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Toward the Next Generation

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COVER: The last* Saturn 5, *the largest rocket ever to leave Earth, lifted off December 7, 1972, carrying* Apollo 17 *and the last humans to walk on the Moon. Today dismembered museum relics are all that's left of these colossal rockets. If we are to send human explorers on ambitious missions again to the Moon or on to Mars, we will once more need heavy-lift launch vehicles. With* Energia, *the Soviet Union is now establishing heavy-lift capability.

Photograph: NASA

FROM THE EDITOR

The Space Age began when, after centuries of dreaming, humanity harnessed the technology to reach beyond Earth's atmosphere. Caught up as we sometimes get in the scientific wonders revealed by our exploring spacecraft, we can forget that without rockets—launch vehicles, as technologists prefer to call them—there would be no great voyages of discovery. These endeavors all begin on top of tubes of fuel, pointed at the sky and ignited at one end to take advantage of a simple Newtonian principle: To every action there is an equal and opposite reaction.

In this issue of *The Planetary Report* we take an overdue look at the future, present and past of launch vehicles. How we plan future missions depends on what machines will be available to launch them. If we want to go Mars, we will need rockets powerful enough to lift interplanetary vessels into Earth orbit, where they will be made ready for their voyages of discovery.

Page 3—Members' Dialogue—The Planetary Society's interest in the study of Earth as a planet seems to be a hit, if we judge by the letters sent to "Members' Dialogue." However, some members question the time-table for human Mars missions and the conduct of the Search for Extraterrestrial Intelligence.

Page 4—Earth's a Planet, Too—It's no coincidence that the environmental movement blossomed just after the *Apollo* astronauts returned their breathtaking photographs of Earth floating alone in space. Emphasizing the connection of the Space Age and environmental awareness, the Society has joined the celebration of the twentieth anniversary of Earth Day.

Page 6—Solar System Exploration: Some Thoughts on Techniques and Technologies—President George Bush has called for the United States to return to exploring the solar system with humans. But NASA now has no launch vehicles capable of lifting the proposed spacecraft into Earth orbit. Former NASA engineer Ivan Bekey shares his thinking about this problem with Society members.

Page 12—Launching Planetary Missions: An International Inventory—The Soviet Union already possesses a vehicle—the *Energia*—that could be used to launch human planetary missions. Many smaller rockets are available to place satellites in Earth orbit or send robots on planetary trajectories, as surveyed here by aerospace engineer Jerry Grey.

Page 16—Masers from Mira Stars: A Scenario Revealing Jovian Planets—To discover planets orbiting other stars would greatly encourage our search for extraterrestrial life, for then we would know that Earth and its neighboring planets are not unique. Physicist Curtis Struck-Marcell has come up with an ingenious suggestion for where to look.

Page 20—Glaciers and *Glasnost*—The crumbling of the formerly Iron Curtain has recently filled the media. For the past few years The Planetary Society had already been supporting cooperation and camaraderie among Soviet space artists and those working in western nations. Artist Michael Carroll reports to members about this program's success.

Page 25—World Watch—President Bush's proposed budget was generous to NASA and to the Human Exploration Initiative, but will it survive the congressional budget process? At a recent international meeting in Hungary, scientists reviewed what we need to know to design and build future Mars missions.

Page 26—News & Reviews—*Galileo* has completed its first planetary encounter: with Venus. Clark Chapman reports on the first results.

Page 27—Society Notes—Renewed support for the Society's asteroid discovery program, recycling *The Planetary Report* and a "Sister Worlds" symposium in the Netherlands are among this issue's topics.

Page 28—Questions & Answers—We tackle queries on planetary rings, tiny spacecraft and lunar dust, and present the first ever image of an asteroid.

—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 motivation for continued space endeavor is now a necessity, not for particular countries, but for the inhabitants of Earth. We now face as *a single people* a series of ecological factors that seriously threaten the long-term survival of humanity. Robotic and human interplanetary missions, as well as those designed to directly study our environment, must be completed and should not be contingent upon the need to correct budgetary imbalances.

In regard to the aforementioned, the January/February 1990 issue of *The Planetary Report* was superb. It boldly addressed the critical issues that face us and directly challenged the view that Earth is not linked to the same forces that control the destiny of other planets. We are children of a planet that is part of the rest of the cosmos and must act to protect that very special grain of sand we call home.

—DANNY B. CRAIN, *Las Vegas, Nevada*

Your January/February issue of *The Planetary Report* is truly a crowning achievement. Aside from the content and emphasis of the articles, several of the space photographs are ones that I have never had the privilege of seeing before.

As our 20th-century world continues to shrink and the importance of maintaining borders is superseded by the necessity to deal with global environmental problems, photographs like the ones in this issue do an exemplary job of demonstrating the artificiality of the geo-political boundaries humankind has drawn. Your January/February issue demonstrates how The Planetary Society is capable of utilizing its resources to help engender such changes.

—KARL MARTIN, *Bellingham, Washington*

The New York Times says that NASA's Search for Extraterrestrial Intelligence (SETI) has just received funding. Great! It worries me, though, that I read so much about SETI's awe-inspiring hardware and so little about how any messages from out there are going to be interpreted or answered. What little I have found on that subject seems to be based on the unlikely assumption that any aliens we contact are prepared to follow a scenario of our devising. The reasoning seems to be that we will be able to reach only technologically advanced civilizations that will have mathematics like ours and that therefore they will be able to communicate with us in mathematical terms.

Where are the linguists, diplomats, explorers, biologists, animal psychologists, social scientists and literary people—the specialists in various aspects of communication—who are going to deal with the messages we hope to receive? It seems to me that without them we have only an awfully expensive toy.

—MARGARET S. HUNT, *Jamaica, New York*

I have mixed feelings about the current push to send humans to Mars. I have no doubt about the importance of this goal or of its eventual achievement. My concern is over the timing. What's the rush? Mars will be around for a long time. I have an excellent chance of seeing this [mission] come to pass. Too many, however, have no chance at all. They will die of hunger in a world capable of providing food enough for all. Clearly there are responsibilities and obligations on Earth that should be fulfilled before we send people to Mars.

A human mission to Mars, particularly a cooperative international one, would symbolically unify the world in a way that the superpowers' race to the Moon could not. But such symbolism would be pointless and hollow if we had not first seen to it that everyone on Earth had enough to eat, clean water to drink and basic literacy allowing them to participate in the mission and appreciate the symbolism. This issue deserves as much, if not more, consideration in the current debate over Mars as the relative merits of space stations and Moon bases. Whether or not we learn to live and work together on Mars, we must learn to live and work together on Earth. Mars can wait, Earth cannot.

So much of what we read in these pages is the result of human curiousity and ingenuity, of hope and adventure, of *dreams*. If we defer our dreams for a little while we can enable more people to share in them.

—BRUCE WOOLLATT, *London, Ontario*

NEWS BRIEFS

On January 24 Japan launched two small satellites to the Moon. Working on a shoestring budget of $41 million, Japan became the third nation after the United States and the Soviet Union to launch a lunar mission.

If all works according to plan, the two satellites will approach the Moon on March 18 and use its gravitational field to catapult the larger of the spacecraft into an elliptical orbit that will hurl it back toward Earth and then again to the Moon. The smaller satellite, only 14 inches in diameter, will orbit the Moon to test systems that Japan hopes to use to send other instruments, including a seismometer, to the lunar surface in future missions.

—from *The New York Times*

Scientists and engineers at the European Space Agency (ESA) are excited over the idea of awakening the *Giotto* probe and sending it to comet Grigg-Skjellerup in 1992. On February 19, they sent a series of commands to the probe via NASA's Deep Space Network tracking station in Madrid. A faint return radio signal from *Giotto* confirmed that the spacecraft could be contacted and reactivated.

Now scientists will attempt to maneuver the spacecraft so that its antenna is pointed toward Earth and tests of its health can be performed. *Giotto* has been orbiting the Sun in a "hibernation" mode since April 1986, following its triumphant encounter with Halley's Comet.

—from the European Space Agency

On February 1, cosmonaut Alexander Serebrov left the Soviet *Mir* space station to flight test a new vehicle for the first time. The Soviet media variously describe the vehicle as a space motorcycle, a space bike and a space armchair. Serebrov took the vehicle as far away as 30 meters (about 33 yards) but never without a tether that kept the vehicle attached to the station at all times. The flying armchair is very similar to the manned maneuvering unit first used by US space shuttle astronauts in 1984.

"It certainly increases their ability to work in the vicinity of the space station. It allows them to retrieve experiments or do repair work," said Marcia Smith, an analyst of the Soviet space program at the Library of Congress.

—from *Space News*

Earth's a Planet, Too

The Planetary Society Supports Earth Day 1990

by Charlene M. Anderson

Photograph: NASA

The Planetary Society's new program to encourage investigation of Earth as a planet, announced in our January/February issue, has led us to join in celebrating the twentieth anniversary of Earth Day. Executive Director Louis D. Friedman is serving on the Environmental Advisory Council of Earth Day 1990. What is the connection between the environmental movement and a group that advocates planetary exploration ?

The Space Age has brought much good and evil to the Earth-born species that created it. With magnificent technology and Promethean effort, humans walked upon the Moon. With intricate and imaginative communication satellites, we "shrank" our planet. We invented new electronic senses to watch Earth—and each other—from orbit. We built weapons that could destroy the world as we know it, and from them created rockets to take us into space.

Perhaps most important, in this Space Age we took a few remarkable photographs that changed forever the way we see our planet. The *Apollo* astronauts on the way to the Moon turned their cameras back on Earth and photographed a warm and nurturing, but small and ineffably lonely, planet drifting through space.

It's no coincidence that, after seeing these photographs, many people were so impressed by the fragility of Earth that they joined the emerging environmental movement. Indeed, those Space-Age images may have provided the impetus the fledgling movement needed to get off the ground

1970 — Earth Day

On April 22, 1970, environmentalists proclaimed the first Earth Day, to "raise the consciousness" of people about dangers that were beginning to reach global proportions. With their own eyes, people could now see that Earth was a small planet. Local activities, such as dumping toxic wastes into rivers, could spell disaster for someone downstream and, eventually, on the other side of the world.

The maturing space program advanced our knowledge of how Earth works. We saw better how seemingly benign or unconnected actions can cause harm planetwide. Using the runaway greenhouse of Venus as an example, scientists modeled atmospheric processes on Earth, and grew alarmed about the warming effects of greenhouse gases here.The destructive effects of chlorofluorocarbons on Earth's protective ozone layer were predicted by scientists using models of aerosol chemistry in Venus' atmosphere. Scientists who studied planetwide dust storms of Mars realized that they could be analogs for atmospheric effects on Earth after a nuclear war, which eventually led to the concept of "nuclear winter."

The planetary program has contributed much more than inspirational images to environmental awareness.

1990 — Earth Day

Twenty years after the first Earth Day, people around the world are preparing to celebrate the still-growing movement to protect the environment.

In 1990 *Magellan* will enter orbit about Venus and begin mapping the surface of Earth's "sister world" with radar. On its way to Jupiter, *Galileo* swung by Venus and will later encounter Earth. The Planetary Society is sponsoring a "Sister Worlds" lecture series to publicize how planetary spacecraft teach us about our own world. The Society has joined with the United Nations Association of the United States of America to generate a report on how international organizations can help deal with global environmental problems.

We are demonstrating how planetary exploration can help protect Earth's environment.

On the fiftieth anniversary of Earth Day, humans may look back on their home from the surface of another planet. If The Planetary Society succeeds in our campaign promoting an international human mission to Mars, we could be celebrating the unique and precious environments of two planets supporting human life.

2020 — Mars Day?

By 2020 we could be exploring Mars to answer questions that bear on our own planet. Did this most Earth-like of planets once harbor life? If it did, what happened to the martian lifeforms? Could we—and should we—introduce terrestrial life to an alien world?

With our technology and effort, we will someday reach out to another planet. When humans explore Mars, we will find out if this new world can support our striving and contentious species. If we have learned the lessons taught on all the Earth Days from 1970 to 2020, it may be that wiser and more careful beings step onto Mars than stepped onto the Moon.

The Planetary Society is working toward that day.

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

Solar System Exploration: Some Thoughts on Techniques and Technologies

by Ivan Bekey

Whether or not the United States builds "heavy lift" launch vehicles is an issue critical to the future of American planetary exploration. If, as President Bush has announced, NASA is to undertake the exploration of Mars with a human crew, then the agency must have access to heavy-lift vehicles.

At first glance, it seems there must be a simple solution to the heavy-lift problem. Twenty years ago the United States already had that capability with the *Saturn 5*. The Soviet Union has recently tested the *Energia*, which can lift as much as a *Saturn 5*. How can this be a difficult problem?

Many experts have suggested that NASA build a "big, dumb" booster—a relatively cheap, expendable launcher. Planetary Society President Carl Sagan and others, reviewing NASA plans for the National Space Council, suggested that the American space agency could use the existing capabilities of the Soviet *Energia* to lift at least some large payloads. These ideas need to be explored.

NASA is working on several launch vehicle concepts: the Advanced Launch System (jointly with the Department of Defense), which would be a modular expendable booster; *Shuttle C*, in which a cargo module replaces the manned orbiter; *Shuttle Z*, a more powerful derivative of space shuttle technology; and a series of even larger vehicles constructed of shuttle-system components. *Shuttle Z* struck us as a very innovative technical idea—quite apart from its value to the space program, which will be decided by its cost and usefulness. We invited the inventor of this idea, Ivan Bekey, then with NASA's Office of Exploration, to present his ideas and their technological context to Planetary Society members.

—Louis D. Friedman, Executive Director

The American space agency NASA, several aerospace firms and many spacefaring nations are working to define the means to make humanity a multi-planet species. Given the nature of the human spirit and its history, I believe that humans will travel throughout the solar system; the only uncertainty is who will go and when. This short article addresses several key technical features of interplanetary missions of the near future and concludes with a launch vehicle concept that could help make these missions happen.

Where to Go

There are many potential destinations in the solar system, but we will go to the Moon or to Mars. There are several routes we could take to either destination, but, to shortcut the perennial arguments, Mars must be our goal in the next two or three decades.

