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The Mars Balloon: It Works!

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COVER: There is no other private group on Earth that can say of a planetary project, "We're scheduled for launch in 1994." But the French-built Mars Balloon, equipped with the SNAKE guide-rope designed by The Planetary Society, is an intrinsic and official part of the Soviet Mars '94 mission. Last summer, during tests in California's Mojave Desert, we proved that our design works. ***Photograph: Charlene M. Anderson***

FROM THE EDITOR

In viewing the prospects for planetary exploration in the 1990s, it's jarring to see how much things have changed since the Space Age began. Our planet once sported wealthy, missile-rattling nations that could afford to loft robotic craft into interplanetary space with the stated altruistic goal of advancing knowledge. In the last few years, that world seems to have disappeared. The belligerent competition that drove early space programs has evaporated with changing governments and sickly economies. The rationale that cooperation on space endeavors could ease international tensions has weakened considerably. Pressing social problems justifiably demand scarce funds.

For advocates such as Planetary Society members, it's time to retrench, to reflect and to reconsider why and how to explore the planets. In this issue of *The Planetary Report* we provide some grist for the mill.

—*Charlene M. Anderson*

Members' Dialogue

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

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

I thank The Planetary Society for the invitation 10 years ago to become a member. Planetary science has since become an avocation I greatly enjoy. *The Planetary Report* is a major contributor to my enlightenment on the topic.

Although my membership has been nothing more than renewal and occasional financial contributions, you have greatly enriched my awareness of what may be the most profound of humankind's adventures—our place in the cosmos. Further, I feel in all our actions, today and tomorrow, the number one priority is to guarantee the survival of our species. This can only be accomplished by our continued and uninterrupted quest for scientific discovery and the eventual settlement of other worlds. We cannot afford the luxury of a philosophy that places space exploration at a low priority.

I congratulate the Society's leadership for their continued work in keeping space exploration in the forefront for many individuals and organizations. This member has greatly benefited from your pursuits.

—BRADLEY A. THOMAS, *Sebastopol, California*

Viva the Pluto-Charon probe! This double planet has been victimized by NASA's budget cuts on the Grand Tour and we space explorers owe it reparations.

If NASA provides the space probes, could not the Soviet Space Research Institute (IKI) and Glavkosmos provide two *Protons* or even an *Energia*? Carl Sagan and Roald Sagdeev, both affiliated with The Planetary Society, could explore the possibilities.

—KEITH GOTTSCHALK, *Claremont, South Africa*

It's a good idea, but one not likely to be implemented soon. The US/USSR Cooperation in Space Agreement cites a limited number of specific areas. However, it is possible to add things to the agenda of the Joint Working Group that implements the agreement. We will make your suggestion known to them and ask them to respond.

—Louis Friedman, Executive Director

I just received my first issue of *The Planetary Report* and am accepting your invitation to comment on the subject of the Search for Extraterrestrial Intelligence (SETI). I do not share the Society's enthusiasm for this project. Passive SETI is unlikely to be productive, although it may be harmless enough, and active SETI is a dangerous, foolhardy undertaking.

An advanced civilization will spread its signals across wide bands of the radio spectrum, making the signals indistinguishable from random noise. They will use narrow beams that would miss us unless they happen to hit us during a transmission. Unless we stumble across a strong, crude signal from a primitive civilization such as our own, we shall hear nothing that we will recognize as intelligent. This window in time is so narrow that the probabilities for SETI success are vanishingly small. There are better uses for the resources.

—FRANCIS J. MERCERET, *Miami, Florida*

You are correct in saying that the normal signals of an advanced civilization, such as routine radio and TV broadcasts, would probably look much like noise. They would be impossible to detect with today's technology. For this reason, most of the SETI projects on Earth assume that at least one extraterrestrial civilization has created a radio beacon designed to attract attention by focusing its energy in one narrow band of frequencies, aimed at stars that might have life near them. This is the philosophy behind The Planetary Society's META I and II SETI projects in Harvard, Massachusetts, and in Argentina.

—Thomas R. McDonough, SETI Coordinator

NEWS BRIEFS

On December 8, *Galileo* successfully swooped in toward Earth and picked up enough speed to slingshot it toward another encounter with Earth in 1992, and then on to Jupiter. The spacecraft met its calculated rendezvous with Earth's gravity with 99 percent accuracy.

As *Galileo* approached and departed, it continuously snapped images of Earth and the Moon. This long-distance view gave scientists a look at the Moon's far side, not visible from Earth; it has not been photographed since the *Apollo* missions.

The differences between images taken by the cameras aboard *Apollos* and *Galileo* are incredible. Clayne Yeates, the craft's science and mission design planner, said it was like comparing a snapshot from a Brownie camera to an image from a high-tech camera with a 400-color spectrum that also gives clues to the physical components of its subject.

Galileo's outer-space perspective will allow the mission to compile a "movie" of Earth as it rotates, creating a "never-before-seen-spectacular." It will also enable researchers to examine substances and conditions that may be contributing to greenhouse warming on Earth.

—from Kathy Braidhill in the Pasadena *Star News*

According to officials at the European Space Agency (ESA), NASA's successful launch of ESA's solar probe, *Ulysses*, from the space shuttle bodes well for future cooperation between the two space agencies.

"I am very, very pleased," said Jean-Marie Luton, Director General of ESA, shortly after the October launch. "We have waited seven years," due to many delays in the shuttle program, "but nevertheless the mission will be of first importance" to ESA. He also said he was "very pleased for NASA," given its recent string of high-profile problems, because "we have a lot of cooperating to do in the future."

—from Douglas Isbell in *Space News*

Humans to Mars: Can

by Carl Sagan

On July 20, 1989, the 20th anniversary of *Apollo 11*'s landing on the Moon, President George Bush laid out his vision of the United States' future in space. With Neil Armstrong, Buzz Aldrin and Michael Collins at his side, Bush proposed that, in the next few decades, American astronauts should return to the Moon, then move outward into the solar system, and land on Mars.

President Bush's speech stirred memories of another exhortation to the American people: In 1961, President John F. Kennedy pledged to put a man on the Moon and return him safely to Earth before the turn of that decade.

The differing reactions to the two Presidents' proposals illustrate vividly how much has changed since the Space Age began. In the 1960s, responding to *Sputnik* and the perceived threat of Soviet rocket technology as well as to their President's challenge, Americans were roused to action and *Apollo* was born. The two most powerful nations on Earth used a race to the Moon rather than a war to prove their technological prowess. In the 1990s, faced with a ponderously multiplying budget deficit and seemingly intractable social problems, Americans paid little attention to their President's new vision.

This response to what has come to be called the Space Exploration Initiative (SEI) is, of course, of great concern to The Planetary Society. It parallels the diplomatic and political cold shoulder given President Gorbachev's repeated proposal for a joint American-Soviet mission to Mars. Since 1984 the Society has vigorously promoted our vision of the human exploration of Mars—the spacefaring nations of Earth going together—as a goal worthy of great effort and expense. The announcement of SEI should have vindicated our labors. Instead, we have had to redouble our efforts to promote this great adventure.

The Bush administration's campaign to build support for SEI in the US Congress, which will have to provide the funding, reached its nadir during deliberations over NASA's 1991 budget. Congress "zeroed out" all monies specifically earmarked for the President's initiative. The campaign will resume with next year's budget debates.

The Planetary Society's Directors have actively participated in the many processes that seek to define, refine and justify human missions to Mars. We have come to suspect that the greatest problem facing our vision of the future is the lack of a generally accepted reason—or constellation of reasons—to expend the effort and money. In the 1960s, the reasons to undertake *Apollo* seemed unassailable to most of the American people, and they were inspired to accomplish, within 10 short years, a goal that for all of human history had seemed unreachable. That rationale has long since evaporated. For the 1990s, we must seek new reasons for humans to explore other worlds.

With this issue of *The Planetary Report* we begin what we hope will be a continuing debate over the why of human space exploration. Our President, Carl Sagan, and Vice President, Bruce Murray, have been raising this topic in many forums, including testimony before the Advisory Committee on the Future of the US Space Program, chaired by Norman Augustine. Their statements represent steps in the Society's evolving position on the rationale for human space exploration. On October 3, 1990, at a Senate hearing on space policy, organized by the Federation of American Scientists, Carl Sagan set out some of his thoughts, which we have excerpted here.

We have asked the members of our Boards of Directors and Advisors to join the debate. We would also like our members to contribute their thoughts on why the United States—as well as the European Space Agency, the Soviet Union, Japan and other spacefaring nations—should send humans to other worlds. In future issues we hope to reprint the resulting essays on this difficult question.

We will be, in effect, putting our heads together to see if there is a valid rationale for the human exploration of the solar system in the fairly near future. It is a worthy challenge.
—Louis D. Friedman

For me, Mars has been calling since childhood. The exploration of other worlds seems to me the natural continuation of the long human history of exploration. Earth is now, except for the sea bottoms, all explored. At this same moment, our technology permits us to go to other worlds. Of course that's where we'll go, sooner or later. The question before us is whether it makes sense in the next few decades to send men and women to other worlds.

In the long term, self-sustaining human communities on other worlds would be a step more significant than the colonization of the land by our amphibian ancestors some 500 million years ago and the descent from the trees by our primate ancestors some 5 to 10 million years ago. It would be a transforming event in human history, in the history of life on Earth. But that doesn't mean it has to happen today. It would be a transforming event if it happens 100 years from now.

Mars challenges us to understand the massive climate change that has occurred there, and to search for past or present life—both of particular interest for us.

I have been advocating human missions to Mars with some vigor since 1984. With The Planetary Society's Mars Declaration, it became clear that a stunningly ecumenical group of American leaders supported such a program, giving a wide variety of substantiating justifications. After a little time, we found the Soviets embracing the idea. President Gorbachev on a number of occasions has announced joint US-Soviet human exploration of

We Justify the Cost?

Mars as a long-term goal for the Soviet Union, and human exploration of Mars is prominent in the 10 stated long-term technological goals of the USSR.

