The PLANETARY REPORT

Volume XV Number 5 September/October 1995

Hubble Space Telescope Spies on the Neighbors

On the Cover:

A rare storm rages across the face of Saturn as seen by the Hubble Space Telescope. The white, arrowhead-shaped feature is about as big across (12,700 kilometers or 7,900 miles) as Earth. The winds at the storm's latitude blow at about 1,600 kilometers (990 miles) per hour. HST has been watching the storm since its discovery in September 1994. Flyby spacecraft such as the *Voyagers* can't give us such repeated coverage, which enhances the value of the HST data.

This image was taken on December 1, 1994, when Saturn was 1,455 million kilometers (904 million miles) from Earth.

Image: Reta Beebe, D. Gilmore, L. Bergeron and NASA

From The Editor

Our efforts are often divided, at The Planetary Society, between portraying for our members a hopeful future in the solar system and alerting them of attacks on that future. This split is graphically illustrated by this issue, in which we lay out Japan's plans for lunar exploration and report on the most potentially devastating budget cuts in NASA's history.

Political skirmishes have become weekly events. And not only NASA is endangered: Some in the United States Congress have threatened to eliminate the US Geological Survey, a main player in planetary science. Meanwhile, members of the European Space Agency can't agree on their space program, and in Russia there's not enough money to fund even approved missions. Only Japan seems committed to a future in space.

This may be the most critical time for citizen action in the Space Age. Contact your government representatives and let them know your vision of the future. Now, more than ever, that future is in your hands.

—Charlene M. Anderson

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Members' **Dialogue**

Moon or Mars?

Tom Harris and Paul Klarer have launched a much-needed debate within the Society (see the May/June 1995 issue of *The Planetary Report*). While our main focus has long been Mars, perhaps the Moon is a more realistic target. Why? Because historically, politics and economics have had more to do with exploration than either science or adventure. When America entered the Moon race, it was in response to geopolitical concerns. Just as the detailed scientific study of the Moon was getting under way, the *Apollo* program was curtailed because our leaders thought there was nothing to be gained politically, nor economically, through continued exploration. Or so it seemed at the time. Now we know that the Moon is a potential source of energy. Helium 3 in the lunar regolith could power fusion reactors here on Earth. Moreover, other lunar resources could be used in the establishment of an Earth-Moon transportation system. Within the next 30 years, lunar exploration could become economically attractive. Which, in my opinion, is the key to generating the political and public support (read "money") that will be required for sending human beings to Mars.

—WILLIAM F. MELLBERG,
Park Ridge, Illinois

I'm responding to Paul Klarer's call for debate on whether we should focus on Mars or the Moon in the next phase of space exploration. We ought to return to the Moon.

Many of us grew up during the *Apollo* program. We were convinced that there would be a Moon base by the time we were in our thirties and forties. Well, here we are, 26 years after Neil Armstrong first set foot on the Moon, and we're still arguing over whether we want to spend money on a space station and watching NASA downsize yet again.

Mars is the sexy goal, and I do agree that we should go there. But, we ought to establish ourselves on the Moon first.

Americans need to lose the "been there, done that" attitude of recent years and consider the real possibilities and scientific benefits. A global effort to return to the Moon ought to be undertaken soon. It's painfully clear that the United States is not going to proceed on its own with such a project.

—CATHERINE KOUNS BORN,
Lakeview, Ohio

Priorities?

Whether humanity's drive to explore is instinctive or cultural is open to debate (see Tom Harris' letter in the May/June 1995 issue of *The Planetary Report*). But the question of why our generation falters at the threshold of the new frontier can be answered in a single word: hypocrisy.

We stand upon the shoulders of humble frontiersmen and women who forged the hostile wilderness into our modern world. They endured deprivation and hardship because they were inspired by the human pioneering spirit—the determination that each generation should live better lives than their predecessors! What would their impression be of today's self-indulgent, self-centered modern culture, which has rotted the Space Age from the inside out as a result of its indifference toward future generations?

Citizens of our time spend billions on entertainment, professional sports and the whims of fashion while projects that hold promise for improving the quality of life for posterity go unfunded. If there are too many problems today on Earth to allow our generation to explore space, then solve them. But let no one indulging in our era's warm and comfortable hypocrisy be allowed to claim that there is no money available to be invested in humanity's future!

—VINCE CREISLER,
Kent, Washington

Impact Crater

In Paul Geissler's interesting article on Earth images returned by *Galileo* (in the May/June 1995 issue), a feature we see commonly on many other bodies in the solar system—but less often on our own planet—went unnoticed in one of the pictures. I refer, of course, to the scar produced when an asteroid or comet collides with us.

In the image of parts of Australia shown on page 10, mention is made of the dry salt lakes on the left. These are mostly of irregular shape, except for one, the most southerly, which is close to circular and about an eighth of an inch across in that picture. This structure is called Lake Acraman. In 1986, it was recognized by University of Adelaide geologists Vic Gostin and George Williams to be an impact scar. I call it a scar rather than a crater because it has been heavily eroded since its formation about 600 million years ago. Currently it is about 22 miles in diameter, but originally the crater would have been three times this size. Gostin, Williams and their colleagues have identified ejecta from the impact over 200 miles away to the northeast in the hills known as the Flinders Ranges, which are slightly to the left of center in this *Galileo* image.

—DUNCAN STEEL,
Coonabarabran,
New South Wales, Australia

Please send your letters to Members' Dialogue, The Planetary Society, 65 North Catalina Ave., Pasadena, CA 91106-2301 or e-mail tps.des@genie.geis.com.

JAPAN Looks to the Future:

As we near the turn of the century, the nations of Earth are working to construct a new world society, one with a brighter future. There are, however, global issues to be dealt with—overpopulation, food shortages, limited natural resources and the deterioration of the environment.

As a member of the Space Activities Commission, which oversees Japan's space program (see sidebar for a look at how that space program is set up), I believe that the exploration of space has the potential to contribute to the building of a society that can overcome these problems, and should be promoted for that reason. If nations work together to this end, the mutual understanding fostered would also contribute to the preservation of world peace.

In this context, Japan intends to play an active role in international efforts while abiding by the principle of limiting its space development to peaceful purposes. We have three goals: First, to tackle the fundamental tasks of challenging the unknown universe and deepening our understanding of Earth. Second, to develop creative and innovative space technologies that can be handed down to the next generation with a view to expanding human activities in space. And third, to promote international space cooperation by working with other countries and sharing knowledge gained.

Moving Toward the Moon

Of all the celestial bodies, the Moon is the closest to Earth and the most familiar to Earth's inhabitants—two very good reasons for humans to choose it as the first object beyond Earth to explore. Its exploration began promisingly, with the United States' and Russia's missions of the 1960s and 1970s, but the lunar activities of these countries have now all but ceased. In the future, we will need to accumulate scientific knowledge to determine whether it is feasible to conduct space activities on the Moon.

