me tell you, we will weep for our children, our grandchildren and their children because we will have denied them the privilege of investing in the future. →

TPR: Our late Director, Tom Paine, had a clear vision of the human settlement of Mars in the next century. What is your outlook on this aspect of NASA's goal? What did you think of the Paine commission's report, *Pioneering the Space Frontier*?

GOLDIN: Tom Paine was a visionary. I found many of his words to be the same words that I am saying about the future. He was a wonderful man, and the only unfortunate aspect of his report is that it came out at the time of the *Challenger*, and most people read the *Challenger* report. Not enough people read *Pioneering the Space Frontier*.

TPR: What's the significance of the new agreement with the Russians?

GOLDIN: It's a starting point for what I hope will be a marathon and not a sprint.

TPR: Do you see it adding to the NASA program? Adding to space exploration? Or do you see it just as a new way of doing things?

GOLDIN: I am hopeful that, as we get to know each other, as stability begins to manifest itself in the Russian government and economy, that it will build the possibilities for tremendous progress in the future. But I believe that it's going to take years to get to that point, and not weeks and months. We want to make this a win–win situation for the people of America and the people of Russia—and the people of the world. You cause that to happen by hard work, not just on technology, but on getting to understand each other culturally and building a strong foundation.

TPR: What do you think of the radio astronomy search for extraterrestrial intelligence?

GOLDIN: What I'm struck with about SETI is that it's a passive approach to the search; you're looking for faint signals, and that's an awfully difficult task. You're relying on the lowest probability of finding something.

Let me give you another version of how that search might go. What if we were to build an interferometer on the Moon as part of a permanent human presence? What if that interferometer were to be big enough and have high enough resolution, spatially and spectrally, that we could not only image planets around distant stars but do spectroscopic analysis of their atmospheres? What if we could put huge antennas on the Moon or on Earth that might focus on specific areas? That might narrow down the possibilities.

Clearly, if we were ever to receive such a signal, it would change our lives in the most dramatic way. It would change our society in matters that we can't even comprehend. ❑

SOCIETY *Notes*

1993 NSTA CONVENTION TO BE IN KANSAS CITY

Mark your calendars! On April 1 to 4, 1993, the National Science Teachers Association (NSTA) will hold its annual convention in Kansas City, Missouri. The Planetary Society will serve as cosponsor.

We are planning a full day of sessions by leaders in the field of space science. In addition, NSTA will provide hundreds of sessions on topics ranging from astronomy to zoology.

Watch for further details in upcoming issues of *The Planetary Report*, or write to me c/o The Planetary Society to be placed on our NSTA Convention mailing list.

—Susan Lendroth, Manager of Events and Communications

EVENTS CALENDAR AVAILABLE

The Planetary Society organizes a great variety of space-related events every year. If you would like to receive a copy of the space events calendar, please write to me at the Society's offices.

—Carlos J. Populus, Volunteer Coordinator

DIVISION FOR PLANETARY SCIENCES TO MEET IN MUNICH

The Division for Planetary Sciences (DPS) of the American Astronomical Society will hold its 24th annual meeting in Munich, Germany, October 12 to 16, 1992. In conjunction with the scientific conference, The Planetary Society and DPS will cosponsor a public event on Monday, October 12. An international panel of scientists will discuss the exploration of Mars.

Planetary Society members in the nearby European community will receive additional information on this special event. *—SL*

SOCIETY CELEBRATES *GALILEO* FLYBY

Galileo will make its second pass by Earth on December 8, 1992, as part of its circuitous route to a 1996 jovian rendezvous. The Planetary Society will celebrate the spacecraft's flyby on that day with an Earth encounter event in Pasadena, California.

Carl Sagan will be the featured speaker, and scientists from the *Galileo* project team will take part in the proceedings. For more information, contact Carlos Populus, c/o The Planetary Society. *—SL*

KEEP IN TOUCH

Our mailing address:
The Planetary Society
65 N. Catalina Avenue
Pasadena, CA 91106

Call for an events calendar and Cassini *update:*
(818) 793-4294

General calls:
(818) 793-5100

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(818) 793-1675

World Watch

by Louis D. Friedman

WASHINGTON, DC—There are few things certain in Washington, but one certainty is that the federal budget process will move with excruciating slowness. As I write this, three matters crucial to Planetary Society interests have still not been resolved:

• *Cassini*, the Saturn orbiter and Titan probe mission, appears to have survived. However, the mission has already been scaled back to cuts costs, and further reductions may be likely if NASA suffers general cuts to its space science program.