The idea, at the height of the Reagan "evil empire" days, of finding a common long-term, constructive, high-technology goal for the two nuclear superpowers seemed to me extremely important—as a means of binding the nations together, sharing a purpose of truly historic proportions and exciting the imaginations of everyone on the planet.

So now the Soviets have indicated their interest and willingness. The United States has, also. The Soviets have explicitly urged doing it cooperatively with the US. The US is at least moving in that direction. We have surely helped to convince them both. So from my point of view, there should be no problem at all. I should be pleased and move on to other debates.

But the trouble is, the world has not remained static in the interim. New facts have emerged which, I claim as a scientist, we have to respect and take account of.

The first new fact is that the US and Soviet national economies are in much worse shape than was generally recognized in high Reagan times, and if we're talking about expenditures of enormous amounts of money, the ability of either nation to make such expenditures becomes a relevant issue.

Second, a major argument for human missions to Mars was the immense danger that the Cold War and the nuclear arms race posed to our global civilization. I advocated human missions to Mars as something that the United States and the Soviet Union ought to do jointly, as a way of creating a shared and worthy goal for the two Cold War adversaries. This was the main argument of my articles in *Discover* and *Parade*, the main part of my argument reprinted in *Pravda,* and the principal reason that President Gorbachev and the Soviet government endorsed the Mars goal. It is a fact that US-USSR relations are now at their warmest point since the end of World War II and that cooperation is occurring on many levels. The Cold War, NATO officially announces, is over.

So the argument for going to Mars emerging from the US-USSR competition has less force today than it did in the mid-1980s. But it is still a fact that the two nations have some 55,000 nuclear weapons between them, some 25,000 of them in hair-trigger strategic readiness. It is therefore possible that benign shared objectives extending decades into the future are still important to help maintain present levels of superpower amity. I don't know whether the increased economic problems and the thawing of the Cold War are significant enough changes to scuttle the case for going to Mars. But they do work, at least incrementally, to weaken the argument.

Human communities on Mars . . . would be a transforming event in human history.

My chief misgiving is that there are now clear, crying national needs, which cannot be solved without major expenditures. At the same time, there is an extremely limited discretionary federal budget that can address those needs. I'm thinking not just of the budget deficit, but of such matters as the disposal of chemical and radioactive wastes, or energy efficiency and alternatives to fossil fuels, or declining technological innovation in America. The US has gone from being the largest creditor to the largest debtor nation on the planet in a decade—a stunning achievement. Also, the collapsing urban infrastructure, the AIDS epidemic, homelessness, malnutrition, infant mortality, education—there is a painfully long list, and nobody can tell me that money is not needed to solve these problems.

Some of these matters have multi-hundred-billion-dollar price tags, or more. Alternatives to the fossil-fuel economy clearly represent a multi-trillion-dollar investment—if we can do it. And every now and then there are unexpected little fiscal perturbations provoked by private and public corruption, such as the savings and loan scandal.

If there were 20 percent more discretionary funds in the federal budget, I would not feel so worried about advocating such enormous expenditures in space. If there were 20 percent less, I don't think the most die-hard space enthusiast would be advocating something like the Space Exploration Initiative (SEI). If, to take a more extreme example, half the people in the Sudan are in immediate danger of starvation, a conscientious board of directors of the Khartoum Art Museum will not be advocating increased government spending to purchase art—no matter how convinced they are of its social benefits. You can have life without art, but not vice versa.

Surely there is some point at which the national economy is in such dire straits that sending people to Mars is unconscionable if it costs hundreds of billions of dollars. The only difference there might be between me and other enthusiasts for human missions to other worlds is where we draw the line. Surely such a line exists, and every participant in such a debate should stipulate where that line should be drawn, what fraction of the gross national product for space is too much.

If we're talking about a relatively minor increment to the NASA budget to accomplish SEI, then I agree, perhaps it is inappropriate to make zero-sum arguments. Or maybe such arguments have so much inherent noise in them, because of the chaotic nature of the federal budget process, that they make no sense. But when the cost gets very high, then I don't see how we can pretend to be insulated from zero-sum arguments. No one knows what SEI would cost, in part because we have no agreed-upon mission design. Conventional wisdom is that it would cost hundreds of billions of dollars over two or three decades. If we advocate $500 billion spent for SEI, that's $500 billion unavailable for other pressing national needs. $500 billion is essentially the currently estimated NASA budget for SEI over the next 30 years. If this cost is to be added on to the total NASA budget at present, then we're talking about doubling that budget to accomplish SEI.

There is some point at which the national economy is in such dire straits that sending people to Mars is unconscionable. . . .

So if we were convinced on other grounds—as I am— that sending humans to Mars is important for the long-term human future, the key to getting there is to save money. One suggestion is that enormous amounts of money can be saved by alternative technologies and bureaucratic conventions that a hidebound NASA is unwilling to consider—for example, inflatable structures, booster technology proposed for the Strategic Defense Initiative, a willingness to take additional risks with the lives of astronauts, and a relaxation of congressional oversight on NASA.

Some propose that quick, dirty and incredibly cheap missions sending humans to the Moon and Mars are possible—not exactly a week from Tuesday at $99.95, but there are proposals in that spirit. In the review panels I'm familiar with, including the so-called "blue-ribbon" White House panel, such proposals have been thought stimulating, but somewhere between unconvincing and specious. Nevertheless, there might be new technologies, missed by NASA, that could produce enormous savings. If such technologies are out there, they may be the keys to sending humans to Mars in the next few decades.

Failing this, the only way for the United States to go without getting seriously into the zero-sum quandary is to do it cooperatively. NASA would then commit to something like SEI, but scale back substantially on such technologies as a space station and heavy-lift launch vehicles where substantial capability is in hand in other nations—in this case, in the Soviet Union. If the cost of going to Mars were shared equally among, say, the Soviet Union, the European Space Agency, Japan and the United States, the costs for each nation might become low enough for the project to be feasible. Without such cooperation, the program may remain wholly infeasible.

I must confess to being perplexed by those who say that such cooperation can never be accomplished, or if it is, we will not save any money because of the interface and communications problems. If this is the only way we can get to Mars, we should be devoting substantial technical, bureaucratic and social efforts to finding ways to solve interface and communications problems. If the Cold War could be made to wind down, if some semblance of true democracy could be introduced in Eastern Europe, we can solve interface problems.

Since there are major, valid social and environmental demands on the discretionary federal budget, it seems to me that advocates of SEI have to address whether SEI, in the long term, is likely to mitigate any of these problems—maybe not all of them, but if SEI addresses none of them in a convincing way, it seems to me that going ahead with it becomes significantly less likely.

Let me list the standard set of justifications given for SEI and indicate my own sense of whether they are valid, invalid or indeterminate:

Clearly such a set of missions will enormously improve our knowledge of the planet Mars and, through the comparison of Mars with Earth, it is very likely—as robotic missions have shown—that we can improve our understanding of our own planet's environment as well. On the other hand, it is very hard to argue that humans are essential for such a goal. Robotic missions, given high national priority and equipped with improved artificial intelligence, seem to me entirely capable of addressing, as well as astronauts can, all outstanding scientific issues—and at 10 percent or less of the cost, without risking human lives.

The Space Exploration Initiative would provide an exciting, exploratory, adventure-rich and hopeful future for young people.

It is alleged that "spin-off" will occur—huge technological benefits that would otherwise not come about without human missions—thereby improving our international competitiveness and our domestic economy. But this is an old argument: Spend $75 billion to send *Apollo* astronauts to the Moon, and we'll throw in a free stickless frying pan. One can clearly see that if we are after frying pans, we can invest the money directly and save almost all of that $75 billion.

That argument is specious for other reasons as well, one of which is that Teflon technology preceded *Apollo*. The same is true of cardiac pacemakers and other purported spin-offs of *Apollo*. But the central point here is that if there are some technologies that we urgently need, then spend the money on developing those technologies. Why go to Mars to do it? Spin-off arguments—for Mars missions, for SDI and elsewhere—are often an acknowledgment of the inadequacies of the arguments publicly offered for huge technological expenditures.

Then there is education, an argument that has proved very attractive in the White House. Ph.D.'s in science peaked somewhere around the time of *Apollo 11*, maybe even with the proper phase lag after the beginning of the *Apollo* program. The cause-and-effect relationship is perhaps not demonstrated, but it's not implausible. But so what? Think of what you could do for $100 billion in terms of teachers' salaries, school laboratories and libraries, scholarships for disadvantaged students, research instrumentation on the ground, graduate fellowships, science education in the mass media. Is it really true that the best way to promote science education is to go to Mars?

Another argument is that SEI will give the military-industrial complex worthy work, and will diffuse the temptation that might otherwise arise to use its considerable political muscle to exaggerate external threats and pump up Department of Defense funding. The other side of this coin is that, by going to Mars, you maintain a standby technological capacity that might be important for future military contingencies. The counter might be to let those guys do something directly useful for the civilian economy. But as we saw with Grumman buses and Boeing/Vertol commuter trains, the aerospace industry experiences real difficulty in producing for the civilian economy. It's much harder to do. It's competitive. You actually have to watch your costs; overruns are unacceptable. Tens of percent downtime is also unacceptable. There is a real question about whether such economic conversion is practical in the real world. All three national weapons laboratories have lately found a great fascination with space and SEI. I think they, like all bureaucracies, wish to maintain their continuance and they see a glimmer of hope in SEI.

There are other arguments for SEI. It is suggested that the ultimate solution to the energy economy is to strip-mine the Moon down to a depth of a few microns, return the solar-wind-implanted helium-3 back to Earth, and use it in fusion reactors. What fusion reactors? Even if this were possible, this is a technology 50 to 100 years away. Our present energy problems seem more urgent.

Can the sum of a large number of individually inadequate justifications . . . add up to one adequate justification?

Even stranger is the argument that we have to send human beings into space to solve the population crisis on Earth. Permit me to point out that 250,000 more people are born than die every day on Earth—which means that you would have to launch 250,000 people every day into space to maintain the present world population. This appears to be somewhat beyond NASA's present capability.

