# The PLANETARY REPORT

Volume X Number 3 May/June 1990

NASA—Recapturing the Spirit

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).

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In Canada, Second Class Mail Registration Number 9567

***COVER: The Space Race of the 1960s spawned a robust, energetic agency to conduct the American space program. NASA launched a series of human missions, working its way, step by step, to the Moon. On June 3, 1965,* Gemini *astronaut Edward H. White II became the first American to "walk" in space, while his orbital companion, James A. McDivitt, remained inside the two-man capsule. (Cosmonaut Alexei Leonov was the first human to "walk" in space.) The* Gemini *program served as a bridge between the* Mercury *program, which sent the original seven American astronauts into space, and the* Apollo *program, which would send three-man crews to their lunar destination.* Photograph: Johnson Space Center, NASA**

# FROM THE EDITOR

Planetary missions—each one ranking among the most ambitious projects ever undertaken—begin with a glimmering image of what might be possible. It is the nature of these undertakings that they cannot be accomplished by an individual alone, however inspired he or she might be. The ideas that enable us to explore the planets can only be rendered real by entities we call "space agencies"—such as NASA in the US, Glavkosmos in the USSR, the Institute of Space and Astronautical Science in Japan and the European Space Agency—bureaucracies created to turn dreams into reality. In this *Planetary Report* we look at ideas soon to reach fruition, at imaginative concepts for the future, and at NASA, the agency that, although recently beset with problems, still looks forward to an expanding future on the Moon and Mars.



*— Charlene M. Anderson, Editor*

# 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 the space station, the 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.***

The NASA photo on page four of the January/February *Planetary Report* is radically wrong. The spiral rain bands feeding the tropical storm are spiralling the opposite way for a low pressure system in the northern hemisphere. I suspect that the photo was reproduced from a slide that was copied backwards or perhaps this storm was in the southern hemisphere.

You are correct in stating that cyclones (or low pressure systems) occur in all planetary atmospheres. What makes these photos so interesting is that similar atmospheric fluid dynamics can be deduced from such photos of different atmospheres. By studying planet Earth, we can extend our knowledge of distant planets by correlation, because many of the same physical concepts are applicable. The really exciting aspect of such comparisons is the awesome magnitudes of planetary atmospheric motions. What you call a storm in the caption of this photo would be a howling vortex of several greater orders of magnitude on a larger and faster rotating planet. The real beauty here is that good estimates can be made of those fierce winds by the connections used by atmospheric scientists who study planetary atmospheres.

The thrust of this particular issue is quite practical—study Earth to gather the facts on planets and study planets to reinforce the lessons needed for living on Earth.
JOEL CURTIS, *Juneau, Alaska*

*Yes, the photo got flopped in production. Seen from above, cyclonic storms rotate counterclockwise in the northern hemisphere and clockwise in the southern. Yours is the most interesting of several letters and calls we received on the subject—evidence that our readers pay attention, and a strong incentive for us to pay attention to every step in publishing* The Planetary Report. *—James D. Burke, Technical Editor*

Although the concept of a lunar observatory has been widely discussed for years, it does not appear to have had the active support of The Planetary Society, which is surprising because a lunar observatory would create an unequalled opportunity to advance research in planetary science as well as other areas of astronomy.

Early in the next century, radio telescopes on the Moon's far side could search for signs of extraterrestrial intelligence without interference from terrestrial radio sources. The most distant planets of our own solar system could be studied regularly at a level of detail comparable to that obtained by planetary probes. The study of other solar systems would enable us to better understand our own. Optical arrays on the lunar surface could image the nearer stars and provide information about their planets. Ultimately, optical arrays might be developed that could produce fairly detailed images of such distant planets themselves.

What a misfortune it would be if The Planetary Society, preoccupied by its pursuit of other objectives, failed to provide effective support for the project that, more than any other that might be undertaken during our lifetimes, would expand our understanding of the universe and of our place in it.
DAVID L. BARRETT, *Wisdom, Texas*

*The Planetary Society is interested in lunar astronomical facilities and we have maintained close liaison with the several scientific committees studying the possibilities. Astronomy, astrophysics and radio observatories are now under study. In order to evaluate the merits of a specific proposal we will need information on its cost as well as alternate methods of reaching the same astronomical goals, such as ground-based or Earth-orbiting observatories. Other people propose Moon mining for the first lunar site. We will continue to monitor the progress of these ideas, and when firm proposals are made, we will report on them. —Louis D. Friedman, Executive Director*

## NEWS BRIEFS

During the International Space Year of 1992 (an international effort to focus space studies on global change), Canada will produce the *Global Change Encyclopedia*. The encyclopedia will not be a book but will consist of computer disks, designed for personal computers with color monitors. The encyclopedia will combine and correlate diverse sets of measurements—global and regional—from a variety of satellite and ground-based studies, updating and adding to the data on a regular basis.

"This will be the first atlas of the world to show animated land and sea changes over an extended period of time," says Wesley T. Huntress Jr. of NASA's Earth Science and Applications Division.
—from *Science News*

In late February, *Pioneer 11* crossed the orbit of Neptune and became the fourth spacecraft (along with *Pioneer 10* and *Voyagers 1* and *2*) to leave the solar system.

Launched in 1973, *Pioneer 11* continues to return good data. In three years it will become difficult to operate the radio transmitter and scientific instruments simultaneously, says NASA project manager Richard Fimmel. However, technical adjustments may extend the craft's life through 1995. *Pioneer 10*, with its stronger power supply, may return data through the year 2000, which would extend its original 30-month design life to 28 years.
—from NASA Ames Research Center

Minor setbacks plagued the Hubble Space Telescope after its release from the shuttle *Discovery* on April 25. Problems with the aperture cover and then the solar panels were eventually remedied. However, a partial loss of maneuverability in one antenna, due to a distended cable, will be overcome by rewriting antenna software.

With an expected life of 15 years, the Hubble Space Telescope has a 94.5-inch primary mirror with a finish so smooth that if Earth's surface had been molded to the same specifications, the tallest peak would be five inches above sea level. Such amazing engineering precision will enable astronomers to study light from sources nearly 14 billion light years away.
—from the *New York Times*

*At sunset, after a long day of drifting with the martian winds, the Mars Balloon sinks gently down to deposit the SNAKE guide-rope on the ground. The guide-rope, being designed by The Planetary Society, will stabilize the balloon at night while the instruments it carries investigate the surface. Data from the guide-rope will be transmitted to the gondola, then on to the* Mars Observer *for relay to Earth.*

*Painting: Michael Carroll*

# The Mars Balloon Relay

**by Jacques Blamont**

**Question:** What's the main requirement for taking part in the exploration of Mars?
**Answer:** Exciting work in the laboratory, in the field, in the test facilities, on the launch pad, at the receiving stations and in front of the computer, and a fine blend of theory, perspiration and experiment.

Wrong. The real answer is: sitting on committees ad nauseam.

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In March 1986, engineers of the Babakin Center, which builds the spacecraft for the planetary program of the USSR Academy of Sciences, suggested that a balloon could be included in the next Soviet mission to Mars, as a follow-on to their successful use of balloons in Venus' atmosphere (see the January/February 1987 *Planetary Report).*

When I heard about it from my friend Slava Linkin of the USSR Space Research Institute, I proposed building a balloon that could lift off in the morning (as the Sun heated the atmospheric gases within the balloon), fly during the day only and sit on the ground at night (see the May/June 1987 *Planetary Report).* Initially, this system needed two balloons; since then an in-depth study by the French space agency CNES (Centre National d'Études Spatiales) has shown that the same flight profile can be achieved with a single balloon—and that is the present design to be put aboard the Soviet/French mission *Mars '94*.

After a Franco-Soviet workshop on the shores of the Black Sea in September 1986, the proposal gelled into an agreement and both sides started to study in earnest what a martian balloon could be and do.

## A Very Light, Very Large Balloon

What the balloon could be was not easy to decide: God did not create the atmosphere of Mars to be flown in by human contraptions. The atmospheric density at ground level is, at best, no greater than the density of Earth's atmosphere at an altitude of 35 kilometers (22 miles), so the balloon has to be light and large. *Light* means that the fabric must be thin, and thus the overall size of the balloon is severely limited. *Large* means that, notwithstanding these constraints, the volume cannot be less than several thousand cubic meters for the balloon to sustain itself, even without the payload. Since there are limits to how much we can practically transport to Mars, it was obvious from the start that the overall mass carried by the balloon could not exceed 20 to 25 kilograms (44 to 55 pounds).

The present design envisions a 15 kilogram (33 pound) gondola that the balloon carries aloft; hanging 100 meters (300 feet) below the balloon is a 13.5 kilogram (30 pound) guide-rope, part of which touches the ground at night. Component responsibilities are divided as follows: The Soviets are responsible for balloon inflation, the French for making the balloon, the Soviets for making the gondola and the French for making the guide-rope (with the help of The Planetary Society).

What the balloon could do was clear from the start: It could gather data needed to engineer future landings of rovers and various other packages on the martian surface. At that time the United States and the Soviet Union both envisioned missions to Mars that would culminate in sample returns. As part of a precursor mission, the balloon could take *zillions* of high-resolution pictures, measure infrared reflectance of rocks and, using electromagnetic waves, sound the subsurface to a depth of one kilometer (0.6 mile). Able to travel more than a thousand kilometers during its mission, the balloon could explore many sites.

A main design premise of today's planetary missions is that resources are limited to what you bring from Earth. For instance, the balloon carries a limited mass of buoyant gas, and we have had to design the balloon to survive and fly as long as possible on that fixed amount.

One of the scarcest and most precious resources is energy. Aboard the balloon all the energy comes from the batteries. Within the allotted mass budget, it is not possible to carry more than 3 kilograms (7 pounds) of batteries, which could at best provide 1 kilowatt hour for the total duration of the balloon mission. The expected lifetime of the Mars Balloon is about 10 days.

The greatest energy consumer is the radio transmitter, which sends out the data collected by the balloon. Since the power required to send data directly to Earth would be enormous, signals from the balloon have to be picked up by a satellite orbiting Mars and relayed to Earth.

## Data Bottleneck

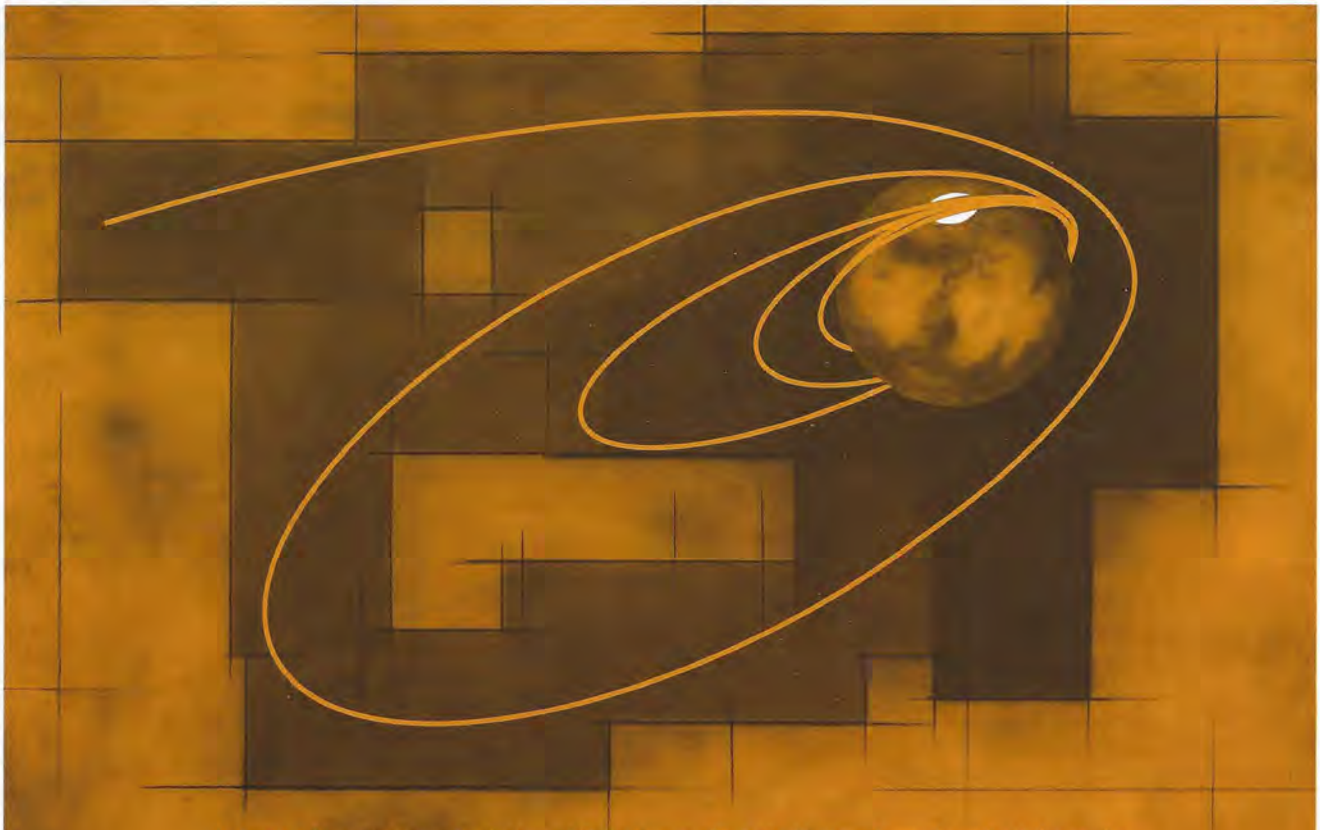
The Venus balloons deployed by the Soviets in 1986 did indeed transmit directly to Earth but at an exceedingly slow rate: for 300 seconds out of every half hour they sent 4 bits per second to the largest and most sensitive antennae available on Earth. One picture—500 by 500 pixels (picture elements)—contains 2 million bits; transmitting one such picture directly to Earth would take three days of uninterrupted reception.