• NASA's Search for Extraterrestrial Intelligence has been cut completely by all four congressional committees responsible for the space agency's budget. The Senate Appropriations Committee has proposed that the project be merged into another NASA program, called Toward Other Planetary Systems (TOPS). NASA's SETI would then be called the High Resolution Microwave Survey of TOPS. This change will still have to survive the final congressional vote on the budget. We do not yet know the effect this action will have on NASA's funding or the project's scheduled initiation on October 12.

• Space station *Freedom* appears certain to survive this year's budget battles, but with its funding reduced. Since delays in its deployment are politically unacceptable, the budget cuts will probably necessitate another design revision. NASA is now studying the capabilities of the Russian space station, *Mir*.

Planetary Society members have called, written and telegraphed their representatives to voice their opinions on these matters. Many members of Congress have been surprised by the amount of popular support for planetary programs and SETI. Our collective voice has been heard. We will wait to see if our views will be heeded.

NEW YORK—The planetary exploration community is closely following the statements of Al Gore and Dan Quayle as they campaign for the office of vice president of the United States. The vice president is, by law, the chairman of the National Space Council, and he is responsible for the administration's space policy.

Senator Gore has been a key player in the yearly NASA budget battles in his position as chairman of the Senate Subcommittee on Science, Technology and Space. He has been a vocal supporter of the planned Earth Observing System and, when he ran for president four years ago, he backed proposals for a US–Soviet human Mars mission.

Vice President Quayle is the current chairman of the National Space Council and has been a strong supporter of space station *Freedom*, the Space Exploration Initiative and the move to smaller, faster and cheaper missions.

MOSCOW—The leaders of the United States and Russian space agencies have signed a memorandum of agreement to undertake and discuss several new cooperative ventures in space. Among the possible projects are life science experiments aboard *Mir*, a joint plan for monitoring Earth's environment, and exchanges of astronauts and cosmonauts for flights aboard the space shuttle and *Mir*.

The new Russian government has recently consolidated its multifaceted space program into a new Russian Space Agency. Director General Yuri Koptev signed the agreement with NASA Administrator Dan Goldin.

Joint planetary projects are also being discussed. As we reported in our last issue, NASA may purchase a small lander on the Russian *Mars '94* mission. The lander would carry American-built instruments, most likely a seismometer and an experiment to test soil composition.

Our demonstrated success in building the Mars Rover test team helped convince the new NASA administrator that such joint missions are eminently possible.

The troubled *Galileo* mission to Jupiter may also receive some help under the new agreement. The Russian Deep Space Communications Network may make its 70-meter antennas available to help gather data from *Galileo* at Jupiter. The spacecraft's capabilities have been reduced by the failure of its main antenna to unfurl.

WASHINGTON, DC—The new NASA administrator's serious commitment to US–Russian space cooperation has been demonstrated by his creation of a new position within the space agency: associate administrator for Russian programs.

Sam Keller has been appointed to the position. He previously served as associate deputy administrator and in that position had handled cooperative ventures with the Soviet Union.

MOSCOW—Valery Barsukov, head of the Vernadsky Institute of Geochemistry and Analytical Chemistry and member of the Russian Academy of Sciences, died in Moscow on July 22. He was one of the leaders of the *Mars '94* and *'96* projects, and his presence will be missed.

Academician Barsukov was a leading figure in Russian planetary science. He was particularly known for his work on the *Venera* series of missions to Venus and had worked closely with US scientists in the exploration of the inner solar system. He regularly attended the yearly Lunar and Planetary Science Conference held in Houston and had participated in many public programs for The Planetary Society.

At the time of his death, Academician Barsukov was a member of the Presidium of the Russian academy and also served as co-chairman of the Russian–US Joint Working Group on Planetary Exploration.

Louis D. Friedman is the Executive Director of The Planetary Society.