Finally, there is a set of less tangible arguments which, I freely admit, I find attractive and resonant. The idea of an emerging cosmic perspective, of understanding our place in the universe, of a highly visible program affecting our view of ourselves—this might have extremely important benefits for us, in clarifying the fragility of our planetary environment and in recognizing the common peril and common responsibility of all the nations and peoples of Earth.

SEI would provide an exciting, exploratory, adventure-rich and hopeful future for young people who are ordinarily provided, by the mass media and by the incompetence and corruption of politicians, with the most dismal view of what their future might be. Typical movie futures involve bikers armed with automatic weapons, riding the residual highways after the nuclear holocaust. What kind of influence does this have on young viewers? Where are the hopeful visions of the future?

I've mentioned the importance—somewhat diminished with the end of the Cold War, but still very prudent—of binding the US and USSR in a grand, long-term common endeavor.

Then there is the argument used by President Bush, that it is human destiny, manifest destiny, or maybe just American destiny to go to other worlds. It's a very brave person who claims to know what is written in the book of destiny. This is essentially a religious argument, and not everyone is an adherent of this faith.

When I run through such a list and try to add up the pros and cons, bearing in mind the other urgent demands on the discretionary federal budget, to me it all comes down to this question: Can the sum of a large number of individually inadequate justifications and some powerful but intangible ones add up to one adequate justification?

I don't think any of the items on my list of purported justifications is demonstrably worth, say, $500 billion, certainly not in the short term. On the other hand, every one of them is worth something, and if—I'm oversimplifying for clarity—I have ten items and each of them is worth $50 billion, maybe it adds up to $500 billion. If we can be clever about reducing costs and making true international partnership work, the justifications become more compelling.

I don't know how to do this calculus, but it seems to me that this is the kind of issue that we ought to be addressing. There ought to be a national debate on this topic. I have been urging it on the White House and NASA with no apparent effect. But perhaps that debate has here begun.

Carl Sagan, President of The Planetary Society, is Director of the Laboratory for Planetary Studies at Cornell University.

Mining the Air

Resources of Other Worlds May Reduce

by Kumar Ramohalli

To send human beings beyond low Earth orbit to live on the Moon and explore Mars is now a declared objective in the United States' space program. However, in its budget deliberations, the US Congress has declined to fund the needed preparatory steps. One reason is surely the perception that any piloted space venture must carry a very high cost, especially if the mission is to the Moon or Mars. At the NASA Space Engineering Center at the University of Arizona, we are pursuing research that may significantly reduce the cost of such missions.

Had cost not been such a major factor, the US probably would never have lost its commitment to space exploration. Prestigious groups, such as the National Academy of Sciences and the National Research Council, and even the presidentially appointed National Commission on Space, continue to recommend a bold approach. But the will and the way to pay for it have not yet been found. The situation is similar in other spacefaring nations.

The single biggest fraction of a space mission's cost is for the initial launch from Earth's surface. This cost now hovers around \$10,000 per kilogram lifted to low Earth orbit. Despite the efforts of NASA, the European Space Agency and Arianespace, realistic launch projections show future costs not less than \$1,000 to \$2,000 per kilogram, even with the promise of cheaper services by China and the Soviet Union. While this is a dramatic improvement, it is still not low enough to take us to the Moon or Mars given the mass currently needed to launch and sustain a mission.

Innovations in space technology are needed if our dream is to become reality. The idea of "mining" resources on another planet to support operations there, plus the return trip to Earth, is such an innovation. By using these so-called *in situ* resources, we can greatly reduce the mass that must be lifted out of Earth's gravity well. With less mass to launch, we can drastically lessen transport costs for settling the Moon and exploring Mars.

Then only a small fraction of a space mission's hardware and consumables (including propellant for the rocket spacecraft) need be launched from Earth. The fuel for the rest of the mission and the return trip can be extracted and processed on other worlds.

The simplest example involves the energy that flows freely from the Sun. We can use the technology of photovoltaics to capture solar energy, instead of sending up chemical or nuclear power modules. We can also harness extraterrestrial resources other than solar energy, although we need research and development before we commit to important space missions based on the availability and use of these resources.

Not only do we need better knowledge of what raw materials are available off Earth, we must also devise efficient and economical processes for using them. Familiar mining and smelting techniques are mostly not usable out there, so we shall have to develop whole new industries that can operate reliably under lunar and martian conditions. This development will not come cheaply, but in the final analysis, the benefits should outweigh the costs.

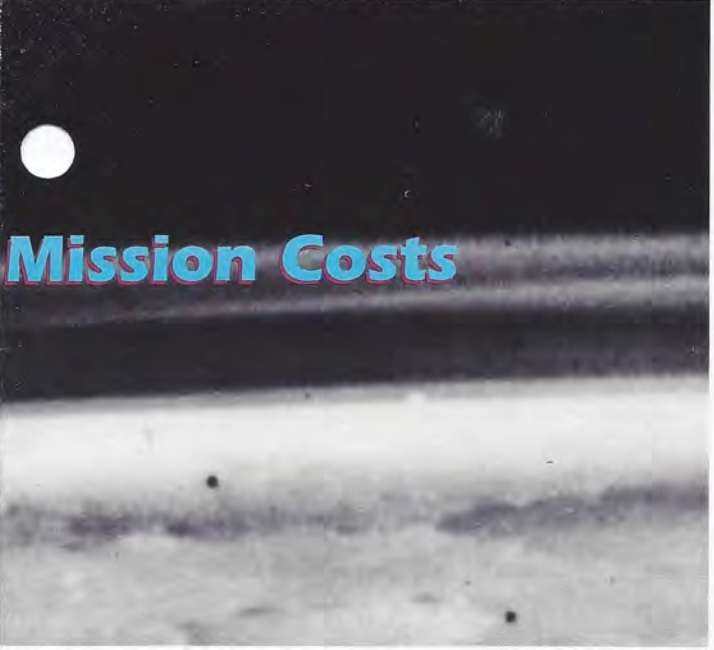
Recognizing that such industrial development is a long process, in 1988 NASA founded the Space Engineering Research Center at the University of Arizona to explore the use of local planetary resources. (In practice, this means the materials and environments of the Moon, near-Earth asteroids and Mars.) One of nine such centers in the US, it is the only one that is concerned with resource development.

Fuel for Mars

In some of our early analyses, we found that we could launch smaller payloads from Earth and return larger payloads from Mars if we were able to make rocket propellants from martian materials and use them for the return trip. For most deep-space missions, the largest part of the mass to be launched is the propellant. Traditionally, vehicles have carried their full propellant needs, since as yet there are no filling stations out there.

A large fraction of any chemical propellant combination is the oxidizer that burns with the fuel to generate the rocket jet. Since we will use oxygen (O_2) for various other purposes, such as life support, some of the oxygen produced from local resources can be used for these purposes also, significantly reducing launch mass.

We can extract oxygen from any of its atmospheric or mineral compounds if we have enough energy of the right type. The lunar minerals ilmenite and anorthite (which contain oxygen), martian permafrost, water ice at the martian poles, and atmospheric carbon dioxide (CO_2) on Mars are all possible feedstocks. At the Center, we are pursuing them all.



LEFT: Haze layers form in Mars' tenuous, primarily carbon dioxide atmosphere. This atmosphere may be able to provide propellant for human exploration of the Red Planet. *Image: JPL/NASA*

After the feasibility of oxygen production is proven, we will develop the prototype hardware. This development will give us valuable experience, provide a means of gathering long-term data, enable us to vary a number of parameters, and lead to simplified designs.

Working within our funding constraints, we chose one process for a pilot plant demonstration system: oxygen production from a simulated martian atmosphere. This system represents the best combination of innovation, realistic complexity, near- and long-term applicability and engineering challenge.

Oxygen from Carbon Dioxide

The heart of our device is a cell, or reaction chamber, that separates oxygen from other gases in a porous solid main-

(continued on page 11)

Producing Propellants on Mars: A Student Project Pays Off

by Robert L. Ash

Space mission planners are excited about the possibilities of producing propellants from materials found on other planets. In a traditional mission plan, an exceedingly large part of the mass launched from Earth's surface is propellant for the landing and takeoff at the target planet. For example, in Mars mission scenarios, much of the mass of the payload launched from Earth would be propellant.

If propellant could be manufactured on Mars, the penalties of weight and cost could be greatly reduced. When chemical fuels propel the space vehicle, liquid oxygen typically accounts for 80 percent of the ascent vehicle's propellant. On Mars, there is a nearly inexhaustible source of oxygen: its predominantly carbon dioxide atmosphere. With the right equipment and the will to do it, it would be relatively easy to produce liquid oxygen on Mars.

This was the inspiration behind a Mars Oxygen Demonstration Project at Old Dominion University in Virginia. In 1986, The Planetary Society provided seed money for students in the Mechanical Engineering and Mechanics Department to purchase the needed hardware.

With additional support from the Universities Space Research Association, our students designed and built a Mars oxygen processor and began producing oxygen in 1988. The apparatus uses bottles of gas custom-mixed to simulate the martian atmosphere, which is over 95 percent carbon dioxide (CO_2), with traces of nitrogen (N_2), argon (Ar), oxygen (O_2) and carbon monoxide (CO). This gas is metered into an electrochemical separation cell made of zirconia and similar to a sealed test tube in shape.

From Atmosphere to Propellant

At a pressure of less than 0.1 Earth atmosphere to simulate Mars conditions, the gas is heated to 1,000 degrees Celsius (1,800 degrees Fahrenheit). Some of the carbon dioxide then dissociates into carbon monoxide and oxygen. The hot, simulated martian atmosphere circulates around the outside of the tube, while a voltage difference is maintained between the inside and the outside of the tube. The voltage acts as a pumping force to remove oxygen from the other gases, and the zirconia then conducts the oxygen through the tube wall.

Initial tests proved successful, with conversion efficiencies of up to 8 percent. Our goal is a 25 percent conversion. One master's thesis and many undergraduate reports have come out of this work. Significant testing remains to demonstrate that the system can function autonomously for an extended period, as it will have to on Mars. That work is now in progress, as described in the accompanying article, at the University of Arizona.