Therefore we planned from the start that a Soviet satellite would be available for relaying the data. The orbit would be eccentric (highly elliptical) with its apogee, or farthest point, between 10,000 and 20,000 kilometers (6,000 to 12,000 miles) from the surface of Mars. (The orbit's eccentricity is necessary to synchronize it with Earth's rotation so that the spacecraft can be in position to communicate with the Soviet tracking station.) The relay could receive signals from the balloon for only one hour twice per day at an average distance of around 10,000 kilometers.

Under such conditions the balloon's electrical power supply could manage a transmission rate of 16 kilobits per second. That translates to—assuming the best possible case—about 60 pictures per day. *(continued on page 7)*

*The Mars Balloon, being built by France to fly on the Soviet Union's Mars '94 mission, will carry an instrumented gondola to measure the atmosphere and image the surface. During the day, as sunlight warms the gases within the balloon, it will ascend and drift with the winds, and so cover more ground than is possible with a robotic surface rover.*

Painting: Michael Carroll



*As the* Mars Observer *approaches its target, it first enters an elliptical orbit above the martian poles. It then settles into a circular orbit from which it will map the planet for at least one martian year of 687 Earth days. The* Mars Observer *will carry a relay to pass information from the Mars Balloon back to Earth.* *Illustration: S. A. Smith*

*(continued from page 5)*

Suppose we want our camera to resolve features as small as 10 centimeters (4 inches) so that we can document a landing site for a future Mars rover. Every picture (500 by 500 pixels) will show us a patch of martian surface measuring 50 by 50 meters (160 by 160 feet). Given these conditions, one day's transmitted data would cover an area of only 1,000 by 300 meters (3,000 by 1,000 feet).

Remember, the point of sending the Mars Balloon is to get *zillions* of high-resolution pictures. But with a bottleneck in the relaying of picture data back to Earth, the outlook was dim. Something had to be done.

### My Mind Wandered . . .

At the end of 1986, NASA created a working group under the chairmanship of the world-renowned Mars expert Michael Carr of the US Geological Survey to help define the scientific objectives of a possible Mars Rover/Sample Return mission. I was appointed a member of this group, which met at the end of May 1987 at the Jet Propulsion Laboratory (JPL) in Pasadena, California. The first task given to the group was to assess, urgently, what improvements could be made to the payload of the *Mars Observer*. The launch of *Mars Observer,* a NASA mission to study the climatology and surface geology of the Red Planet (and well known to members of The Planetary Society, who supported it massively through its vicissitudes), had just been postponed for budgetary reasons from 1990 to 1992. Therefore, in 1987, there was a little time available for some slight modifications.

On May 22, during a splinter group meeting, my mind wandered somewhere outside the room and an idea suddenly struck me: *Mars Observer* would be placed on a circular orbit, timed in such a way that the spacecraft would always cross the martian equator at two o'clock in the morning and two o'clock in the afternoon, at the constant altitude of 360 kilometers (230 miles). That meant that any station on the martian surface, whether fixed or slowly moving like the balloon, would be able to "see" *Mars Observer* twice each day, in the afternoon and in the early morning.

From orbit to orbit, the shortest distance between *Mars Observer* and a ground station could be anywhere between 360 kilometers (if directly overhead) and 900 kilometers (600 miles) —much less than the average 10,000 kilometers between the Mars Balloon and the Soviet *Mars '94* spacecraft. Thus we would use far less of the Mars Balloon's battery power for transmitting if we placed a relay on *Mars Observer,* and for the same power we would get much more data.

I immediately consulted a few knowledgeable friends in the working group and was unanimously encouraged to think more deeply about this fledgling idea. After some homework, I found that a small antenna placed on the *Mars Observer* could provide a data retrieval rate as high as 160 kilobits per second, compared to 16 kilobits per second for the Soviet spacecraft. As I faxed to the working group chairman: "Since the balloon mission is power limited, the first guess seems to indicate that the presence of a receiver on *Mars Observer* would be of great benefit to the balloon mission and also to the small permanent stations we want to propose to the Soviets."

At the next meeting of the working group—on June 29 in Houston, Texas—I presented the concept, suggesting that it could be raised at the upcoming first meeting of the US/USSR cooperative agreement group (established that year for cooperation between the two nations in planetary and other science endeavors).

It was then that I learned that the data system of *Mars Observer* was "all booked up." To solve this problem, I suggested sending the balloon's data stream through the *Mars Observer* camera (MOC) and storing it in the MOC memory. With proper formatting of the balloon data, the MOC data system would not distinguish these data from its own, and no change to the spacecraft hardware would be required. Without this trick, the proposal would have stopped there.

### More Meetings

The idea of the relay was received enthusiastically and included at the top of the list of recommended modifications to *Mars Observer*. NASA Headquarters reacted immediately, initiating a preliminary study. The concept survived the study, and from a technical point of view looked better and better.

Now I had to scale a high mountain: convincing the American, the Soviet and the French space agencies to accept the idea of an American facility as a major subsystem of a Soviet mission. *Perestroika* had not yet been accepted as a political fact.

Slava Linkin, as a delegate in the USSR cooperation group, agreed to raise the issue as a Soviet proposal: The *Mars '94* project would provide a receiver for inclusion in the *Mars Observer* mission. The US satellite would arrive at Mars in 1993, perform its tasks and then serve as a relay for the balloon launched in the martian atmosphere by the Soviet spacecraft.

Now the relay proposal was in the hands of others—I was "out of the loop," but still had the technical work to do. I have a painful recollection of sitting one day in the Space Research Institute, just myself and André Ribes, a bright engineer from CNES' Toulouse Space Center, writing the specifications for a system receiving signals from a gondola transmitter that did not exist yet even in concept. That was November 1987.

### Behind Closed Doors

In the December 21, 1987 issue of *Aviation Week* I saw this headline with pleasure: "Soviets Propose Relay Role for *Mars Observer* Mission." Accompanied by a painting of the Mars Balloon by Michael Carroll (commissioned by *The Planetary Report*), the article said: "The Reagan Administration and NASA are seriously studying the *Mars Observer* proposal, which could lead to a low-cost but significant US/Soviet cooperative effort doubling or tripling the amount of low-altitude imagery of Mars that could be transmitted from the Soviet/French mission, set for launch in 1994."

A cloud of secrecy had descended from the Top: There was no hint of the progress of the relay idea through the Government of the United States; no third partner, and especially no miniscule froggies, would be admitted to the august assembly of the superpowers discussing their business on a strictly bilateral basis.

Let us not follow the tortuous itinerary of the idea through the bureaucratic maze. It took about one year for the decision to be reached: The French space agency CNES, acting as a subcontractor to the Soviets (and paying for the entire system), agreed to provide the relay to JPL. The bilateral agreements are still not signed, even though the equipment is being built in Toulouse by the French company Alcatel-Espace, which is under contract to CNES.

### 1,000 Pictures a Day

The Mars Balloon relay system, as it is implemented now, draws upon experience with the EOLE project, which I proposed to CNES in 1963 and which flew successfully as a US/French study of Earth's atmosphere in 1971. CNES launched 500 balloons designed to float at an altitude of about 20 kilometers (60,000 feet) and take atmospheric readings; then a French spacecraft, launched by a NASA Scout rocket, relayed the meteorological data obtained by the balloons.

The operational outline is similar for Mars: the French box on *Mars Observer* sends a signal that triggers the electronic package aboard the balloon, which replies to *Mars Observer* at 128 kilobits per second. The duration of the transmission—from 300 seconds to 1,000 seconds—depends on the relative positions of the balloon and the spacecraft.

The balloon gondola first empties its 32-megabit memory of the data collected since the last pass; then it sends images of what it is seeing at that moment, providing of course the pass is taking place during daylight. During the night pass, no pictures are taken in real time.

We have included in the balloon camera a compression procedure that multiplies the number of pictures tenfold; by relaying data through both the available spacecraft, American and Soviet, we expect to obtain about a thousand pictures per day of balloon life.

The importance of the *Mars Observer* relay to the balloon mission cannot be overestimated. Very recently, it has been agreed that the small Soviet stations placed on the martian surface during the *Mars '94* mission will also use the *Mars Observer* relay.

### Everybody Is Happy

From a political point of view, the Mars Balloon relay is palatable to both sides since it has high visibility as cooperation yet does not create a lot of technology-interface problems for them to solve. It is French equipment integrated into the spacecraft by French engineers. CNES is happy to participate since the relay improves the scientific value of the balloon mission, and also because it continues the French space agency's tradition of working actively toward a rapprochement of the major space powers. NASA is happy because American scientists and engineers will have immediate and direct access to data needed for the future exploration of the Red Planet. The US agency is paying for the mechanical interface between the spacecraft and the relay antenna.

Everybody is happy about the *Mars Observer* relay—cheap and sanitized. I was proud to find it as an individualized item in President Bush's 1991 NASA budget, a $2 million project alongside other items with price tags in the hundreds of millions of dollars. There must be a reason.

All I need hope for now is that all the partners will still be alive in October 1995, when the Mars Balloon is scheduled to begin its cross-country trek on Mars.

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*Jacques Blamont, Professor of Physics at the University of Paris and Chief Scientist at CNES, has been a Planetary Society Advisor since 1981.*

# The Key to Mars, Titan and Beyond?

## Nuclear Rockets Using Indigenous Propellants

***by Robert M. Zubrin***

*Early visions of spacecraft to carry humans to the planets bore little resemblance to the eminently functional but awkward-looking craft that have carried us to Earth orbit and the Moon. As exemplified in this Mars landing craft painted by Chesley Bonestell, sleek winged rockets carried out the space exploration imagined in the 1940s and 1950s. (The 1954 film* The Conquest of Space *cinematized this view of a glider landing on a martian desert.) If future human explorers use advanced propulsion systems such as those described in this article, sleek winged rockets may yet become reality.* Painting: Chesley Bonestell, courtesy Space Art International

Back in the 1960s, when NASA last was serious about launching a human mission to explore Mars, a program was initiated to develop a new kind of rocket engine. A "classical" rocket works by burning a chemical propellant and directing the exhaust gases out through a nozzle, thus providing thrust to drive the rocket (see the March/April 1990 *Planetary Report* for more background on rocketry). This new engine, called NERVA (Nuclear Engine for Rocket Vehicle Applications), was to have an exhaust velocity twice that of the best possible chemical engines. The increase in exhaust velocity was a big step forward in preparation for a human mission to Mars, cutting the mass required for such a mission to less than half.

The principle was simple enough: Using a nuclear reactor, heat hydrogen to high temperature and exhaust it out a rocket nozzle. And it worked. More than 20 NERVA engines were built and successfully ground-tested with power levels between 40 and 4,000 megawatts, thrust levels up to 100,000 kilograms (200,000 pounds) and the desired ultra-high exhaust velocities. A flight test model of NERVA was being prepared when, in 1972, the whole program was cancelled after the Nixon administration eliminated NASA's post-*Apollo* plans for human exploration of Mars.

Today, as we once again think of opening up the Red Planet, it makes sense to re-examine NERVA technology. In addition, there is a way to use nuclear engines—not examined during the NERVA program—that can radically benefit space exploration: In principle at least, these engines can make use of any gas as propellant, including gases found naturally on extraterrestrial bodies. Therefore, if we design a spacecraft that can refuel itself on Mars, rather than carrying round-trip fuel from Earth, we will drastically reduce the mass and cost of the mission while increasing its capability.

### NIMF: Hopping Around on Mars

The atmosphere on Mars is 95 percent carbon dioxide ($CO_2$). Ordinarily, nobody would consider $CO_2$ an ideal propellant for a nuclear engine. This gas can only achieve an exhaust velocity of 2.75 kilometers per second (km/s) when superheated to 3,000 kelvins in a nuclear engine, which compares rather poorly to the 4.5 km/s performance available from a good chemical engine using liquid hydrogen/oxygen, or the 9.0 km/s in a hydrogen-fueled NERVA.

On the other hand, all that martian $CO_2$ is there for the taking. At the temperatures that prevail on Mars, $CO_2$ can be liquefied simply by compressing it to about 100 pounds per square inch, or six to seven times Earth's sea level atmospheric pressure. A landing vehicle of 40 metric tons sitting on the surface of Mars would easily be able to fuel itself for a flight into orbit in about five days. The pump used to compress $CO_2$ for fuel would need only 100 kilowatts (134 horsepower), produced by running the 2,000 megawatt engine reactor at very low power.

In half that time, this $CO_2$ hopper could fuel itself for a suborbital hop of some thousands of kilometers (or, if it is a winged craft, supersonic flight for similar distances). Such a craft would then land and refuel itself again, thus giving astronauts unlimited mobility for planetary exploration. I call this vehicle a NIMF, for Nuclear rocket using Indigenous Martian Fuel.

### Chemical vs. Nuclear

It has been proposed that chemically fueled Mars landing and ascent vehicles and hoppers could also use indigenous propellants. For example, martian $CO_2$ could be split into CO (carbon monoxide) and $O_2$ (molecular oxygen) bipropellants. Or, if water is available, methane ($CH_4$) could be synthesized and burned with oxygen in a rocket combustion chamber. While such an approach can reduce the mass of a piloted Mars mission, the problem is that the energy required for such chemical synthesis (about 100 times greater than required for simply acquiring $CO_2$) implies a power source that is too large to travel with the vehicle. Thus a conventionally fueled craft would need a base camp with a large power supply and chemical-engineering infrastructure. For any sortie from the base camp it would have to carry enough propellant for the round trip. The NIMF would only need to carry enough for a one-way hop.

At some point the need to carry round-trip propellant becomes too burdensome. The $CO/O_2$ chemical hopper has an exploratory range of only about 1,300 kilometers (800 miles) from base camp, and the methane/$O_2$ hopper can go as far as 2,200 kilometers (1,400 miles) before turning back. When returning to base, the chemical vehicle must land precisely on target: If it lands a few miles off course, there is a risk it may never be refueled, as transporting large quantities of chemical propellant from the base over the rough martian terrain may prove impossible.

### Water Power

Carbon dioxide may not be the only NIMF propellant available on Mars. Many scientists believe that Mars possesses large quantities of water in the form of permafrost or even ice covered by a few feet of sand—after all, the planet seems once to have had flowing rivers.