Questions & Answers

Now and then someone asks a question for which the answer is different from one scientist to the next. Here we present two answers to such a question.

If Mars' atmospheric pressure precludes the possibility of liquid water existing at the surface, why were liquid solutions used for life detection in two of the three* Viking *lander biology experiments?
—Alex R. Blackwell,
Wahiawa, Hawaii

This question has puzzled me since 1969, when NASA selected four biology experiments to be carried on the *Viking* landers. Three of the four used aqueous media for culturing the hoped-for martian organisms; one of these was eventually dropped for lack of space.

Since it had been known since 1965, when *Mariner 4* measured Mars' surface pressure, that liquid water could not exist on the planet, one has to conclude that the selection committee either did not know of the *Mariner 4* results, did not believe them, did not understand their implications, or was simply being cautious by covering all possibilities. In the last case, however, why choose three wet experiments when one would have been sufficient?

Although I was a member of the *Viking* biology team, representing the one dry experiment (known in the early days as the Horowitz-Hobby-Hubbard experiment), I never learned the answer to this question. Fortunately, the wet experiments, although unsuitable for discovering martian life, revealed important properties of Mars' surface material. The whole episode is consistent with the self-deception that was common among scientists studying Mars in pre-*Viking* days. The *Viking* mission swept this away, but martian delusions still smolder and, on occasion, flare up. But that is another story.

—NORMAN HOROWITZ, *Pasadena, California*

Actually, all three of the *Viking* lander biology experiments included water as part of their instrumentation. One experiment was designed to detect metabolic activity under conditions that closely paralleled those expected on Mars. For this, samples were incubated in the presence of radioactive carbon dioxide and smaller amounts of carbon monoxide to see whether either of these would be incorporated into organic compounds, much as they are in plants.

Provision was made in this experiment to inject traces of water vapor (but not *liquid* water) into the incubation test cell to see whether the vapor would have an effect. During the multiple runs of this experiment—both totally dry and with water *vapor* added—small and varying amounts of organics were produced, but adding water vapor did not enhance the reaction.

In the other two experiments, there was the implicit assumption that something in the martian "biota" would be able to decompose added organic nutrients. These nutrients were supplied as aqueous solutions. The use of water was justified on the assumption that martian organisms (in the currently dry environment of the planet) might now be in a dormant state and water might be necessary to elicit metabolic activity.

There were major differences, however, in how water was added to the test cells in the two experiments. In one, a small drop of the nutrient solution was injected directly into the soil sample. It was thought that the soil sample would then experience a gradient of "wetness" from the point of injection of liquid out to the edges of the sample, providing a range of moisture to any organisms that might be present.

The other "wet" experiment was conducted in two modes. Initially, enough of the nutrient solution was added to the test cell to humidify the atmosphere without contacting the soil. In this mode, the experiment tested the hypothesis that indigenous nutrients were already available in the martian samples but water was the sole limiting factor for biological activity. In the second mode, enough aqueous nutrient solution was added to the test cell to actually wet the soil samples, thereby also providing a complex nutrient mixture of organic and inorganic components. This final concept tested the idea that the (dormant) martian organisms required both food and water to elicit metabolic activity.

With regard to the use of water in these experiments, it is extremely important to note that only from the data obtained from these two "wet" experiments was it possible to infer that strong oxidants were present in the samples. Without the inclusion of water in these experiments, it is likely that we would not now have this important insight into the reactive nature of Mars' surface material.

—HAROLD P. KLEIN, *Santa Clara University*

Metallic hydrogen is said to make up much of the interior of Jupiter and Saturn. What is metallic hydrogen, and what makes it metallic?
—Robert Schuster,
Oshkosh, Wisconsin

A metal is any dense material (solid or liquid) in which many or all of the electrons are free to move distances that are large compared to the size of an atom. By being able to move in this way, they can provide an electric current when a voltage is applied.

Now, the hydrogen we normally encounter is in the form of atoms or molecules where the electrons are tightly bound to the nuclei. However, if you take molecular hydrogen gas and squeeze it to at least the density of liquid water, then the molecules are so close together that the electronic orbitals become disrupted. The electrons become free to migrate, and metallic hydrogen is formed. The pressure must be at least a few million times the pressure in Earth's atmosphere, but this is easily achieved deep within Jupiter and Saturn, because of their gravity and mass.