The path to Mars may be direct or via the Moon. Each would be worthy of an outpost in its own right: Mars because it is a relatively hospitable planetary laboratory with perhaps a record of past life, and the Moon because it is a close source of extraterrestrial materials and a laboratory for learning to live and work on a world other than Earth. In fact, President Bush has set both the sequence and the goal.

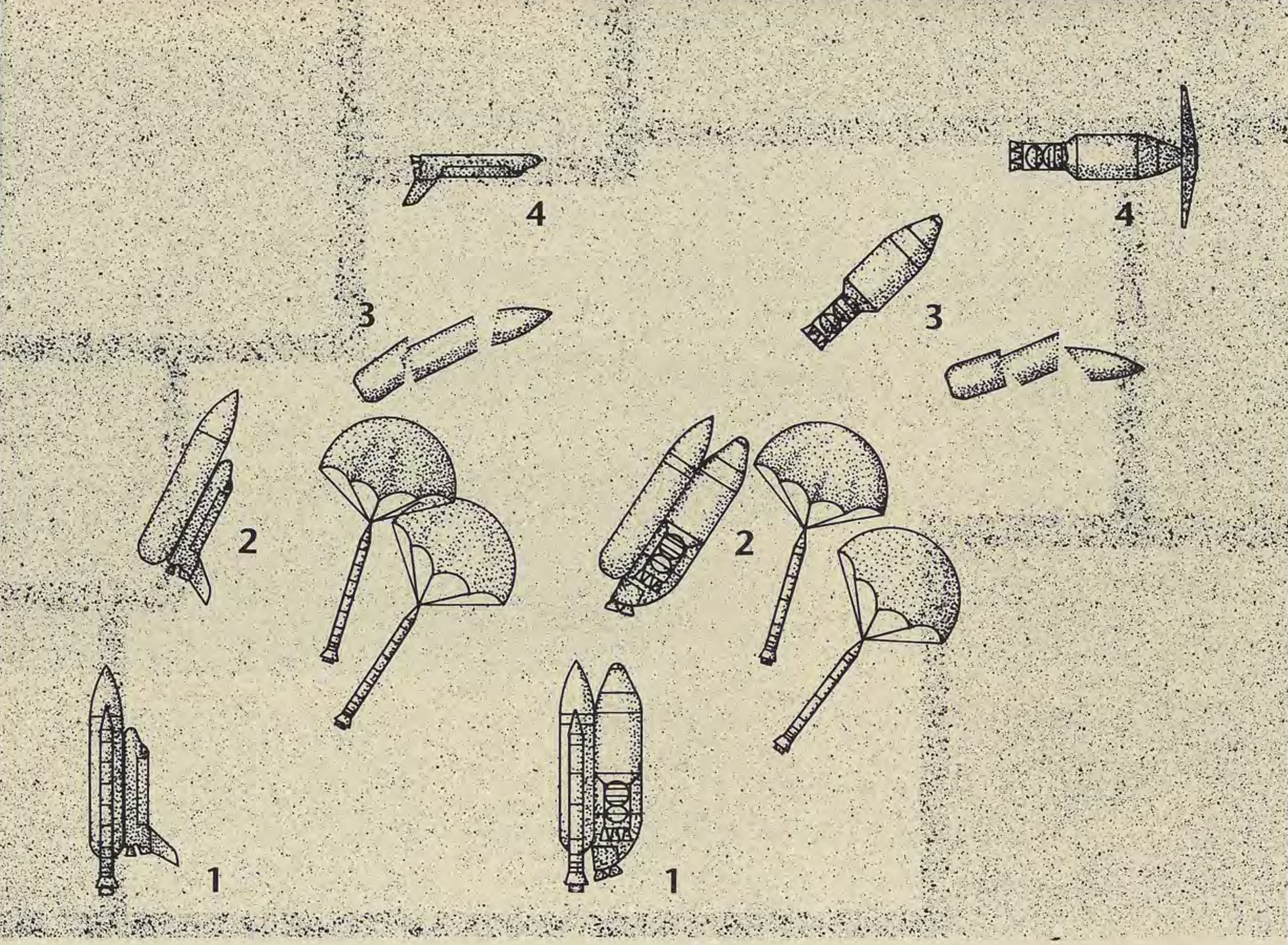
Shuttle Z, a proposed adaptation of shuttle technology, could deliver all the elements of a piloted Mars expedition for assembly in low Earth orbit in only five launches.

The questions that will shape the design of Mars missions center on the effects of long flight times on humans and the related issues of prolonged weightlessness, radiation protection, life support and spacecraft reliability.

Using chemical propulsion, most high-energy trips would take 14 to 20 months, with a stay on the surface lasting about one month. Flying minimum-energy trajectories would lengthen the trip to about 36 months. The surface stay times for these longer missions could be chosen from a few months to over one year, but the total trip time would stay about constant.

To g or Not to g

We don't know enough about the effects of zero gravity on human beings during extended missions. For even the shortest Mars trips, we cannot be certain that a program of exercise and drugs to mitigate the effects of weightlessness will ensure the safety and productivity of the crew. Thus we have two main choices: We can provide artificial gravity by spinning the spacecraft to produce centrifugal force to simulate gravity, or we can find a way to speed up the spacecraft so that the exposure to zero gravity is at most six months, a period for which the database from Earth-orbital flights is good.



Conventional Shuttle Launch

1. Configuration consists of two Advanced Solid-fuel Rocket Motors (ASRMs), the External Tank (ET) and the shuttle.
2. ASRMs are jettisoned and recovered for re-use. Shuttle continues ascent powered by ET.
3. ET falls away and breaks up.
4. Shuttle lofted to low Earth orbit.

***Shuttle Z* Launch**

1. Instead of a shuttle, this configuration carries a Mars spacecraft plus a transfer stage.
2. ASRMs are jettisoned. *Shuttle Z* continues powered by ET.
3. ET falls away. Transfer stage is used as third booster stage, powering the remainder of the flight to low Earth orbit.
4. The Mars spacecraft and now-empty transfer stage wait in orbit to be refueled by another *Shuttle Z.*

Illustration: S. A. Smith

Providing artificial gravity can be done readily in either of two ways. The first is to separate the spacecraft into two parts, connecting them by a tether about one kilometer (0.6 mile) long, and then spinning the two parts about each other at one to two revolutions per minute. This rate, by consensus in the life sciences community, is probably low enough to avoid motion sickness. In early 1991 a shuttle program with a tether 20 times longer than required for artificial gravity will have proven the requisite technology, paving the way for life-science research missions.

Another choice is spinning the vehicle about its longitudinal axis at six or more revolutions per minute. Such vehicles could have much shorter and rigid arms, with swing-out habitats and pressurized access tunnels. But these advantages may be immaterial if this configuration produces nausea, which it is quite likely to do. The choice between these two means of artificial gravity will depend on research that is not yet scheduled. But in either case, studies have shown that their cost and weight penalties compared to zero-g designs may be very small.

To Mars and Back in Four Months

A different solution for a Mars mission, using a zero-gravity vehicle, would require new technologies in very high power nuclear-electric or thermal propulsion; these methods could reduce round trip times to four to six months. We already have technological concepts for achieving power levels of hundreds of megawatts, enough to

The US Space Transportation System (STS)—comprising the shuttle and its booster rockets —has launched **Magellan** *to Venus and* **Galileo** *to Jupiter and will soon place the Hubble Space Telescope into a low Earth orbit. Still, the shuttle's capability is limited by the requirements for sustaining a human crew. Engineers are exploring ways to increase the STS's versatility. Two concepts on the drawing boards are* **Shuttle C**, *which would replace the shuttle with a cargo carrier, and the even more capable* **Shuttle Z**, *which would refuel after attaining orbit.* *Photograph: NASA*

From Fireworks to Rockets

Our modern rockets are simply fireworks grown to enormous size. Fireworks apparently originated centuries ago in China. Someone must have discovered that a faulty firecracker with a hole in one end (perhaps due to a loose fuse) could fly up into the air. With a stick added for aerodynamic stability, this became the "fire arrow."

One simple way to see why a rocket accelerates is to think about the pressures due to the explosion. At the front of the combustion chamber the gases are pushing; at the rear they are expanding to lower pressure through the nozzle. This difference in pressure creates the thrust.

A view more pleasing to physicists is that, in the chamber,

make short trip times possible. But if left to mature at their own pace, they would take decades to become ready for flight. On the other hand, if very aggressively pushed and well funded, these techniques might become available in the time frame of the first Mars missions—that is, in the first two decades of the 2000s.

Such short trip times—well within our database for human spaceflight —would ease the requirements for technology development in other areas, such as aerobraking, artificial gravity and closed-cycle life support. Funds could be concentrated on propulsion, the technology with the highest payoff, and the risk of Mars trips would thus be greatly reduced. Nuclear propulsion technology alone could open the solar system to human exploration.

Mining the Moon and Mars

One popular concept for use of extraterrestrial materials has liquid oxygen being produced on the Moon and sent to low Earth orbit to fuel Earth-Moon and Earth-Mars transportation. This is called "lunar leverage" in analyses that show more mass coming back to Earth orbit than was used in establishing the capability.

But the savings in fuel mass do not equate with cost savings. Separate analyses at NASA and at Martin Marietta Corporation indicate that propellant export from the Moon probably doesn't make economic sense. This is because of the costs to transport the propellant far from the Moon.

It may make economic sense, however, to supply propellant and other consumables produced from extraterrestrial materials for "local" use. Thus lunar liquid oxygen could be used in transportation between the Moon's surface and lunar orbit. Likewise, propellant produced on Mars may only make sense for use in the martian neighborhood.

Helium 3 and Fusion

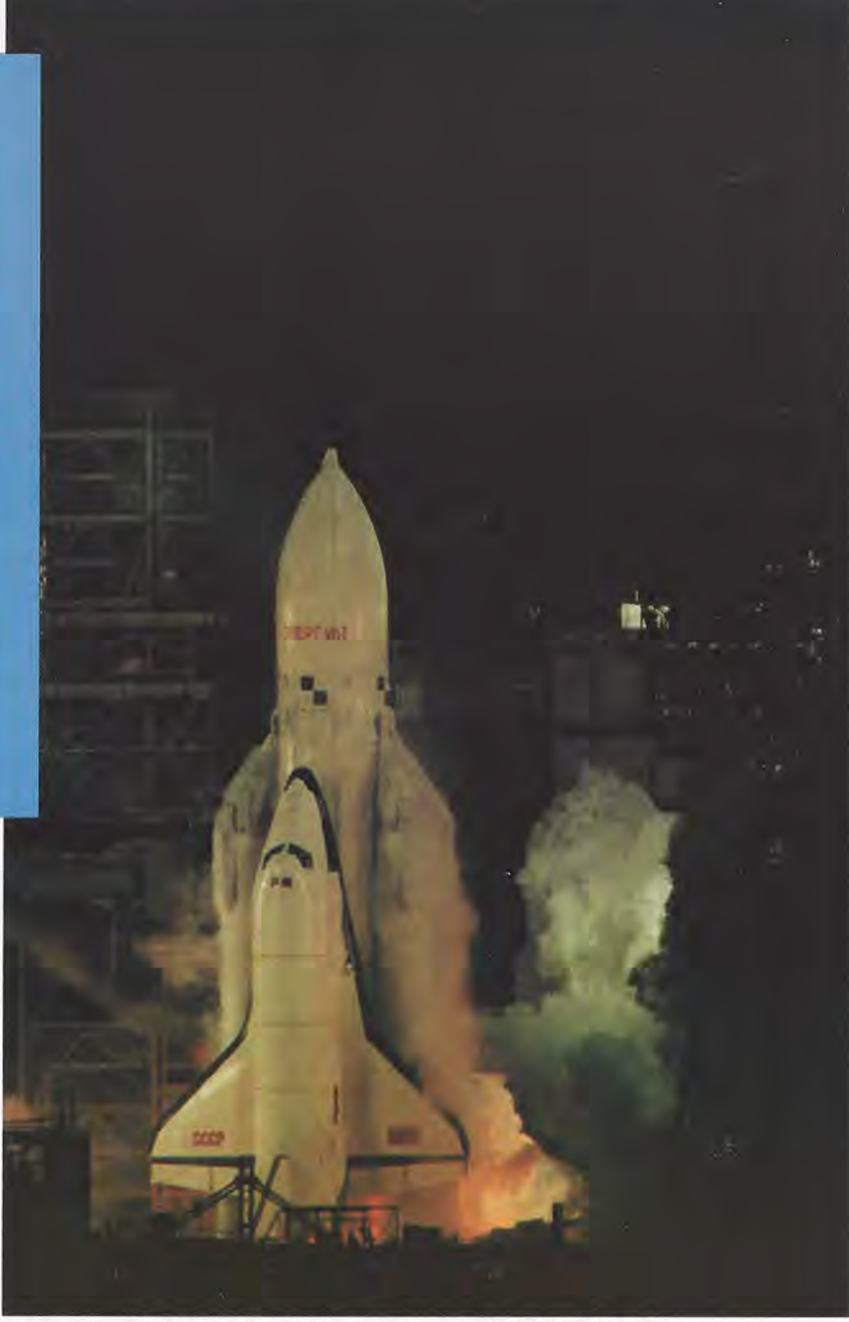
One of the most intriguing possibilities of a permanent presence on the Moon is mining helium 3, which could be sent to Earth as a fuel for generating electricity by fusion. Helium 3 would make fusion reactors much cleaner and available up to a decade earlier, according to the US Department of Energy.

With helium 3 the fusion reaction produces primarily protons, not neutrons, and thus it is three orders of magnitude more benign in terms of radioactivating the reactor's structures. Helium the random thermal energy of the hot gases, whose molecules are moving in all directions (the hotter it is, the faster they go), is converted by flow through the nozzle into directed momentum of the jet.

Either picture leads to the same conclusion: If mass is ejected toward the rear, the rocket is propelled forward. The rearward ejection can be due to any of several means—chemical or nuclear heating of gas, electric acceleration of ions or throwing dirt or rocks with an electromagnetic mass driver—the net result is forward thrust.