If water is accessible, it could make an attractive NIMF propellant, yielding an exhaust velocity of 3.4 km/s. This level of performance is good enough to allow a piloted NIMF vehicle to ascend from the surface of Mars and propel itself directly back to low Earth orbit (LEO). A robotic NIMF could probably do this with $CO_2$ propellant, if we stretch the engineering a bit.

If water is available on the martian moon Phobos, a NIMF could travel to Earth orbit and then back to Phobos (or Mars), without any additional propellant from Earth. NASA is current-

### Key Terms

**Nuclear engine:** an engine that uses a nuclear reactor to heat a single chemical substance—such as hydrogen, water or carbon dioxide—to produce hot exhaust gas for rocket thrust. For example, if water were the propellant, such an engine would be essentially a flying steam kettle.

**Exhaust velocity:** the speed of propellant gas as it is fired out of a rocket nozzle. We want the highest possible exhaust velocities because the greater the exhaust velocity, the less propellant is required to attain the desired vehicle velocity. Less propellant, of course, means less mass to carry on the mission.

**Thrust:** the force with which a rocket engine pushes on the spacecraft; measured in pounds or newtons (1 pound of thrust = 4.45 newtons). Vehicles traveling in deep space can get by with very little thrust, but a vehicle like the NIMF, which takes off from a planetary surface, must have thrust greater than its weight if it is to get off the ground.

**Power:** measured in megawatts, the power of a rocket engine is proportional to the product of thrust times exhaust velocity. The NIMF engine needs about 2,000 megawatts of power.

**Bipropellants:** two chemicals, such as hydrogen and oxygen, that are combined and burned to produce hot exhaust gases for rocket thrust.

**Kelvin:** the scale of temperature that begins at absolute zero, the temperature at which molecules are almost "stationary." We use the Kelvin scale because it reflects the energy content of a gas, which is proportional to its temperature in kelvins. Subtract 273 from the temperature in kelvins to obtain the equivalent in degrees Celsius.

ly studying the concept of breaking down Phobos water into propellants that would allow a chemical vehicle to perform the same maneuver. [The environmental consequences of mining Phobos or other solar system bodies still need to be assessed. See "Phobos—A Surface Mine or an International Park," September/October 1988 *Planetary Report*.] But the energy needed to break water into hydrogen and oxygen and then refrigerate them to liquefying temperatures for use as fuels is 500 times that required to melt the ice into water as propellant for the NIMF (and the technological complexity of the equipment needed for chemical processing and refrigeration would be considerable).

### Nuclear Byproducts

There's no such thing as a free lunch even for a system with the simplicity and versatility of NIMF. One challenge to overcome in development of nuclear engines arises from the fact that $CO_2$ or water, when heated to very high temperatures, will become an oxidizer and severely corrode the carbide fuel elements developed in the early NERVA program. We will have to develop new types of fuel elements for the NIMF, probably of uranium-thorium oxide (whose melting point is 3,300 kelvins) surrounded by a layer of oxide of nonfissionable material (this layer will prevent radioactive products from migrating into the propellant exhaust).

On the issue of nuclear safety, I should note that because they would operate at high power only for short periods, NIMF engines would typically contain about one millionth the radioactive material of today's civilian nuclear power reactors. This small quantity is easy to shield effectively and, in case of mishap, represents no significant threat to the martian environment.

### Mother Ship Syndrome

The NIMF concept, in addition to making it easy to get around on Mars, makes possible a drastic reduction in the mass and cost of a Mars mission. Since the days of the *Apollo* program, it has been axiomatic that a piloted planetary mission requires a combination of an orbiting mother ship (containing long-term living quarters), a landing craft providing surface habitation, and a small ascent vehicle.

The reason for using a detachable lander, rather than landing the entire spacecraft, is to minimize mass: Any mass lowered to the planet surface will require fuel to return to space, and that ascent-fuel means additional mass. Furthermore, if this fuel has to be transported from Earth, still more fuel, and mass, are required to get to Mars in the first place. The total mass and cost of the mission multiply.

With the advent of NIMF, any mass landed on Mars can be lifted to orbit using propellant readily available on the ground. Thus we can abandon the concept of detachable landers and orbiting mother ships altogether, and instead land the entire spacecraft, living quarters and all, on the planet surface. If the NIMF and the interplanetary vessel are one and the same, then all that need be left in orbit is an automated propulsion unit with fuel and supplies for the return trip to Earth.

Under the conventional thinking, a piloted Mars mission requires that two complete sets of living quarters be driven to Mars, one for the orbiting mother ship and one to be abandoned on the surface. By eliminating the extra set of living quarters, as well as the landing/ascent vehicle and associated propellant, a NIMF mission can cut the total mass of a Mars trip by a factor of three.

### To Mars in One Launch

In fact, a complete Mars mission can be started from LEO with a mass of about 100 metric tons if we use a 3-person/40-metric-ton NIMF spacecraft, which is conveyed from Earth orbit to Mars orbit (and Mars orbit to Earth orbit) by a hydrogen-fed NERVA "tug." Delivering this entire mass to LEO is within the capability of the proposed NASA launcher *Shuttle Z* or the Defense Department's Advanced Launch System, not to mention the already flown and tested Soviet *Energia*. (For more on these launch vehicles and Mars mission lift requirements, see articles by Ivan Bekey, Jerry Grey and Saunders Kramer in the March/April 1990 *Planetary Report*.)

In other words, we can accomplish a piloted Mars mission in a single launch. This is in sharp contrast to the conventional approach, which requires about six launches of a heavy-lift vehicle to deliver 700 or more metric tons to LEO, as well as an extended and expensive effort in assembling the six payloads in orbit.

Another advantage of a NIMF mission is that the science return will be much greater: Instead of being limited to the single landing site of a conventional mission, the NIMF will be able to visit dozens of locales.

Furthermore, when it returns from Mars, the NIMF can be "parked" in LEO and reused. To send the next Mars mission will thus require only 60 metric tons to be lifted to LEO (100 metric tons less the 40 metric tons of the NIMF). With cheap, repeatable access to Mars, we'll be on the way toward settlement of the Red Planet.

### On to Titan

Mars is not the only potential port of call for nuclear rockets using indigenous propellants. Water ice exists in nearly pure form on Jupiter's moons Europa, Ganymede and Callisto; on Saturn's moons Enceladus, Tethys, Rhea and Dione; and on Uranus' moons Ariel, Umbriel, Oberon and Titania. Along the way, ice may also be found on the asteroid Ceres and on several Trojan asteroids (which are clustered 60 degrees ahead and 60 degrees behind Jupiter as they orbit the Sun), as well as in the cores of comets. Thus there are numerous bases from which water-fueled NIMF spacecraft might carry out the exploration of the solar system. A winged automated NIMF using atmospheric $CO_2$ as propellant could conceivably explore Venus' surface, collecting ground samples and performing low-level aerial reconnaissance from every part of the planet and then returning to orbit.

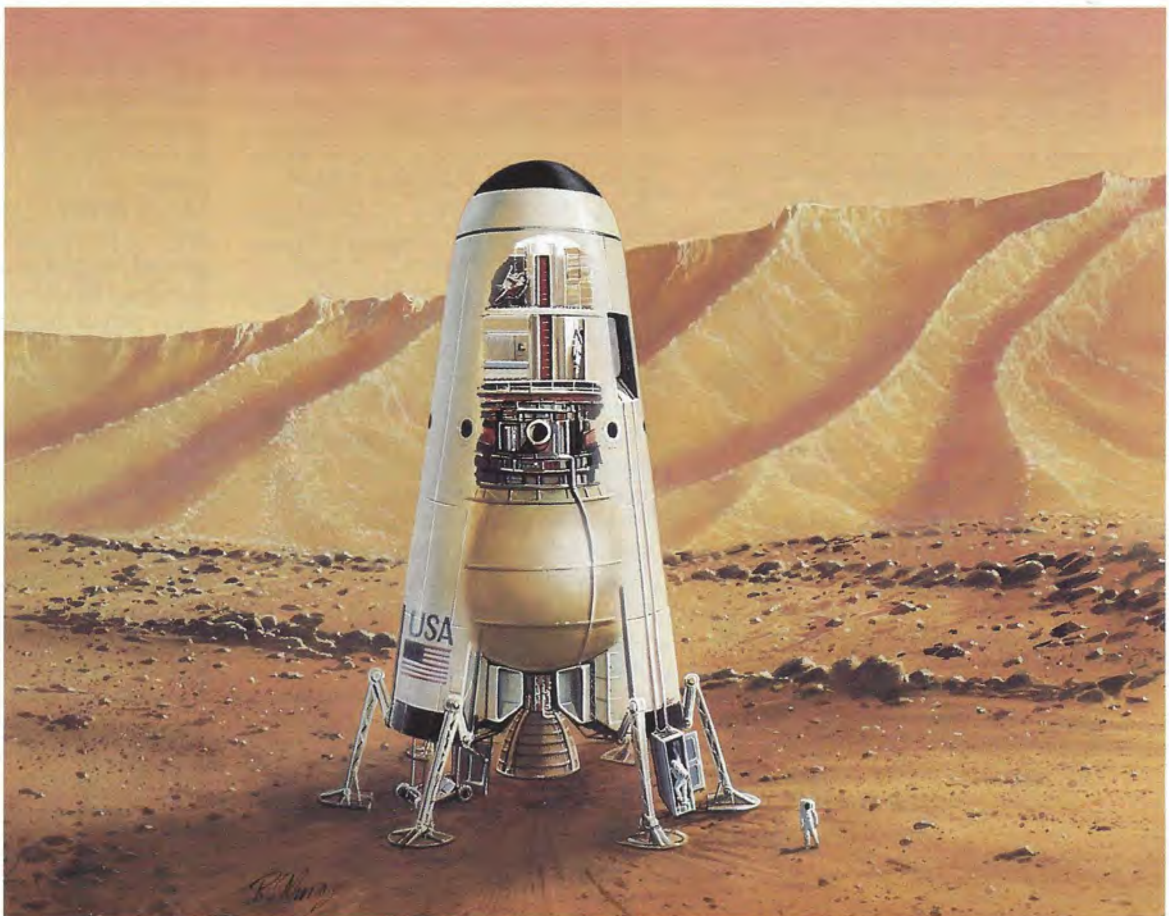
But to my way of thinking, the most exciting target of all for post-Mars NIMF missions is Titan, Saturn's largest moon, a world whose nitrogen and methane atmosphere, postulated hydrocarbon lakes and oceans, and continents of rock and water ice contain in great abundance all the elements needed for the origin of life. Indeed, many scientists think that the chemistry of Titan may resemble in certain respects that of Earth during the period when life began. But Titan is frozen in time by the slow rate of chemical reactions in a low-temperature environment. While life may never have evolved on Titan, humans may one day use some of its billions of tons of readily accessible carbon, nitrogen, oxygen and hydrogen, together with such "imports" as reactor-generated heat (converted to electricity at 80 percent efficiency with the aid of Titan's very low temperature), seeds and a few breeding pairs of livestock, to create a huge agricultural base within an artificial biosphere. [The idea of transforming Titan into a world useful to human industry is controversial. Some feel it might be important to preserve this planet-sized laboratory on the origin of life in its pristine state.]

Because of its thick, cloudy atmosphere, Titan's surface is not visible from space; the *Voyager* cameras returned only images of a fuzzy, orange ball. Many essential facts about this world remain mysterious. A mission that could penetrate Titan's clouds, perform a low-level aerial reconnaissance and bring back samples from Titan's air, land, sea and submarine regions would be of immense scientific interest. A NIMF can accomplish such a mission.

## Aviator's Paradise

What I propose is a small automated NIMF Titan Explorer (NIFTE) with foldout wings and a NERVA engine. The NIFTE—with a dry mass of eight metric tons (including a scientific payload of two metric tons) plus its ten metric tons of hydrogen propellant when fully fueled—could be lifted to LEO by a *Titan 4* or the space shuttle. The hydrogen propellant would power a four-year course to Titan, where the NIFTE would use the atmosphere for braking, open its wings and commence slow-moving, air-breathing aerodynamic flight.


***RIGHT: One of the many exciting missions beyond Mars made possible by NIMF technology is the exploration of Saturn's largest moon, Titan. After a four-year flight from Earth, the automated spacecraft called NIFTE unfolds its modest-sized wings, taking advantage of Titan's high atmospheric density and low gravity to perform a low-altitude, low-speed reconnaissance of the entire satellite. To collect samples for scientific study, the NIFTE releases small, tilt-rotor aircraft that can land and takeoff from solid ground or ocean and can even explore submarine regions. Its exploration completed, the NIFTE fills its tanks with liquid methane from Titan's atmosphere and rockets back to Earth with a massive science return from this mysterious cloud-covered world.*** **Painting: John Tieleman, Martin Marietta Astronautics**




***RIGHT: In a surface-hopping configuration, the NIMF vehicle might have its parachute compartment on top with the control deck and habitation deck below. In the midsection of the craft, $CO_2$ compressors sit atop the main propellant tank, and underneath is a nuclear reactor, surrounded by a secondary, donut-shaped propellant tank for extra shielding.***

**Painting: Robert Murray, Martin Marietta Astronautics**

Titan, with one-seventh Earth's gravity and four and a half times Earth's atmospheric density, is an aviation paradise: A NIFTE flying at 90 kilometers per hour (55 miles per hour) would require a wing area of only 20 square meters (70 square feet) to remain airborne. (A human standing on the surface of Titan could strap on wings and fly like a bird.) As the NIFTE cruises along, it could dispatch small electric-powered aircraft (which could take the form of mini-helicopters, tilt-rotor seaplanes, dirigibles or even flying submersibles) to retrieve samples from Titan's land and sea.

With its exploration of Titan complete, the NIFTE would fill its propellant tanks with methane from the atmosphere. In the NERVA-type nuclear engine, methane is a high-performing propellant (exhaust velocity 5.4 km/s), and the NIFTE's empty hydrogen tanks would contain up to 64 metric tons. The refueled NIFTE could then make round trips to the surface of every other saturnian satellite except Mimas (which would be out of range), or it could make a rapid (two-year) return to Earth.

Thus, in a single mission, we could explore Titan and prospect Saturn's other moons and, even more important, test and prove a transportation system that will enable humans to venture to the saturnian system.