Fundamentally, the metallic state

arises because of quantum mechanical effects—the Pauli exclusion principle and the Heisenberg uncertainty principle—but the above explanation is qualitatively adequate.

Within Jupiter and Saturn, the temperature is high enough that the metal is a liquid. Of course, it would be a metal whether or not there are electrical currents, but we also think that the cores of these planets have large electrical currents and that this explains the large magnetic fields observed outside. This is analogous to Earth's magnetic field, which is generated in our liquid metal core.
—DAVID J. STEVENSON, *California Institute of Technology*

FACTINOS

In June, NASA released the first radar images that show clear evidence of landslides on Venus. *Magellan* captured the images while orbiting the planet (see photos, below left). Scientists don't know exactly when the landslides occurred, but they believe that the activity took place thousands or even millions of years ago.

The landslides shown in the new images spilled down the sides of volcanoes. Jet Propulsion Laboratory scientists have three basic theories for the cause of the avalanches: First, a buildup of cooled lava on the steep slopes may have succumbed to gravity and broken loose. Second, an eruption could have sheared off the side of a mountain. Third, a "venusquake" may have shaken loose tons of unstable debris.
—from M. Stroh in *Science News*

Eliot F. Young and Professor Richard P. Binzel of the Massachusetts Institute of Technology have released a new map of Pluto. The map (pictured below, right), which took six years to make, shows a bright polar cap that they believe is evidence for seasons on Pluto.

Young used precise measurements of the brightness changes during several eclipses of the planet and its moon Charon to reconstruct a map for one hemisphere of Pluto. Binzel and Young believe that the high albedo, or reflectivity, seen at Pluto's south pole and the pole's high contrast compared to other regions of the planet indicate that Pluto undergoes seasonal variations over the course of its 248-year orbit around the Sun.

Calculations of the physical state of methane suggest that large quantities of the compound evaporate from Pluto's frost-covered surface as the planet approaches the Sun, giving rise to its wispy atmosphere. As Pluto is now receding from the Sun, most of that methane will recondense onto the surface. At the same time, the orientation of Pluto's axis will plunge its south pole into darkness, making this region a favored location for the condensation of methane frost.

Thus, the researchers believe it is these annual fresh deposits of bright methane frost that give the south pole its extremely high albedo. Even though the south pole is in continuous sunlight for half of its orbit while approaching the Sun, its high reflectivity keeps it fairly cool, allowing it to retain a permanent bright frost layer.
—from the Massachusetts Institute of Technology

LEFT: This small volcano erupted from the southwestern Navka Region of Venus. The northwest and northeast flanks of the dome have collapsed, dumping debris onto the surrounding plain.

RIGHT: These three volcanoes reside in Venus' Guinevere Planitia lowland. The northern rim of the center volcano has a steep scarp, probably formed as material slid away from it and was then covered by lava flows. The southeastern volcano's scalloped edges, making it look like a bottle-cap, were probably caused by multiple slides along the volcano's rim. ***Photos: JPL/NASA***

The light to dark shades on this map of Pluto represent the areas of highest and lowest reflectivity on the planet's surface. Although it has been "summer" at the south pole for over a century, the large, bright ice cap clearly outshines the small cap at Pluto's colder north pole.
Map: R. Binzel and E. Young, MIT

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Isaac Asimov's Guide to Earth and Space, *by Isaac Asimov.*
Arranged in a question-and-answer format, this book guides the reader around Earth, the solar system and the stars beyond. Asimov travels back into the history of science and into the future in this enjoyable read for young adults as well as seasoned scientists.

Retail price: $20.00
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Five Billion Vodka Bottles to the Moon: Tales of a Soviet Scientist

By Iosif Shklovsky; translated and adapted by Mary Fleming Zirin and Harold Zirin, with an introduction by Herbert Friedman; W.W. Norton & Co., New York, 1991, 268 pages.

Retail price: $19.95
Price for Planetary Society members: $17.95, plus $2.50 shipping and handling charge for the United States, Canada and Mexico, $5.00 for other countries.