Of perhaps equal importance, *in situ* propellant production, recognized by The Planetary Society in 1986, has become an accepted element in NASA planning exercises. In addition to the work at the University of Arizona, the Martin Marietta Corporation has begun research on advanced systems for oxygen and methane production on Mars.

From small but inventive projects such as this we may find the answer to affordable martian exploration. The Planetary Society seeks out such endeavors and, with a little luck, we may bring our shared dream of human missions to Mars much closer to reality.

Robert L. Ash, faculty advisor for this project, is a Professor of Mechanical Engineering at Old Dominion University in Virginia.

Mars Direct: A Mission Made Possible by In Situ Propellant Production

by Robert Zubrin and David Baker

President Bush's 1989 announcement of the Space Exploration Initiative stimulated many proposals for accelerated human thrusts to the Moon and Mars. The use of resources on other planets is a way to lower costs and push forward the timetable. Here is one fast-paced scenario that assumes a bold acceptance of physiological and other risks.

Mars Direct is an approach to the United States' proposed Space Exploration Initiative that could possibly enable human exploration of the Red Planet to begin as early as 1999. The key technology that makes this possible is the production of rocket fuel oxidizer on the surface of Mars.

This approach does not require that the spacecraft be assembled or refueled in Earth orbit. It does not require a space station. And it can be carried out using chemical propulsion systems that can be produced today. Plus, this is not merely a "flags and footprints," one-shot expedition: It would immediately put into place an economical method of Earth-Mars-Earth transportation. Humans would have the ability to travel over large regions of the martian surface, and eventually we would be able to set up Mars bases that might someday evolve into self-sustaining communities.

This, briefly, is the Mars Direct plan: In December 1996, a single, shuttle-derived, heavy-lift launch vehicle, with a substantial hydrogen-oxygen upper stage, blasts off from Cape Canaveral and hurls a payload of 40 metric tons directly to Mars. The payload is an unfueled, 2-metric-ton Earth return vehicle (ERV), 5.8 metric tons of liquid hydrogen (H_2) cargo, an inert, 100-kilowatt nuclear reactor mounted on a truck fueled by methane (CH_4) and oxygen (O_2), a set of compressors, a chemical processing unit and a few small robotic rovers.

The payload will use the martian atmosphere to "aerobrake" into orbit, then land with the help of a parachute. As soon as it can, the telerobotically controlled truck will drive a few hundred yards off, deploy and activate the reactor, which will power the compressors and the chemical processing unit. This chemical plant will then use the liquid hydrogen cargo and the plentiful carbon dioxide (CO_2) in the martian atmosphere to produce methane and water (H_2O). These can, in turn, be transformed into liquid oxygen for fuel and hydrogen, which can be recycled to continue the process. More oxygen can be produced by direct splitting of carbon dioxide.

Reaching a "Do-able" Level

Thus we can turn 5.8 metric tons of hydrogen brought from Earth into 107 metric tons of methane and oxygen propellant. This 18 to 1 leverage is what will allow us to reduce the mass of the payload launched from Earth to such a small amount that on-orbit assembly is no longer required. Thus the mission requirements are reduced to an eminently "do-able" level.

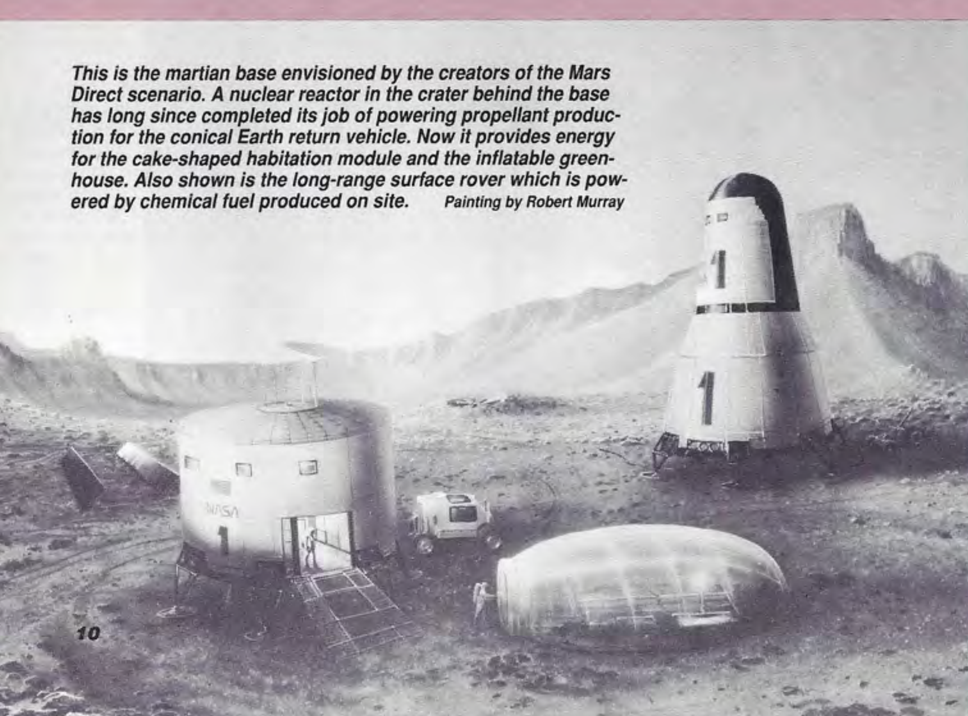
Most of the propellant produced will have to be used to fuel the ERV, but there will still be 11 metric tons left to fuel high-powered, long-range ground vehicles.

Then, in 1999, two more heavy-lift rockets blast off from Earth, one carrying an ERV payload identical to the first, the other carrying a human crew of four, provisions for three years and a pressurized methane-oxygen-powered rover that they will drive across Mars.

The explorers will follow a radio beacon to the robotically studied site, where their fully fueled ERV awaits. The other payload will land several hundred kilometers away, where it will get ready to accommodate another human crew in 2001. Thus every other year two more heavy-lift launch vehicles would leave Earth, for an average launch rate of only one per year to pursue a continuing program of Mars exploration.

Each crew will remain on Mars for 1.5 years, taking advantage of the chemically powered, long-range rovers to explore large expanses of this alien territory. With their mission accomplished, they will return to Earth in the ERV that has been waiting since their arrival. As this tag-team approach progresses, a string of small bases will be left behind on Mars, ready to open up increasingly broad stretches of this neighboring world to earthly explorers.

Robert Zubrin and David Baker are senior engineers with the Martin Marietta Astronautics Division working on plans for lunar and martian exploration.



This is the martian base envisioned by the creators of the Mars Direct scenario. A nuclear reactor in the crater behind the base has long since completed its job of powering propellant production for the conical Earth return vehicle. Now it provides energy for the cake-shaped habitation module and the inflatable greenhouse. Also shown is the long-range surface rover which is powered by chemical fuel produced on site. *Painting by Robert Murray*

This unassuming apparatus, built at the Space Engineering Research Center at the University of Arizona, is the experimental prototype of a device that may someday produce oxygen from carbon dioxide on Mars. The ability to use extraterrestrial materials to fuel missions from Earth may help make the human exploration of Mars and the Moon affordable.

Photograph: UA Space Engineering Research Center

(continued from page 9)

tained at about 1,000 degrees Celsius. Under these conditions, carbon dioxide dissociates to carbon monoxide (CO) and oxygen. We are considering several options. Data are available on porous zirconia (zirconium oxide, ZrO_2), so we selected it as the material for our initial plant. We are, however, studying other cell materials and alternative configurations.

With the hardware shown in the photograph (right), we produced oxygen at the expected rate of 6 milliliters per minute. The total mass of zirconia for a pilot martian propellant plant that would produce 10 kilograms of oxygen per day is calculated to be 150 to 200 kilograms. We think it is technically feasible to reduce this to 100 kilograms. Using our current configuration, a bank of 180 cell units would be needed to produce 10 kilograms of oxygen per day.

Oxygen from Lunar Soil

We are also pursuing chemical extraction of oxygen from the lunar mineral ilmenite. Carbon, carbon monoxide and hydrogen (H_2) are currently being used as the reducing agents to pull oxygen from its mineral matrix.

A different approach to ilmenite reduction involves using ionized, reactive gases, or plasmas. High concentrations of ions can promote some chemical conversions. Usually, plasmas are associated with high temperatures. Our innovation has been the generation of a cold plasma. This approach has already increased the reaction rate by 10 times; this presages very compact reactors.

Direct solar heating of the reaction zone also appears feasible. Electrolysis of molten lunar rock, first using simulates and then actual samples, is being carefully studied, as is the possibility of microwave heating for selective processing.

Building Materials

One of our goals at the Center is to make missions ecologically acceptable. Waste production is to be kept to a minimum. This implies not only biological recycling but also the use of local resources to produce building materials as well as propellants. After we have mined lunar soil for its oxygen, we can process the leftover soil into bricks, beams and "concrete." From these we can build structures as well as equipment such as solar collectors.

In one of our laboratories, simulated lunar soil is robotically compressed from six directions into a cube. We measure its response to varying loads. To overcome the inherently poor tensile strength of this soil, we have developed innovative composites.

Here we use glassy fibers that could be imported from Earth. The fibers are mixed into the soil matrix, which is heated to promote melting during soil compression. These imported fibers make up less than 5 percent of the structural material, yet they increase the overall structural integrity of the finished product by two orders of magnitude. For this gain, we are willing to pay a small penalty in using fibers transported from Earth. Alternatively, the fibers might be made on the Moon, since lunar soils contain much natural glass. We have research projects in this area, as does the privately funded Space Studies Institute.

A striking example of this technology is a solar collector dish made with one pressing from simulated lunar soil and 5 percent glass fibers. It was produced by Science Applications International in San Diego, under a subcontract from our Center. We are now extending this technique to build other solar thermal devices.