Worlds await human explorers—Mars, Jupiter's moon Ganymede, Titan, even Neptune's Triton. Nuclear rockets using indigenous propellants can open up the entire solar system to humanity.

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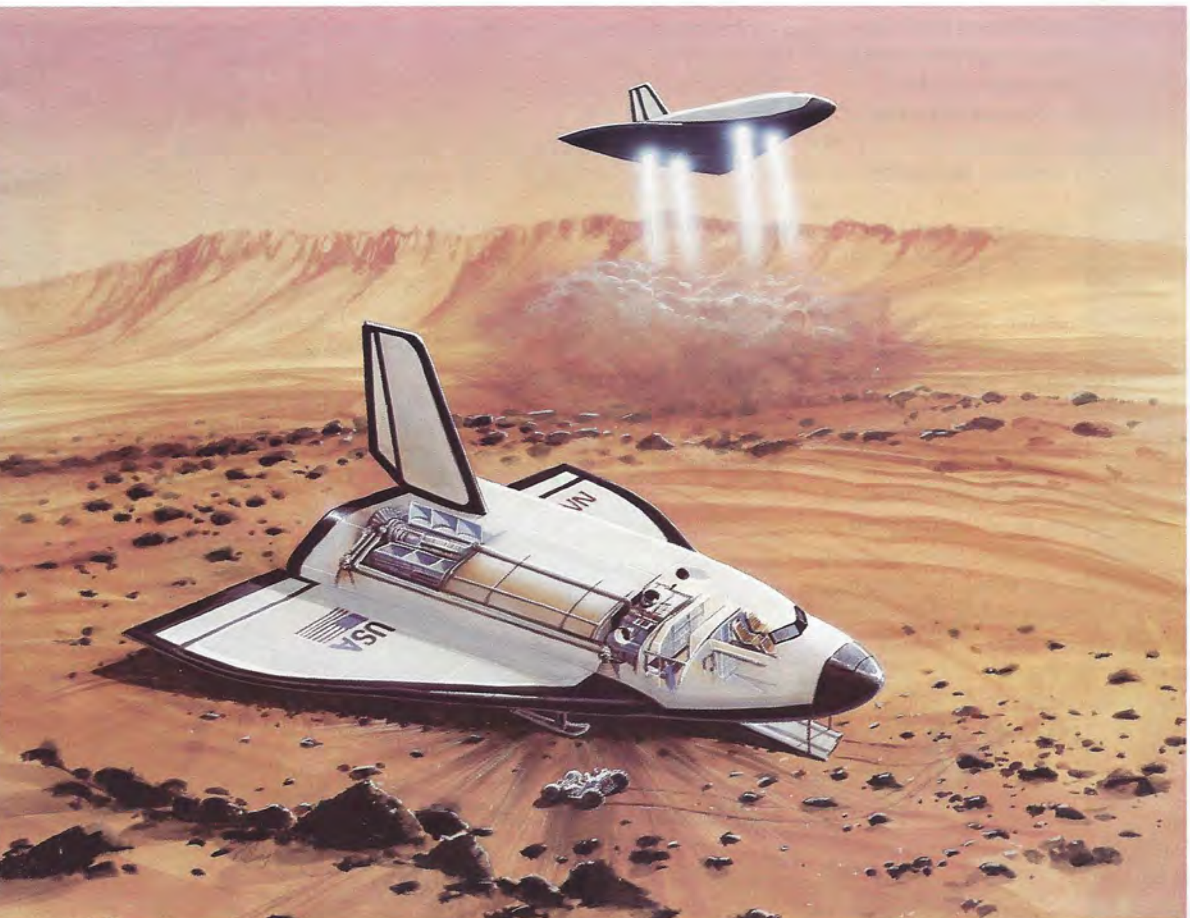
*Robert M. Zubrin is Senior Engineer at Martin Marietta Corporation's Astronautics Division.*




***LEFT: The rocketplane version of a NIMF could attain supersonic (Mach 3 to 5) aerodynamic flight with modest wing area, even in Mars' thin atmosphere. Winged flight allows for greater exploratory freedom and flexibility; this craft would also be able to propel itself out of the atmosphere to orbit.***

**Painting: Robert Murray, Martin Marietta Astronautics**

# European Space Agency

**by Agustin F. Chicarro**

During the last quarter century, robotic spacecraft have taught us much about Mars. Although it is geologically less evolved than our world, Mars is far more Earth-like than any other planet in our solar system. Mars has evolved over the past few billion years as internal pressures deformed its crust, volcanism reshaped its face, and meteorites and comets battered its surface. Still, Mars is the most Earth-like planet, with an ancient environment that seems to have been even still more Earth-like. Therefore, Mars is an obvious target for us in the search for present or extinct lifeforms.

The European Space Agency (ESA) has formed a team to study outstanding questions about the nature of Mars and to determine how European space scientists and engineers might contribute to their resolution. We recently published the results of our investigation, entitled *Mission to Mars: Report of the Mars Exploration Study Team*. Here are some of our conclusions:

**Scientific Objectives:** The future international exploration of Mars must address major scientific questions, such as:

—What is the present internal structure, composition and geologic activity of the planet?

—Why has the northern hemisphere been more geologically active than the southern hemisphere, which retains more scars of ancient cratering episodes?

—What is the chronology of its tectonic phases in which internal forces deformed the crust?

—What are the most common minerals in martian rocks?

—How has the martian atmosphere changed?

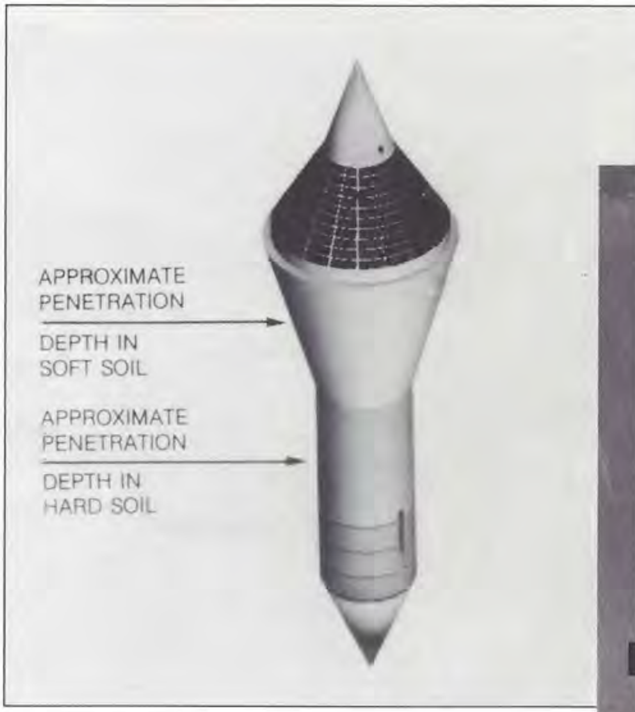
—What is the present distribution of surface and subsurface water?

—When did liquid water flow on the surface of Mars?

—How closely did early Mars resemble Earth when life appeared on our planet about 3.8 billion years ago?

—Are there sediments on Mars containing organic compounds or fossils?

**Strategy:** After analyzing the key scientific issues, ESA has identified three possible areas of European participation in the exploration of Mars. Several strong requirements shaped our study, including the need for a major and novel scientific return; use of state-of-the-art technology, now available or under development in Europe, to maximize scientific return within limited financial resources; and adaptability to American and Soviet missions to Mars now planned for the near future.




# Aims High—at Mars

Figure 1 (left): *Penetrator surface station*
Figure 2 (below): *Mini-probes ballistic-entry vehicle*

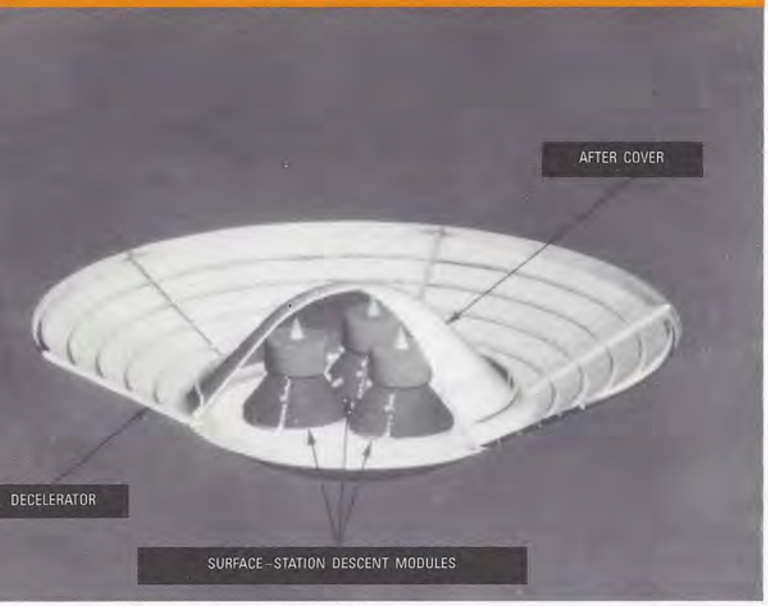
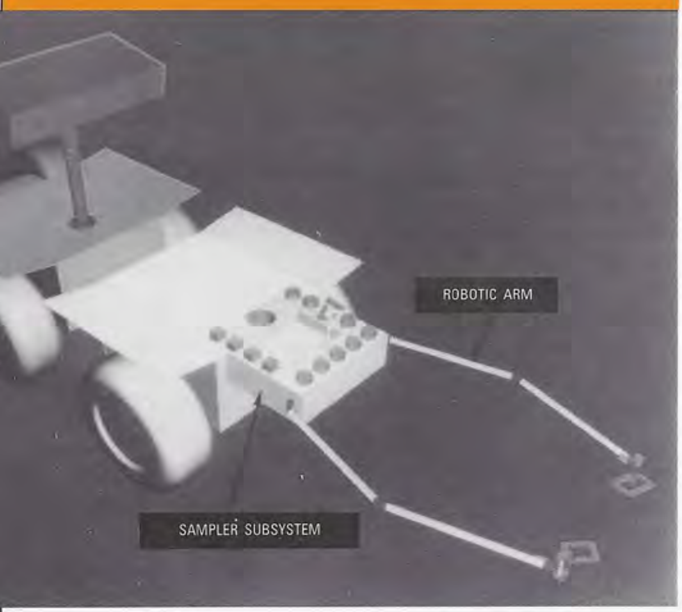



Figure 3 (left): *Proposed landing sites in the Tharsis region*
Figure 4 (below): *Mars rover configuration with sampler subsystem*




*Network Science:* An array of small surface stations, including two surface penetrators *(Figure 1)* and a cluster of three mini-probes *(Figure 2)*, would define a seismological network. After taking atmospheric measurements during their descent, these small stations would land at scientifically interesting sites *(Figure 3)*. They would be designed to operate for one martian year. The returned data would help define the planet's structure, its mineral and chemical composition and its surface meteorology. This network would be part of a precursor mission to a Mars Rover/Sample Return effort and to human exploration.

*Rover Science:* A complex sample-acquisition subsystem, including an intelligent robotic arm, would be placed on board a rover from another space agency *(Figure 4)*. The subsystem would be capable of stereovision as well as handling and sampling rocks and soil. It would analyze chemical and mineralogical samples, study subsurface structures, perform biological experiments and take atmospheric measurements in several locations within its area of mobility. This sampling subsystem could contribute to a Mars Rover/Sample Return mission.

*Orbiter Science:* A facility on board an orbiting spacecraft would acquire very detailed images, provide radar altimetry and subsurface sounding, help identify the mineralogical and chemical composition of surface features or study atmospheric processes. This orbital facility would include an advanced imager, a microwave radar instrument or a lidar (a laser atmospheric sounder), and would have scientific potential for any surveillance mission to Mars. The technology could be adapted to many mission scenarios.

**International Cooperation:** Any of these areas of possible European participation would represent a major and independent contribution to future international missions to Mars; some would complement the already scheduled American *Mars Observer* and the Soviet *Mars '94* missions. ESA is now conducting in-depth technical and scientific assessment studies, with emphasis on the network mission. Following the cooperative path initiated by *Cassini* (a joint US-European mission to the Saturn system), such participation in international planetary missions stands as a sensible and viable approach for Europe to take its proper place in the exploration of the solar system in the next decade and beyond.

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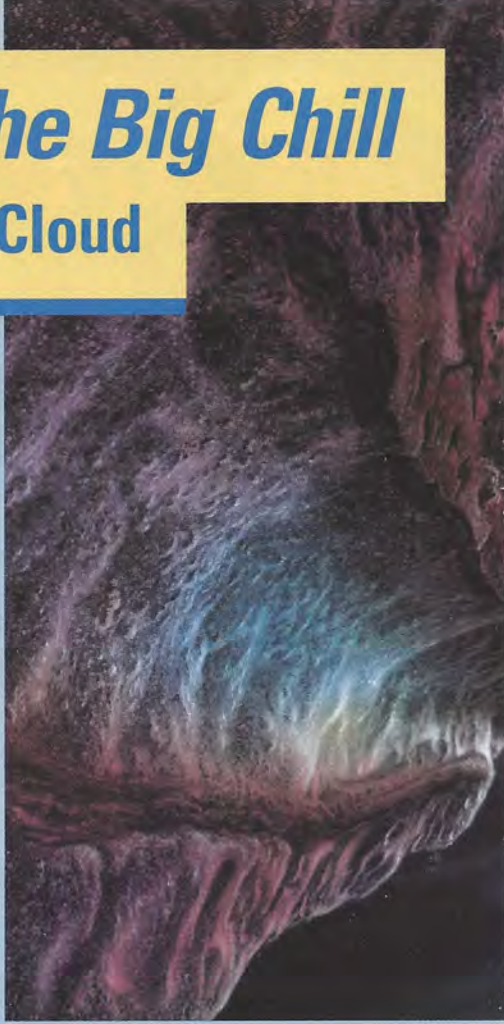
*Agustin F. Chicarro is Study Scientist for Mars Exploration at the European Space Agency.*

# A Little Warmth Against the Big Chill

## The Evolution of Comets in the Oort Cloud



### *by S. Alan Stern*

Stretching over one thousand times as far from the Sun as Pluto, a vast sphere of comets called the Oort Cloud surrounds our solar system. This frozen reservoir likely contains over a trillion icy comets ejected from the planetary region as the giant planets formed some 4.6 billion years ago.