On a late March afternoon in the early 1970s, Iosif Shklovsky, then chief of the astronomy program at the Institute for Space Research in Moscow, was talking with some journalists about the bleak statistics of Soviet life. Playing with numbers, he later figured out that his compatriots spent 15 billion rubles a year on vodka, which works out to 5 billion half-liter bottles. With each bottle measuring 8 centimeters in diameter, he realized that, lined up side by side, these vodka bottles would reach from Earth to the Moon. "Of all our country's considerable achievements in space," he mused, "that is surely among the most impressive."

That Soviet astronomers managed other achievements in the paranoia that pervaded the Soviet years is nothing short of a miracle. The world Shklovsky describes is often arbitrary and brutal. Yet the Soviets did launch *Sputnik* and conducted an impressive program of human spaceflight.

As these memoirs begin, in the fall of 1941, we meet the author as a Jewish graduate student being evacuated with his classmates from German-besieged Moscow. It was on this long train trip that he met Andrey Sakharov, a shy, brilliant youngster, in the first of the remarkable encounters that pepper these memoirs.

We rejoice with Shklovsky in the golden days that followed the launch of *Sputnik 1* in 1957. While Americans scrambled to catch up, in Russia "on October 1, 1961, a score of us gathered in the memorable office in the Institute of Applied Mathematics on Miussy Square for one of our regular discussions of space projects. The enthusiasm generated by the launch of the first Soviet *Sputnik* had yet to cool, and our ventures into space had gone from one success to the next. The world had just witnessed Gagarin's magical flight and shared the rapture of our glimpse of the reverse side of the Moon. . . . Already over forty, I felt like a kid who'd fallen in love, and that state lasted more than five years."

Space exploration liberated his imagination. In 1964, as host of the first conference on the Search for Extraterrestrial Intelligence to be held in the Soviet Union, Shklovsky speculated on the possibility that a nearby supernova could have triggered genetic mutations in life on Earth. This led to a collaboration with Carl Sagan and their 1966 publication, *Intelligent Life in the Universe*.

Loving travel, Shklovsky describes his first adventure out of the Soviet sphere in 1947 as a junior member of a Soviet expedition to monitor an eclipse in Brazil. But soon afterward his passport was suddenly withheld, and his later travels were few. The Cold War, anti-Semitism and the vagaries of Soviet politics affected the lives of scientists—and the life of science. Astronomy was less affected by politics than was genetics or physics, but some astronomers did suffer arbitrary sanctions.

In the 1980s, again encountering Sakharov, whose scientific career had been ruined by his political stands, Shklovsky recalls the physicist's remark: "You, astronomers, are happy people. The poetry of facts is still intact in your field!"

Shklovsky wrote about those facts in 1977, enraging some of his Soviet colleagues. The greatest accomplishment of the Space Age has been that *no* new principles have emerged from space research, he said, validating by default the accuracy of the conception of the universe as constructed by earlier, pre-Marxist generations of astronomers.

Five Billion Vodka Bottles to the Moon takes us into the "enemy camp" in the Space Race through the eyes of one of its leading astronomers. Shklovsky died in 1985. Although his life had been affected by the Soviet system, Shklovsky was lucky in many ways, not the least of which is the translation and editing of these recollections by Mary Fleming Zirin and Harold Zirin, who know well both his language and his science.
—Reviewed by Bettyann Kevles

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News & Reviews

by Clark R. Chapman

We humans like to categorize things and give them names. Nomenclature and taxonomy are necessary preliminaries to the more insightful analysis of nature that leads to fundamental understanding. In planetary science, we have such categories as "planets," "asteroids," "comets," "meteoroids" and "satellites." Some of the most interesting insights develop from thinking about those objects that can't be neatly categorized.

Consider the small planet Pluto. Although, shortly after its discovery in 1930, it was thought to be Earth-like in size, Pluto is now known to be tiny—it would take 500 Plutos to make one Earth. Does it even qualify as a planet? Or is it a large comet? Maybe Pluto is a small "double planet," since its satellite, Charon, is fully half its own size.