High-Tech Mining

In all our efforts, it would be beneficial to locate the richest deposits of local source material. We have to find these deposits without mining vast amounts of soil. With ground-penetration radar mounted on a lunar rover or an orbiter, we could quickly identify subsurface anomalies that could indicate concentrated sources. At the Center, our studies on a dry soil near Tucson have demonstrated this technique. The radar can penetrate several meters. This subsurface vision can avoid wasteful moving of soil or other prospecting exercises.

Only two years after its founding, our Arizona Center is flourishing, with research under way on a variety of fronts, all directed to the time when humans may confidently develop and use the resources that await our ingenuity in space.

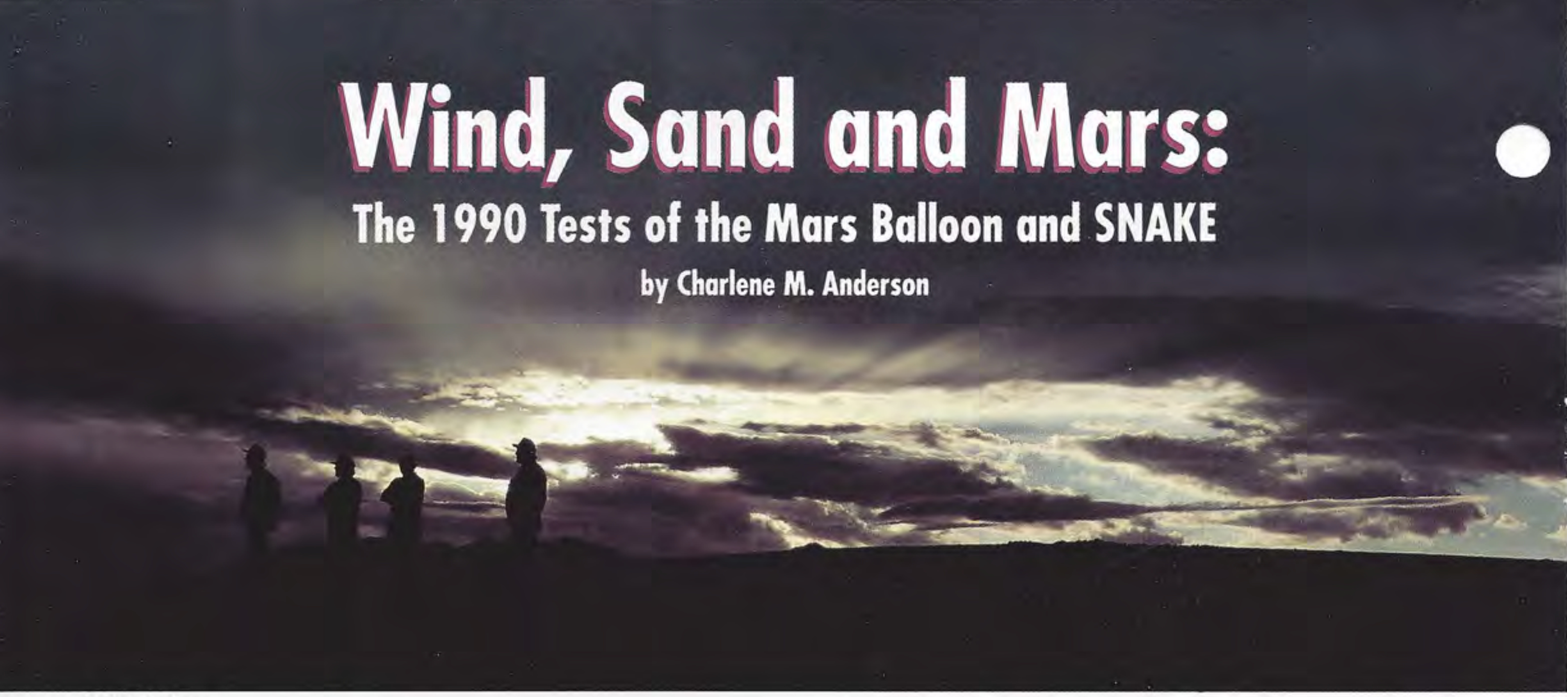
Kumar Ramohalli is the Principal Investigator for Engineering at the University of Arizona/NASA Space Engineering Research Center and is a Professor of Aerospace Engineering at the University of Arizona.

Further information can be obtained by writing to the Space Engineering Research Center, University of Arizona, 4717 East Fort Lowell Road, Tucson, AZ 85712.

Wind, Sand and Mars:

The 1990 Tests of the Mars Balloon and SNAKE

by Charlene M. Anderson



ABOVE: As dawn breaks over the Mojave, the Mars Balloon team scouts the test site at Palen Dry Lake. Such early starts increased our chances of getting the balloon inflated before the desert winds picked up. Then, of course, we wanted some wind to drive the balloon and SNAKE across the test region. On the whole, nature cooperated, though there were some anxious moments.
Photo: Charlene M. Anderson

At 4:30 in the morning it's sometimes hard to appreciate the significance of what you're doing.

Before dawn on this early fall morning, under a residual drizzle from the thunderstorms of the night before, I was standing outside a motel lobby in Indio, California, consuming cup after cup of coffee and waiting to begin a day of testing the Mars Balloon and the SNAKE guide-rope. The van that would drive me to the test site in the sand dunes of Palen Dry Lake had not yet pulled up, so I was leaning against a four-wheel-drive truck heavily loaded with generators, a portable weather station and miscellaneous equipment. I must have looked particularly forlorn or perhaps still asleep, for Jacques Blamont, Chief Scientist for the French Centre National d'Études Spatiales (CNES), Society advisor and father of the Mars Balloon (see the May/June 1987 *Planetary Report*), came up and gently chided me for my seeming lack of enthusiasm.

"You must realize how lucky we are to be able to take part in these tests," he told me. "Very few people have had the opportunity to see equipment built to explore another planet actually fly. Since the beginning of the Space Age, only a few dozen spacecraft have been sent to other planets. Of those, even fewer were tested on Earth.

"We are privileged to witness these tests that will determine if our balloon/SNAKE configuration will work. If it does work, and if it flies across Mars, we will remember this day and the parts we played in making it possible."

I must admit that, at the time, the significance of what Jacques had said did not sink in. My brain did not begin to function fully until the rising Sun broke through the departing storm clouds over the test site. By then I was too busy to ruminate much on his words. But later, after a day of flawless flights, with both the balloon and its guide-rope performing better than any of us had dared imagine, I thought back on his morning admonition.

Jacques was right. We were extraordinarily privileged and lucky to be part of an improbable venture: Here in the California desert were people from the French, Soviet and American space programs, working together on tests supported by the members of The Planetary Soci-

FOUR PHOTOS, RIGHT:
Within its protective orange sack, the test balloon is inflated by the skilled CNES team. The California team trucked in helium and nitrogen to fill the transparent, gossamer cylinder. Rough handling—or an encounter with the ground—could have shredded its polyester skin. The amounts of the gases were computer-monitored to give independent control of the balloon's size and its buoyancy. This was necessary so that the balloon would lift the right proportion of the SNAKE and, at the same time, experience the right amount of wind drag to model the expected conditions on Mars.

Photos: Charlene M. Anderson

ety. This small non-profit organization (tiny relative to the spacefaring nations) was an equal partner in an imaginative exploratory mission to another planet. Private citizens from around the world had joined together through the Society to give this balloon and guide-rope design a chance to fly on Mars.

And in that desert, despite heat and dust, wind and thunderstorms, we had proved something even more extraordinary:

IT WORKS!

On these pages we share with our members who were unable to participate a little of the excitement and even triumph felt by the Mars Balloon team during our testing program. The team was made up of scientists and technicians from CNES; observers from the Babakin Center, which builds the Soviet spacecraft; scientists from the Space Research Institute of the Soviet Academy of Sciences; engineers from the Jet Propulsion Laboratory, who donated their ideas and labor to the project; students from the University of Arizona, Utah State University, UCLA and Caltech; and Planetary Society volunteers, whose

dedication, energy and perseverance inspired the entire team.

The tests were designed to challenge the balloon and SNAKE designs under a variety of Mars-like conditions. The chosen sites were smooth ancient lake beds, jagged frozen lava flows and gently rolling sand dunes. The balloon flew flawlessly in both heavy and light winds. The SNAKE slithered obliviously over sand, hardpan and lava boulders. The combination passed every test with flying colors.

The French and the Soviets were impressed with the performance of both the SNAKE and the Planetary Society team. They all expressed the hope that we will be able to continue our participation in this exceptional project.

The Planetary Society has fulfilled its initial obligation: the design of a guide-rope to enable low-altitude flight over martian terrain and to carry instruments to the surface. We have transferred all of our data and designs to CNES for incorporation into the Soviet *Mars '94* mission. We will continue to work with the French and the Soviets to the limits of our available funds.

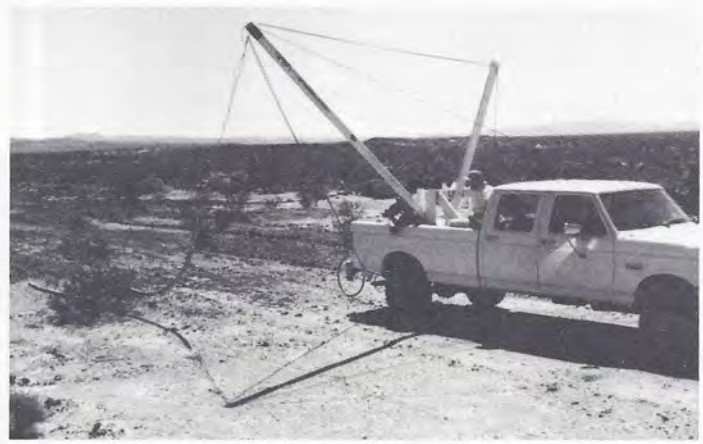
The Soviets were so happy with our work that they even suggested that The Planetary Society take the lead in designing another sort of exploratory vehicle: a midget robotic rover

ABOVE: The SNAKE waits patiently as the balloon is readied, disturbed only when Society Executive Director Lou Friedman tweaks its tail. The "nested Dixie cup" design gives the SNAKE the flexibility to serve as a self-ballasting guide-rope for the balloon, as well as the rigidity to avoid snagging and to protect its internal instruments.