In 1950 Jan Oort published a landmark paper deducing this cloud and describing its origin. Until just a few years ago, scientists believed that comets had been *perfectly* preserved since their exile to the Oort Cloud. On first inspection, this idea seems reasonable. After all, during the four-billion-year night between their ejection from the planetary region to today, comets experienced ambient temperature only a few degrees above absolute zero (minus 273 degrees Celsius), far too cold for any chemical evolution to take place. Compared to temperatures in the Oort Cloud, conditions on Triton—a relatively sweltering minus 236 degrees Celsius—would seem to be a veritable Miami Beach!

To understand the significance planetary scientists place on comets, we must know a bit about what they are. The *Giotto* and *Vega* probes to Halley's Comet showed that comets are rich in frozen water, carbon dioxide and other ices, mixed with dust particles, much as predicted by Harvard astronomer Fred Whipple's "dirty snowball" model. (See the July/August 1985 *Planetary Report.*) Having been stored in the deep freeze of the Oort Cloud, well out of the warmth of the planetary region, comets are likely to be nearly unchanged relics of the solar system's birth. This makes them an important target for scientific study and spacecraft exploration. Indeed, NASA is now preparing the Comet Rendezvous-Asteroid Flyby (CRAF) mission for a 1995 launch and a rendezvous in 2000 with comet Kopff, a former Oort Cloud denizen perturbed into the planetary region.

With so much effort being invested in understanding these frozen messengers from the genesis of our solar system, it is important to ask just how pristine cometary material really is, and how much they have been modified during their long stay in the Oort Cloud.

### *Radiation Damage*

The first indication that comets evolve in the Oort Cloud came in the early 1980s when researchers, including Yugoslavian astronomer I. G. Draganić, Fred Whipple of Harvard, Louis Lanzerotti of Bell Laboratories and Robert E. Johnson of the University of Virginia, began calculating the radiation dose comets receive in the cloud. They found that cometary surfaces are likely to be heavily damaged by cosmic rays, very high energy particles that can penetrate many meters into comets. Using measurements of flux of cosmic rays in space, they calculated that cometary surfaces may have been hit by tens of trillions of cosmic rays per square centimeter over the age of the solar system. These particles disrupt molecular bonds, ionize atoms and molecules, and induce chemical reactions along their paths.

The next indication that Oort Cloud comets change came as a result of my own research. Late in 1985, I began to examine whether the Oort Cloud's intimate relationship with the surrounding galactic environment might modify comets. Far from being empty, the space between the comets is instead filled by a current of gas and dust that we call the interstellar medium.

Owing to the solar system's motion around the galaxy, these gases and dust flow through the Oort Cloud at typical speeds of 20 to 30 kilometers per second (10 to 20 miles per second). Although some interstellar gas molecules stick to cometary surfaces, collisions with microscopic interstellar grains slowly but continually sandblast away cometary surfaces. This erosion is much more efficient than the build-up of gas molecules, and the net effect is to strip away comets' outermost layers while they are in the Oort Cloud. Because the interstellar medium contains some regions that are rarefied and others that are more dense, this sandblasting effect varies greatly over time.

Computer models that simulate the variation in sticking and erosion rates as the Sun orbits the center of the galaxy indicate that between 60 and 600 grams (2 and 20 ounces) of material may have been lost from each square centimeter of cometary surface. Thus, if comets have surface densities similar to water ice, several meters of material may have been stripped away. If their densities are more like snow, tens of meters may have been lost during their stay in the Oort Cloud. In any case, this erosion may erase much or all of the radiation damage that cometary surfaces experience.

### *Getting Heated Up*

In 1987, astrophysicist Mike Shull of the University of Colorado and I began to study the thermal effects that passing stars have on comets in the cloud. Stars have long been known to penetrate the Oort Cloud regularly. Indeed, Oort himself recognized errant stars as a major influence on comets' orbits around the Sun. Over time about 6,000 stars have probably passed through or near the Oort Cloud. Shull and I constructed a computer model of the encounters between

***New research suggests that the subsurface of comets within the Oort Cloud, once thought to be pristine relics of our solar system's formation, may have evolved over the eons. Cosmic rays, heat from passing stars and impacts from interstellar grains may all have affected these icy bodies as they have traveled with the Sun around the Milky Way galaxy. In this painting, the artist imagines the comets passing near a dust-rich nebula.***
***Painting: Don Dixon***

stars and the Oort Cloud to determine how much heating each comet has received from passing stars.

We found that the great majority of stars heat the comets very little. Most stars, being only about as luminous as our Sun, simply cannot heat much of the cloud to interesting temperatures when they pass by. However, occasionally, a very bright O-type star (several hundred thousand times as luminous as our Sun) will pass through or near the cloud, substantially raising the temperature of all the comets. By carefully modeling the encounter rates of various stellar types, we estimated that most Oort Cloud comets should have been heated at least once by a passing luminous star to a temperature near minus 250 degrees Celsius. Because the stars pass by so slowly, we found that these heating events, though rare, each last many thousands of years.

We also found that nearby supernova detonations, which sometimes approach a billion times the energy output of the Sun, could heat all the comets in the cloud. This probably happened on several occasions, raising temperatures for a few weeks to minus 240 degrees Celsius. Probably one supernova has raised temperatures as high as minus 220 degrees.

### Galactic Influences

Heating from passing stars and supernovae may have leached out the most easily evaporated cometary constituents and generated complex chemical reactions in the comets' surface layers. If estimates of the conductivity of cometary ices are accurate, the effects of passing stars and supernovae may have penetrated tens of meters below the cometary surfaces.

Together, cosmic rays, interstellar grain erosion and stellar heating have driven Oort Cloud cometary surfaces to evolve significantly. These evolutionary influences are inevitable in the galactic environment. By neglecting these influences and calculating the evolutionary history of comets solely on the Sun's influence, early researchers failed to appreciate some subtle but important effects.

Rather than being the perfectly preserving icebox we once thought it was, the Oort Cloud is now perhaps best described as an icebox whose door is left ajar from time to time. As such, the outer layers of comets, though still the best preserved relics of solar system formation, are likely to have ripened a bit over the last 4.6 billion years.

Exploring spacecraft will soon test this work. During its two-year-long rendezvous, CRAF will fly in formation with comet Kopff, while sensors on the spacecraft and in a penetrator probe determine the comet's mass, composition and surface properties. Later, perhaps as early as 2010, a joint NASA/European Space Agency mission known as *Rosetta* is intended to return samples from a comet to laboratories on Earth.

As we prepare to send CRAF and *Rosetta* to comets, we now realize that in addition to learning about the origin of our solar system, we will also learn about the galactic environment through which the Sun has traveled. We also now recognize that truly pristine material from the solar system's formation is probably buried many meters below cometary surfaces.

As with many things in planetary science, our view of the Oort Cloud has grown richer and more complex with time. And our understanding of the environment in which comets—and our Earth—reside has also grown more interesting.

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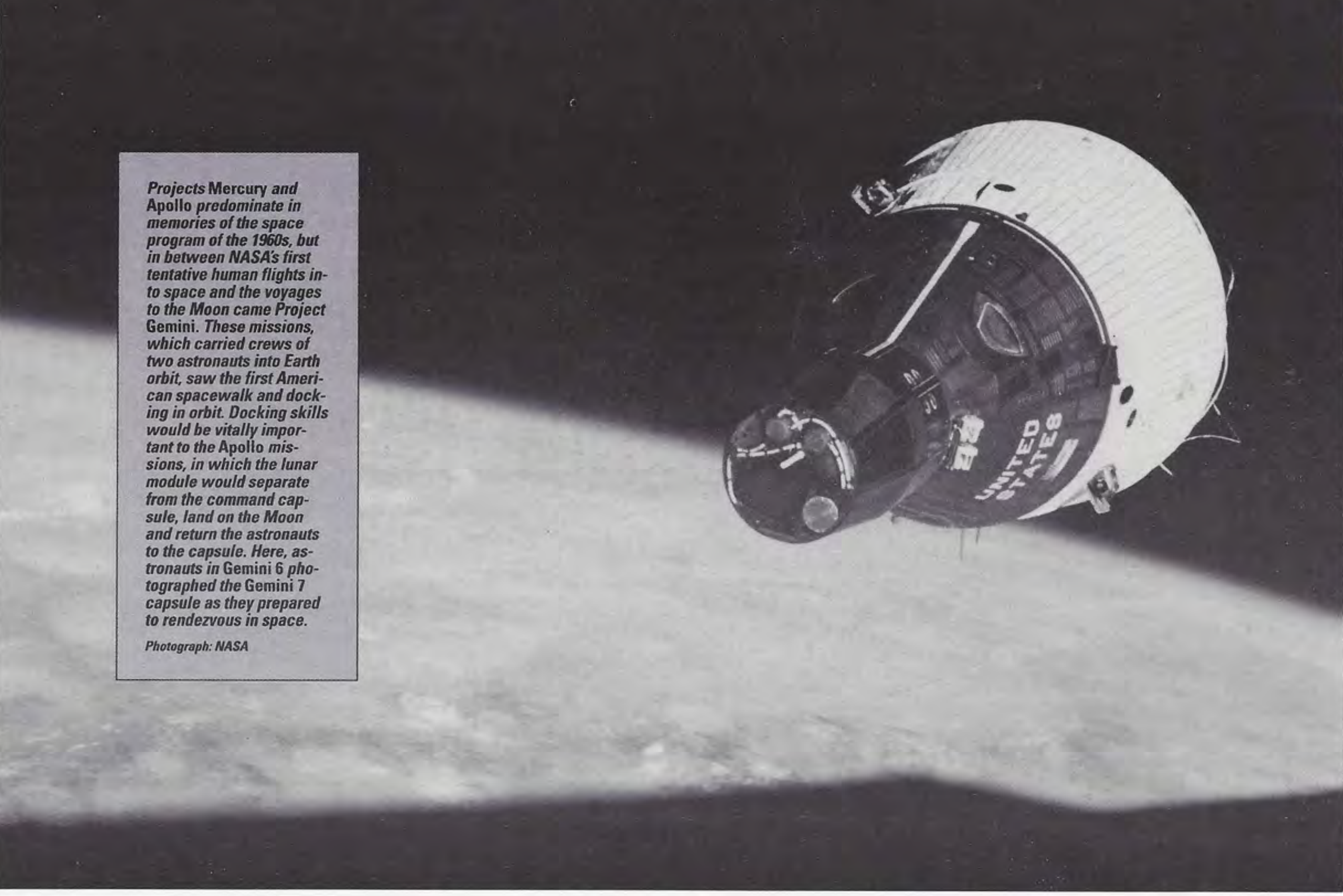
*Alan Stern is a planetary scientist at the University of Colorado, Boulder. He likes to fly, ski and raise his family.*

# Can NASA Still Do the Job?

## Six Veterans of the US Space Agency Consider Its Future

**by David F. Salisbury**



*Projects* Mercury *and* Apollo *predominate in memories of the space program of the 1960s, but in between NASA's first tentative human flights into space and the voyages to the Moon came Project* Gemini. *These missions, which carried crews of two astronauts into Earth orbit, saw the first American spacewalk and docking in orbit. Docking skills would be vitally important to the* Apollo *missions, in which the lunar module would separate from the command capsule, land on the Moon and return the astronauts to the capsule. Here, astronauts in* Gemini 6 *photographed the* Gemini 7 *capsule as they prepared to rendezvous in space.*

*Photograph: NASA*

The United States' space program is going through a critical period. Having passed the 20th anniversary of the Moon landing, the National Aeronautics and Space Administration (NASA) is now in transition. The veterans who have staffed the agency since the glory days of *Apollo* are retiring in large numbers and the reins are being passed to a new generation.

At the same time, NASA faces a new challenge. President Bush chose significantly to present his vision of the future in space—now known as the Space Exploration Initiative—during celebrations marking the triumph of *Apollo 11*. In the 20 years since Armstrong and Aldrin walked on the Moon, the once bold, aggressive agency matured into a government bureaucracy.

While all long-lived organizations evolve, several developments have made the changes at NASA particularly rapid and significant.

Budget limitations, personnel ceilings and top policy decisions in the 1970s worked against younger employees' advancement to middle and upper management and restricted new hiring to "fresh outs," people immediately out of college. The average age of NASA's top management gradually climbed. Many career employees stayed beyond normal retirement age, in large part because they were dedicated to the agency's mission.

Then came new policies making government employment less attractive, followed by the *Challenger* tragedy in 1986. After the disaster the retirement rate at NASA jumped up significantly. Since then there has been a steady out-flow of knowledge and experience from the agency.

If NASA is to rise to the President's challenges—to culminate in a human mission to Mars—it must possess the energy, creativity and drive that sent humans to the Moon over 20 years ago. To gain a better perspective on the agency, we talked to several NASA veterans in two sets of interviews, with the second set following up on two key developments: the appointment of Admiral Richard Truly as NASA Administrator and the announcement of the Space Exploration Initiative.

Six former NASA officials who have made major contributions to the planetary research program gave us their views on the status and the future of the US space program:

—Philip Culbertson, past Associate Deputy Administrator, General Manager and Associate Administrator for Planning and Policy, now an aerospace consultant;

—Donald Hearth, who served as Director of the Planetary Program at NASA Headquarters, Deputy Director of Goddard Space Flight Center and Director of Langley Research Center and now teaches at the University of Colorado at Boulder;

—Gentry Lee, Mission Operations Manager for *Viking*, who also served in the Solar System Exploration Office and on the Ride Committee, and who is now writing science fiction novels with Arthur C. Clarke;

—Hans Mark, formerly Director of the Ames Research Center and Deputy Administrator of NASA, now Chancellor of the University of Texas System and a Planetary Society Advisor;

—Norman Ness, who established and headed the Goddard Space Flight Center's Laboratory for Extraterrestrial Physics before becoming president of the Bartol Research Institute at the University of Delaware;

—Thomas Young, Mission Director on *Viking*, Director of the Planetary Program, Deputy Director of Ames Research Center and Director of the Goddard Space Flight Center before going to work for Martin Marietta Corporation, of which he is now President.