Japan's Institute of Space and Astronautical Science (ISAS) has a program called Lunar-A. ISAS plans a 1997 launch for this mission using the *M-5,* a medium-lift launch vehicle. The *M-5* will carry the 520-kilogram (1,100-pound) Lunar-A spacecraft to orbit around the Moon. From there, the spacecraft will send three penetrators, equipped with ultrasensitive seismometers and heat-flow instruments, to the lunar surface.

These penetrators will form a seismic and heat-flow measurement network much larger than that of *Apollo*. Seismic observations are expected to provide basic data on the size and physical properties of the lunar core and on the structure of the mantle. The heat-flow instruments will also give us important information on the thermal structure and the heat-generating elements of the Moon. With this information, we will be able to elicit some geophysical constraints related to the origin and evolution of the Moon.

ISAS and the National Space Development Agency of

Future of Moon Exploration

Future of Space Science Field

In Japan, policy makers have laid out careful plans for the next 30 years in space. As these charts illustrate, those plans are ambitious. Earth's Moon will be an early destination, with a variety of scientific endeavors to be conducted on the lunar surface (top). But the Moon is not Japan's only goal: Its space strategy includes sending spacecraft to study near-Earth space, sampling an asteroid and traveling to other planets (bottom).

Illustrations: Space Activities Commission of Japan

A Long-Term Lunar Plan

by Tamiya Nomura

Japan (NASDA) are planning a joint feasibility study program for systematic lunar exploration in the future. The program consists of two parts: an initial stage using robotic explorers and a subsequent stage leading to missions involving humans on the lunar surface.

The First Stage: Reconnaissance

The initial stage of the lunar program, to be carried out using the *H-2* heavy-lift launch vehicle, will have a twofold purpose: to pursue scientific surveys of the Moon and to explore its utilization. This program will be a cooperative effort involving NASDA, ISAS and other agencies in Japan and elsewhere and will consist of three phases.

Phase 1: Observation of the lunar surface by spacecraft in lunar orbit. These spacecraft will survey the surface to obtain high-resolution spectra giving geologic, topographic and geochemical information. This information would also be used for site selection for later lunar stations, construction of paths for robotic vehicles, and resource exploration.

Phase 2: Exploration of the lunar surface with landers and rovers. These robotic explorers will examine firsthand the surface of the Moon. The rovers will travel through selected areas of the lunar maria and around the edges of the craters. They will also explore polar regions with the aid of a relay satellite in orbit around the Moon. The landers will make observations and perform experiments. They will monitor moonquakes and examine lunar surface material.

Phase 3: Retrieval of samples from the lunar surface. Using the information provided by the rovers and the relay satellite, we will identify interesting sites for picking up samples for scientific research. This phase calls for the development of technology that will permit automated sample collection, in situ experiments and reentry/retrieval operations.

The Second Stage: Settling In

After about the year 2010, it is likely that there will be an international program of lunar activities, such as the construction of facilities for scientific observation and experimentation (an astronomical observatory, for example), and a series of robotic missions.

In the third decade of the 21st century, we can expect the development of space infrastructures to ensure highly reliable and low-cost transportation for humans, followed by the construction of a human-tended lunar observatory under international cooperation. Needless to say, these activities should be fully justified in terms of human safety and socioeconomic factors.

Then, advanced launch vehicles will transport to the Moon robots, communications equipment and plants to supply energy and other resources there. We think that robotic technology is a key factor in building facilities suitable for a permanent human presence. Several modules will be launched aboard advanced rocket vehicles to provide the habitat, and units for gas, metal and oxygen production, together with landing and takeoff vehicles and passenger cabins. People will be able to live and work in these facilities for about a year at a time.

The timetable for this scenario is tied to the degree of commitment that the spacefaring countries of the world are willing to make, since such a program can only come to pass through a major international effort. To effectively tackle the global issues we are facing and to make the world a better place for future generations will also take a collective human effort, and the development of space is one of the most promising pathways for such an endeavor.

Tamiya Nomura is deputy chairman of the Space Activities Commission and professor emeritus at Tokyo University.

An Overview of Japan's Space Program

Each spacefaring nation organizes its space program in a distinctive way, and Japan is no exception. Overall space policy is set by the Space Activities Commission (SAC), which in 1994 released "Toward Creation of a Space Age in the New Century," a paper laying out Japan's ambitions in space exploration. The commission reports directly to the prime minister's office, while the various institutes and agencies that carry out the work report to different ministries in the government.

This organizational scheme is similar to those of the United States and Russia, but there is one large difference: In Japan, the military has no role in space. The great bulk of Japan's space effort is carried out by two organizations: the National Space Development Agency (NASDA) and the Institute of Space and Astronautical Science (ISAS). Officials from these two agencies are now working out the details of a joint proposal for the lunar missions outlined on these pages.

NASDA is by far the larger agency, with almost 10 times the budget of ISAS. It was established in 1969 and reports to both the Ministry of Transportation and the Ministry of Post and Telecommunications. Its mission is to develop the practical applications of space. Its primary responsibilities are Earth-orbital satellites and its stable of launch vehicles. NASDA launched its first satellite, *Kiku,* in 1975 using the *N-1* rocket, which was developed largely with US technology. Since then, the agency has developed its launch muscle, and the newer *H-2* is a potent force in the world launcher market.

ISAS grew out of university space research and was organized into its current configuration in 1981. It is responsible to the Ministry of Education, Science and Culture. Its mission is science, and this is the agency that conducts Japan's interplanetary missions.

In 1985, ISAS sent two spacecraft, *Suisei* and *Sakigake,* to explore comet Halley. In 1990, *Hiten* began its mission of close swing-bys of the Moon. Two years later, ISAS sent *Geotail* to investigate the solar-terrestrial system.

Before this decade is out, ISAS plans to launch Lunar-A, which will drop penetrators into the Moon, and Planet-B, which will explore Mars' upper atmosphere. The institute is also considering a Mars penetrator mission and a lunar polar orbiter. For the more distant future, a sample-return mission to a near-Earth asteroid or a comet, and upper atmospheric missions to Mercury, Venus and Jupiter are being studied. —*Charlene M. Anderson*

World Watch

by Louis D. Friedman

Pasadena—This past summer, the Society conducted its biggest, most active lobbying effort ever. "Lobbying" conjures up many conceptions and misconceptions. Legally, it means the attempt to influence pending legislation in Congress—*only* in Congress, not in the administration. That is precisely what we tried to do this summer: Influence the NASA authorization and appropriation bills in Congress to preserve existing programs and initiate the new programs for which we seek government support.

A typical misconception about lobbying is that nonprofits cannot do it. We can, and we should. We can lobby as much as we want—but if we lobby too much (sometimes defined as about 5 percent of our budget), then we can lose our tax-exempt status. We have never come close to the limit in our spending.

Many members want us to do more lobbying; many want us to avoid it—to stick to publications, or planetary mission development, science and research and not get mixed up in the dirty world of politics. The Board of Directors understands both views, but we believe we must be involved. Space exploration is a government enterprise—and it either will remain so, or it will disappear. Entrepreneurs, industrial consortiums, states and cities are unlikely to explore Mars, send fast flybys to Pluto, orbit the Moon or visit any other celestial body. Not for a while.