Alan Stern considers the larger implications of Pluto's unusual traits in the September issue of *Astronomy*. The mystery of how Pluto formed as a double planet has perplexed astronomers since the discovery of Charon in 1978. The best guess is that it involved a process akin to that now thought to explain the existence of our own Moon, which might have formed as the result of a collision between Earth and a Mars-sized body. Proto-Pluto and proto-Charon, both originally in independent orbits around the Sun, might have collided, allowing part of proto-Charon to go into orbit around Pluto. As Stern explains, however, such a collision in the immense volume of the outer solar system is exceedingly unlikely. It is unlikely, that is, unless there were thousands of such bodies.

Personally, I find this suggestion—which has been kicked around the planetary science community for the last decade or so—to be unsatisfying. A collision between two such bodies *might* produce a double body, but it also might not. No matter how high we raise the collision probabilities by postulating that there was a vast swarm of Plutos in the early solar system, it still seems improbable that the only one left that is close enough to see from Earth would be a double one. Many of the others, according to Stern, were either swept up long ago by the growing outer planets or ejected from the solar system by close gravitational encounters with Uranus or Neptune. Others still reside, along with their smaller cometary cousins, in the vast Oort cloud of comets that surrounds the solar system. But, if colliding objects usually result in doubles, most asteroids should be twins—and they aren't.

Nevertheless, there is other indirect evidence for numerous icy "dwarf" bodies once residing in the outer solar system, according to Stern. Such bodies may include Neptune's captured moon, Triton. A larger, Earth-sized body may be responsible for tilting Uranus' spin axis. Smaller "subdwarfs" include the comets.

Whether or not Stern's extrapolations from the existence of Pluto are valid, his article is clear, logical and interesting. He begins with a good summary of modern views about how the planets were formed by accretion of smaller, comet-like planetesimals. I am not entirely convinced, as Stern is, that there is much simple, *direct* evidence that accretion took place. Planetesimal accretion, rather, is a theoretical scenario that seems to explain many features of our solar system. But my acceptance of it depends more on my belief in physical laws than on the observation that many planets and moons are heavily cratered. After all, we know why there are craters: Asteroids and comets are flying around in space. That asteroids and comets—and Pluto—are remnant planetesimals is a modern consensus of planetary science. But planetesimal bombardment and destruction in planetary surfaces have helped to shield us from direct evidence about the early accretionary epochs of solar system history.

Other goodies in *Astronomy*'s September issue include the cover story on Mars.

Clark R. Chapman has been elected to the Council of the Meteoritical Society, which held its latest annual conference in Copenhagen in late July.