Photo: Charlene M. Anderson

LEFT: Technicians from CNES prepare the SNAKE for its mission. Painted fluorescent orange for visibility, it carried instruments to measure its speed as it was dragged beneath the balloon and a system to measure friction between it and the ground.

Photo: Charlene M. Anderson



ABOVE: Tests early in the summer involved dragging the SNAKE behind a truck and monitoring performance. Here it encounters scrub brush, an obstacle unlikely to be encountered (unfortunately) on Mars. Photo: Lazlo Keszthelyi

LEFT: Both the SNAKE and the gondola suspended beneath the balloon carried instruments to measure our apparatus' performance. The back of one of our four-wheel-drive trucks was turned into a mobile laboratory to monitor the incoming data. We compiled information on the system's speed, its dynamic state and the inclination of the tethers as it moved, the wind speed relative to the balloon, gas temperature within the balloon and the temperature of the surrounding air. All this will help to predict how the balloon and SNAKE will perform on Mars.

Photo: Charlene M. Anderson

to travel across Mars. We are considering their request very seriously—and with growing excitement.

Every member of The Planetary Society can feel privileged and lucky—as Jacques explained to me—to have been part of this adventure. With a little more luck, in 1994 we will watch as our balloon drags its SNAKE across the deserts of Mars.

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

ABOVE: The SNAKE left distinctive tracks in the Mojave sand. Here its trail crosses ripples formed by wind erosion. As the fluctuating, gentle wind moved the balloon from side to side, the SNAKE rolled, leaving wide, sinuous patterns on the dunes. The SNAKE tracks were especially visible because the previous night's rain had darkened the dune surfaces.

Photo: Charlene M. Anderson

ABOVE: When the wind caught the balloon, it could take off across the desert at a clip too fast to follow on foot. And even four-wheel-drives can get stuck in soft sand. So an important member of the team was pilot Jim Raeder (code name, "Avid Flyer"), whose small and agile home-built plane chased the balloon as it skimmed across the desert, carried a passenger with video camera, and guided the ground-recovery team by radio.

Photo: Charlene M. Anderson

ABOVE: Members of the balloon team track the SNAKE as it slithers over the Pisgah lava flows. Since early spring we had been scouting test sites that could simulate the types of terrain we expect on Mars. Coyote Dry Lake provided a flat, hard-packed surface covered with small chunks of lava, such as might be found on martian plains. Pisgah sports relatively fresh flows of basaltic lava, partly covered by windblown sand, not yet heavily colonized by desert plants, and resembling some expected surfaces on Mars. From *Mariner* and *Viking Orbiter* images, we also know that windblown sand dunes are common on Mars; hence our tests at Palen.

Photo: Louis D. Friedman

Eureka!

The Recovery of 1982DB

by Eleanor F. Helin

ABOVE: There it is. (See arrow.) Eight years after Eleanor Helin discovered it, Malcolm Hartley found the image of 1982DB on this photographic plate taken by Ken Russell with the 1.2-meter UK Schmidt telescope at the Anglo-Australian Observatory. During this one-hour exposure, the telescope was tracked at the predicted rate of the asteroid's motion, so the background stars appear as streaks, but 1982DB does not.

Photograph courtesy of Rob McNaught

Our persistence paid off. It took eight years, but on September 16, 1990, we finally recovered asteroid 1982DB. I had discovered this near-Earth asteroid, using the 1.2-meter (48-inch) Schmidt telescope at Palomar Mountain Observatory, in February 1982, just after it had passed within 1.9 million kilometers (1.2 million miles) of our planet. We had been very excited about this little asteroid, for analysis of its orbit showed it to be the easiest known object to reach from Earth—even easier to reach than the Moon. But our attempts to recover it—to re-observe it on another swing by Earth—had been unsuccessful until this day.

We had been foiled by the crowd of stars in the Milky Way. 1982DB was too faint on our photographic plates for us to pick it out from the densely packed stars. Furthermore, we had had only the sightings in 1982 from which to determine the asteroid's orbit, so we couldn't be that certain of its location. Then, in 1988, Rob McNaught of the University of Adelaide went back over some old plates taken with the 1.2-meter United Kingdom Schmidt telescope of the Anglo-Australian Observatory in Siding Spring, Australia. He found a previously unnoticed 1981 image of the asteroid taken six months before its discovery. With this additional position, Brian Marsden, Don Yeomans and Gareth Williams were able to refine its orbit, thus improving the accuracy of its projected positions.

With this more precise orbit, Rob and I requested that a photographic plate be taken of the sky at the refined coordinates. Anglo-Australian/UK Schmidt staff astronomer Ken Russell took the plate, and on the following day his colleague Malcolm Hartley found 1982DB very close to its predicted position. Rob measured and reported its positions for September 16 and 17.

The UK/Australian team immediately sent out word of the recovery through the Central Bureau for Astronomical Telegrams so observers around the world could turn their telescopes toward 1982DB. Definitive positions have been reported by Ted Bowell, Brian Skiff and Bobby Bus of Lowell Observatory in Arizona, while Jim Gibson also observed it from Palomar Mountain. In November, further observations from Lowell Observatory provided the final positions qualifying 1982DB for an official number.

An asteroid's recovery is important because, with the additional measurements of its position, we are able to plot its orbit about the Sun with a high degree of confidence. The object then becomes eligible to move up the solar system's social scale and graduates from a discovery designation (1982 for the year of discovery, D to indicate it was found in the second half of February, and B says it was the second asteroid found during that part of the month) to a catalogued number. 1982DB is now officially 4660. At this point, the asteroid can be named. The discoverer has the honor of selecting a name. (See next page.)

The Story Behind 1982DB

Longtime Planetary Society members may remember 1982DB as the first asteroid discovered by our Planet-Crossing Asteroid Survey after the Society began supporting our program. We first recounted its story in the July/August 1982 *Planetary Report*.

That February, Gene Shoemaker and I were attempting to recover comet DuToit 2-Hartley (yes, the same Malcolm Hartley who helped recover 1982DB) with the 1.2-meter Palomar Schmidt telescope. This comet is unusual in that it had split into two pieces. While examining the photographic plate, I discovered the telltale streak of an asteroid between the two parts of the comet. From history we often hear of an unexpected discovery made while searching for something else. Here was another example of that curious phenomenon.

After the discovery, Jim Gibson followed up with more observations, just as he did for the recovery. Ted Bowell also observed it, giving us more data to use in calculating its orbit. From its orbital elements, which showed that it regularly passed very close to Earth, we suspected that this little asteroid just might be a good candidate for a spacecraft mission. Neal Hulkower, then at the Jet Propulsion Laboratory, confirmed that suspicion and determined that 1982DB was the best mission candidate so far discovered.

The continuing story of 1982DB is one of international collaboration. Teams at Palomar Observatory and at the UK Schmidt telescope of the Anglo-Australian Observatory have worked together for eight years now to tie down the orbit of this object which has so much potential. We continue to collaborate, and we hope that our combined efforts will produce more discoveries of these fascinating solar system bodies.

One last bit of serendipity: On the recovery plate of 1982DB, Rob McNaught discovered another near-Earth asteroid, 1990SA. Our work goes on . . . .

Planetary scientist Eleanor F. Helin is a member of the Technical Staff at the Jet Propulsion Laboratory. She leads the Planet-Crossing Asteroid Survey, the discovery program supported by The Planetary Society.

HELP NAME 1982DB

The discoverer of an asteroid is given the privilege of naming it. Now that 1982DB has been recovered and a precise orbit has been determined, it is eligible for a name. This is such a special asteroid, I would like to select a very special name. Since it was found with the support of NASA, the World Space Foundation and Planetary Society members, I'd like to give you the opportunity to help name it.

Here are some ideas to consider when suggesting a name:

✍ Asteroid names need not be in English, but since 1982DB is an Apollo asteroid (one that crosses Earth's orbit), traditionally a Greek or Roman name is appropriate.
✍ 1982DB is the most accessible mission candidate.
✍ Its name should have a ring to it so that "Rendezvous with . . . " can stir the imagination.
✍ Asteroids are primordial objects that hold keys to the solar system's past.
✍ Near-Earth asteroids, like 1982DB, are periodic visitors to Earth's neighborhood.
✍ An asteroid is hard to find, somewhat like a mythological land.

If you have a name you'd like to suggest, please send it before March 30, 1991, to:

Name the Asteroid
The Planetary Society
65 North Catalina Avenue
Pasadena, CA 91106

If one of the submitted names for 1982DB is selected, I will propose it to the Minor Planet Center's committee for the International Astronomical Union charged with certifying names for astronomical bodies. If they approve it, 1982DB will forever after bear this name. And if someday, as we hope, a spacecraft visits this asteroid, this name will go down in the history of planetary exploration. *—Eleanor F. Helin*

Editor's Note: If Mrs. Helin chooses a name for 1982DB that was suggested by one of our members, we will give the winner an all-expenses-paid trip to San Juan Capistrano, California, for the International Asteroid Conference being co-sponsored by The Planetary Society. The conference, to be held this June, is being chaired by Clark Chapman, our "News & Reviews" columnist, so the winner will have the chance to meet him, as well as Mrs. Helin and other members of the international asteroid community.

This promises to be an important and exciting conference, so enter early and enter often!

SOCIETY *Notes*

LET THE COMPETITIONS BEGIN

Our 1991 scholarship competitions have begun! We are now accepting applications for:

- New Millennium High School Scholarships, with up to $5,000 to be awarded;
- College Fellowships, with up to five $1,000 awards;
- Mars Institute Contest, with a $500 prize, plus a trip to a conference about Mars.

If you would like an application form or more information, write to the Society, Attention: Scholarship Department. All entries must be received by May 1, 1991.*—Louis Friedman, Executive Director*

DOUBLE YOUR MONEY

You can double your donations to The Planetary Society if you work for a company that offers a matching gift program. In such a program, the company matches the value of an employee's gift to a non-profit organization, in effect doubling its value.