We wrote you in June about the threat to NASA's budget. President Clinton proposed a budget showing a 20 percent decrease over the next five years. NASA said it would absorb that cut by reducing infrastructure, cutting civil service jobs and eliminating duplicate facilities and functions. That still preserves the major programs in NASA: the shuttle, the space station, space science and planetary exploration missions, Mission to Planet Earth, advanced technology and aeronautics research.

Then, some in Congress proposed huge additional cuts. House Republicans called for large reductions in Mission to Planet Earth, a House Appropriations subcommittee initiated a bill to cancel the *Cassini* mission to Saturn and Titan, and the House Science Committee announced it would oppose all new starts in NASA, including the Lunar Prospector and the New Millennium technology spacecraft.

As we write this, Congress is still working on the budget. Thousands of Society members contacted congressional representatives. With your donations, we set up a campaign office in Washington, and we organized other groups and individuals in the space interest community in a common effort.

We are making progress. The congressional budget allocation is still too low—more than half a billion dollars less than that proposed by the president, which was already a cut from the previous year. But, the *Cassini* threat seems to be gone, the new starts for science and exploration are still in the budget and the effect of our members' letters and phone calls is beginning to be felt.

We do not know how the votes will go, nor do we know what will happen in the final bill. But we are still fighting.

Washington, DC—In the week between the House Appropriations subcommittee attack on *Cassini* and the House Appropriations Committee rejection of the cancellation attempt, the Society spent an eventful three days in Washington:

Thursday, July 13: Political meeting with key staff, lobbying strategy meetings, release of two information sheets to 150 members of Congress and to 100 key media people, interviews with leading members of the media.

Friday, July 14: Students in three countries and five sites link up in our Red Rover, Red Rover project, teleoperating LEGO model rovers over nine time zones; press conference with *Apollo–Soyuz* astronauts and the winner of the international Name the Mars *Pathfinder* Microrover contest (see Society News, this issue); formal dinner to honor the *Apollo–Soyuz* crew, who were the winners of the Thomas O. Paine Award for the Advancement of Human Exploration of Mars.

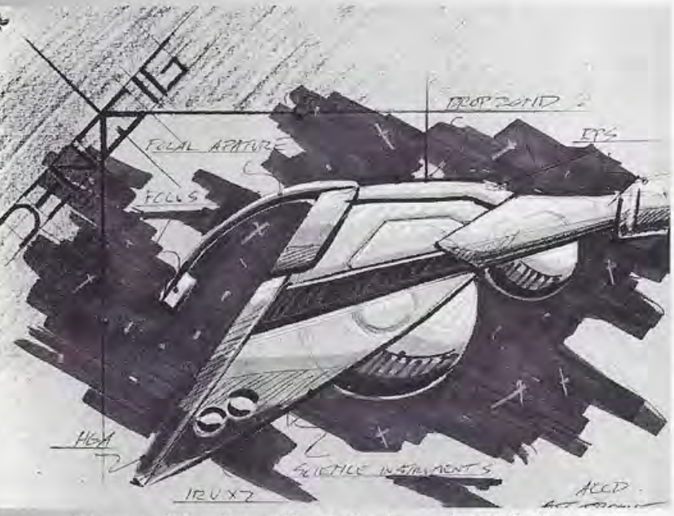
Saturday, July 15: Steps to Mars II conference, where Dan Goldin and other leaders join shuttle–*Mir* astronauts to share thoughts on the goal of sending humans to Mars.

These events did not go unnoticed. We like to think they contributed to the House Appropriations Committee's reversal of the subcommittee's actions.

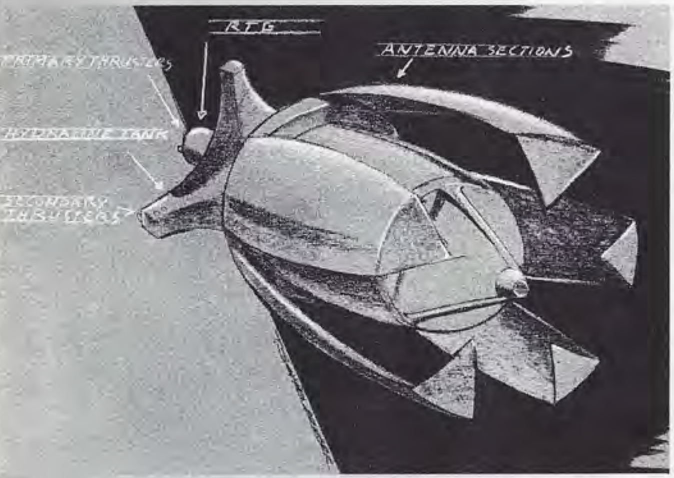
Louis D. Friedman is Executive Director of The Planetary Society.

The New Pluto Express

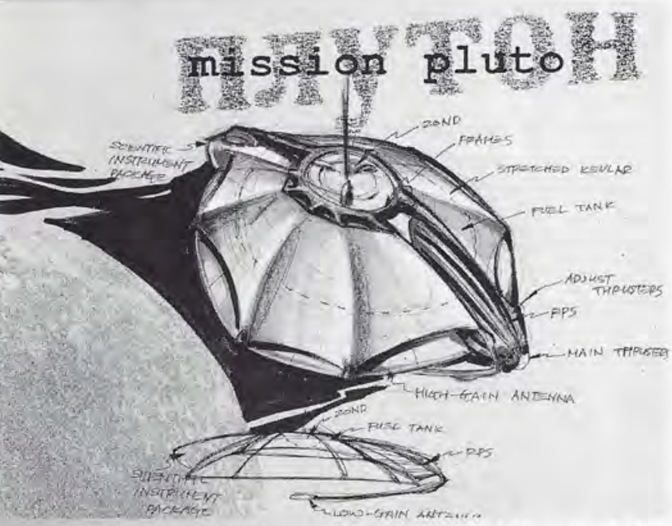
by Jackie Giuliano



"Denzig," by Priscilla Tedeschi and Art Osborne



"Team Nemesis," by Allessandro Ioviero and Toshiro Stehrenberger



"Mission Pluto," by Geoffrey Kater and Wonjin John

Pluto has captured the imagination of many since its discovery 65 years ago by Clyde Tombaugh. And with the discovery of Pluto's moon Charon in 1978 and an atmosphere around Pluto in 1988, the fascination has deepened.

The science rationales for a mission to Pluto, the farthest planet from our Sun and the only double planet in the solar system, are evident. And there is an urgency driving such a mission, because as Pluto continues in its eccentric orbit, now journeying away from the Sun, its atmosphere seems likely to collapse, freezing out onto the planet's surface, and we may for centuries lose the opportunity to study it.

These were some of the considerations outlined in a September/October 1994 *Planetary Report* article on the Pluto Fast Flyby mission. In the year since that story appeared, the project has undergone a transformation, right down to its name, to produce a concept constrained by a budget of unprecedented austerity and using revolutionary technologies.