At the close of the nineteenth century, Konstantin Tsiolkovsky first wrote the exponential equation relating a rocket's supply of reaction mass, or propellant, to its final speed: The higher is the speed of the ejected particles, the smaller is the amount of propellant needed to reach a given speed. To escape Earth's gravity, the rocket's payload must be accelerated to more than 11 kilometers per second.

Going that fast is the only way to depart from our heavy home and today chemical rockets are our only means to reach the needed speeds. In the far future our descendants, possessed perhaps of new Promethean fires, may marvel at our achievements as we now do at what our forebears did with ox carts. *—James D. Burke, Technical Editor*



The multi-purpose launch vehicle* Energia *carried the Soviet space shuttle* Buran *on its maiden flight on November 15, 1988. With its central fuel tank and strap-on boosters,* Energia *resembles the American shuttle launch system, but there are significant differences; most important,* Energia *can carry either a shuttle or a heavy-payload module to Earth orbit and beyond. This heavy-lift capability has led some American space observers to suggest that instead of developing another shuttle-based launch system, NASA might buy* Energia *launches from the Soviets. In fact, a Houston-based attorney has secured the rights to market* Proton *and* Energia *launches.

Photograph: Novosti from Sovfoto

3 does not exist on Earth in commercial amounts but is plentiful (though dilute) on the Moon.

A NASA workshop concluded in 1988 that it may be economically viable to mine the Moon for helium 3 to supply virtually all the electrical power needs of all nations on Earth for millennia to come. A NASA-chartered task force has analyzed the opportunities for commercial ventures to supply electrical energy to Earth from the Moon. It endorsed the potential of helium 3 (as well as power-beaming satellites built from lunar materials) and concluded bullishly that the Moon *must* play a role in long-term energy supply to Earth.

Space Station Freedom

According to NASA studies, the space station *Freedom* will be necessary to assemble, check out, fuel, repair and service departing and arriving lunar and Mars vehicles. Contrary to some popular arguments, NASA's analysis is showing that *Freedom*'s configuration is well suited to support these operations as the station evolves. Short (perhaps two month) periods of disturbance while spacecraft are assembled would alternate with quiescent times, perhaps lasting for the rest of the year, for microgravity experiments.

While the studies are not yet complete, it is already clear that if a station like *Freedom* were not available, something very similar in function would have to be provided to carry out lunar or Mars programs. Thus space station *Freedom* is not only a necessary infrastructure to go to the Moon or to Mars, its design is very well suited to grow to the orbital facility that will be needed.

Heavy Lift: Shuttle Z

To build the orbital infrastructure and mount these ambitious missions, we will need heavy-lift transportation. Recent studies indicate that for practical lunar missions we'll need launch vehicles that can place at least 70 to 90 metric tons in orbit per launch. For practical Mars missions we need to be able to put 100 to 200 metric tons in orbit per launch.

While new launchers, such as the Advanced Launch System, would probably have the lowest operating costs, their development costs will be very high. But it is not necessary to develop an entirely new vehicle. An unpiloted shuttle-derived vehicle, known as *Shuttle Z*, could fill the bill. Being a modification of an existing vehicle, *Shuttle* Z would have low development costs and, as an add-on to an existing fleet, reasonably low operations costs for the fairly infrequent flights anticipated.

The *Shuttle Z* concept, which I proposed and named for NASA's recently dissolved Office of Exploration (Code Z), is based on a new way of using a component common to all missions that go beyond low Earth orbit—they all carry a large propulsive stage to power the transfer from low Earth orbit to a higher trajectory (to the Moon, to Mars or to geostationary Earth orbit).

This transfer stage has always been considered (along with the spacecraft) as part of the "payload" that the booster has to lift from the ground to low Earth orbit. Since the weight of a Mars or lunar transfer stage would be four to five times as great as the spacecraft, the capability of the booster, if configured in the conventional way, would have to be very great indeed—with four to five times the capability required just to launch the spacecraft.

But suppose the transfer stage, instead of just being part of the payload, could be used to assist the booster in reaching orbit. Once there, the transfer stage could be refueled and reused to power the spacecraft into its final trajectory.

The *Shuttle* Z concept centers on this dual use of the transfer stage, which also operates as a booster third stage on top of a shuttle stack (see figure, page 7). The launch vehicle is deliberately overloaded so as to burn out at a suborbital velocity. The transfer stage is then ignited, supplying the rest of the velocity needed to reach orbit. The resulting mass in orbit is much greater than could have been orbited by the basic vehicle alone. And it is attained by expending during ascent to orbit the propellant that would ordinarily have been, as part of the payload, dead weight.

The next step is to launch additional *Shuttle* Z's, which will carry propellant tanks rather than a spacecraft as their payload. After docking with the empty transfer stage and refueling it in Earth orbit, all transfer stages are then burned to gain the velocity to reach Mars or the Moon.

Preliminary analyses forecast impressive performance for *Shuttle* Z. A shuttle-derived vehicle with its normal complement of two advanced solid rocket boosters, a strengthened external tank and three SSMEs (Space Shuttle Main Engines) would be able to lift a Mars spacecraft and transfer stage weighing 113 to 137 metric tons to low Earth orbit if the Mars transfer stage were burned as a dual-use third stage. This is almost double the payload capability without the upper stage.

Super Z's

If *Shuttle* Z were equipped with four SSMEs, the payload capability would increase to 125 to 150 metric tons.

Even bigger configurations are possible: Two pods of four engines each could be mounted on a beefed-up external tank. This design would involve considerably more development, as the basic vehicle would have to be modified to support the two thrust structures, and the launch platform modified for a second flame opening and sound suppression system. The upper estimate of the capability of such a six- to eight-engine *Shuttle* Z is over 200 metric tons.

Vehicles in this heavy-lift class might benefit from in-line configurations—carrying the payload on top of the fuel tank, not on the side as is now

A metric ton is 1,000 kilograms or 2,204.6 pounds, and so represents about 10 percent more weight than the short ton familiar to US readers.

Energia and the Mars Trip: A Soviet Watcher's View

by Saunders B. Kramer

Ever since the appearance of the Soviet Union's *Energia*, the very large payload launcher of the present era—and for some time to come—questions have been asked, especially in the US, which all boil down to: Why so much capacity when there is no payload in sight to warrant it?

Energia stands 60 meters high on its launch pad. It consists of a core stage, looking very similar to the external tank (ET) used for the US shuttle, with four liquid-hydrogen/liquid-oxygen engines, each having 806 metric tons of vacuum thrust (thrust measured in vacuum rather than in an atmosphere). In addition, *Energia* has four strap-on modules—effectively its first stage—each with a vacuum thrust of 200 tons. The strap-ons are a modification of the *Zenit* booster, which with an upper stage places 12 to 14 metric tons in low Earth orbit. Altogether this configuration of *Energia* weighs 2,400 metric tons on the pad (with its payload) and places 100 metric tons in low Earth orbit.

Because its engines are attached to the core stage (unlike the ET for the US shuttle), *Energia* can launch not only the Soviet shuttle *Buran* but also a wide variety of 40-meter-long payloads, any of which can have its own propulsion module for further orbit or trajectory changes. The US shuttle configuration is made exclusively for the shuttle and does not have *Energia*'s flexibility. However, the expensive engines of the US launch system are recovered and reused, like the shuttle to which they are attached. So far, *Energia* uses expendable engines.

With only two strap-ons, *Energia* can deliver 65 metric tons to low Earth orbit; with eight, the payload is 200 tons. The US *Saturn 5* (optimized for large lunar-bound payloads) was able to place 109 metric tons in low Earth orbit using its three-stage configuration. It was not designed to handle the shuttle.

What's It For?

The US military has claimed darkly that only something like a Soviet version of the Strategic Defense Initiative can explain the development of *Energia*. This view reflects a lack of imagination and an incomplete search of readily available Soviet literature. I can immediately think of four program uses, all described publicly by the Soviets, though not necessarily in concert with *Energia*.

1. Solar power stations, which have been noted by Gury Marchuk, President of the Soviet Academy of Sciences, and by Konstantin Feoktistov, cosmonaut and spacecraft designer. Such station designs call for masses of 80,000 to 100,000 metric tons in geosynchronous orbit (a high orbit synchronized with Earth's rotation, on the order of 35,000 kilometers).

2. Large orbiting mirrors to reflect sunlight down to farms and cities during nighttime hours to permit around the clock productivity. The mirrors would be a kilometer or more in diameter. The Soviets who have suggested this idea have attached no timetable for its deployment.

3. A lunar base, which should include a lunar orbiting space station.

4. A piloted expedition to Mars.

The fourth item in this list is the one that's most exciting to me (and presumably to most readers of *The Planetary Report).*

Payloads to Mars

Even before humans arrive on Mars, *Energia* could be used for precursor missions to ensure a fruitful trip by a Soviet or international crew. Such missions would include: placing a well supplied space station in Mars orbit (it might carry propulsion to bring the crew back to Earth); placing on Mars' surface a module to supply a crew on the ground (possibly for several months); placing on Mars' surface a vehicle for return to Mars orbit (that is, an extra one); and—a lesser but not dismissible possibility—placing a base sufficient to support a crew till the next "window" to launch a return trip to Earth.

Any of these possibilities would require multiple *Energia* launches. This being the case, and recognizing that Earth-Mars launch windows come about every 25 months and last only about 30 days, one would like to avoid dependence on a single launch pad. For those who wonder why three launch pads were built for *Energia* at the Baikonur Cosmodrome, the discussion above offers an answer.

A Dozen Launches

A piloted launch to Mars is no trivial undertaking. Roald Sagdeev, then head of the Soviet Space Research Institute, once said such a Mars spacecraft might be 2,500 metric tons in low Earth orbit. For a story I wrote (but did not publish), I gave long study to the design of an interplanetary spacecraft: It weighed in at 2,540 metric tons. This configuration included a Mars lander and an Earth return vehicle of 100 metric tons each. Two Mars rovers of substantial capability were also included.

In any scenario one can depict for the foreseeable future, a human trip to Mars using the present *Energia* configuration would require a minimum of 25 launches. (A rather large mass must be assumed for the docking hardware alone.) Boris Gubanov, one of *Energia*'s chief designers, has said that an expanded version of *Energia* could carry payloads in excess of 200 tons to low Earth orbit. That would, of course, reduce the number of launches to perhaps 12 or 14. [It should be noted that other competent estimates of Mars mission requirements rate the mass to low Earth orbit between 500 to 1,000 metric tons and four or five *Energia* launches.]

Assuming a Mars mission is in the cards, who can question the need for *Energia*?

Saunders B. Kramer, a member of the space community for more than 35 years, has been involved in the design of space stations, interplanetary spacecraft and bases, and lunar bases for much of that time. He is a Fellow of the American Astronautical Society and the British Interplanetary Society and is a charter member of The Planetary Society.

done with the shuttle orbiter. They would probably be more practical with multiple solid boosters, even though the commonality with an operating shuttle fleet would be reduced and the development cost would increase.

A Mars Launch Sequence

Using the "smaller," three-engine *Shuttle Z*, we could operate from the existing shuttle launch pads and orbit an entire Mars spacecraft—fully assembled and checked out—in a single launch, or at most two. Such a Mars craft could easily carry a four to six person crew, outfitted for a three year mission, and the return module. The propellant for transfer to a Mars trajectory would then be delivered with three *Shuttle* Z vehicles serving as tankers. Thus we could have the spacecraft ready for a Mars flight with at most five *Shuttle Z* launches and one regular shuttle launch for the crew.

The development costs would probably be an order of magnitude lower than for a new launch vehicle, and the cost per flight not very different from that of the shuttle now flying (but with four to six times the payload). That would imply a cost of about $1,000 to $1,500 per pound, an acceptable launch cost for infrequent operations, and not likely to be greatly bettered, even by the Advanced Launch System.

Robotic Missions

The *Shuttle* Z concept can also be used for robotic missions. For example, a three-engine *Shuttle* Z could send:

- 75 metric tons into Mars orbit with two launches, one for the spacecraft and transfer stage and the other for propellant;
- 74 metric tons into geostationary orbit around Earth; or
- 62 metric tons on a comprehensive reconnaissance mission to Saturn.

Perhaps the most telling indicator of its amazing capability is that with *Shuttle* Z we would be able, for the first time ever at modest cost, to orbit heavier spacecraft than we can probably afford to build at current spacecraft costs.

Do We Need This Technology?

To be sure, we could go to the Moon again, and probably to Mars, without the advances discussed here. After all, in the late 1960s and early 1970s, the post-*Apollo* program proposed to do all that, and would already have achieved those goals if funded at then-expected *Apollo* levels.

We could go to Mars and the Moon with current technology, but every aspect of such an undertaking would rely on brute force. The spacecraft weight in Earth orbit would be enormous, as would be the number of launch vehicles required to place it there and provide it with propellant. The spacecraft would be launched on a long, slow trajectory and would spin for artificial gravity to avoid long-term weightless effects on the crew. Heavy shields would ensure radiation protection during the long trip. Water and air would not be recycled.

It would be enormously expensive and risky. Each mission would be, like *Apollo*, a magnificent achievement, but we would be doomed to transient and limited exploration. We should instead be creating the knowledge and infrastructure that make for permanence and reduce risks. We should be preparing the way for humankind's journeys away from the home planet.

At the time of writing, Ivan Bekey was Special Assistant for Systems Engineering and Planning Integration in NASA's Office of Exploration (designated within NASA as Code Z).

Launching Planetary Missions:

by Jerry Grey

Exploration of the solar system begins on the ground, with a launch vehicle. In the US, early lunar and planetary missions used variations of today's *Delta* and *Atlas* launchers. The *Delta* evolved from the *Thrust Augmented Thor Delta*, a vehicle with three stages plus strap-on *Castor* rocket boosters. The *Atlas Agena D* was a "two and a half stage" vehicle, so termed because two of its three booster rockets dropped away early in flight, leaving only a single "sustainer" engine to continue boosting the *Agena* upper stage (or transfer stage) and the payload. The *Agena* upper stage was replaced by the much higher-performing *Centaur*. The *Delta* also uses a more advanced upper stage now.