These programs are especially helpful to an organization like ours, which gets nearly all its operating and research funds from members.

We thank the following companies and their employees for matching donations: Arco Foundation, Atlantic Richfield, Cray Research, Digital Equipment, Equitable Foundation, General Dynamics, Household Finance, John Hancock Life Insurance, MacArthur Foundation, Martin Marietta, Morton Thiokol, Newhall Land & Farming, Olin, Pepsico, Pfizer, Philip Morris, Pitney Bowes, Power Technologies, Quaker Oats, RCA, Security Pacific, Target, Thrifty, Transamerica, TRW, United Banks Service, US West Foundation and Westinghouse.

If you work for one of these companies, or another that offers a matching gift program, make sure your donations are included in their programs. *—Lu Coffing, Financial Manager*

MISSION TO MARS

"Mission to Mars," an elaborate new interactive exhibit, has just opened at the Center for Science and Industry in Columbus, Ohio. The Planetary Society contributed a component on international robotic exploration of the Red Planet.

The exhibit features a human outpost on Mars, a simulated martian landscape and a space station, which includes a module where students can simulate space missions. "Mission to Mars" will travel for the next four years, appearing in cities across the United States, including Atlanta, Boston, Chicago, Indianapolis, Los Angeles and St. Paul.

We are holding a special event for members at the exhibit in Columbus, and as "Mission to Mars" travels to other cities, we will plan more members' activities around the exhibit.*—Susan Lendroth, Manager, Events and Communications*

KEEP IN TOUCH

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News & Reviews

by Clark R. Chapman

There were beginnings, endings and milestones reached in our exploration of the cosmos during the last few months. It was exciting to be at the Jet Propulsion Laboratory (JPL) during early December. I was there to participate in *Galileo*'s historic encounter with Earth and the Moon on December 8, 1990. Never before has a spacecraft made a reconnaissance flyby of our own planet, although several others have occasionally returned to the vicinity of Earth. As *Galileo* sailed past at an altitude of only 950 kilometers (about 600 miles) it snapped beautiful pictures of Antarctica and Australia. A few days later it recorded a 25-hour film of the spinning Earth.

More interesting from the scientific perspective are the first-ever color pictures and spectra of the back side of the Moon. (*USA Today* and countless headline writers with Pink Floyd on the brain notwithstanding, *Galileo* observed the sunlit "back" side of the Moon, not its "dark" side.)

This Earth-encounter milestone was reached just over 13 years after the *Galileo* project's official kickoff. During encounter week, a new group of scientists from many countries gathered at JPL for their first meeting: the teams of scientists selected to participate in the *Cassini* mission to Saturn. The same week, another project came to a frustrating end as the space shuttle *Columbia* brought *Astro 1*'s telescopes back for a night landing at Edwards Air Force Base. Several astronomy flights had been planned originally; the first one turned out to be the last one, and it was unfortunately plagued by computer, plumbing and down-on-Earth weather problems.

Venus Extravaganza

The biggest accomplishments of the final weeks of 1990 concerned the planet Venus. At the annual San Francisco meeting of the American Geophysical Union, hundreds of scientists turned out to view *Magellan*'s spectacular radar pictures of the surface of Venus. Geologists are already beginning to understand the complex shapes of Venus' prominent, but rather heavily scattered, population of impact craters. Evidently, the planet's thick atmosphere protects it from being pockmarked by craters much smaller than about 8 kilometers (5 miles) in diameter. Larger craters also reveal the influence of the atmosphere. For example, there appear to be huge horseshoe-shaped deposits over 800 kilometers (500 miles) long, which may be wind-carried deposits from the most recent impacts.

Galileo researchers also reported Venus results in San Francisco. Data collected during the Jupiter probe's gravity-assist encounter with Venus in February 1990 were finally radioed back during late November as the spacecraft approached Earth. Both the camera and the Near-Infrared Mapping Spectrometer obtained images of Venus' lowermost cloud layer, where the winds were found to be blowing much more slowly than in the sulfuric acid hazes near the top of the atmosphere.

One Picture's Worth a Thousand Words

I've just seen a beautiful book that should appeal to space buffs young and old. Called *Space Places* (Collins Publishers, San Francisco), the large-format book collects the extraordinary space photography of Roger Ressmeyer. The photographer/author claims that no darkroom tricks were used for some of his special effects. But he clearly is a master of controlling his camera and even manipulating his subjects to show sides of astronomy and rocketry never before captured on film. My favorite shows the glowing Sun nestled within the network of the dish of the 64-meter radio telescope in Parkes, Australia. Another juxtaposes nature and technology with a shuttle launch framed by a flock of birds and a Floridian waterway. The diverse portraits of observatories, launch facilities, laboratories and astronaut training centers are augmented by a selection of telescopic and spacecraft pictures of the solar system and the universe.

Celebrating Another Ending

Teenagers especially should appreciate *The Great* Voyager *Adventure* by JPL researchers Alan Harris and Paul Weissman (Julian Messner, 1990). The time certainly is ripe, following the Neptune encounter, for recapitulating *Voyager*'s historic flights to the outer planets. This thin, 79-page, illustrated account treats the history of the project, its design and engineering, and its six planetary encounters. The book also manages a brief overview of the solar system and a preview of future missions.

Down-to-Earth analogies are especially good and the book is generally authoritative. There is an exception: A picture labeled *Mars Observer* shows instead the innovative design for a penetrator that the Comet Rendezvous/Asteroid flyby mission was to have fired into a comet nucleus, but NASA recently canceled the penetrator due to its inability to maintain the low mission costs promised to Congress.

With *Voyager* Project Scientist Ed Stone now installed at the helm of JPL, and with the Augustine committee's recommendations that *science* should be NASA's foremost goal, there is renewed hope that the promises of Harris and Weissman's final chapter may bear fruit. Perhaps the younger generation, to whom their book is directed, will participate in a rebirth of the Golden Age of Exploration, epitomized by *Voyager*.

Clark R. Chapman has been named editor of a newly established section of the chief research journal of the American Geophysical Union, the Journal of Geophysical Research: Planets.

World Watch

by Louis D. Friedman

The American civil space program is "at a crossroads," according to the Advisory Committee on the Future of the US Space Program. The path NASA is now following has led to a series of failures and setbacks and has generated a landslide of criticism, "some deserved and occasionally even self-inflicted," as the committee said in its report. There is a path out of the morass, however, and the committee has laid out a series of sweeping recommendations that could, if followed, lead to humanity's first footfalls on Mars.

The Advisory Committee was appointed by the Bush administration and was chaired by Norman Augustine, chairman and chief executive officer of Martin Marietta Corporation, a major NASA contractor. Yet its report could almost have been written by The Planetary Society. For years we have been arguing that scientific exploration should be NASA's primary mission, that the space shuttle should not be the workhorse of the launch program, and that the proposed space station should be redesigned and redirected.

These were among the main conclusions of the Augustine committee. Let's look at some of their statements:

- "The civil space program is overly dependent on the space shuttle for access to space."
- "It is our belief that the space science program warrants highest priority for funding."
- "We would recommend two major undertakings: a Mission *to* Planet Earth and a Mission *from* Planet Earth."
- "We share the view of the President that the long-term magnet for the manned space program is the planet Mars—the human exploration of Mars, to be specific."
- "This is a challenge that could be constructively shared among a number of nations."
- "The fundamental reason for building a space station [is] to gain the much needed life sciences information and experience in long duration space operations."
- "We do not believe that the space station *Freedom*, as we now know it, can be justified solely on the basis of the (non-biological) science it can perform."
- "NASA should proceed immediately to phase some of the burden being carried by the space shuttle to a new unmanned (but potentially man-rateable) launch vehicle."
- "Yet perhaps the most important space benefit of all is intangible—the uplifting of spirits and human pride in response to truly great accomplishments."

These statements should sound familiar to Planetary Society members. We have been sounding these themes for years. We are delighted with the Advisory Committee's recommendations.

Of course, the issuing of this report doesn't instantly cure all problems in the American civil space program. To do that will require the combined efforts of the administration, Congress, NASA and the public. The Planetary Society has launched a campaign to enlist Congress' support for the committee's recommendations.

There were some areas, however, where we wish the Augustine committee had gone a little further. Specifically and notably, we feel that it did not pay enough attention (at least in its summary; the full report is not yet released) to the potential of international cooperation in space endeavors. The European and Japanese partners in the space station will have to be consulted in its redesign, and their participation was not adequately discussed.

Nor did the committee adequately deal in its summary with the Soviet capability in human spaceflight. A fully functional space station, *Mir*, is already orbiting Earth. The *Energia* is a highly capable heavy-lift launch vehicle.

The Officers of The Planetary Society feel that greater cooperation among the spacefaring nations can significantly advance the pace of planetary exploration and the capability of humans for interplanetary flight, and make space ventures more affordable for all nations concerned.

If you would like a copy of the Executive Summary of the committee's report, please send $1.00 (to cover postage and handling) to: Augustine Report, The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106. The full report is available for sale by the US Government Printing Office.

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

Summary of Recommendations

The Advisory Committee on the Future of the US Space Program recommends:

1. Shifting the priorities of the space program to place primary emphasis on science.
2. Obtaining exclusions for a portion of NASA's employees from existing civil service rules or, failing that, beginning a gradual conversion of selected centers to Federally Funded Research and Development Centers affiliated with universities, using as a model the Jet Propulsion Laboratory.
3. Redesigning the space station *Freedom* to lessen complexity and reduce cost, taking whatever time may be required to do this thoroughly and innovatively.
4. Pursuing a Mission *from* Planet Earth as a complement to the Mission *to* Planet Earth, with the former having Mars as its very long-term goal—but relieved of schedule pressures and progressing according to the availability of funding.
5. Reducing our dependence on the space shuttle by phasing over to a new unmanned heavy-lift launch vehicle for all but missions requiring human presence.