The craft that will travel to Pluto is no longer considered a spacecraft—it is now a "sciencecraft." It will be unlike *Galileo* and other planetary flight systems, whose science payloads were attached to a spacecraft bus and interfaced with the main onboard computer. On the new Pluto Express, the science instruments will be fully integrated into the craft's electronics, complicating the project's management but reducing cost, mass and complexity.

The baseline mission plan calls for two sciencecraft to be launched shortly after the turn of the century aboard two Russian *Protons*. Their paths will take them directly to Pluto, and each will carry a Russian "Drop Zond" probe, which will give us information about Pluto's atmosphere.

Using "just in time" technology capture to incorporate microelectronics stacked in three dimensions, onboard autonomy software and other breakthroughs from NASA's New Millennium technology program and pioneering efforts, a whole new approach to reaching the most distant planet has become possible. As part of this approach, students from universities all over the United States have been asked to contribute to the design of the mission.

The pictures on this page illustrate the innovative concepts produced by one group of students from the Art Center College of Design in Southern California. For 13 weeks ending April 20, 1995, 16 students from the school's Department of Transportation Design worked with the Jet Propulsion Laboratory's Pluto Express design team. The students had to follow strict design criteria, but once those constraints were satisfied, they were free to use their imagination. The results were remarkable, as you can see here. Hoppy Price, leader of the Pluto Express design team, found many viable features that had not been considered before. It is hoped that many of them may be incorporated in the Pluto sciencecraft design. The models the students produced, built to half-scale, will be on display at JPL.

Jackie A. Giuliano is educational outreach coordinator of the Pluto Express Preproject at JPL (818-354-3812).

Romancing the Stone: The Near-Earth Asteroid Rendezvous

by Robert Farquhar and Joseph Veverka

Near-Earth asteroids have long been considered attractive targets for space missions, for two reasons: First, some of them may be debris left over from the beginnings of the solar system, and as such contain clues to the earliest processes that shaped our solar system. Second, they are relatively close, making them easy to reach from Earth.

Many people have proposed missions to explore these small bodies, ranging from simple flybys to the full-scale *Apollo*-style missions proposed by Hannes Alfvén and Gustav Arrhenius in the early 1970s. However, most scientists soon realized that one of the most cost-effective methods of studying asteroids close up would be to design a mission to orbit one of these objects—a rendezvous, in space mission parlance.

In 1986, a NASA study group recommended that a mission to follow *Mars Observer,* then in the initial planning stages, should be the study of a near-Earth asteroid. Some years later, as the low-cost Discovery program began to take shape, planners realized that such a mission would be an ideal candidate to initiate the program: a mission to a new, exciting place, doing important science and not costing very much! This was the origin of the Near-Earth Asteroid Rendezvous (NEAR) mission.

Mission Description

The original baseline mission plan for NEAR called for a launch in January 1998 to the near-Earth asteroid 4660 Nereus, formerly known as 1982 DB. (This asteroid was discovered by Eleanor Helin as part of The Planetary Society's asteroid program. Planetary Society member Robert M. Cutler named the small body.)

The primary reason for selecting this target was that its orbit makes it easy to reach in terms of energy. Nereus satisfied the requirements of the Discovery program's science working group for a first mission, but some scientists were concerned that its small size (diameter, about 1 kilometer or 0.6 mile) could limit the quantity and diversity of the science return. (In other words, observations of such a tiny object might become repetitive after the initial results were obtained.) So mission

The NEAR spacecraft approaches the asteroid Eros, the target of this mission to study one of the thousands of objects that populate near-Earth space. Eros may look like Gaspra and Ida, two asteroids visited by **Galileo** ***on its way to Jupiter; both were revealed as elongated bodies bearing the scars of countless collisions. While*** **Galileo** ***gathered data only during a brief flyby, NEAR will travel alongside Eros for nine months, giving us a far deeper understanding of asteroids.***

Painting: Pat Rawlings for Applied Physics Laboratory/NASA

planners tried to find a way to send NEAR to a much larger near-Earth asteroid, 433 Eros, roughly 40 kilometers (25 miles) long.

Unfortunately, a rendezvous with Eros takes a lot of energy, requiring a launch on a trajectory highly inclined to Earth's equator, so the spacecraft cannot receive the full benefit of Earth's rotation. (See the Basics of Spaceflight column in the March/April 1995 issue of *The Planetary Report*.) Under current NASA guidelines, Discovery missions can't use launch vehicles larger than a *Delta 2,* so we could not use a larger rocket. However, in September 1992, NEAR mission designers found that a two-year ΔVEGA (from delta *V,* velocity, and Earth Gravity Assist) trajectory could solve this problem. (See the May/June 1995 Basics of Spaceflight column for an explanation of the gravity assist technique.) Both the inclination of the trajectory and the spacecraft's launch energy were reduced, and the Eros rendezvous using the *Delta 2* became possible.

NEAR's trajectory to Eros is shown on page 10. The flight begins with a launch on February 16, 1996. (A more appropriate date would have been February 14, but the energy requirement was a little too high.) A deep-space maneuver on July 3, 1997, lowers the perihelion distance of NEAR's trajectory, which increases the spacecraft's energy at the Earth swing-by on January 22, 1998. Following that swing-by maneuver, NEAR reaches the vicinity of Eros in January 1999, where it executes a series of rendezvous maneuvers over a four-week period.

The spacecraft will make its initial close pass at Eros on February 6, 1999. It will fly by Eros on its sunward side at a distance of about 500 kilometers (300 miles). In addition to gathering scientific data, this first pass will enable scientists to improve their estimates of Eros' physical parameters, which are needed for navigation. Goals for the initial pass include determining the asteroid's mass to about 1 percent accuracy, identifying several hundred surface landmarks and refining our knowledge of the asteroid's shape and spin. As the spacecraft closes in on the asteroid, these measurements and estimates will become increasingly precise.

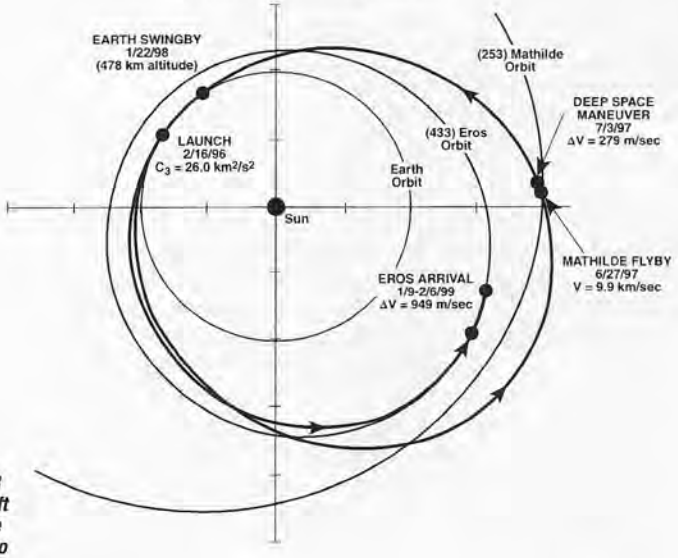
Nevertheless, navigating and controlling the NEAR spacecraft in Eros' complex and irregular gravity field will be extremely challenging. This is especially true at altitudes under 25 kilometers (16 miles). Orbits so close to the surface can be unstable and could intersect it in a few days' time, sending the spacecraft crashing down. Therefore, to operate NEAR safely during its nine-month prime science phase, the science, mission design, navigation and operations teams will have to work closely together. The mission operations control center for NEAR will be at Johns Hopkins' Applied Physics Laboratory. Navigation support will be provided by a team at the Jet Propulsion Laboratory.