Major upgrades of the three US expendable-vehicle workhorses —*Delta, Atlas* and *Titan*—recently became available due to substantial procurements by the Air Force. The *Titan 4*, designed for large military satellites that previously could be lifted only by the space shuttle, brings the top payload capacity of US expendable launch vehicles to 18 metric tons to low Earth orbit.

In addition to the *Delta, Atlas-Centaur* and *Titan,* the space shuttle is available for planetary missions. Missions brought to low Earth orbit aboard the shuttle can use any of several solid-propellant upper stages.

A more capable upper stage for use with the shuttle, the *Centaur G,* was cancelled as unsafe for astronauts after the *Challenger* failure. The *Centaur G* was to have carried the *Magellan* spacecraft to Venus and *Galileo* to Jupiter, but both these shuttle-launched missions eventually used the less powerful IUS (Inertial Upper Stage). As a result, *Galileo* must employ a much longer and more complex trajectory involving several gravity assists by Earth and Venus.

International Launchers

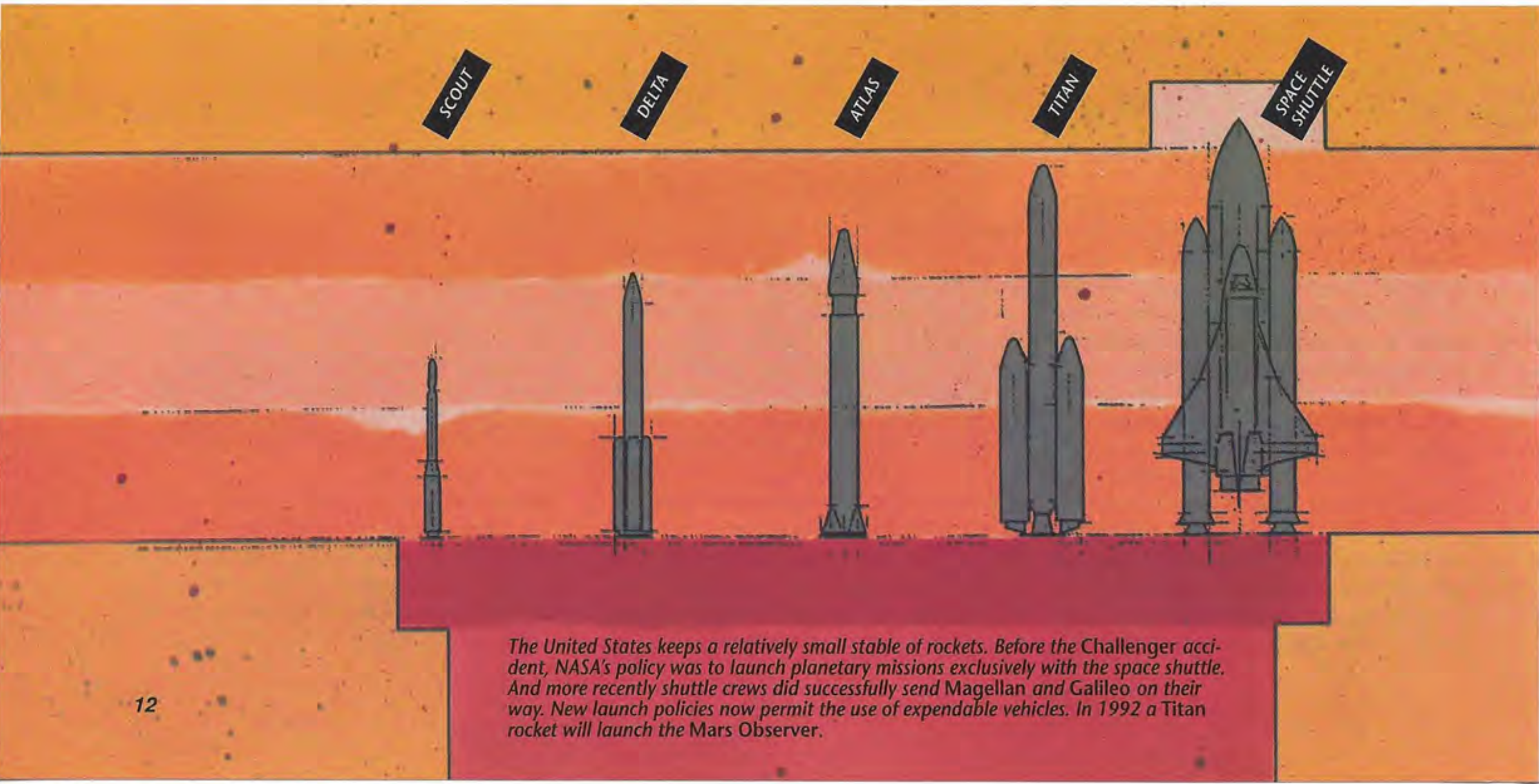
The USSR has an extensive stable of launch vehicles, with the *Titan*-class *Proton,* currently being offered for commercial satellite launches, as their workhorse. In 1987 the Soviets added a giant launch vehicle, the *Energia*, which was used in late 1988 to launch the first flight (unpiloted) of their space shuttle *Buran* ("Snowstorm").

The European *Ariane,* particularly the *Ariane 4* series, which spans the payload range of *Delta*, *Atlas* and *Titan*, is admirably suited to planetary missions, as was most recently and successfully demonstrated when *Giotto* brushed Halley's Comet in 1986. China's *Long March 3*, also being marketed for commercial satellite launches, is quite able to launch planetary spacecraft.

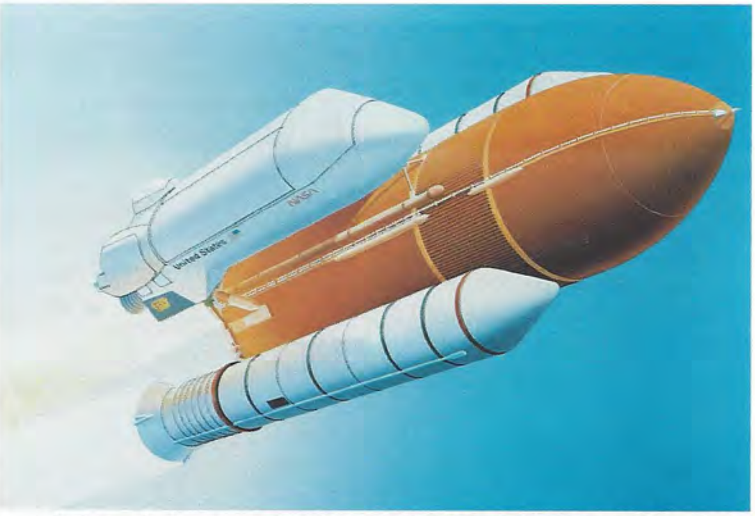
The Next Generation (US)

The next generation of US launchers remains clouded by uncertainty. NASA is in urgent need of launch capability to supplement the shuttle for deployment and assembly of the space station; the National Research Council has identified transportation as the highest-risk element in completing the station's development and emplacement.

The best prospect for that task, an unpiloted version of the shuttle called *Shuttle C* (for "cargo"), could be available in 1995 for the space station at relatively low invest-



The United States keeps a relatively small stable of rockets. Before the Challenger *accident, NASA's policy was to launch planetary missions exclusively with the space shuttle. And more recently shuttle crews did successfully send* Magellan *and* Galileo *on their way. New launch policies now permit the use of expendable vehicles. In 1992 a* Titan *rocket will launch the* Mars Observer.



To capitalize on the investment already made in the space shuttle system, NASA engineers have proposed building Shuttle C, *which would replace the piloted shuttle with a cargo carrier. This simpler configuration, freed of crew-associated mass, would enable the already designed main engines, liquid fuel tank and strap-on solid rocket boosters to carry much heavier cargoes into space.* *Illustration: Martin Marietta/NASA*

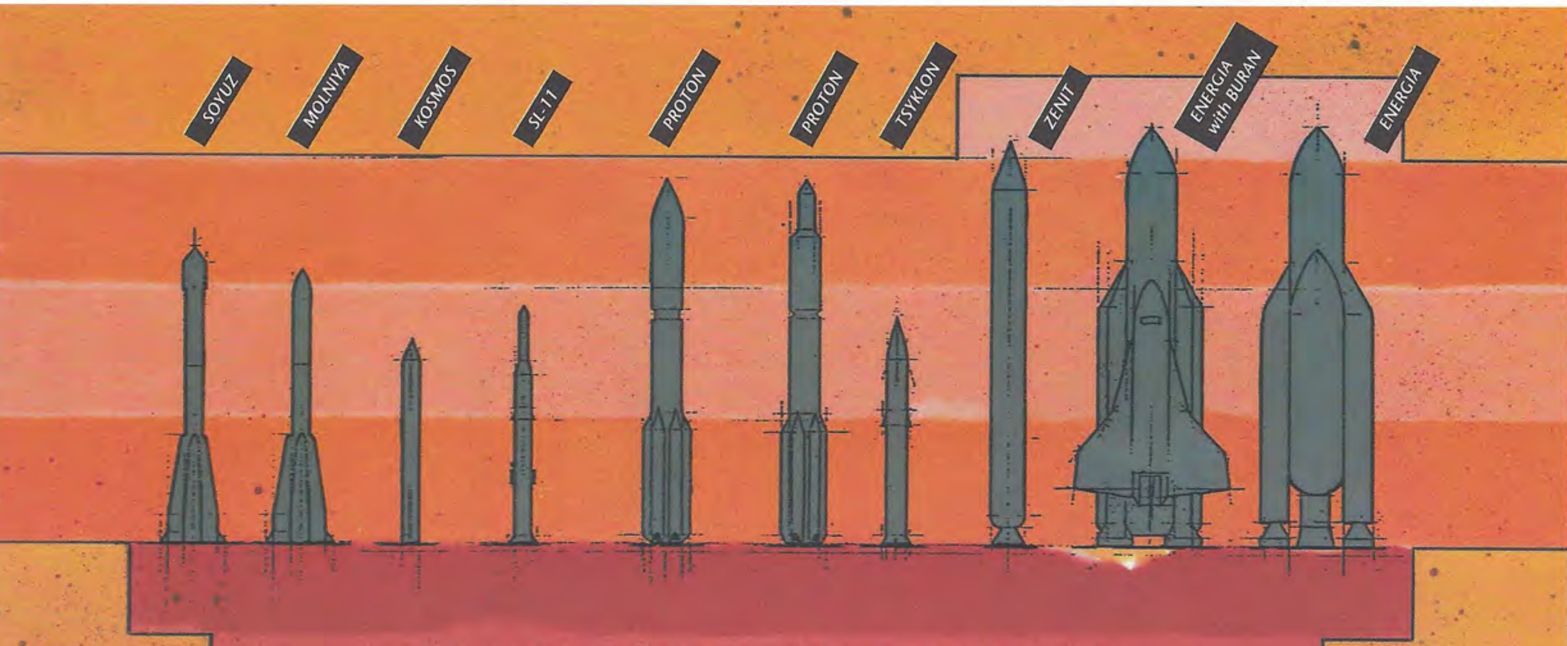
ment—about $1.5 billion—and would offer the US a payload capability of 68 metric tons to low Earth orbit. *Shuttle C* operational costs would be nearly as high as regular shuttle launches, except that with triple the payload the cost per pound would drop dramatically.

Until recently *Shuttle C* was perceived as being in competition with a much longer-term development, the Air Force's Advanced Launch System (ALS) family, whose goal was to reduce the payload costs (including the indirect costs associated with launch-vehicle reliability and resiliency) by a factor of ten below those of current launchers. ALS development has been sharply curtailed, although NASA plans to continue its involvement in the rocket engine aspect of the program.

Shuttle C or ALS could offer the US a heavy-lift capability that it does not now possess (the piloted shuttle's capacity of 20 metric tons to low Earth orbit is our current limit). But because of the chicken-and-egg syndrome—that is, the payload needed to justify heavy-lift capability will surface only when it becomes obvious that such capability will be developed—neither *Shuttle C* nor ALS has been able to muster the support necessary for vigorous and timely development.

Heavy Lift

The Soviet *Energia*, which boasts a payload capability to low Earth orbit well over 90 metric tons, has flown twice, the latter flight spectacularly successful in the maiden launch of the Soviet space shuttle. Meanwhile, the European Space Agency is committed to developing *Ariane 5*, whose payload capacity of 20 metric tons to low orbit and compatibility with unpiloted-payload characteristics will make it superi-



The Soviet Union maintains a large and varied fleet of launch vehicles, including the Proton *used for planetary missions and the current "heavyweight champion," the* Energia. *This heavy-lift launcher can be used to hoist the Soviet shuttle,* Buran, *to low Earth orbit or, with upper stages, to launch other payloads of 100 metric tons or more.*

or to the US shuttle for planetary missions. *Ariane 5* will be available in 1995, and may be used to back up the shuttle on space station deployment should the US not proceed with *Shuttle C*.

China is developing its *Long March 4* family, which will reach into the *Titan 4* class for unpiloted payloads, and Japan's H-2 launcher, with capability similar to the *Titan 3*'s, will be ready for service in 1993. It is becoming clear that an accelerated program of planetary exploration could be conducted without US launchers.

A Rocky Path

Several choices are open to the Bush administration. If we are to expand planetary exploration under the Human Exploration Initiative, with the goal of setting up human settlements beyond Earth orbit, we will need lift capability well in excess of the shuttle's. *Shuttle C* is a short-term prospect, but its high recurring costs limit it to interim use only.

Development of a low-cost, reliable heavy-lift vehicle by the US, perhaps in cooperation with industry, would make sense only if it became "America's Launch System" (using the basic design principles laid down for the ALS family) and were used not only for human exploration of the planets but also for national security and applicable commercial missions.