Questions & Answers

Assuming that Uranus once rotated in a more conventional alignment and that it was indeed "knocked on its side" by a collision, how can the present orbits of its moons and rings be explained, since they are now in the plane of its equator? Had those orbits been there before the collision, or did they "migrate" to their present alignment?
—Gerry Bogacz, Yonkers, New York

The satellites of Uranus formed after the planet reached its present angle of rotation about its axis, which is tilted 98 degrees from the plane of its orbital rotation about the Sun. Compared to the other planets, Uranus seems almost to be reclining as it spins.

Let's imagine that the satellites had formed in Uranus' equatorial plane. When the planet was suddenly tilted to a new orientation, perhaps by a giant impact, each satellite would find itself in an orbit inclined to the planet's equator. Thus disturbed, the satellites' orbits would start to precess (wobble around their orbital axes) at different rates. After a while, the satellite system would be hopelessly scrambled: Each satellite's orbit would maintain the same inclination, but the orientations of the orbit to the planet and to the other satellites would be everchanging. Uranus and its retinue do not look this way today, so we know that its satellite system could not have pre-dated a planet-tipping impact.

The giant impact may have ejected material from Uranus out into an orbiting disk—a disk from which the satellites may have formed. The material in the disk would have settled gradually toward the plane of Uranus' equator. A fluid gas disk can do this; a solid satellite cannot. This is why the satellite systems of Jupiter, Saturn and Uranus lie in the equators of their parent planets: The disks of gas and dust from which they formed also circled the equator.

Bearing the foregoing in mind, it would be implausible for Uranus' satellites to have formed in their present inclinations while Uranus was tilted in a more conventional direction, and then have a chance impact knock the planet into alignment with them.

The only way to have gotten the moons to migrate to their present alignment is to have tipped Uranus over very slowly. In this case, the satellites' orbital inclinations would have been maintained throughout.

The rings of Uranus behave like a more fluid gas disk because rings are composed of an enormous number of colliding particles. Rings always form in the equatorial planes of planets. This means an old ring system could, in principle, realign itself if a planet rapidly changed its angle. The plane defined by planetary rings is so precise that, before the *Voyager* encounter, Uranus' equator (and thus its rotation axis) was best determined by ground-based measurements of its rings.

Your question speaks of a "conventional alignment" for planetary spins. I wonder if there is such a thing. After all, three out of nine planets are retrograde rotators, spinning from east to west in opposition to the rotations of the other six planets. I will leave this question for someone else.

—WILLIAM B. McKINNON, *Washington University*

What major discoveries resulted from the* Apollo *landings? How many experiments were left on the Moon, and are any of these still operating?
—Robert L. Wilson, Fullerton, California

A central discovery, among many made by *Apollo*, is the absolute age-dating of samples of lunar rocks and soils returned to Earth. Each mission also left a variety of instruments operating on the surface, powered by small radioisotope thermoelectric generators. On *Apollo 15*, for example, astronauts deployed a seismometer, a magnetometer, a solar wind spectrometer, a solar wind particle collector, heat-flow probes, lunar atmosphere and ionosphere detectors and a laser ranging retroreflector on the lunar surface—all of these in addition to their surface geological reconnaissance and sample collecting, and numerous investigations from the orbiting command module.

After several years, the instruments on the surface were commanded off irrevocably for budget reasons and to release their part of the radiotelemetry spectrum for other uses.

—JAMES D. BURKE, *Jet Propulsion Laboratory*

Large planets are often used to give gravity assists to spacecraft, and, in a pinch, even small planets are used, as* Galileo *used Venus and Earth flybys to gather the velocity to reach Jupiter. Yet, the largest object in the solar system, the Sun, has never been used for a gravity assist. Why not?
—Michael Samuelson, Seattle, Washington

A spacecraft can't use the Sun for gravity assist when it is in orbit about the Sun. The planets in our solar system and the spacecraft we send to explore them travel in elliptical paths or orbits, anchored by the dominating gravitational attraction of the Sun.

Sometimes a spacecraft needs an extra push to get it to its target planet. This can come from a gravity-assist maneuver, which can be accomplished when the spacecraft, launched on a solar orbit, passes close by a third body (for example, a planet or a moon). This body's gravity changes the spacecraft's velocity vector (a combination of both speed and direction) so that a small part of the third body's orbital energy is transferred to the spacecraft, in effect speeding it up. It then proceeds to its next target.

The Sun cannot be both the focus of the spacecraft's orbit and the third body that imparts the gravity assist.

It is possible, however, for a spacecraft to receive a gravity assist from a planet and change its path from a closed ellipse to an open hyperbola. That sort of open-ended trajectory can take it out of solar orbit. *Pioneers 10* and *11*, and *Voyagers 1* and *2*, used close passes by the giant planets to bend their trajectories into paths that are now taking them out of our solar system.

—LOUIS FRIEDMAN, *Executive Director, The Planetary Society.*

FACTINOS

Last September, amateur astronomers discovered a white "spot" near Saturn's equator. Over the next few days planetary astronomers saw the spot grow from an area the diameter of three Earths to a storm that nearly encircled the giant planet, with ammonia clouds billowing 240 kilometers (150 miles) high. So in November NASA turned the Hubble Space Telescope on Saturn, and it returned pictures like the one at right. The Space Telescope, with its faulty optical system, can still see relatively close objects reasonably well, scientists said during a press conference at NASA headquarters.

"It might just be the largest atmospheric structure right now in the solar system outside the Sun," said Andrew Ingersoll, a planetary scientist from the California Institute of Technology. But astronomers do not know what is causing the great storm. "If you like, Saturn burped," he offered.

"These planets like Jupiter and Saturn are fluid objects, all the way to the center," Ingersoll said. "There are no volcanoes erupting, because there are no volcanoes. There is no solid crust. These planets are sort of bubbling cauldrons of liquid gas."
—from the *Los Angeles Times*

The Hubble Space Telescope imaged the great storm on Saturn in both blue and infrared light. By combining images taken in these two colors, which penetrate to different atmospheric depths, scientists could study movement in the storm clouds. Here the lower clouds appear in blue, with the higher areas in red. ***Image: Space Telescope Science Institute/NASA***

Dust from disintegrating comets, rich in the molecular building blocks of life, may have rained down upon early Earth, providing a relatively gentle way for the chemicals to have reached the surface without being burned up. How these molecules could have survived the fiery heat of atmospheric entry has been a major stumbling block for scientists who believe that chemicals from deep space may have played a role in the origins of life on Earth.

But Kevin Zahnle and David Grinspoon of NASA's Ames Research Center recently reported in *Nature* that the breakup of giant comets in the inner solar system could have produced clouds of dust rich in the chemicals. As Earth passed through these clouds, the compounds could have reached the surface without the excessive heating associated with violent impacts.

The scientists reached their conclusion after studying the distribution of specific amino acids above and below a layer of sediment associated with a giant meteorite impact 65 million years ago.
—from the *Los Angeles Times*

Those five-mile-high black plumes identified as geysers on the surface of Neptune's moon Triton may really be swirling funnels of dust, gas and nitrogen ice, according to some *Voyager* scientists. In the October 19 issue of *Science,* Caltech's Andrew Ingersoll and graduate student Kimberly Tryka argue that Triton's plumes are actually dust devils, like those in windy deserts on Earth and Mars.

"The majority theory is still that they're geysers. But we're having a lively debate," said Ingersoll. One of the reasons he gave for the plumes being dust devils is that they remain narrow as they rise.
—from the Associated Press

The Solar System in Pictures and Books

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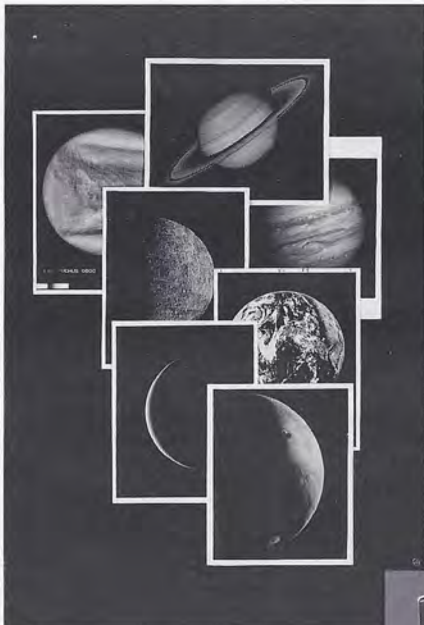

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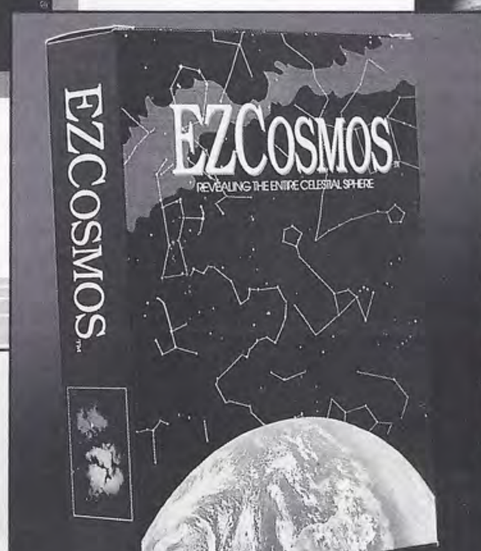

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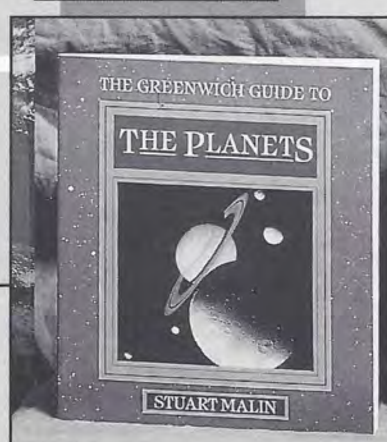

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Rick Sternbach has worked as a professional space artist since 1972 and is a founding member of the International Association of Astronomical Artists. He is currently the senior illustrator and a technical consultant on Star Trek: The Next Generation.

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