Science Background

Eros is an S asteroid, a member of the class that dominates the population of the inner asteroid belt. Asteroids are classified by their albedos and colors as determined by spectrographic observation. The spectra of S types imply a composition of iron- and magnesium-bearing silicates (pyroxene and olivine) mixed with metallic nickel and iron. Scientists try to match the asteroid's spectra with the mineralogy of meteorites that have fallen to Earth. For example, some carbonaceous meteorites have minerals rich in water, and some C-type asteroids appear to be made of similar stuff. The most common meteorites, ordinary chondrites, made of small grains of rock, seem primitive and relatively unchanged since the solar system formed 4.6 billion years ago. Stony-iron meteorites, on the other hand, appear to be remnants of larger bodies that were once melted so that the heavier metals and lighter rocks separated into different layers.

There has been a long-standing scientific debate over whether S asteroids are undifferentiated bodies related to ordinary chondrite meteorites or whether they are geochemically processed bodies akin to stony-irons. The issue is an important test of our understanding of the connection between asteroids and meteorites. If S asteroids are unrelated to ordinary chondrites, then where do these most common

NEAR Trajectory Profile



The NEAR spacecraft will make nearly two swings through the solar system before it reaches the asteroid Eros. This looping path will consume three years of flight time, but it will enable NEAR to make a pass by another asteroid, Mathilde, providing the opportunity to increase the science return of the mission.

Chart: Applied Physics Laboratory

of all meteorites come from? If the two are related, then why don't they look spectrally identical?

Three decades of increasingly detailed telescopic observation have not resolved the dilemma. Even *Galileo*'s flyby observations of two S-type asteroids, Gaspra and Ida, have not provided a solution. The difficulty is that remotely sensed spectral data cannot accurately determine the relative abundance of the three key minerals present in such surfaces: olivine, pyroxene and nickel–iron metal. A precise measurement of the abundances of key elements (iron, silicon, magnesium and so on) associated with such minerals would resolve the dilemma once and for all. This is a major goal of the X-ray and gamma-ray investigations on NEAR.

The NEAR payload consists of a high-resolution camera, a near-infrared spectrometer, a gamma-ray/X-ray spectrometer, a magnetometer, a laser altimeter and a radio science package.

The camera will take images that cover the entire asteroid, but it will also take detailed views of the asteroid with resolutions as high as 3 meters (10 feet), 20 to 50 times better than what *Galileo* was able to get at Gaspra. These images will reveal details of the geologic processes that have shaped the evolution of the target asteroid.

On a slightly coarser scale, the near-infrared spectrometer will map the mineral makeup of the surface. The capabilities of this instrument will be comparable to *Galileo*'s near-infrared mapping spectrometer (NIMS); however, unlike the snippets of spectral data *Galileo* gathered at Gaspra and Ida, NEAR will map the entire asteroid. Such maps will make it possible to relate variations in minerals to surface features and elucidate the connection between geological and geochemical processes. The gamma-ray/X-ray spectrometer will measure the abundances of several dozen key elements; this analysis will make it possible to relate the asteroid's composition to those of meteorites. The capabilities of this instrument far exceed those of devices used decades ago for elemental mapping of the Moon.

Finally, the magnetization and radio science measurements will tell us about the internal state of the body and answer such important questions as these: Is the asteroid a solid object? Is it a pile of rubble produced by countless collisions? Does it have a metallic core? These measurements will be especially accurate because they will be obtained from an orbiting spacecraft, instead of from one just flying by. In particular, they will yield the first-ever precise measurement of an asteroid's mean density. This quantity is a sensitive measure of the body's internal composition and, added to the surface composition measured by the spectrometers, will greatly increase our understanding of asteroids.

Science at Eros

On approach to Eros, the camera will search for satellites and debris around the asteroid. This search should pick up any bodies bigger than about 5 meters (17 feet) across. For comparison, Ida's satellite Dactyl, discovered by *Galileo*, is 700 meters (2,300 feet) in radius. We'll also use approach images to produce a preliminary shape model and map of the asteroid, as well as to locate the rotation pole. (Based on analyses of ground-based observations, we believe that, on NEAR's arrival, the south pole of Eros will be pointing in the general direction of the Sun.)

The extended orbital operations at Eros will give us unprecedented details about asteroids. By mission end, we will have mapped the surface at scales of 3 to 5 meters, and we will know the mineralogy at scales of several hundred meters. We'll have the measured abundances of key elements to compare the composition with those of major meteorite types. We'll have determined the asteroid's mean density and internal mass distribution, and we'll have charted the topography with 5- to 10-meter accuracy.

Among the many questions that this wealth of data will resolve is the S-asteroid debate mentioned previously. For the first time, we will be able to accurately determine the iron–silicon ratio on an asteroid surface. From this and other elemental abundance ratios, we can find out whether the composition of Eros matches that of an ordinary chondrite or that of a stony-iron, or whether we have no sample of Eros-like material in any of our meteorite collections.

Another crucial question that NEAR will answer is whether small asteroids tend to be solid fragments of rock with densities like those of meteorites or whether, as some theoreticians suggest, they tend to be porous piles of collisionally fragmented rubble. The discovery of Ida's satellite Dactyl led to an estimate of Ida's mean density. Taken at face value, this result yields a density somewhat lower than is typical for solid meteorite samples. But the estimate is not precise enough to be definitive. NEAR will determine the mean density of Eros with sufficient precision to answer this important question.

A closely related question that NEAR will answer is whether Eros possesses a magnetic field. Many meteorites show measurable magnetization, but if Eros were a pile of collisional fragments, we would not expect there to be a body-wide magnetic field. Tantalizing hints of possible magnetic signatures were detected during *Galileo*'s flybys of Gaspra and Ida, so it is possible that Eros will turn out to have a measurable magnetic field. If so, mapping its structure will provide further clues to the internal makeup of the asteroid.

Flyby of Main-Belt Asteroid

One of the routine things we do in planning a planetary mission is to examine the spacecraft's trajectory to see if it comes close to any interesting objects. We did this for NEAR's original trajectory to Nereus, but for one reason or another we didn't search for interesting objects near the new trajectory (to Eros) until late 1994. As a matter of fact, the first indication that an extremely fortuitous flyby opportunity might exist came on November 30, 1994, when NEAR's mission design team casually reviewed the first results from the search program. We saw that NEAR's trajectory would pass within 0.05 AU of several asteroids, but most of them were rather small. (An astronomical unit, abbreviated AU, is equal to about 150 million kilometers or 93 million miles; 0.05 AU is 7.5 million kilometers or about 5 million miles.) In particular, we noticed a miss distance of only 0.015 AU (about 2.25 million kilometers or 1.4 million miles) at the large main-belt asteroid 253 Mathilde!