Another option open to the administration is to foster a degree of international cooperation that goes

The Dawn's Early Light

Rocketry is not a new science. Its origins lie somewhere in China around the turn of the first millennium A.D., when clever technicians discovered that black-powder could propel both fireworks and weapons into the sky to great effect. This technology spread from the East through Europe, where several centuries later a clever Englishman named William Congreve (1772-1828) advanced the art of rocketry in warfare. Congreve's missiles are commemorated in a poem by Francis Scott Key recounting the September 1814 battle between British and American forces for Fort McHenry: In their national anthem, Americans still sing of "the rockets' red glare."

It took nine centuries for someone to realize that rockets might be useful for something else: travel through space. Konstantin Tsiolkovsky (1857-1935), a Russian schoolmaster, realized that Newton's Third Law—for every action there is an equal and opposite reaction —explained how rockets work, and that they could be used to travel from Earth through space. Tsiolkovsky worked out equations expressing this reactive propulsion and developed the concept of staging, whereby each of the sections or stages of a rocket is used up and then jettisoned, thus imparting velocity to the next stage and reducing the weight it must carry skyward.

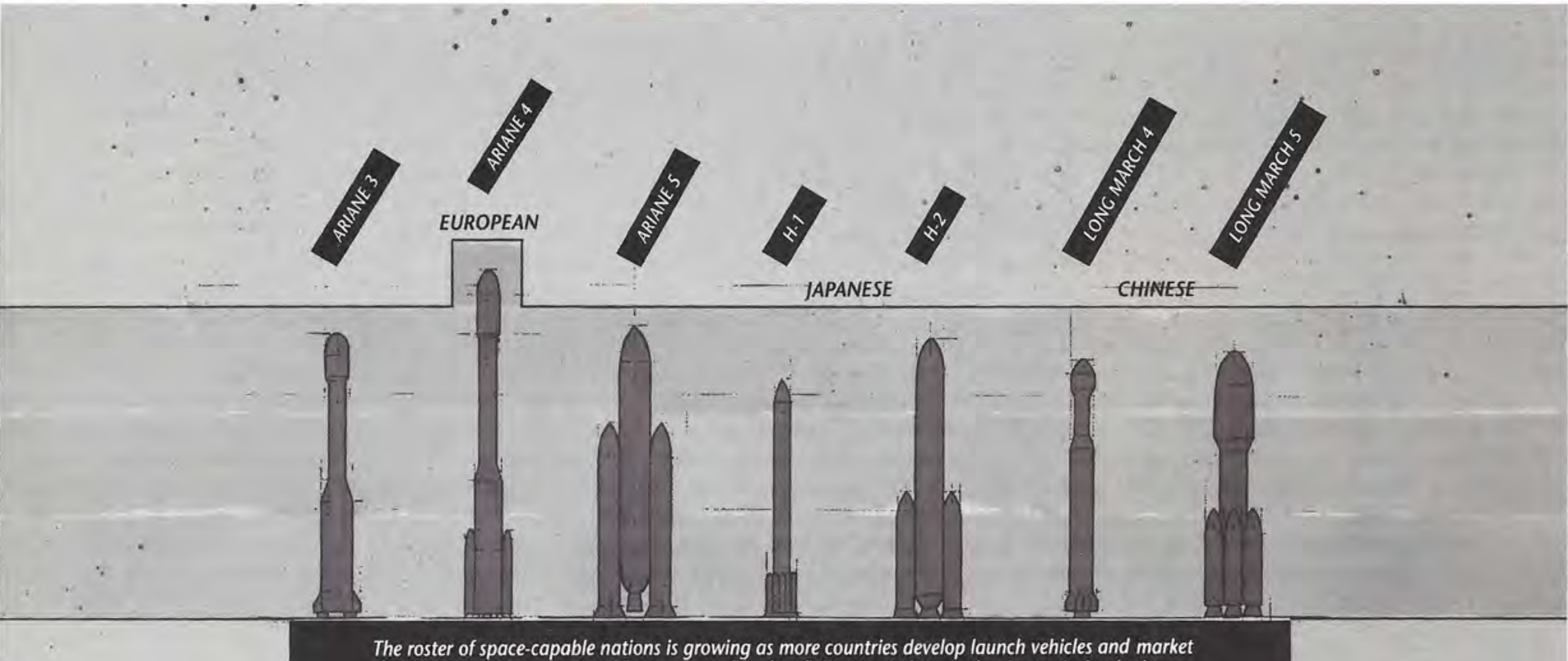
Tsiolkovsky was a theoretician, not a builder. The honor of building the first successful modern rocket goes to a Yankee tinkerer, Robert Goddard (1882-1945). Goddard seems to have independently worked out the principles of spaceflight, and on March 16, 1926 he launched the first liquid-fueled rocket. Goddard's introduction of liquid fuel instead of powders gave rocketeers a thrust source that was more powerful and easier to control.

Goddard continued developing and building ever more powerful rockets, but even through World War II his country discounted the martial potential of his gadgets. Germany, the adopted country of Hermann Oberth (1894-1990), the third great pioneer of space travel, was more imaginative.

Independent of Goddard, the native Transylvanian Oberth worked out principles of interplanetary flight (for example, that rockets can operate in a void and can travel faster than the velocity of their exhaust gases). A circle of rocket enthusiasts grew around Oberth and helped him with his experimental models. Among his helpers was Wernher von Braun, who at the Nazi rocket works at Peenemunde would develop the V-2. *—Charlene M. Anderson, Director of Publications*

Fires of the Second Dawn

On September 8, 1944 two supersonic shock waves and then a large explosion announced the arrival of the first German V-2 rocket on London. More



The roster of space-capable nations is growing as more countries develop launch vehicles and market their services. A consortium of European nations has fielded the Ariane *series; Japan is developing its own family of rockets; and China recently began marketing its* Long March *launchers.*

than two thousand of them hit London and other cities before their sources were overrun and destroyed. With its thrust of 25 metric tons the V-2 powerplant was then by far the largest rocket engine ever built. Several years passed before its performance was surpassed by American and Soviet engines. Gradually we mastered this new fire, fitful in the V-2 and still sometimes deadly, that may someday take us to new worlds.

In the 1950s, the US and the USSR built the first generation of intercontinental ballistic missiles. Designed to carry the heavy nuclear weapons of that era, the US launchers had dual or triple rocket engines with a total thrust approaching 200 metric tons, while the Soviet launcher used a cluster of smaller units to give a total thrust of more than 400 metric tons. The American missile boosters, *Atlas* and *Titan,* after a period of frequent failures, went on to become reliable workhorses of the early space program, launching *Rangers* and *Surveyors* to the Moon and *Mariners, Vikings* and *Voyagers* to the planets, as well as many Earth satellites. The big Soviet booster also had troubles, particularly with the upper stages needed to fling spacecraft into deep space, but in due course it too became highly reliable. Still in use today, it launches numerous satellites including the *Soyuz* vehicles that take cosmonauts to and from the space station *Mir.*

The next step for the Soviets was the *Proton* rocket, whose six engines give a total thrust of 900 metric tons. With various upper stages *Protons* have now launched many automated spacecraft to geosynchronous orbit and to the Moon, Venus and Mars, as well as sending two *Vega* spacecraft to Halley's Comet. *Protons* also carry heavy space-station modules into low Earth orbit. The US built a vehicle with similar performance, the *Saturn 1,* but unlike the *Proton* it did not go into regular service. Instead it was a development step toward the giant *Saturn 5,* the *Apollo* Moon rocket whose 3,400 metric tons of thrust made it the mightiest rocket ever successfully flown.

During this same period, the Soviets were building a monster rocket of their own called the N-1. According to *Izvestia,* which in its August 18, 1989 issue made the story public for the first time, the N-1 effort began in the early 1960s, but several tests of the enormous Moon rocket failed. In the early 1970s, faced with the overwhelming success of *Apollo,* the Soviets ended the N-1 program.

After the demise of the *Apollo* program and its Soviet competitor, NASA created its Space Transportation System (STS), with rocket engines totaling about 2,700 metric tons of thrust. STS shuttles people and cargo to and from low orbit but cannot send piloted craft to the Moon. Meanwhile, according to *Izvestia,* Soviet designers went on with work that led to *Energia,* now the world's largest launch vehicle.

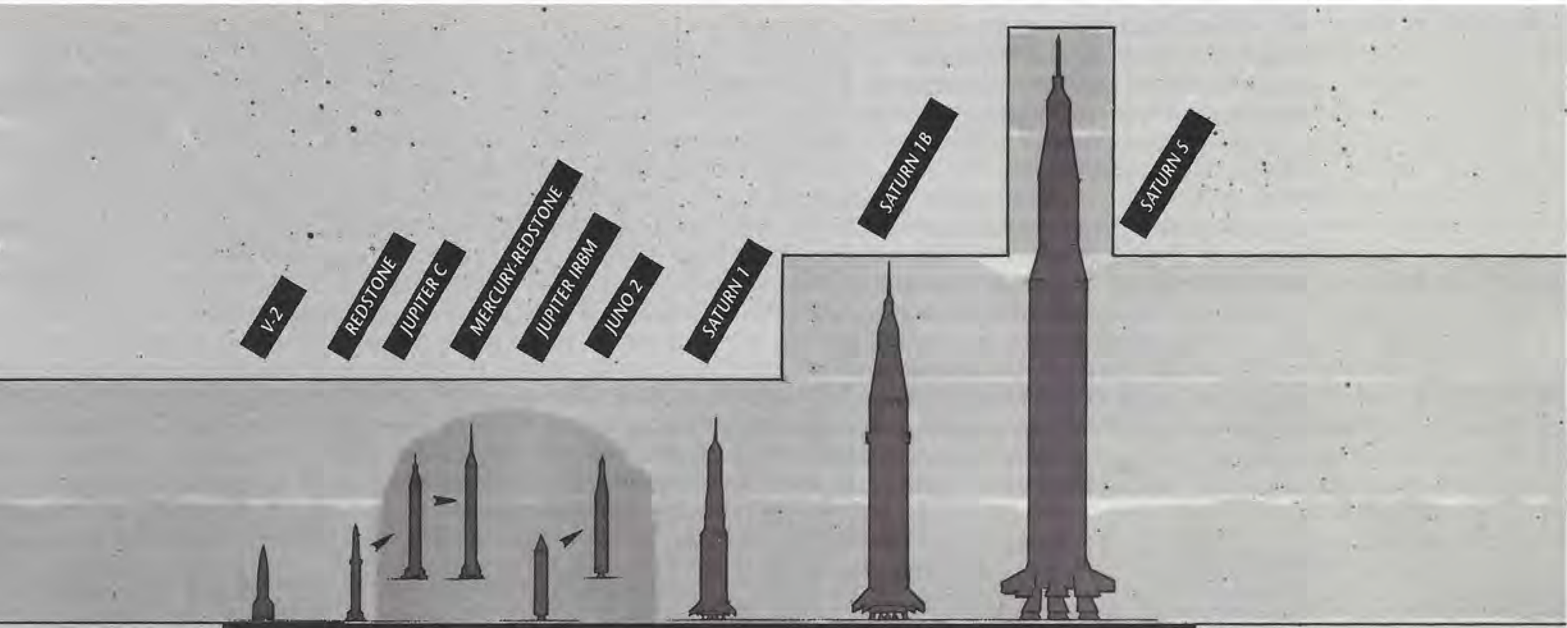
—James D. Burke, Technical Editor

far beyond any historical precedent: joint-program use of a foreign launcher such as the Soviet *Energia.* The current political thaw appears to support such a prospect; indeed, the January 1989 Soviet offer to market their Topaz nuclear reactor to the West as a power supply in space surely goes far beyond any previous overture!

However, experience with past cooperative programs that involved major system interactions (*Apollo-Soyuz,* for example) highlighted a host of mundane but knotty compatibility problems—hardware, software, technology perceptions, procedures, standards, etc.—that could hamper any significant joint effort involving multiple interfaces, despite the best of bilateral intentions.

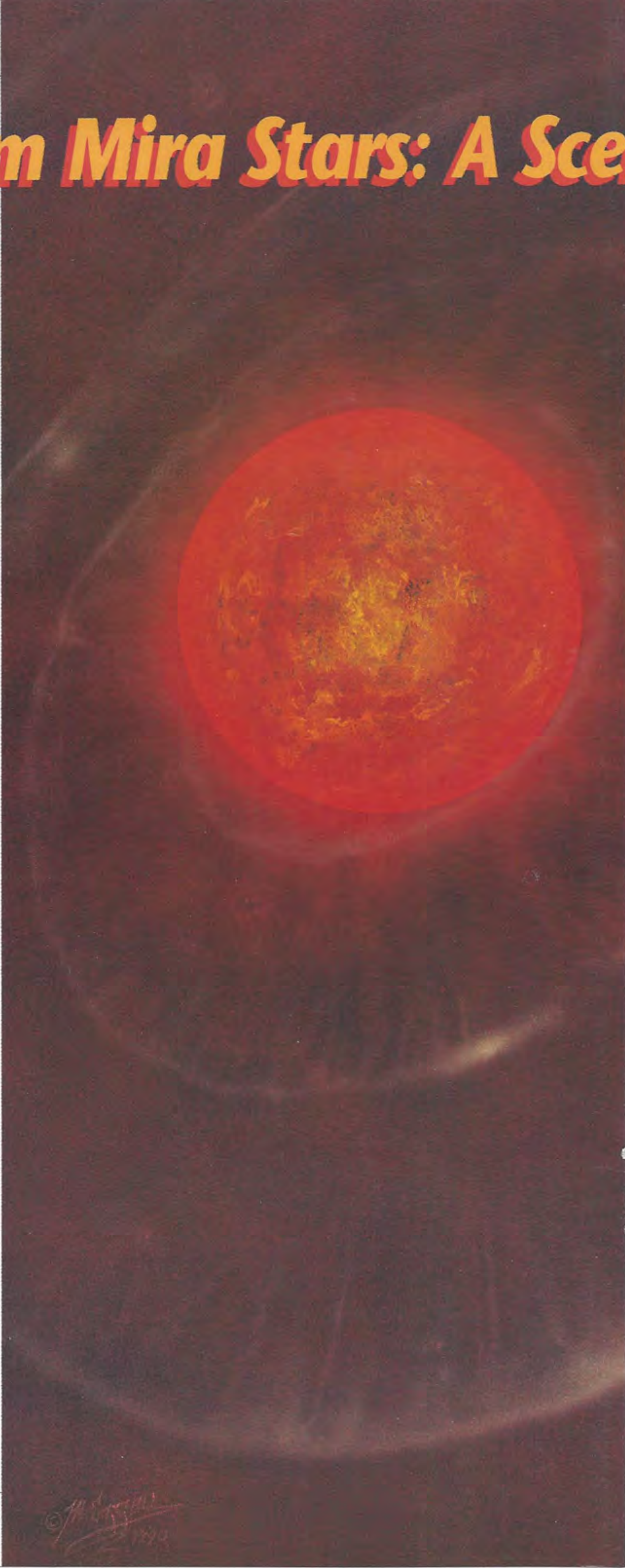
There is no question that planetary exploration will continue, and probably it will expand. But the magnitude of that expansion, and the role of the US, will be determined in good measure by President Bush's forthcoming decisions on US launch vehicle development.