While their views differed considerably, many common themes emerged.

## Cautious Optimism

Most profess at least cautious optimism about the future of the space program.

For example, Tom Young says he is "more optimistic than he has been in some time" because he believes the space program is on the threshold of a major resurgence. Donald Hearth concurs: "I see a growing recognition in Washington, DC that space exploration is part of the national agenda and that it is time to get on with doing meaningful things in space."

While Gentry Lee expresses optimism about the future of the human space program, he is considerably less sanguine about the prospects for space science in the presence of possible cost overruns on piloted space efforts.

At the other end of the spectrum, Norm Ness characterizes his view as "pessimistic, in the context that I am a well-informed optimist."

## NASA Strengths

When asked what they considered NASA's major strength, the group gave a variety of answers.

According to Phil Culbertson, it is the agency's ability to tackle "very large, very tough systems problems." He adds: "The state of the art in the analysis, design, fabrication and operation of extremely complex systems owes much to NASA." Similarly, Hans Mark responds that it is NASA's ability "to plan and execute complicated programs."

"NASA has always been the organization that takes on the 'impossible' assignments—landing on the Moon, landing on Mars and building the shuttle —and carries them out in a very visible fashion," Young says.

In Lee's view, however, NASA's fundamental strength has been its "ability to excite the imagination of its employees and industry associates. This has brought immense dedication and caused people to put in 60- to 80-hour work weeks."

At the same time, Ness considers NASA's greatest strength to be its heritage: "It has epitomized in many of its projects what is best about the United States as a society. Give it a well-defined goal. Give it adequate resources. Assign the best people to it. And let them do their specialties."

## Concerns

At the same time, some of the NASA veterans expressed serious reservations on several fronts: that the US space program as a whole has lacked an adequate sense of direction, although President Bush's initiative has the potential to change things; that NASA hasn't aged

PHILIP CULBERTSON

DONALD HEARTH

GENTRY LEE

HANS MARK

NORMAN NESS

THOMAS YOUNG

*LEFT: Sunsets in space became familiar vistas even to those who never left the ground as astronauts and cosmonauts captured on film evocative images like this, taken on December 6, 1965 during the* **Gemini 7** *mission. Such perspectives of Earth are perhaps the most enduring legacy of the early space program.*
*Image: Johnson Space Center, NASA*

*BELOW: In 1970, a human explorer meets the robot that blazed the lunar trail for him, as an* **Apollo 12** *astronaut examines* **Surveyor 3**. *During the 1960s both the United States and the Soviet Union launched a series of spacecraft to investigate the Moon. NASA sent* **Rangers** *and* **Surveyors** *while the USSR launched* **Lunas** *and* **Zonds**.
*Photograph: Johnson Space Center, NASA*

well; and that the agency has been adversely affected by a growing spirit of risk aversion within US society as a whole.

Gentry Lee expresses doubt about the agency's priorities. NASA's "natural tendency," he believes, is to ignore science unless externally motivated. "We need competitive tension to keep us active in space," he says. Thus the recent Soviet failures in the *Phobos* missions to Mars are cause for some misgiving. If the Soviets reduce their planetary program, he is worried that the US program might be scaled back as well.

"It's not fair to say that the US has abandoned space science. It is simply that planetary research is such a low priority with the press and with top NASA management that any major budget crunch in the future could totally wipe it out," Lee asserts.

Such comments reflect a continuing debate on the proper priorities within the space program. Our interview subjects, and many other members of the space science community, have long-standing concerns that space science tends to lose out relative to other agency priorities, such as developing the space shuttle and, more recently, constructing the space station.

Hearth, however, fears that this internal argument has damaged the program as a whole: "One of my concerns has been with us since the *Apollo* program. It is the seeming inability of policy makers, and NASA, and the external communities involved in space—including the scientific community—to recognize that there are two distinct elements of the program with two different constituencies."

One aspect of the problem, he says, is that the constituency for the robotic program tends to treat the division of the space budget as a zero-sum game, in which you win by imposing a loss on the other player. What they don't seem to understand is that "the manned program has the 'sex appeal' with the public that enables NASA to market the space program as a whole."

At the same time, Hearth objects that NASA officials repeatedly make the mistake of trying to justify elements of the piloted program, such as the space station, on scientific grounds. "The justification [for the space station] is not space science or microgravity experiments. The only reason for the space station is to serve as a zero-gravity laboratory for human beings to determine if we can send men into deep space," he says.

## Aging

When asked what changes they have noticed in NASA during the years they worked there, several of the veterans commented on the way the agency has aged.

"NASA is getting old. It is caught in an aging process which it struggles to try to turn around," Culbertson says.

According to Hearth, this problem is partly self-inflicted. "The average age of people at NASA today, as compared with 1962, is so dramatically different that it is scary. Today, those with the corporate memory are in their 50s and

*LEFT: During the 1970s NASA operated an orbiting space station where astronauts lived and studied the space around them and the Earth below them. In this image taken in February 1974 during the* Skylab 4 *mission, an infrared camera looks back at Cape Canaveral (upper right), its point of launch. There has been no NASA space station since then.* Photograph: Johnson Space Center, NASA

*BELOW: The* Pioneer *missions to Jupiter and Saturn, and the* Voyagers *that followed them to the outer solar system, were spawned during a "Golden Age" of planetary exploration made possible by the race to the Moon.* Pioneer 11 *flew by Jupiter on December 12, 1974, giving us a perspective and detail impossible from telescopes on Earth.* Photograph: Ames Research Center, NASA

really close to retirement. And the financial incentives today are for them to get out. There are a lot of good young people, but the age distribution is definitely bimodal. So an important question is how to get past this gap."

While Young agrees that passing the torch to a new generation is a major challenge, he is more optimistic than some of the others. "There has been a lot of turnover. A number of people who have led the program have left. The real challenge is to bring in new people to lead the program over the next decade. However, I see that happening," he says.

There is general agreement on what must be done to rectify this problem. "People went to work at NASA because of their pride in the agency. That comes from leadership and programs. We must give them the tools of competitive salaries, support and prestige," Young argues. The veterans point out that top NASA talent can make two to four times as much money working for aerospace companies as they can working for the agency.

While Young sees progress being made on this front, several of the others do not.

"NASA's charter is to do something fundamentally important, something that can resuscitate the human spirit. However, NASA has ossified as an organization. It has been rewarding mediocrity rather than merit. There has been no advancement for young people. Someone needs to reinvigorate the agency from the bottom," Lee says.

Ness, too, has seen an "increasing cerebral calcification, a growing mentality of assured success and an increasingly bureaucratic agency that began spending more and more time concerned with paper pushing."

Since "paperwork has become more important than engineering," projects take longer and cost more, Ness asserts. "Enclaves of power have been set up and the number of checks and balances, the number of hoops that people have to jump through, have increased considerably."

In addition to a growing bureaucracy, the NASA veterans list other side effects of the agency's aging process. One is a weakening of the engineering capabilities of several of the NASA centers. "Today some of the field centers are so bereft of in-house technical expertise that they can't attend project meetings unless their contractors are available. You can't be smart managers and smart buyers if you can't read and understand technical specifications," says Ness.

"I don't know what all the causes are, but the symptoms are slowly made decisions, conservatively made decisions, heavy-handed overview on the part of Congress and a diffusion of authority and responsibility within the administration," Culbertson summarizes.

## Growing Risk Aversion

As Culbertson's comment suggests, several of the veterans perceive the agency as becoming progressively less willing to take risks. "NASA is not simply afraid of failure, it has allowed that fear to dominate its decision making. In part, NASA is the victim of its own success.

*In July 1975 NASA flew the last* Apollo, *an Earth orbital mission to rendezvous and dock with a Soviet* Soyuz *spacecraft. The competition between the two superpowers, which started with the race to the Moon, ended with the two contestants orbiting their home world together. Here the* Soyuz *drifts outside the window of the* Apollo *capsule.*
*Photograph: Johnson Space Center, NASA*

The public and the press got to the point that they just couldn't imagine that NASA could fail. So when failure came, the whole roof fell in," Culbertson continues.

Ness explains this increasing risk aversion as part of a larger process: "As the costs [of spacecraft] went up, everybody became concerned. If you had a failure it was going to be very bad news. People were also consolidating all of the experiments on these large observatories so one failure would affect many, many more experiments than it had in the past when you had lots of small spacecraft."

However, Young sees this trend as one that is being imposed upon the agency by society at large. "As a country we're becoming more risk averse, as illustrated by the response to the *Challenger* disaster, to Three Mile Island and Chernobyl [nuclear reactor accidents]. We may be losing our appetite for risk-taking because we consider the costs to be too high. It is a current that NASA might succumb to."

## Objection and Caution

Hans Mark strongly disagrees with those who feel that NASA has lost its edge in recent years. "I think you are getting some 'great old days' nostalgia from those you are interviewing. You need to talk to people who aren't jaded. If you analyze it, we're probably doing better today than we were 20 years ago."

Donald Hearth adds "a note of caution, based on my own experience in NASA." The criticism the agency received for underestimating the costs and complexity of the space shuttle and the space station programs, and for the loss of *Challenger,* he feels, has made NASA even more conservative than before.

Hearth worries that the ambitious scope of President Bush's space initiative might induce the agency "to make commitments it can't meet," because meeting them would require a greater willingness to take risks. "This could exacerbate the problem of underestimating cost and complexity. One has to be careful in how one responds to high-technology projects."

## Increased External Oversight

Another problem for NASA is increased external oversight. Culbertson comments:

"Congress is trying to play too great a role in the program. They are trying to make technical decisions. They are trying to dictate actions to an unbelievable level of detail. If the President, with the consent of Congress, appoints an Administrator and 22,000 people to do the job and they don't like the way he does it, they should fire him and find someone else to do the job. But to tie his hands with a myriad of directives and restrictions is a lousy way to produce a creative and productive civil space program.

"Also, there are so many review processes set up now. There are boards set up at the drop of the hat reporting to everybody up to the President to help NASA figure out what to do.

"For example, the President approved the space station in principle in 1984. Now, five years later, we've spent about $800 million defining and re-defining that program. It's had more people on committees reviewing it than the number of people working on it."

Young has observed the same trend. "There is now a much higher degree of oversight by Congress and others now, as opposed to the past. NASA officials must spend much more time dealing with this oversight. It is part of the stretch-out and interruption in the development of our space transportation system. It is part of the country moving toward a more risk-averse society."

## An Ideal NASA

The view that NASA should remain preeminently a research and development agency was voiced by most of those interviewed. "NASA's role should be leadership in technical areas, doing things that others cannot. It is important to focus priorities on those things NASA is unique at: the advancement of aeronautical technology, scientific and technological aspects of planetary exploration, and man-in-space," Young says.

If NASA is to retain its focus on exploration, the agency must face up to what may be a difficult decision. "The big question that NASA faces internally is to what degree should it retain operations responsibility in contrast to development responsibility. In the long term, that must be solved because at a time in the late '90s when we are operating both the shuttle and the space station and two or three big observatories, well beyond 50 percent of NASA's budget and manpower will be operational," Young explains.

Culbertson would like to change the collegial fashion in which space policy decisions are currently made: "I would like to see a departure from this posture we seem to have gotten into in the last few years where there are a bunch of departments involved in different pieces of space and they are all co-equal and solve all problems on a congenial basis." This is a problem, he says, because

NASA, which has the biggest budget devoted to civilian space, is not equal to other departments, which are headed by individuals at the cabinet level, such as the Secretary of Commerce and the Secretary of Transportation. "The NASA Administrator is not an equal at the table. So it is hard for him to play poker in that game," Culbertson argues.

Instead, Culbertson thinks that NASA should be the US's lead agency in civil space. "I believe the NASA Administrator should have two roles: He should be the senior among equals of all the agency and department heads, including those who carry the title of Secretary, in determining what our civil space policy should be. He should also manage the organization charged with the responsibility of carrying it out."

## New Administrator, New Hope

The NASA veterans' responses to President Bush's appointment of Admiral Richard Truly as NASA Administrator ranged from enthusiastic applause to qualified delight. Most feel that he will make a positive difference to the agency. "He's first class," Culbertson says.

Truly is the first astronaut to rise to agency Administrator, and Culbertson believes "the big difference is that Dick has straightforward, practical experience in space that we haven't had in NASA for a long time." However, Culbertson admits to "mixed feelings": He believes that Truly will be a very good Administrator but worries that the agency may become more conservative and less willing to take risks.

Hearth believes that Truly will do well in implementing the ongoing program but doubts that he can make a major difference. President Bush's initiative will be a major challenge to the new Administrator. "At this point in our nation's history, I'm not sure that Admiral Truly or any recent Administrator can make a difference. The situation is not analogous to the situation in 1962. Any Administrator would have trouble convincing Congress and the people [to take on the Space Exploration Initiative]."

## Space Exploration Initiative

If the NASA veterans interviewed share a new optimism about the agency's future, it is because of the plan President Bush put forward on the 20th anniversary of *Apollo 11*. Most feel that, after years of no leadership from the White House, a President has finally put forth a vision that NASA can follow.

"I'm much more optimistic than I was before the President's speech. The final analysis depends on how the implementing organization—NASA—reacts to what the President has said," Gentry Lee states. "It should be a call for NASA to reinvigorate itself," he adds, "and get out the old weight, to get new, young, enthusiastic people with dreams in their eyes."

Hans Mark feels the stepping stones laid out by the President—first, a space station, then a lunar outpost, finally a human mission to Mars—are "exactly right."

Ness demurs: "The study is very incomplete and to make any comment at this stage of the game is inappropriate." He adds: "There were no guidelines provided by the White House. The agency had to essentially fabricate the charge by the President based upon his very general remarks."

Culbertson is pleased yet cautious in his enthusiasm for the initiative. "It has re-energized NASA right now. The question is does it have a chance at life? Will it survive the administration reviews, will it survive the congressional reviews, will it survive the budgetary reviews? If it does, it will put a vitality in NASA that will be reminiscent of the vitality that NASA had in the mid-'60s."