At first, we did not get overly excited because a miss distance of 0.015 AU could still require a significant trajectory modification—and expenditure of fuel. But further analysis revealed that the penalty associated with the trajectory change was quite modest. When news of the Mathilde flyby opportunity was passed on to NEAR science team members, their response was very enthusiastic. Nevertheless, a final decision on whether or not to incorporate the Mathilde flyby into the baseline mission plan will not be made until sometime after launch.

Although Mathilde was discovered in 1885, it was not until early 1995 that it was observed to be a C-class asteroid. The 1995 observations also revealed that its rotation period is unusually long (about 17 days). With a diameter of 61 kilometers (38 miles), it is substantially larger than either of the asteroids that *Galileo* flew by—Gaspra (16 kilometers or 10 miles in diameter) or Ida (33 kilometers or 20 miles). It is also worth mentioning that Gaspra and Ida are S-class asteroids. The NEAR encounter with Mathilde will give us our first close-up images of a C-class asteroid.

As the diagram of the mission trajectory shows, the Mathilde flyby would take place on June 27, 1997, about one week before the deep-space maneuver. Our preliminary plans call for a closest approach distance of 1,200 kilometers (about 750 miles). We will take optical navigation images about three days before the encounter; using these images, targeting errors at Mathilde should be less than 25 kilometers (15 miles).

NEAR's flyby of Mathilde is an extremely valuable addition to the mission. The primary science instrument will be the camera, which will image the entire illuminated side of the asteroid in color at about 1 kilometer resolution. The best monochrome views will show details 200 to 300 meters (roughly 700 to 1,000 feet) across. As it recedes from Mathilde, NEAR will make a thorough search for satellites.

Spacecraft Description

Simplicity and low cost were the main drivers we used in developing the NEAR spacecraft design. The total development cost was less than $115 million, well under the Discovery cost cap of $150 million. The development phase lasted only 27 months. This compares favorably with the *Clementine* experience ($75 million and 22 months), especially when you consider that a rendezvous with Eros is far more demanding than a lunar mission or a simple flyby of 1620 Geographos, as was intended for *Clementine.* (See the September/October 1994 *Planetary Report.*) NEAR is a true planetary spacecraft that can operate at distances of 2.2 AU from the Sun and has a design lifetime of four years.

The asteroids that orbit the Sun in Earth's vicinity are small objects—the largest known is 41 kilometers (25 miles) across—so even though they are close, it's extremely hard to study them from the ground. One tool that's recently proven useful is radar. By bouncing radio waves off an asteroid, scientists are able to discern the object's shape. Here is Geographos as seen on August 30 and 31, 1994. From these images, scientists determined that it is the most elongated body yet seen in the solar system.

Images: Steven Ostro and colleagues, JPL/NASA

NEAR is three-axis stabilized with four reaction wheels for pointing control. (See the Basics of Spaceflight column in this issue.) The instruments, solar panels and high-gain antenna are fixed and body-mounted. The four large gallium arsenide solar panels can provide 350 watts of power at NEAR's maximum solar distance. In addition to the 1.5-meter high-gain antenna, there are two low-gain antennas, and a medium-gain antenna with a fan-shaped radiation pattern. Data rates during the rendezvous and the orbital phase of the mission are quite respectable and can be as high as 18 kilobits per second when using the 70-meter Deep Space Network antennas. NEAR can also store as much as 1.7×10^9 bits of data on its two solid-state recorders. The dual-mode propulsion system uses a hydrazine and nitrogen tetroxide combination for the single large 100-pound bipropellant thruster and pure hydrazine for the 11 smaller monopropellant thrusters. The spacecraft's large fuel capacity gives it a great deal of maneuverability.

Mission Firsts

NEAR will provide the first test of the "faster, cheaper, better" philosophy in the planetary mission arena. If everything goes as planned, it will accomplish a number of important firsts in space exploration:

- First spacecraft to orbit a small body
- First in-depth exploration of a near-Earth asteroid (433 Eros)
- First reconnaissance of a C-class asteroid (253 Mathilde)

There are still other mission features that deserve mention. The main-belt asteroid 253 Mathilde will be the largest asteroid visited by a spacecraft thus far. NEAR will be the first planetary mission for the *Delta* launch vehicle, and the spacecraft will be the first one powered by solar cells to operate beyond Mars' orbit.

Robert Farquhar, of Johns Hopkins University's Applied Physics Laboratory, is the mission manager for NEAR, and Joseph Veverka, of Cornell University, is the principal investigator for two of NEAR's instruments, the camera and the near-infrared spectrometer.

Traveling Through a Mirror: The Hubb

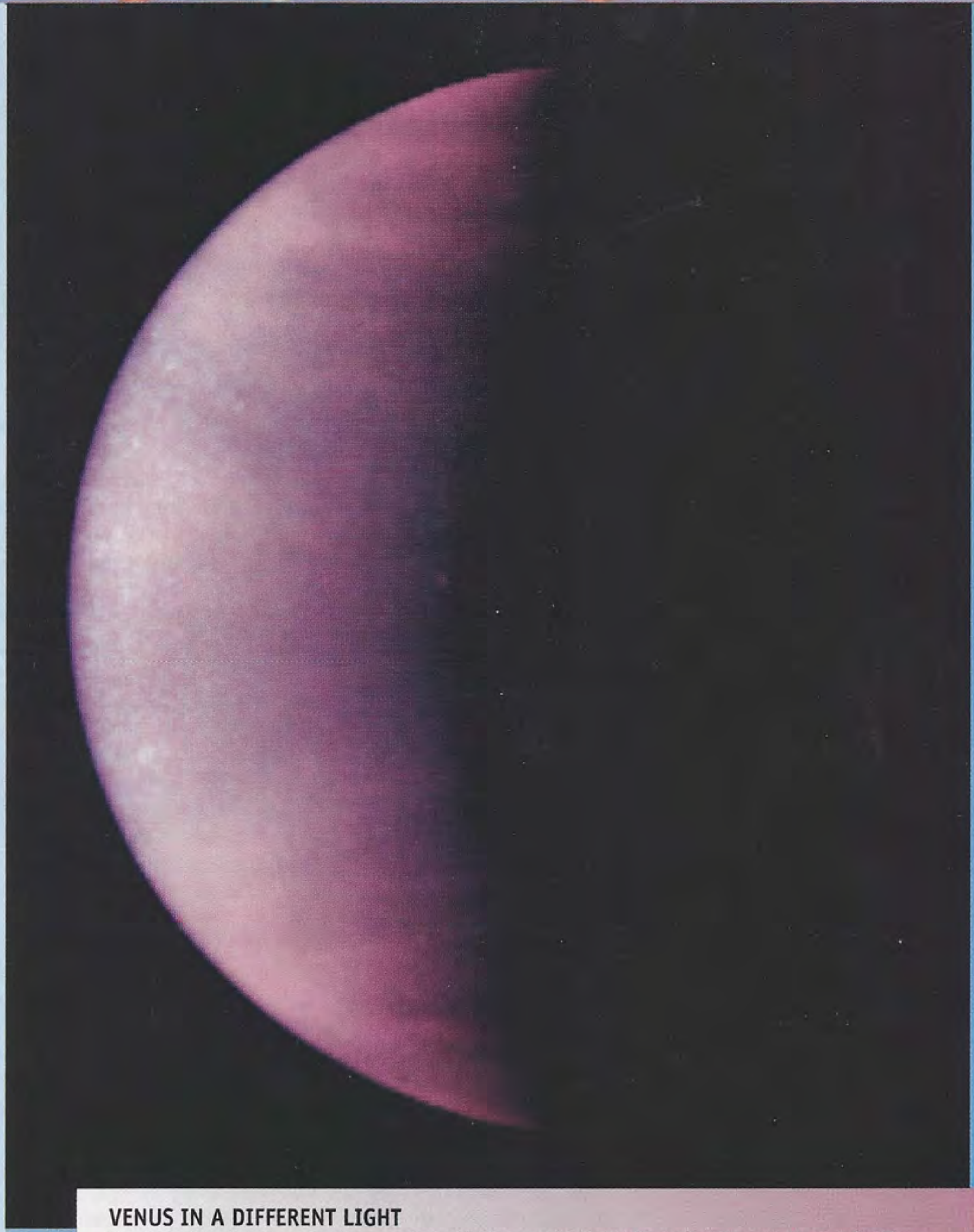
In The Planetary Society, we encourage missions to send robots or humans to explore the planets. But humans have had the ability to travel to other worlds for only three short decades. Before that, telescopes were the tools we used to extend our knowledge of our neighboring planets.