Jerry Grey is Director of Science and Technology Policy for the American Institute of Aeronautics and Astronautics. He was professor of aerospace science at Princeton University for 15 years and is currently a visiting professor there. His last two popular books, Enterprise *(William Morrow, 1979) and* Beachheads in Space *(Macmillan, 1983), dealt extensively with launch capability.*



Modern rockets trace their descent from the V-2, the Nazis' "Vengeance Weapon" of World War II. In the 1950s and 1960s, the Cold War fueled development of missiles to carry nuclear weapons, producing such vehicles as Intermediate Range Ballistic Missiles (IRBMs) and Intercontinental Ballistic Missiles (ICBMs). The Space Race spurred production of even larger launchers, culminating in the mighty Saturn 5 *Moon rocket. This giant breed is now extinct.*

Masers from Mira Stars: A Sce



by Curtis Struck-Marcell

The search for extrasolar planets, to paraphrase Hubble Space Telescope astronomer Robert Brown, is the nearest thing in astronomy to the quest for the Holy Grail. We have yet to develop an instrument—probably not even the Hubble Space Telescope—that can detect an extrasolar planet directly. We must search for indirect evidence: a star seeming to "wobble" from the gravitational tug of nearby planets, displaying excess infrared radiation that might come from cool orbiting bodies, or varying in velocity due to unseen companions.

Within the radio emissions of certain stars, astronomers have discovered intense, narrowly focused microwave emissions that might help in our search. It is possible that these emissions are betraying the existence of Jupiter-like planets within the extended atmospheres of red giant stars. If this is so, we may have another way of detecting extrasolar planets from Earth.

A star in a red giant phase is in the autumn of its life. Our Sun with its retinue of planets is a middle-aged star, but in a few billion years, it too will become a red giant. Its core, depleted of its primary hydrogen fuel, will contract while its outer layers bloat to many times their original size. As they expand, these regions will cool, and our star that now burns white hot will shine with a reddish glow.

From the puffed-out atmospheres of certain red giant stars astronomers have detected strange and distinctive masers. "Maser" is an acronym for Microwave Amplification by Stimulated Emission of Radiation. Maser and laser are acronyms for similar phenomena: electromagnetic energy emitted in waves whose crests and troughs are synchronized. The visible light of a laser is energy at wavelengths that human eyes can detect. Masers occur in the microwave

nario Revealing Jovian Planets?

(short radio) portion of the electromagnetic spectrum.

On Earth, we've discovered how to produce and use lasers in many ways. We've also discovered naturally occurring masers in planetary atmospheres: near young massive stars, and in the huge, extended atmospheres of red giants. If masers are relatively common phenomena, why should they be of special interest to readers of *The Planetary Report?* Certain masers observed at red giant stars are behaving in ways difficult to explain unless objects with large and strong magnetic fields are orbiting those stars. We have an example of such an object in our solar system: Jupiter.

Many molecules in space are natural sources of maser emissions and, although they are all fascinating, we'll concern ourselves here with three maser molecules that astronomers have studied in detail in red giant atmospheres: water vapor (H_2O), hydroxyl (OH) and silicon monoxide (SiO).

To release microwave energy in synchronized waves, a molecular species—in our case a population of OH, H_2O or SiO molecules—must first receive energy from some prolific source. In the hot gas of a stellar atmosphere the molecules are jostled violently about by other molecules and atoms. They are also bombarded by photons of visible and infrared light emanating from the star. As a result, our molecules are pushed out of their "ground state," their lowest energy level, into a higher-energy or "excited" state. Usually the excited state is too short-lived for very much to happen; an excited molecule quickly settles back into its ground state, getting rid of the excess energy by emitting a photon, a massless "packet" of radiation.

LEFT: Could maser emissions from a red giant star betray the existence of a Jupiter-sized planet? As shock fronts pulsate through the bloated star's extended atmosphere, they would collide with the strong magnetosphere generated by a jovian planet. This interaction could explain the puzzling polarization of silicon monoxide masers observed near some red giant stars. Painting: Michael Carroll

But in the distended atmosphere of a red giant star, excited molecules can accumulate in a "metastable state." When they are stimulated by radiation or collisions, they can release the stored energy as photons. This stimulated emission triggers the release of more and more photons, all of the same wavelength, produced as more and more molecules release their excess energy. When this happens in a star's atmosphere, maser radiation streams out.

Maser Mysteries

You might wonder why the intense masers don't rapidly use up the excited molecules' excess energy, shutting themselves off. So the first mystery is: What keeps stellar masers turned on?

It is possible that radiation from the star and collisions could boost the molecules into metastable states to balance the maser emission. However, the star's average gas density seems too low for such rejuvenation. Another possibility is that the metastable molecules are recharged by absorbing photons radiating from the star. But this explanation also seems to require greater density than average in the maser regions.

A related mystery concerns the location and number of maser sources. OH masers are numerous and spread out over a huge volume extending quite far from the star, 30 to 500 astronomical units (one astronomical unit is the average distance of Earth from the Sun), while the H_2O masers are closer to the star. SiO masers are distributed quite differently: There are fewer of them and they occur in groups, with a few sources in each group.

The biggest mystery of all is that SiO masers are highly polarized, while radiation from the other masers is not. The waves of radiation from these masers are not only synchronized, but they are vibrating along the same plane—that is, they're polarized. The best explanation is that the SiO masers are formed within a strong magnetic field, stronger than that at the surface of our own star, the Sun. Rotating bodies with fluid interiors, such as stars and most planets in our solar system, act as dynamos and generate magnetic fields.

By interacting with the microwaves a magnetic field could polarize a maser. However, if we took our Sun's magnetic field and spread it out over the volume of a red giant's extended atmosphere—a billion times greater than the Sun's—we would get a very weak field, not an extra strong one.

Pulsating Stars

To solve the maser mysteries, we need a bit more information about red giant stars. In this stage the star's outer envelope becomes convective, with columns of gas rising and falling, and it puffs out to a radius larger than Earth's orbit. Eventually, the star begins to contract and expand. Once it begins to pulsate, it's known as a Mira (in Latin, the wonderful!) variable star.

The recent computer models of G. H. Bowen of Iowa State University have shown how profoundly these pulsations affect the atmosphere of a Mira star. Before the Mira stage, a star like the Sun has a surface called the photosphere, beyond which gas density and pressure fall off rapidly. Once it has entered the Mira stage, the star's pulsations create an extended atmosphere whose density declines only slowly as you go outward.

The pulsations push material out of the star's body, past the outermost envelope and into the extended atmosphere. The densities in this atmosphere are roughly a trillion times less than those of Earth's atmosphere at ground level, and about a hundred times too low to maintain the SiO maser emission.

The star's convecting outer envelope might occasionally splash high-density blobs up into the atmosphere, and these blobs could be the SiO maser sources. Blobbing would explain the distinctive grouped distribution of SiO masers. SiO maser emissions might also be coming from regions of high density formed as materials cool unevenly behind the shock waves generated by the stellar pulsations. But these theories do not account for the extreme maser polarization. Fortunately, there is an alternative.

Engulfing Planets

When the Sun becomes a Mira, the whole solar system will be contained within its extended atmosphere. The innermost planets, perhaps all the terrestrial planets, will be vaporized. The outer planets will also be engulfed in the pulsating Mira atmosphere, but the effects of the tenuous atmosphere will be hardly noticeable. However, one very significant effect will be the bow shock and wake generated by each of the outer planets as it plows through the atmospheric gases like a bullet rushing through air.

This shock and wake will have a relatively high density of molecules, raised even higher as the stellar atmosphere pulses over the planets. Thus, an outer-planet shock and wake probably could provide a good site for SiO to accumulate and emit masers. Moreover, the strong magnetic field surrounding planets provides a means to polarize these masers.

Additionally, if each jovian planet in our solar system had an SiO maser source or small group of sources associated with it, the number and distribution of the sources would be quite like that observed at other stars by radio astronomers.

Apparently we can help solve all of the mysteries of the Mira masers if we assume the presence of jovian planets orbited by moons rich in water and silicon to fuel the SiO masers. But do such planets exist around stars other than our Sun?

Computer models of R. Isaacman of NASA's Goddard Space Flight Center and C. Sagan of Cornell University have shown that the formation of jovian planets between 3 and 30 astronomical units out from the center is a common outcome of aggregation processes at work in early planetary systems. SiO masers may be the natural beacons broadcasting the presence of planets around other stars.

There is another important wrinkle in this story: The computer models indicate that satellites like the large Galilean moons around Jupiter should also commonly form around jovian planets. Since the temperature in the extended Mira atmosphere is above the boiling point of rock, these primarily water and silicate moons could be vaporized. The result would be a great many SiO molecules orbiting the planet. This could provide very favorable conditions for producing polarized masers.

Testing the Theory

In science, speculative theories live or die by their predictions. The conjecture that Mira SiO masers are associated with jovian planets offers some pretty obvious predictions. The first is that as planets orbit their star, astronomers using VLBI (Very Long Baseline Interferometry, a technique that combines signals received by radio telescopes separated by a continent or ocean to achieve highest resolution) should be able to see the maser sources following an orbital path. However, we will need observations repeated over many years to confirm such orbital motions.

The theory makes a second prediction that we can test. For most targets we will observe, the planets' orbits will be tilted relative to us. Thus for half of its orbit a planet will be moving toward us, and away from us during the other half. This motion relative to our point of observation will give rise to tiny Doppler shifts in the maser signals we receive. That is, while the planet is coming toward us, the signals will appear shifted toward the shorter wavelengths of the spectrum, shifting toward the longer wavelengths as it moves away. We've found some evidence for such Doppler shifts in data already collected, though the picture is complicated by the fact that the brightness of individual maser sources changes substantially over an orbital time. For this prediction, too, we'll need more observations and careful analysis. At least these spectral readings are easier to obtain than VLBI observations.

Pursuing the evidence, we may very well discover many planetary systems in the next few decades. It is a little disappointing that these systems orbit stars in the throes of either birth or death, but such discoveries would still provide the first solid information about how common planets are. That's exciting.

Even with the naked eye it's simple to pick out from a starry background the red supergiant Betelgeuse. Sitting in the left shoulder of the winter constellation Orion, this is one of the most easily recognized of stars. The distinct red color tells us that Betelgeuse is in its death throes, expanding and cooling as its fires burn down. Any small planets closely circling this dying giant would have long since been vaporized or burnt to a crisp. This computer-enhanced image shows a halo of gas surrounding the supergiant star.

Image: National Optical Astronomy Observatories

Curt Struck-Marcell is Associate Professor of Physics at Iowa State University.

Glaciers and *Glasnost*

by Michael Carroll

Across the central region of southern Iceland, in a magical place called Landmannalaugar, sprawls an immense valley of lava. The volcanic rock lies in jumbles of spires, arches and columns. Within such rocky shapes it is said the *Hildefolk*—or "hidden people"—live. Looking at the ghostly shapes of tortured lava, one can easily imagine these elves in their houses and cathedrals of pumice. It seems an unlikely place to find a cosmonaut, a physicist, an astronomer and a host of artists whose specialty is painting the cosmos.

But in Landmannalaugar the unlikely has become reality. It is July 1988, and some 30 astronomical artists from the Soviet Union, Canada, Great Britain and the United States have convened a workshop to sketch side by side as they study the majestic landscapes of Iceland. The workshop is part of a five-year collaboration spearheaded by The Planetary Society, the International Association for the Astronomical Arts and the Union of Artists of the USSR. Spanning 1987 through 1992, the project includes several international art exhibitions, visits to the USSR and US during planetary encounters by *Phobos* and *Voyager,* and workshops in Iceland, Moscow, Utah and the Crimea.

Beginnings of the Dialogues Project

In 1987 the Space Research Institute (IKI) of the Soviet Union held a huge symposium in celebration of the 30th anniversary of the launch of *Sputnik,* our world's first artificial satellite. Some 890 dignitaries were invited to attend as IKI's guests, among them scientists, journalists, astronauts and cosmonauts, and seven artists from North America. The Planetary Society acted as liaison between the artists of the International Association for the

ABOVE: **From the Stars** *by V. A. Myagkev*

This painting and the one on page 23 will appear in a book about the Dialogues Project by William K. Hartmann, Andre Sokolov, Ron Miller and V. A. Myagkev, scheduled for release in fall 1990 by Workman Publishing.

ABOVE: The great volcanic rift called Thingvellir cuts across the Icelandic landscape. American artist Joel Hagen peers carefully from its edge during the first of the Dialogues workshops.
Photograph: Michael Carroll

RIGHT: Artist Mari Flynn used Thingvellir as inspiration for this otherworldly landscape titled **N_2ice and CH_4illy.** *Painting: Mari Flynn*

Astronomical Arts (IAAA) and IKI. Under an agreement between the Union of Artists and The Planetary Society, the artists put together a five-year agenda to continue the cultural exchanges, promote the sharing of information about space missions and science, and initiate artists' workshops throughout the world. The project was christened Dialogues.