Hearth sums it up: The Space Exploration Initiative "is going to be a very tough sell."

With a new Administrator at the helm and a presidential administration that is willing to put space exploration on its agenda, things seem to be looking up for NASA. President Bush has re-established a National Space Council, headed by Vice President Quayle, to further define US space policy. The glory days of *Apollo* may be gone, but there are positive signs for the future.

"Hopefully, Congress and the administration will understand that the space agency is like a thoroughbred: You have to give it its head if you are to get the most out of it," Young entreats.

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*David F. Salisbury is a veteran science writer currently working for the University of California at Santa Barbara.*

***The* Viking *mission to Mars remains the most ambitious robotic space mission ever launched. It was conceived in the 1960s and reached its destination in 1976. This panorama was compiled from images taken by* Viking Lander 2 *from its station on Utopia Planitia.***

***Mosaic: Mary Dale-Bannister, Washington University in St. Louis***

# World Watch

**by Louis D. Friedman**

**WASHINGTON, DC**—A *Lunar Observer* has been proposed in NASA's FY 1991 budget. Scheduled for launch in 1996, *Lunar Observer* will go into a near-polar orbit of the Moon and provide a large and varied data set, including the first maps of the entire lunar surface. Of particular interest is the investigation of lunar polar regions, which some scientists speculate may harbor frozen water in permanently shadowed areas. On the rest of the Moon, where sunlight strikes the surface at least part of the time, frozen water could not survive the heat from the Sun.

This mission will be the second, after *Mars Observer* (scheduled for launch in 1992), in the *Observer* series of spacecraft, built by adapting the design of Earth-orbiting satellites with new sensors and instruments.

The US/USSR joint working group on planetary exploration, which has already set up effective bilateral cooperation on *Mars Observer* (see "The Mars Balloon Relay" by Jacques Blamont in this issue), is investigating possibilities for Soviet participation on the *Lunar Observer* mission as well. A proposed Soviet "sub-satellite," working in concert with the American orbiter, would provide valuable data characterizing the Moon's gravitational field.

Meanwhile Japanese space scientists are studying a lunar orbiter of their own for possible launch in the mid-1990s. Japan's Institute of Space and Astronautical Science (ISAS) flew MUSES-A, a systems-testing mission around the Moon in March of this year.

The Space Studies Institute (SSI) of Princeton, New Jersey, a privately funded group promoting the discovery and use of extraterrestrial resources, commercial space development and human settlements off-Earth, has announced plans to develop a lunar orbiter using a left-over *Apollo* instrument as its primary science payload. NASA plans to release to SSI a gamma-ray spectrometer that has been in controlled storage since 1972. If placed in a low, polar lunar orbit, this instrument might detect cold-trapped ices. (See the March/April 1989 *Planetary Report*.) A different private venture, by a group at MIT, wants to send robotic microrovers (5-pound walkers) to the Moon via a small rocket.

**WASHINGTON, DC**—As a result of studies conducted under the aegis of the National Space Council (chaired by Vice President Quayle, reporting to President Bush), the White House has issued a set of guidelines for the Moon-Mars initiative presented by President Bush on July 20, 1989 in a speech commemorating the 20th anniversary of the *Apollo* Moon landing. The new name for the program, which was known for a while as the Human Exploration Initiative, is the Space Exploration Initiative or SEI.

The presidential guidelines describe, in the words of one NASA official, "a general science and technology program." The guidelines assert that it will be at least two years before any decision is announced as to what the program content and "architecture" will be. In the meantime Moon and Mars missions, human and robotic, are to be studied.

In addition to NASA, the Department of Energy and the Department of Defense are to be strongly involved in SEI, while the National Space Council coordinates the activities of these three agencies. Both departments can call on the talents of national laboratories and think tanks to contribute to civilian space exploration.

Not mentioned in the presidential guidelines is international cooperation. However, on March 30 the White House announced that the US would seek international cooperation in the SEI, citing the USSR as a possible partner as well as Europe, Canada and Japan. Members of The Planetary Society should feel gratified to see this new direction for US space policy, advocated by our organization since 1983.

In addition to the guidelines, Quayle sent a letter to NASA directing the agency to conduct further studies on human exploration and to search outside the NASA space community for more innovative approaches. The objective in seeking new approaches is to put humans on the Moon and on Mars, perhaps at lower cost, perhaps with less demanding mission requirements and perhaps with near-term milestones. The search for innovation has caused NASA to cast a wider net in looking for new technological ideas and concepts.

NASA has reorganized its program office to deal with SEI. The Office of Exploration has been merged into the Office of Aeronautics and Space Technology, now called the Office of Aeronautics and Exploration Technology. This new office is headed by Associate Administrator Arnold Aldridge. In addition, plans call for the appointment of a deputy to Aldridge to head the exploration studies. A new Deputy Administrator will report directly to NASA Administrator Richard Truly to coordinate all the agency's activities in support of the SEI.

The National Research Council of the National Academy of Sciences conducted a review of the NASA 90-day report (so called because it was presented three months after President Bush announced the Moon-Mars initiative) and generally supported the level, if not the breadth, of the technical work done by NASA in that study. In what is sure to be a controversial and important finding, the council urged that greater attention be paid to nuclear power and nuclear propulsion, saying that nuclear energy was essential for future human exploration of the solar system.

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

# The Planetary Society's Family Grows

## New Directors and Advisors Join Our Boards

***by Charlene M. Anderson***

Filmmaker Steven Spielberg and *Apollo 11* astronaut Michael Collins have joined The Planetary Society's Board of Directors, deepening the talent and vision of the Society's governing body. We've also expanded our Board of Advisors, welcoming five international members who will help broaden our influence around the world.

Our new international Advisors include: Canadian astronaut Marc Garneau, Soviet atmospheric scientist Georgiy Golitsyn, Soviet physicist Sergei Kapitsa, Japanese space leader Jun Nishimura and Australian space scientist S. Ross Taylor.

"We are honored to have such an outstanding group of world citizens become part of The Planetary Society's official family," says Society President Carl Sagan. "Our two new directors, Michael Collins and Steven Spielberg, have helped broaden our perspective beyond the Earth to the boundless possibilities in space. Their insight and expertise will help expand the Society's horizons in important new directions."

**Steven Spielberg**—Steven Spielberg is possibly the most successful filmmaker of all time. In 1983 he gave the Society $100,000 to begin building META (Megachannel Extraterrestrial Assay), the most powerful radio search for extraterrestrial intelligence now operating on Earth. META has been operating continuously from Harvard University's Oak Ridge Radio Observatory since 1985, when in a special ceremony Mr. Spielberg switched it on. Later this year, META II will begin scanning the skies from our new site in Argentina, giving us full coverage of the sky. (See the January/February 1989 *Planetary Report.*)

Mr. Spielberg has directed or produced 7 of the 20 most-watched films of all time. His credits include *ET the Extra-Terrestrial*, the three *Indiana Jones* films, *Jaws* and *Close Encounters of the Third Kind*. In 1987 he received the prestigious Irving G. Thalberg Award from the Academy of Motion Picture Arts and Sciences.

**Michael Collins**—The *Apollo 11* mission to the Moon marks the zenith of human exploratory endeavors. As *Apollo 11* command module pilot, Michael Collins orbited the Moon as Neil Armstrong and Buzz Aldrin left their footprints in the lunar soil. Mr. Collins is the first astronaut to join our Board of Directors, and the rare perspective he brings to our deliberations will be invaluable to The Planetary Society's progress.

Mr. Collins' distinguished career of public service has included service as an Air Force test pilot, Assistant Secretary of State for Public Affairs and Director of the National Air and Space Museum. He now works as an independent consultant, writing and lecturing about aerospace issues. Mr. Collins' new book, *On to Mars*, is soon to be published.

**Marc Garneau**—In October 1984, on board the space shuttle *Challenger*, Marc Garneau became the first Canadian astronaut to fly in space. He received a doctorate in electrical engineering from the Imperial College of Science and Technology in London. He has served in the Canadian Navy with expertise in communications and electronic equipment and systems. In January 1986, he was promoted to captain. Dr. Garneau now provides technical and program support to the Canadian space agency and is helping to prepare experiments to fly on board the shuttle during future Canadian missions.

**Georgiy Golitsyn**—Georgiy Golitsyn is the Director of the Soviet Academy of Sciences' Institute for Atmospheric Physics. He has served on the governing Presidium of the Academy, one of the most prestigious positions a Soviet scientist can hold. Academician Golitsyn works primarily on the physics of planetary atmospheres and has contributed to understanding the possible effects of greenhouse gases and nuclear winter on Earth's environment.

**Sergei Kapitsa**—As host of the most popular Soviet television program about science, Sergei Kapitsa is one of the best-known scientists in the USSR. He is an Associate of the USSR's Institute for Physical Problems, Professor of the Moscow Physicotechnical Institute and President of the USSR Physical Society. During The Planetary Society's 1987 "Together to Mars?" spacebridge between Soviet and American scientists (later a PBS television special), Dr. Kapitsa shared the duties of moderator with Society Carl Sagan.

**Jun Nishimura**—Jun Nishimura is Director-General of the Institute of Space and Astronautical Science (ISAS), the space agency for Japan's scientific missions. ISAS recently sent a spacecraft into lunar orbit, making Japan the third nation, after the Soviet Union and the United States, to explore the Moon. Professor Nishimura's research specialties include cosmic rays, space physics and scientific ballooning.

**S. Ross Taylor**—S. Ross Taylor is a Professorial Fellow at the Research School of Earth Sciences at the Australian National University in Canberra. He also works as a visiting scientist at the Lunar and Planetary Institute in Houston, where he is a Principal Investigator for lunar samples. Dr. Taylor is an Honorary Fellow of the Geological Society of London and in 1988 received the Norman L. Bowen Award of the American Geophysical Union for "important contributions to our understanding of the origins and early history of Earth and Moon."

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*Charlene M. Anderson is Director of Publications for The Planetary Society.*

# News & Reviews

***by Clark R. Chapman***

For more than a decade, only one American planetary mission has brought us new views of other worlds—*Voyager.* Its final planetary encounter, with Neptune last August, is now past. So our eyes turn toward two recently launched spacecraft, *Galileo* and *Magellan*. *Magellan*'s prime mission will soon be upon us: It arrives at Venus in August. *Magellan* is very unlike *Voyager*, and we should get used to its differences.

While *Voyager* is a complex spacecraft, carrying numerous esoteric scientific instruments, many of its remarkable discoveries were made with a fairly ordinary camera system. At the risk of oversimplifying, one could say that all *Voyager* did was carry a slow-scan video camera to unimaginably distant parts of our solar system, snap a large number of pictures and radio them back to Earth.

*Magellan*'s goal is very different, and so is its technology. To begin with, this is not our sole opportunity to study the surface of Venus. Moreover, the problem in learning about our sister planet is not that it is so far away but that its surface is hidden beneath optically impenetrable clouds. There are no clear days, or even partly cloudy ones, on Venus. So sending a TV camera over to Venus would do geologists little good. (Such cameras have studied its atmosphere, from Earth-based telescopes as well as from spacecraft, such as *Mariner 10*, the *Pioneer* Venus orbiter and—most recently—*Galileo*.)

*Magellan* will use the modern technology of side-looking radar to see through the clouds and map the surface of Venus. This technique is much more complex than TV imaging. Indeed, the main limit to how well *Magellan* can map Venus is computer power for image reconstruction back here on Earth. Trying as hard as they can, the *Magellan* Project people will probably fall far behind the spacecraft as they try to convert the massive quantity of data into visualizable "maps" of Venus. Then geologists will have to unlearn the intuitive ways in which they habitually interpret ordinary photographs of Earth and other planets. While the radar maps will look something like photographs, they will really be quite different.

But the geologists have been preparing for the *Magellan* data for years—too many years, in fact, as funding cutbacks in the early 1980s caused cancellation of the Venus Orbiting Imaging Radar (VOIR) and delays in implementing VRM (Venus Radar Mapper, "son of VOIR," now called *Magellan*). During the interim, the Soviet *Venera 15* and *16* missions produced good radar maps of the northern part of Venus beginning in 1983, resolving features down to 1 to 2 kilometers.

Ground-based radar, from Puerto Rico's giant Arecibo dish, has managed 1 kilometer resolution in some locations on Venus. The geologists have been studying these radar data—whetting their appetites for *Magellan*—and practicing their interpretational skills on side-looking radar images of familiar terrains on Earth.

Soon there will be a flood of data from *Magellan*, if all goes well. The maps will be at better resolution than any previous data set, but the leap will be nothing so enormous as we have been used to with landscapes from *Voyager*. At least as important as the improved clarity of the maps will be that most of Venus will be mapped, uniformly, rather than just small pieces of it.

### *Become Venus Literate*

What scientific issues about Venus as a planet will *Magellan* address? I recommend two recent articles to introduce readers to the perplexing questions about Venus that planetary geophysicists have been wrestling with. The easier article to read ("Venus: The Hellish Place Next Door") appeared in the March issue of *Astronomy* magazine. R. Stephen Saunders, the Project Scientist for *Magellan*, has written a picturesque, easy-to-understand description of the basic issues in venusian geology and geophysics.

For readers willing to tolerate a terse, much more technical article, there is a tour de force on the same subject in the March 9 *Science*, written by the UCLA geophysicist William Kaula ("Venus: A Contrast in Evolution to Earth"). With much clarity, Kaula offers the "big picture" on why Venus and Earth are so different from each other, before he bogs down in some very technical discussions of global geophysics.

Both Kaula and Saunders are geophysicists by training, so they spend little time on the "runaway greenhouse effect," which is the most common topic of comparisons of Venus with Earth. Instead they ask why does Venus lack a system of global plate tectonics such as dominates the geology of our own planet (although there are intriguing exceptions in Venus' Aphrodite province), how thick is the crust, how does Venus get rid of its internal heat, is there active volcanism and what kind of erosion operates on Venus, among other geological and geophysical questions that *Magellan* will illuminate if not answer.