A powerful new telescope is now extending our knowledge with magnificent success. Made possible by our ability to reach space, the Hubble Space Telescope (HST) is observing the universe from low Earth orbit—allowing us to view the solar system almost as if we were traveling through it.

Of course, no telescope can ever be a substitute for actually being there, but flights to planets have become few and far between, so chances to collect in situ data have become rare. In the case of the distant outer planets, such as Uranus and Neptune, the chances may come only once in a lifetime—and scientists now working got that one chance with Voyager *2 in the late 1980s.*

But with HST repaired and working wonderfully, planetary scientists are taking advantage of its power to continue to advance our knowledge. It can't replace actual deep-space missions of discovery, but while we're waiting, what a show!

On these pages, you'll see



VENUS IN A DIFFERENT LIGHT

Thanks to *Magellan,* Venus' surface, marked with bizarre volcanic landforms, has become its most familiar face. But before scientists developed cloud-penetrating radar-imaging techniques, we could see only the tops of its clouds. This HST image reminds us that swirling sulfuric acid clouds are Venus' dominant visible feature.

The image shows Venus at ultraviolet wavelengths. In this light, and with the help of image processing, the cloud patterns stand out and enable us to make out atmospheric motions. At the center is a horizontal Y-shaped feature that seems to be a pattern distinctive to Venus. *Mariner 10, Pioneer Venus* and *Galileo* all recorded this phenomenon. The Y may be formed by atmospheric waves, similar to high- and low-pressure cells on Earth. Hazes of small particles lie above the main clouds concealing Venus' polar regions, brightening their appearance in this image. The dark regions indicate areas of enhanced sulfur dioxide near the cloud tops. During spacecraft missions, scientists were able to track such features, learning that they travel east to west with the prevailing winds to circle the planet in four days.

This image was taken on January 24, 1995, when Venus was 114 million kilometers (71 million miles) from Earth. Image: Larry Esposito and NASA

le Space Telescope Studies the Planets

some of the images HST has recently returned. Scientists have been able to monitor changes to the outer planets since the Voyager *flybys, adding an extra dimension to the brief glimpses from the spacecraft. For the inner planets, the telescope is adding to the store of data illuminating the workings of these worlds. Even a tiny asteroid has been the target of its incredibly sensitive optics.*

These spectacular images will satisfy our craving for new findings about the planets while we wait for the next wave of spacecraft to reach their planetary targets. Galileo *arrives at Jupiter at the end of this year, and next year will see the launches of* Pathfinder *and* Mars '96. *Then we will have short waits for Japan's Planet-B to Mars,* Cassini *to Saturn, the Near-Earth Asteroid Rendezvous to Eros, Japan's Lunar-A, Lunar Prospector and the Surveyor missions to Mars at every two-year opportunity.*

What other missions the future may hold we don't yet know. We don't even know if there will be other orbiting telescopes of HST's class. Whether or not humans will continue such missions of discovery may, in large part, depend on our political actions today.
—Charlene M. Anderson

MARTIAN SPRING
If Percival Lowell had had a telescope as powerful as the Hubble, the "canals" of Mars would never have entered the popular imagination. Here we can pick out details that would have amazed astronomers only a few decades ago: The volcano Ascraeus Mons, 400 kilometers (250 miles) across, pokes above the cloud deck near the morning limb (left) of the planet. The great canyon Valles Marineris cuts across the planet at the lower left. The round white feature at the bottom is the impact basin of Argyre, filled with clouds or frost.

The dark linear features that suggested canals to Lowell and other astronomers are actually streaks of sand deposited in the lee of craters by the martian winds. The dark regions that change with the seasons were once interpreted as areas of vegetation following a yearly cycle. They are now seen to be areas of coarse, dark sand, moved about by seasonal winds. At the top is the north polar cap. The springtime Sun has sublimated much of the carbon dioxide frost that accumulates during the winter. What we see here is the permanent cap of water ice several hundred kilometers across.

The telescope recorded this image on February 25, 1995, when Mars was 103 million kilometers (64 million miles) away. Image: Philip James, Steven Lee and NASA