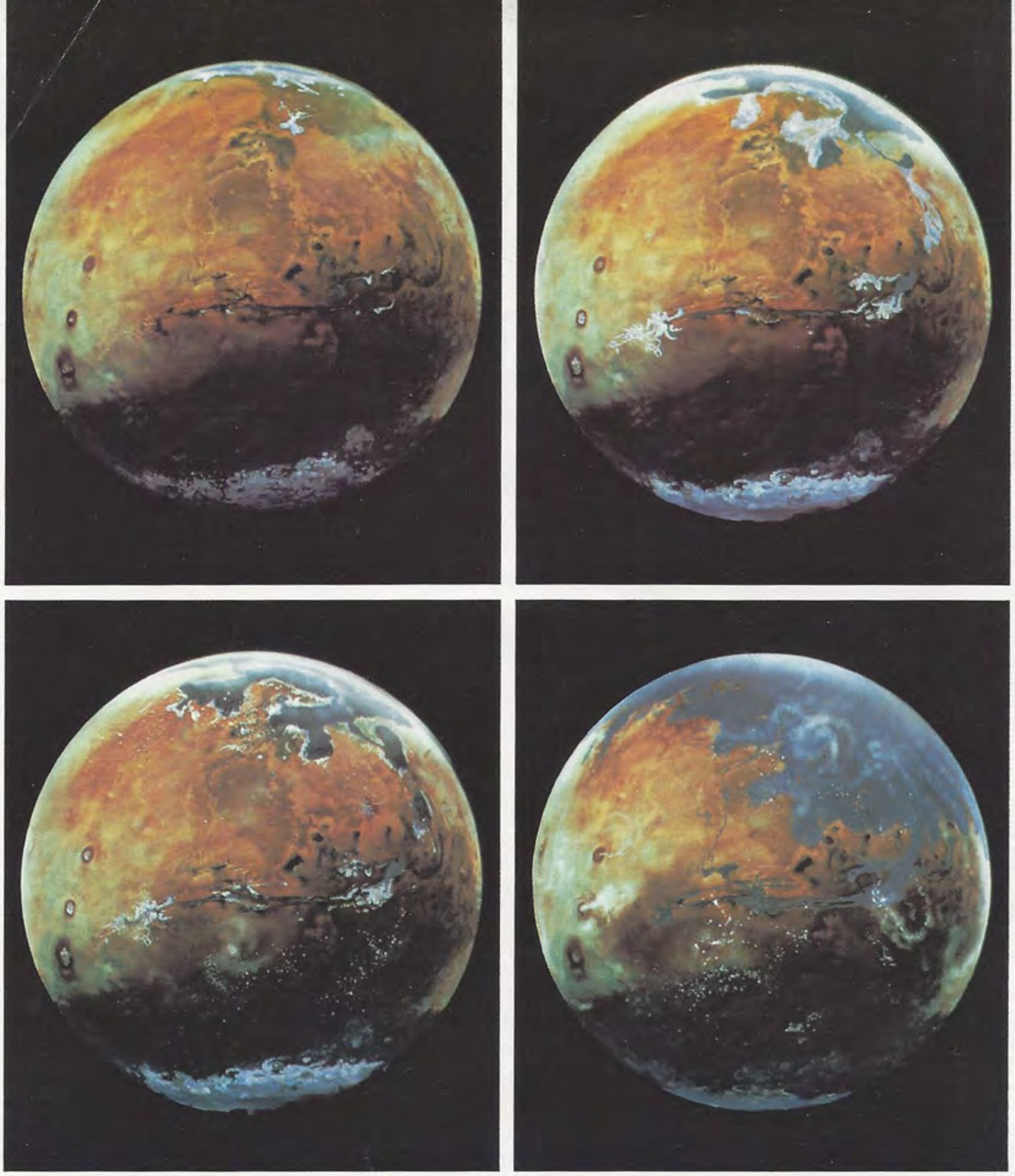
A SPECIAL ANNOUNCEMENT

As we go to press, we have just learned that Eleanor "Glo" Helin, leader of the Planet-Crossing Asteroid Survey supported by Planetary Society members, has named an asteroid after Thomas O. Paine. Asteroid 1990TX2, will now officially be known as (5188) Paine.

Glo discovered asteroid Paine from Palomar Mountain Observatory on October 15, 1990. It is a main-belt asteroid circling the Sun every 4.15 years between the orbits of Mars and Jupiter. As seen from Earth, it has a magnitude of 12.7. This is bright for an asteroid, indicating that Paine is a large object, perhaps 10 to 15 kilometers in diameter.

After Glo's initial plotting of asteroid Paine's path across the sky, other observers tracked the object and their measurements enabled a precise orbit to be determined. With that information, researchers were able to plot the orbit backward in time, and they discovered that this bright asteroid was first recorded in 1938 from an observatory in Heidelberg. Those unfortunate observers hadn't realized what they had seen, so asteroid Paine remained "undiscovered" until Glo saw it 52 years later.

Tom Paine will be remembered on Earth in histories of our planet's early space program, but this singular memorial of a celestial object will ensure that his name will be remembered among the planets. —*CMA*



If the planets in our solar system were to attend their high-school reunion, Mars would surely win the title of "Most Changed." This dry, cold and lifeless world shows evidence of once having been more like Earth, with its welcoming warmth, atmosphere and vital liquid water.

In "Mars Evolution," Michael Carroll paints a changing portrait of our rusty, mysterious neighbor: (1) Over 3 billion years ago, Mars may have been covered by extensive oceans across its northern lowlands. (2) As the climate cooled, rivers dried up and ice formed at the oceans' edges. (3) The atmosphere thinned, leaving vast glaciers to the north. (4) In the recent past, polar caps of water and carbon dioxide shrank to their present boundaries.

Michael Carroll is a space artist who lives and works in San Diego, California. Last May, The Planetary Society commissioned him to document on canvas the Death Valley Mars Rover tests.

THE PLANETARY SOCIETY
65 North Catalina Avenue
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