It is fitting, as NASA turns a major focus toward the new agenda of Mission to Planet Earth, that *Magellan* will provide us with a rich set of data about a planet that should be the most Earth-like but in many ways is hellishly different. That difference is unsettling. We need to learn why Venus is the way it is so we never make mistakes that could send our own green planet along a similar course of evolution.

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*Clark R. Chapman is a Senior Scientist at the Planetary Science Institute in Tucson, Arizona, a division of Science Applications International Corporation.*

# SOCIETY Notes

### SOCIETY ADVISOR MARVIN MINSKY HONORED

Marvin Minsky, a pioneer in the field of artificial intelligence, has been named the winner of this year's Japan Prize. The award honors Minsky, co-founder of MIT's Artificial Intelligence Laboratory, for work over four decades that has centered on the question of how to organize the "brain" of a computer so that it can improve its own performance, "learning" from experience as people do.

A mathematician by training, Minsky is one of the few scholars who are members of both the National Academy of Sciences and the National Academy of Engineering. He joined the Society's Board of Advisors in January 1988.

The Japan Prize, presented by the Emperor, was established in 1985 to recognize achievements in science that promote peace and prosperity. *—Louis D. Friedman, Executive Director*

### ABE GOMEL JOINS NEW MILLENNIUM COMMITTEE

Abe Gomel of Montreal, owner of Liberty Yogurt, has joined the New Millennium Committee, a select group of contributors organized to fund annual scholarships and special Planetary Society projects.

Mr. Gomel, a member of the Society since 1982, is committed to the ideal that everyone can become involved in the adventure of planetary exploration, and he believes that involvement begins with education. He has directed his initial donation to "Sister Worlds: Earth and Venus," the Society's educational program on environmental issues. *—LDF*

### TEAMING UP WITH NSTA

Society President Carl Sagan and Soviet Academician Roald Sagdeev, speaking on "Exploring Other Worlds and Protecting This One: The Connection," drew a sold-out, spill-over crowd at the Regency Ballroom of the Hyatt Regency Hotel in Atlanta, April 6, at the National Science Teachers Association annual conference. (Audio tapes of this event will soon be available for purchase by Society members.)

The Planetary Society will continue its working relationship with NSTA at their convention next year in Houston, where the Society will sponsor seminars, lectures, tours and workshops. The 1991 NSTA meeting will include a special Planetary Society day, highlighted by a plenary-session address by Carl Sagan and special programs on the exploration of Mars, Society scholarships, the 1992 International Space Year and the Society's Dudley Wright International Student Contest, which is being administered in the US by NSTA. *—Susan Lendroth, Manager of Events and Communications*

### CASE FOR MARS IV

The international Case for Mars IV conference, to be held June 4 to 8, 1990 at the University of Colorado in Boulder, will consider the potential for human habitation of Mars and will cover scientific, technological, social, economic and policy strategies for robotic and human missions to Mars. The Society is sponsoring a public event the evening of June 6. For further details, contact Case for Mars Event, c/o the Society. *—SL*

### ALDRIN IN AUSTRALIA

The Society will host a special event in Australia featuring *Apollo 11* astronaut Buzz Aldrin on August 25. The Society, in cooperation with the National Space Society, will present a lecture by Aldrin at the Australian Space Conference in Sydney.

With over 1,400 members, Australia has the largest concentration of Planetary Society supporters outside the United States and Canada. Volunteer groups are active in several regions of the country, and the Society hopes to enlist more volunteers through special meetings to be held in Sydney and Melbourne this August. For more information on these volunteer meetings and the Buzz Aldrin events, write to Australia Volunteer Meetings, c/o the Society. *—SL*

### MEMBERSHIP DEPT. TIPS

You can help us deliver better service by remembering these tips:

- Renew early. We send out renewal notices four and a half months in advance to conserve Society resources and make delivery more efficient.
- Send us a change of address card when you move. The post office won't forward or return magazines, so we won't know you've moved until you tell us.
- When ordering gift memberships, be sure to include your name and address as well as the recipient's name and address. Gift memberships must be paid before we can put the names on file.
- Donations to special funds are restricted by law and may not be used toward your membership dues.
- Put your membership number on all correspondence (and on your check when renewing membership). This number is printed on your membership card and above your name on your *Planetary Report* mailing label. *—Sue Pratt, Membership Correspondent*

### WILL YOUR EMPLOYER MATCH YOUR GIFT?

Hundreds of companies in the US will match their employees' gifts to The Planetary Society, doubling your donation to our many programs. If you would like more information on matching-gift programs, please check with your company's personnel department, or write to Matching Gift Information, c/o the Society. *—Lu Coffing, Financial Manager*

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# Questions & Answers

***Thinking about impact craters made me wonder if observatories could detect a large approaching object before it struck Earth. Could we have a warning?***
**—William H. Matzke, St. Paul, Minnesota**

Yes, we could. However, no such search system is yet in operation. As more and more small Earth-crossing asteroids are discovered by existing astronomical searches (see "The Asteroid Project Shows Results" in the January/February 1986 *Planetary Report*), a "protective" search may eventually begin. However, the chances of having adequate warning and an action capability and plan are not great now. Even now, human preparations (except in Japan) for the earthquakes that are certain to occur (we just don't know when) are lamentably inadequate. The asteroid threat, although potentially more destructive, is much more remote.
—JAMES D. BURKE, *Jet Propulsion Laboratory*

***Why is there an asteroid belt between the orbits of Mars and Jupiter and not anywhere else in the solar system?***
**—Stacey A. Maxwell, Syracuse, New York**

Given the positions and masses of the planets in the solar system, the location of the asteroid belt is the only place where a fairly wide band of orbits can be stable. It's stable there because the gap between Mars and Jupiter is unusually wide relative to the sizes of their orbits. In fact, there would be plenty of room for an extra planet in this gap. Between other pairs of planets, nearly any small body would experience gravitational pulls that would soon (on a cosmic time scale) destabilize its orbit by driving it across the planetary orbits.

A deeper reading of your question requires us to consider the formation processes that led to the wide interval between Jupiter and Mars and populated it with small objects, or asteroids. The planets grew from a nebula of gas and small bodies around the Sun. Current thinking suggests that once Jupiter grew large enough by gravitational accretion of small bodies, gases collapsed onto it, quickly creating the giant planet. Then Jupiter's gravity was strong enough to scatter other growing planets through what is now the asteroid belt, resulting in collisions that aborted planet growth in that region. What we now see there are partially formed and broken planets.

The asteriod belt is not the only part of the solar system populated with small bodies. Beyond the outer planets lies the Oort Cloud of comets (icy asteroids). Near Earth, thousands of little bodies are traveling in orbits that are unstable over geologic time; in fact, some of these occasionally hit Earth. A zone inside Mercury's orbit would allow for fairly stable orbits, but we don't know whether any small objects are there, or even whether formation of solid bodies was possible so close to the Sun.
—RICHARD GREENBERG, *University of Arizona*

*Solar system objects plowing into Earth can, depending on their size, wreak all manner of havoc. Manhattan Island might look like this if a small cometary nucleus were to crash down into its center.*

*Painting: Michael Carroll*

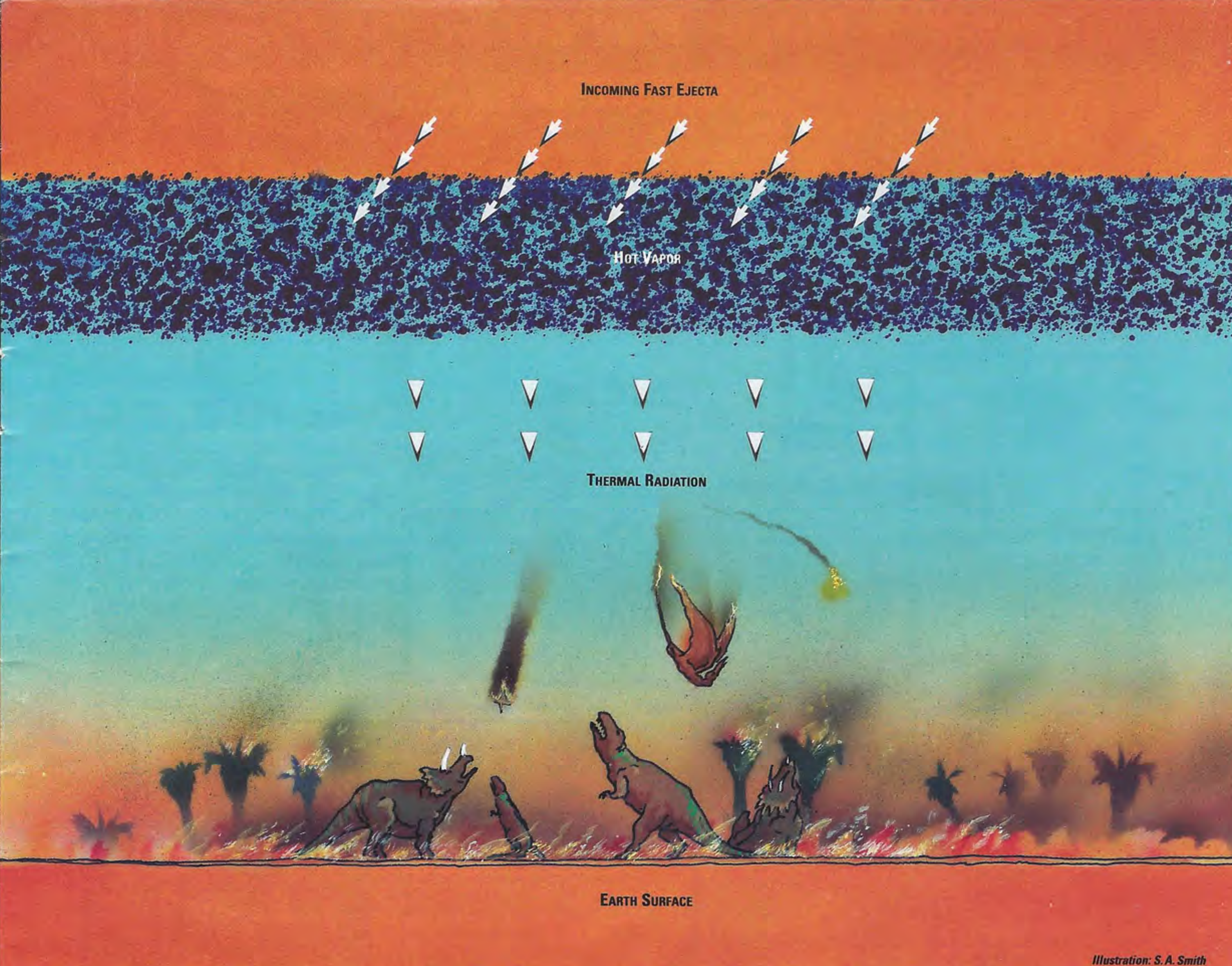


Illustration: S. A. Smith

# FACTINOS

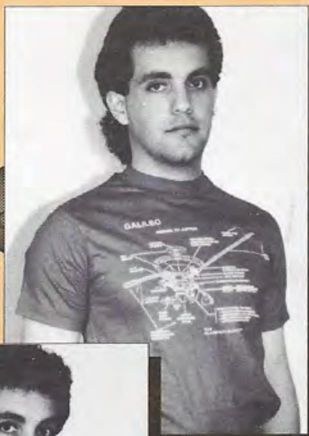
Intense heat, produced when sand-sized particles shot through Earth's atmosphere millions of years ago, may have started global wildfires and cooked dinosaurs alive (see illustration, above), a team of scientists reported in the journal *Nature*. Such incendiary grains could have been produced by the impact of a large comet or asteroid, vaporizing nearly all of the projectile and at least as much Earth material. In seconds, tiny grains would have condensed from the explosively expanding vapor plume as it cooled, acquiring enormous energy as they blasted at high velocities through Earth 's upper atmosphere. The particles would have released their energy as heat, said the research team, which included Jay Melosh of the University of Arizona at Tucson and Donald Latham of the United States Forest Service Intermountain Fire Sciences Laboratory at Missoula, Montana.

Atmospheric carbon dioxide and water vapor would have shielded Earth's surface from about two-thirds of the downward radiation, but the energy that filtered through would have been enough to irradiate the surface with heat 10 to 30 times as strong as normal sunlight. Surface temperatures would have shot up far higher than a household oven set on "broil".

"If you had been there," Melosh said in an interview, "you would have seen the entire sky light up with bright, blue light—and stay that way for at least an hour. Imagine the entire sky packed with bright fireballs, so close together that you can't see spaces between them. Anything on the ground would get broiled."
—from the University of Arizona

The total cost of the *Voyager* project from May 1972 through the Neptune encounter in August 1989 was $865 million. Although it's well known that the project was a bargain, here are some amazing facts: 1) This is only 20 cents per United States resident per year, or about half the cost of one candy bar a year since project inception. 2) The daily interest on the US national debt is a major fraction of the entire cost of *Voyager*. 3) A total of 11,000 work-years were devoted to the project through the Neptune encounter. This is one-third the amount of effort required to complete the great pyramid of King Cheops at Giza. 4) The deep-space tracking antennas had to capture a signal so weak from *Voyager* that a modern electronic digital watch operates at a power level 20 billion times greater.
—from the Jet Propulsion Laboratory

# Summer's Here, Put on Some Planets!



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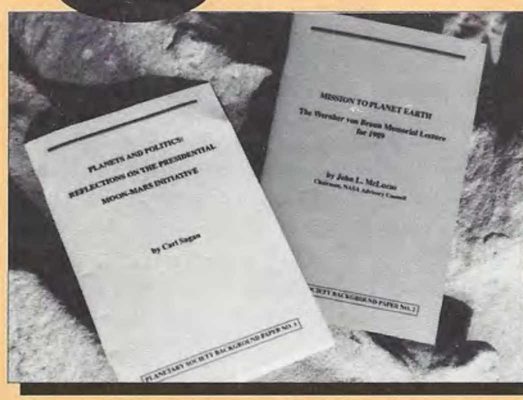


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Artist Paul Hudson and his wife Colette live on their farm in the Cascade Mountains of Washington, where they are engaged in design work for the new Space Exploration Initiative.

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