Astronomical Art

The focus of this exchange was the genre of astronomical, or space, art. Space art is the natural descendant of classical landscape art of the European Renaissance and later schools. During the Renaissance, as explorers were pushing southward into remote regions of Africa, Asia and perhaps even Antarctica, artists incorporated reports from distant lands into their paintings. And this practice continued into the latter half of the

(continued on next page)

ABOVE: British artist David Hardy paints a lake filling a volcanic crater at Landmannalaugar.

LEFT: Oksana Smborskaya examines the effects of wind and water on rock formations in Arches National Monument.

BELOW: Soviet artist Narimanbekov Togrul sketches a waterfall cut from the volcanic landscape of Iceland.

Photographs: Michael Carroll

19th century. Masters such as Thomas Moran and Albert Bierstadt displayed the wonders of the North American West to an avid public on the eastern coast. In fact, the stunning canvases of Thomas Moran helped convince Congress to preserve Yellowstone and Yosemite as the first two national parks in the United States.

In many ways astronomical art fills the same role today. As humankind is beginning to explore the new frontier of space, reports from distant lands are being returned by robot spacecraft and human voyagers. In the not too distant future, the vistas portrayed by the space artist will be the landscapes familiar to those who call other worlds their home.

Mars on Earth

To depict planetary vistas accurately, the astronomical artist studies landscapes resembling those on other worlds. Of all places on Earth, Iceland may have the geology most similar to that of Mars. Iceland's ancient volcanoes, which have erupted under ice, its glacier- and wind-sculpted valleys and its subsurface lakes frozen into permafrost all echo landscapes on the rusted plains on Mars.

The first of the Dialogues workshops, with 30 participants from four countries, was held in Iceland. The Planetary Society played a key role by partially funding the IAAA-hosted workshop, as well as assisting in its organization.

Gathering in the southwestern city of Reykjavik, the North American and British contingent of artists traveled eastward through Thingvellir (site of the Viking Althing, a tenth-century "parliament") and Fludir and on into the wilderness of Landmannalaugar. The second day in Landmannalaugar was a special one: The 13 Soviet artists and translators arrived, joining their 22 American, British and Canadian colleagues amidst great celebrating with smoked lamb, halibut and—naturally—vodka. Then it was time to go north, into the interior. Here was the opportunity to see Mars on Earth. Here, too, was the opportunity to learn of each other's art, a time for new friendships, a time for true international cooperation.

"This is very reminiscent of *Viking*," observed William K. Hartmann, recalling views of the martian surface sent back by the 1976 US landers. Hartmann, a planetary scientist and space artist, was on the *Mariner 9* imaging team, which made the first full reconnaissance of the Red Planet. Others echoed Hartmann's sentiment as cameras clicked and sketches materialized. Cosmonaut Alexei Leonov sketched a nearby mountain that would be a later destination.

Ahead lay the small glacier Tungnafellsjokull, accessible on foot, and important because of its layered terrain. The edge of the northern ice cap on Mars exhibits similar terrain, formed of alternating layers of dust and ice de-

LEFT: **Meeting of the Planets** *by V. A. Myagkev*

posited by Mars' seasonal dust storms, which can cover the entire planet for weeks.

After a few days of sketching and photography, the entourage traveled into the volcanically active Myvatn area in northeastern Iceland. The spatter cones, pseudocraters and bubbling mud pots brought other worlds to mind, especially Venus, the primordial Moon and Jupiter's moon Io. In Myvatn thermal energy from Earth is used to generate electricity. Perhaps thermal plants will someday dot the landscapes of other geologically active worlds.

Then to Moscow

On April 20, 1989, eleven IAAA artists began the third phase of the Dialogues project. They spent nearly two weeks at Senejh, a small city north of Moscow. There the Union of Artists has a Creativity House at the edge of a scenic lake, surrounded by forest. Senejh can accommodate up to 80 artists, who may stay up to two months and receive special training from some of the most famous of the Union of Artists' 23,000 members. If the artists work during their stay, the union pays all expenses.

While in the Soviet Union, the IAAA artists went with cosmonaut Alexei Leonov to visit Star City, the site of cosmonaut training facilities and a mock-up of the *Soyuz-Mir* space station. Later sightseeing included the Kremlin, Red Square and the Cosmos Pavilion. A scheduled trip to IKI had to be cancelled because of the problems with the *Phobos 2* spacecraft, as it encountered Mars and the moon Phobos.

In the months leading up to the Moscow workshop, an exhibition of art had been assembled, in the Soviet Union and among members of the IAAA. Eighty pieces of art from five countries were accepted into a juried IAAA show and combined with a counterpart Soviet show.

The combined show opened at the Pavilion of Achievement amidst great fanfare, including an address by cosmonaut German Titov, the second human in space. Speaking to the artists as well as the public, he urged the continuation of the cultural enrichment that elevates humankind and its spirit in friendship and in peace, both on Earth and in space. This spectacular art exhibition, reflecting humanity's ventures into the cosmos, was to travel next to the United States, where it opened during the *Voyager* encounter with Neptune, as an official part of The Planetary Society's Planetfest '89. Soviet artists and translators accompanied the exhibition to the US for the next step of Dialogues.

A Blue Planet and Red Deserts

The *Voyager* flyby of Neptune fulfilled its promise as one of the most spectacular planetary encounters of the decade and perhaps of the century. The mission was controlled by the Jet Propulsion Laboratory (JPL), where the pace was frantic, as billions of bits of information beamed across great distances in the course of only hours. Despite this intense schedule, the workshop participants were permitted to witness the encounter alongside scientists at the Lab.

"We've never seen anything like this," commented Soviet artist Yuri Orlov. "The photographs are quite stunning."

Meanwhile, the joint Union of Artists-IAAA art exhibition opened at the Pasadena Center as part of Planetfest '89. On display were more than 100 works of art relating to humankind's exploration of the cosmos. A major collaborative work titled *The Seeds of Tomorrow* was donated by the artists to The Planetary Society in recognition of its contribution to this multinational cultural exchange. [It now graces the upstairs hall at the Society's headquarters.]

After the encounter, as scientists around the world prepared to pore over the *Voyager* data from the great blue planet Neptune and its exotic moon Triton, the workshop members headed on for the deserts of Utah. The geological formations of Canyonlands and Arches National Monument made for rich artistic inspiration.

The art exhibition of the Dialogues project continues to tour the United States. In San Diego, where it was cosponsored by the Reuben H. Fleet Space Theater and the San Diego Historical Society, more than 20,000 people saw the exhibition in less than three months, and current plans call for the show to tour several major cities. In 1992 it will serve as a base for a new exhibition of astronomical art at the National Air and Space Museum.

The art of the cosmos—which the Dialogues workshops have stimulated with fresh ideas and techniques—will show people that the planets are real places, places where our children will work, and their children will live. As it has in the past, artistic vision will point the way to the new frontier.

Michael Carroll is an astronomical artist whose work appears frequently in The Planetary Report. *He was a founder of the IAAA and helped organize Dialogues.*

BELOW: Where volcanoes have recently erupted, the Icelandic landscape is desolate, seemingly swept bare of the life that characterizes our planet Earth.
Photograph: Michael Carroll

BOTTOM: Iceland is the most volcanically active region on Earth; Io is the most volcanically active body in our solar system. Artist Michael Carroll used the Myvatn craters as analogs for features on Io. *Painting: Michael Carroll*

World Watch

by Louis D. Friedman

WASHINGTON, DC—In his budget for fiscal year 1991, President George Bush has proposed increasing NASA's funding by 24 percent. This would be the largest increase for any major federal agency, if approved by Congress. However, that is a very big "if." Bush has requested $15.1 billion for the US space agency, up $2.8 billion over last year. Analysts expect legislators to trim about $1 billion, roughly the same amount they cut from the President's FY 1990 request.

This budget proposal reflects the Bush administration's new support for the space program, including an emphasis on what they call the "Human Exploration Initiative"—human expeditions to the Moon and Mars. The *Mars Observer*, as a "precursor" to human landings, received a $15 million "enhancement" to improve the data transmitted back to Earth and extend the mission from one to two years.

Of special interest to Planetary Society members, the proposed budget continues funding for a relay that will transmit data from the Mars Balloon, the French/Soviet mobile probe set to fly on the Soviet *Mars '94* mission. The Society is designing the balloon's SNAKE guide-rope, which will land instruments on the martian surface.

In this NASA budget, mission planners would begin advanced development of the *Lunar Observer* mission. The mission would be a forerunner to humans returning to the Moon. This polar orbiter would examine the surface in detail, looking especially for evidence of water possibly frozen in permanently shadowed regions of the lunar poles.

Reflecting the administration's new emphasis, support for the Mars and Moon missions is considered part of the Human Exploration Initiative budget request.

Society members will remember that last year CRAF (Comet Rendezvous-Asteroid Flyby)/*Cassini* received a "new start," enabling scientists and engineers to begin work on the mission in earnest. These two missions—one to a comet and an asteroid, the other to Saturn and its large moon Titan—would receive $148 million in FY 1991 to allow work to continue.

The administration has proposed that the largest share of the increase—$700 million over last year—go to the space station, now touted as "the cornerstone of the President's exploration initiative." Once it was sold as a toehold in space for commercial development, but the emphasis is shifting to exploration. European and Japanese participants in the station program are concerned about the conflict between commercial research and preparation for human missions. Congress has scheduled hearings on this matter.

NASA's Mission to Planet Earth will get underway in FY 1991, if Congress approves this budget. The space agency will be given $636 million to begin building the two proposed polar-orbiting platforms in the Earth Observation System. (See the January/February 1990 *Planetary Report*.) The administration has proposed over $1 billion next year for studies of global environmental change; NASA's share of the proposed funding is the largest for any agency.

SOPRON, HUNGARY—In late January some one hundred leading scientists and engineers preparing for missions to Mars met in this small town near the Austrian border. The "Workshop on Environmental Models of Mars" was organized by the Central Research Institute in Hungary. The setting proved ideal for the gathering: a good place for Soviets, Americans and Europeans to get together and compare notes.

The participants were primarily after more information on Mars' atmosphere and surface. Although several spacecraft have returned data from Mars, including the two *Viking* landers, we still have tremendous gaps in our knowledge, making vehicle design very uncertain: Imagine designing a car to drive on Earth based solely on what we know from weather satellites and ground views from two locales.

The Mars Balloon was a focus of discussion throughout the meeting. Not only will the balloon's scientific measurements be valuable in themselves, they will also help designers plan robotic-rover and human missions. Its ability to traverse great distances and yet see the surface close up makes the balloon a unique contributor to exploration.

Nonetheless the balloon has a difficult job because it must fly in an atmosphere that we do not know well. The design must be resilient enough to accommodate great uncertainties about the martian atmosphere. Similarly the guide-rope must traverse a surface of relatively unknown characteristics and obstacles when the balloon descends, mostly at night.

The Mars rover situation is even more difficult. Rovers must be highly intelligent or big and robust to survive the martian surface. Either approach (and the answer may be a combination of both) requires that the best possible information be obtained before the rovers are finally designed.

American and Soviet groups showed several different rover designs; the French space agency CNES and the European Space Agency also expressed interest in developing rovers. The Soviets showed field tests of a Mars rover working in some very difficult terrain in the Kamchatka region of Siberia. Former *Viking* project manager James Martin, who chaired the rover session, observed that it was a shame so much duplicative work was being done by different national groups and that a coordinated international program could make faster progress in this difficult field.

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

News & Reviews

by Clark R. Chapman

Just about 13 years ago, I arrived at NASA's Jet Propulsion Laboratory in Pasadena for the first meeting of *Galileo* scientists. Political battles over funding the mission had been won, and more than a hundred researchers had gathered in JPL's Von Karman auditorium to get the mission underway. On that first morning, JPL monitors showed the test space shuttle *Enterprise* successfully gliding to a landing in the nearby Mojave Desert.

There was enthusiasm for this planetary mission that would follow the *Voyagers* (launched just a few months earlier) out to Jupiter, then orbit the planet for two years after shooting an instrumented probe into the bowels of the planet's thick atmosphere. Launch via the shuttle was scheduled for 1982 and arrival at Jupiter for 1984. By the end of the mission in 1986, we would have a treasury of data about Jupiter, its moons and its space environment. But that was not to be.

Galileo has been an epic tale of frustration with budgets, launch-vehicle delays and all the woes that beset NASA's planetary program during the 1980s, culminating in the *Challenger* tragedy just three months before *Galileo*'s scheduled launch, which by then had slipped to May 1986.

Galileo's *first picture of Venus was taken February 12, 1990 through a violet filter from a range of about one million miles. The circular features faintly visible are artifacts of processing that will be removed after the camera is calibrated.*

Photo: JPL/NASA

On February 13, 1990, I was again at JPL, attending perhaps my 150th *Galileo* meeting, but this one was different. I had witnessed *Galileo*'s magnificent launch from Cape Canaveral four months earlier, and we were busily planning the instrument sequences for *Galileo*'s pass through the Earth-Moon system this December. Finally we were working on plans that had a real chance of being executed! In another JPL conference room, my colleagues were preparing for *Magellan*'s encounter with Venus later this year.

Most gratifying of all, word came in during a break in our meeting that *Galileo*'s first picture of Venus was being displayed in JPL's image-processing laboratory. Acting Imaging Team Leader Joe Veverka and other team members, including myself, Jim Head, Ken Klaasen and Mert Davies hurried over to look. Seated by the monitor was a beaming Maurice Clary, who had shepherded development of the camera for many long years.

Clary had been anxious the previous Friday night, when he was awakened and told of anomalies in the telemetry from *Galileo* as it passed Venus. The media had trumpeted problems with the camera, but now a relaxed Clary explained that his camera had worked fine. Minor command errors may have affected two Venus frames, but the other 79 were expected to be okay.

Then the first picture was displayed on the monitors. Taken through a violet filter, the picture is a crisp portrait of the chevron-shaped cloud patterns of Venus, familiar from *Mariner 10* and *Pioneer Venus* imagery. Planetary atmospheres specialist Peter Gierasch of Cornell, who had planned *Galileo*'s Venus sequence, leaned over to study the picture more closely. He exclaimed over the sharpness of detail and the absence of "noise" in the picture, a hallmark of *Galileo*'s new CCD (charge-coupled device) detector.

Later that day, an infrared frame came down. Although it was bland, as expected, some very low-contrast features were visible. Venus had never before been imaged this close up in infrared, which "sees" beneath the upper smog-clouds pictured in the violet frames. And the next morning we had the third picture; with this third picture, taken two hours later than the first one, we'll be able to make preliminary measurements of wind velocities. The remaining images will be played back from *Galileo*'s tape recorder as the spacecraft approaches Earth this November.

During the Valentine's Day meeting of the *Galileo* Project Science Group, scientists representing several instrument teams made preliminary reports of results concerning the space environment (from the four-day period in December 1989 when the instruments were turned on for calibration) and the infrared spectra of Venus. The day culminated with an announcement that new calculations combined with better-than-expected trajectory correction maneuvers meant that *Galileo* can almost certainly study the small asteroid Gaspra, and perhaps Ida as well, en route to Jupiter.

Clark R. Chapman is a member of Galileo*'s imaging team.*

SOCIETY Notes

NEAR-EARTH ASTEROIDS

Mt. Palomar Observatory's 48-inch Schmidt camera telescope will search the sky for near-Earth asteroids this summer as The Planetary Society renews its efforts in this field of exploration.

Eleanor Helin of JPL, whose program is also supported by NASA and the World Space Foundation, will use the Society grant for computer analysis of the Palomar images, from which she and her team will be able to identify and plot the courses of as-yet-undiscovered asteroids. There may be as many as 1,000 "large" objects (with a diameter greater than a kilometer, or 0.6 mile) whose orbits cross Earth's orbit.

Meanwhile, the Society is working with NASA to set up a major conference on asteroid studies, with the focus on the significance of near-Earth asteroids in the evolution of the solar system. *—Louis D. Friedman, Executive Director*

A RECYCLED REPORT?

Several members have written asking us to consider printing *The Planetary Report* on recycled paper. We have taken this request very seriously.

It appears, after some investigation, that the technology is not yet available to produce a recycled paper stock nearly as good as the clay-coated one we use now. If we switched to recycled paper, the quality of the planetary images would unavoidably suffer, and suffer badly.

Another option would be to use recycle*able* paper, such as supercalendered stock. The quality of this type of paper is approaching that of clay-coated stock, so we are closely watching developments in this area.

Meanwhile, the Society's staff is recycling every available piece of paper in the office. All those computer forms and letters that you send us are recycled back into more forms. Nonprofit, membership organizations live by the mail, and we're doing our part in this paper-intensive endeavor. *—Charlene M. Anderson, Director of Publications*

ANNUAL TPS AUDIT

The annual audit of The Planetary Society, conducted by the firm of Arthur Andersen, has determined the Society's 1989 financial statement to be in conformity with generally accepted accounting principles. Copies of the financial statement, which includes a report on member donations restricted to special use, are available on request. *—Lu Coffing, Financial Manager*

SAGAN/SAGDEEV IN ATLANTA

Carl Sagan, President of The Planetary Society, and Academician Roald Sagdeev, Member of the Congress of Deputies, USSR, will be the speakers in a program on "Exploring Other Worlds and Protecting This One: The Connection" this April 6 in Atlanta, Georgia.

Cosponsored by the Society and the National Science Teachers Association, this event is a rare opportunity to hear two preeminent figures in science addressing some of the most important issues facing the world today.

Admission is $10 and seating is limited. Call the Society for ticket information. *—Susan Lendroth, Manager of Events and Communications*

COSPAR/SISTER WORLDS

In the Netherlands, in conjunction with the 20th plenary meeting of the Committee on Space Research (COSPAR), The Planetary Society will present a symposium on "Sister Worlds: Earth and Venus," examining the role of planetary missions and research in identifying and understanding the potential crises facing Earth's environment, such as the greenhouse effect and ozone depletion.

The speakers—five distinguished scientists from the US, USSR, the Netherlands and Great Britain—will consider how Venus, "Earth's twin," can teach us about our home planet.

Admission is free for this symposium, which will take place from 2:00 to 4:00 p.m., June 30, at Mondriaan Hall in the Netherlands Congress Centre, The Hague.

Volunteers, if you can help staff a Planetary Society information table at this event, please contact Carlos Populus, Volunteer Coordinator, at the Society. *—SL*

10TH ANNIVERSARY THEME CONTEST WINNER

Peter Newbury, Sam Newbury and Tom Newbury of Eagle River, Alaska jointly signed the winning entry in the Planetary Society 10th Anniversary Theme Contest.

When offered the prize of a free trip to a planetary event, the Newburys chose to "turn the invitation around: We invite a person associated with The Planetary Society to use our free trip for an Alaska visit, and to address Anchorage high school science teachers and students." Always open to a new opportunity to promote planetary science, and acknowledging the ingenuity and generosity of the Newburys, the Society will send a speaker to the October 8-10 Arctic Science Conference.

The winning theme for our 10th anniversary is: One Earth, Many Worlds. *—Tim Lynch, Director of Programs and Development*

OVERSEAS SALES ORDERS

Several merchandise orders from overseas have come in recently with payment being sent by separate mail. We do our best to process your order quickly, but in these cases it can take some time to be sure whether the check is a donation or part of a sales order. Please help us by enclosing a copy of your merchandise order with the payment, and include your member number in all correspondence. *—Cosma Norton, Sales Manager*

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Questions & Answers

Why do some planets form rings while others do not?
—Steve Douangsithy, West Covina, California

Before addressing this question, we should first consider how rings are thought to have formed. Some 4.6 billion years ago, the very young Sun was surrounded by a spinning cloud of dust and gas called the solar nebula. Within this cloud, bits of material collided and stuck together. The largest clumps became the seeds of planets, and their gravity attracted more material until they, too, were surrounded by flattened disks of gas and dust.

Within these disks, the planet-making process repeated itself, and smaller particles accreted onto larger ones to form satellites. But close to the planet, within a boundary called the Roche limit, tidal forces raised by the planet would prevent any large clumps from agglomerating, so that in this region the planet would be surrounded by a thin ring of small particles.

Thus, theoreticians believe that near the end of our solar system's formation, each planet was orbited by a retinue of satellites located at some distance from the planet. Closer to the planet, within the Roche limit, which is a few planetary radii away, a ring system would encircle the planet. These primordial disks may be the planetary rings around Jupiter, Saturn, Uranus and Neptune today.

Whether these original rings could have survived until today is not certain. The ones we now see may instead be secondary systems, formed when satellites that were dragged into the region were catastrophically struck by errant comets. The resulting debris could have spread out into rings.

How do we account for the remarkable diversity of the rings arrayed about the giant planets? The amount and nature of ring material depends on the precise timing of events in each planet's history. Since a planet's satellites would play major roles, their precise size and placement would affect the final outcome. The planet itself might be a major heat source for modifying circumplanetary material, and its own evolution would alter the structure of the ring system. The Sun may also have a part in the story. Before it settled down as a relatively stable, middle-aged star, the young Sun probably passed through a "T-Tauri stage," when it explosively shed material, perhaps blowing out much of the original circumplanetary gas.

Since Jupiter, Saturn, Uranus and Neptune are surrounded by rings as well as extensive satellite systems, theoreticians believe that this scenario may describe the formation of planets in the outer solar system. On the other hand, the inner, terrestrial planets have no known rings and few satellites. This suggests a different formation process for these bodies.

Tides raised in the solid bodies of the inner planets may explain the scarcity of satellites and the lack of rings. For example, Earth's Moon, which is slowly being moved outward by tides (see the January/February 1987 *Planetary Report*), could have swept up any smaller satellites in its path. The Sun's tidal effects on Mercury and Venus may account for their anomalous spins: Mercury rotates about once every two months; Venus rotates only once every 225 days. These slow rotations mean that planetary tides could have pulled any original satellites into the planets, and on the way in, they would have eliminated any rings. The meager satel-

Although we now know that all the outer giant planets are encircled by ring systems, Saturn's extraordinary rings put that planet in a class by itself. The beautiful brightness of the rings is due to their being composed mainly of water ice, which makes them highly reflective. This painting of a saturnian ring shows that the particles are very close together, and that accounts for their "solid" appearance as viewed from Earth.

Painting: Rick Sternbach

Using the giant radar dish at Arecibo, a team of scientists led by JPL's Steve Ostro imaged asteroid 1989 PB. These images reveal 1989 PB to be a "contact binary"—that is, it seems to consist of two chunks of rock in contact as they orbit the Sun. This asteroid was discovered by a team led by Eleanor Helin, principal investigator for the asteroid project supported by The Planetary Society.

Image: Steve Ostro/JPL, John Chandler and Irwin Shapiro/ Harvard-Smithsonian Center for Astrophysics and Alice Hine/Arecibo Observatory

lite system about Mars may be related to the proximity of the asteroid belt, since projectiles from that region may have shattered tiny Phobos and Deimos innumerable times.

Thus the origin of rings is intimately tied to the evolution of planets. The absence of rings about the terrestrial planets gives us a poorly understood clue to a different origin for those planets.
—JOSEPH A. BURNS, *Cornell University*

How technically and economically feasible would it be to send **now** ***a very small and very fast spacecraft with the limited objective of obtaining just one image of Pluto (and perhaps Charon)? Even one close-up image would be infinitely better than what we now have.***
—William J. Conklin, Wanaque, New Jersey

It is technically feasible to send a very small spacecraft to Pluto on a very fast trajectory. Limiting the mission objective to obtaining just a few images of Pluto and Charon would allow the payload to be only a small camera. A conceptual design of a very small camera that could provide images similar to those obtained by *Voyager* at Neptune is available. A conceptual design for the spacecraft using microspacecraft technology would limit its total mass, including the camera and a propulsion subsystem, to about 20 kilograms (44 pounds).

In order to provide a backup, two identical 20-kilogram microspacecraft could be sent to Pluto on a six-year trajectory by a *Titan 3* launcher. The mission would require four upper stage rockets in addition to the *Titan 3*. Commercial upper-stage rockets could fulfill the requirements of this mission. The mission would not require any gravity assists and, therefore, could be launched during any year. The project would still require at least three years from approval to launch. If it were given an immediate go ahead, we could expect to see the first close up pictures of Pluto and Charon before the year 2000.

The economic feasibility of this idea is more difficult to discuss. The cost of just the launch vehicle and upper stages would be about $250 million with the spacecraft development requiring at least another $50 million. Is it worth $300 million to obtain the first pictures of Pluto and Charon before the millennium? Your answer is as good as mine.
—ROSS M. JONES, *Jet Propulsion Laboratory*

I've read that the layer of dust on the Moon, or the lunar regolith, is five to nine meters (about five to ten yards) thick. Is there an explanation for why the dust at the **Apollo 11** ***landing site was loose for only a few inches and then became hard packed?***
—Dan Van Eycke, Gig Harbor, Washington

The lunar regolith, which consists of particles of all sizes from the finest dust to house-sized rocks, is indeed many meters deep—there is evidence that the endless pounding of impacts has pulverized the lunar crust to depths of kilometers, with the material then being re-consolidated by later, smaller impacts. The very top layer is like moist beach sand in that it will take an impression a few centimeters deep when a person walks on it. Thus, though fine dust is present to substantial depths, it is only part of a consolidated mix of dust, pebbles and rocks, and hence spacecraft and people do not (as was feared early on by some scientists) sink out of sight.
—JAMES D. BURKE, *Jet Propulsion Laboratory*

FACTINOS

In Puerto Rico last summer, radar astronomers captured their first asteroid ever on film (see image, left) and found it to be double lobed. Eleanor Helin of the Jet Propulsion Laboratory and her associates first spotted the oddly shaped object on August 9 from the Palomar Observatory. She quickly alerted Steve Ostro and his radar team at the Arecibo Observatory so that they could observe the asteroid during its close pass by Earth. The asteroid, called 1989 PB, orbits the Sun about every 400 days and moves from beyond Mars' orbit to an area between Venus and Mercury and back.

"These first images of 1989 PB have picture elements less than 1,000 feet across, comparing favorably with *Voyager* spacecraft images," said Ostro. "Within a few months, detailed analyses will let us reconstruct the asteroid's three-dimensional shape, make some statements about how tightly gravity is holding the two lobes together and begin to formulate theories about how it was formed."
—from the Jet Propulsion Laboratory

* * *

Samuel Bowring of Washington University in St. Louis has found some 3.96 billion-year-old rocks in Canada's Northwest Territories. These rocks are about 160 million years older than those previously thought to be the oldest rocks on Earth.

The newly discovered rocks narrow the span of time between when Earth and the solar system formed and the date of the first preserved Earth rocks. Now this gap is only about 600 million years wide. Bowring said, "There's a possibility that even older rocks will be found and our research team will be actively involved in hunting for them."
—from *Astronomy*

* * *

A team of propellant specialists is developing a piece of hardware that could make extraterrestrial pit stops possible for spacecraft by allowing rocket fuel to be manufactured on Mars. It's a refinery that can separate oxygen (a principal ingredient in rocket propellant) out of the abundant carbon dioxide on Mars. "We start with a tank of simulated martian atmosphere," says Robert Ash of the Jet Propulsion Laboratory, "and then we run it through the machine. So far for every cubic foot of Mars air we process, we get a tenth of a cubic foot of oxygen. Ultimately, we'd like to get five times that."
—from *Discover*

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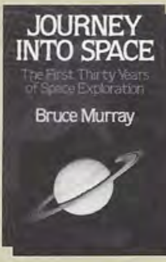

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THE GEYSERS OF TRITON, discovered last August by Voyager 2, are not violent eruptions like those we see on Earth or on Jupiter's moon Io. Rather, they are probably columns of nitrogen steam or vapor that drift straight up into the rarefied atmosphere. When the columns reach up about eight kilometers (five miles), they enter a wind shear that can carry them horizontally as far as 100 kilometers (60 miles). Here artist Michael Carroll portrays his vision of an erupting Tritonian geyser.

Space artist, writer and lecturer Michael Carroll lives and works in San Diego, California.

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