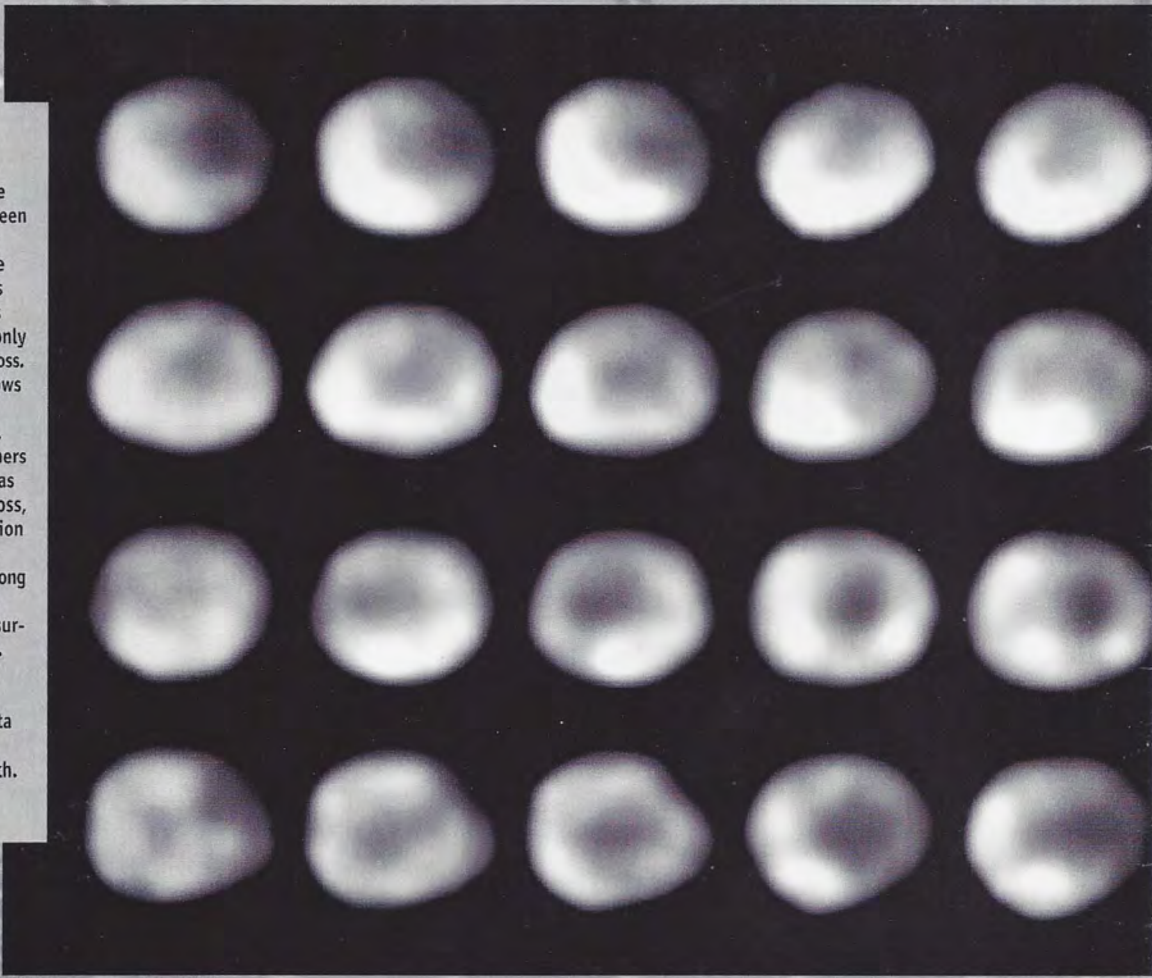
VIRGINAL VESTA

The asteroid Vesta, one of the largest in the main belt between Mars and Jupiter, was seen for the first time with discernible features by HST. Although it's large for an asteroid, Vesta is small for a telescope target, only 525 kilometers (326 miles) across. This series of 24 images follows the irregularly shaped body through a 5.34-hour rotation.

In these images, astronomers can pick out details as small as 80 kilometers (50 miles) across, giving them enough information to begin to map the asteroid. Lava flows mark its surface, along with an impact basin so deep that we can see through the surface into the mantle beneath.

These images were taken between November 28 and December 1, 1994, when Vesta was 250 million kilometers (155 million miles) from Earth.

Images: B. Zellner and NASA

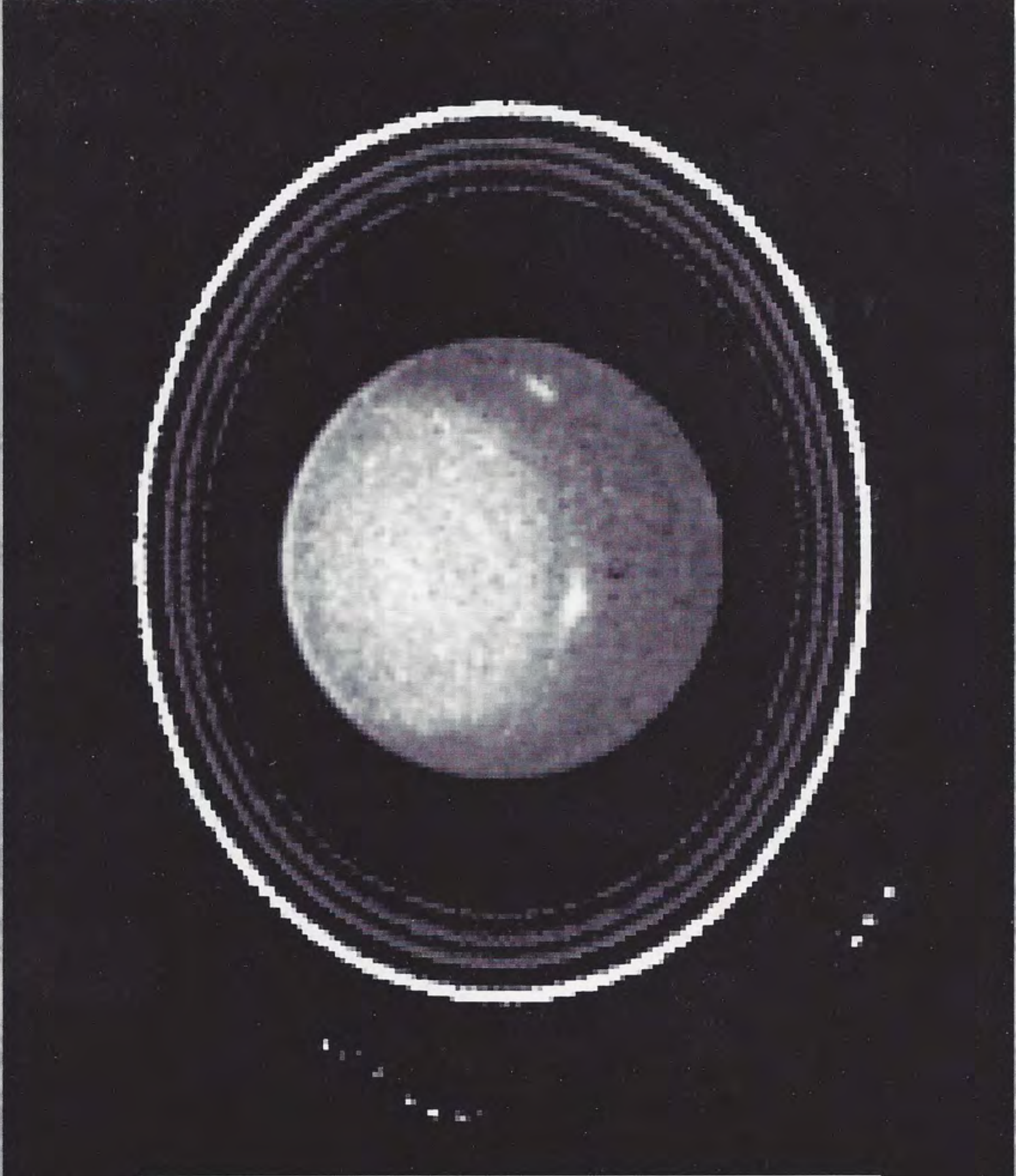


PORTRAIT OF A DOUBLE PLANET

Astronomer Clyde Tombaugh discovered Pluto in 1930, but not until 1978 did another astronomer, James Christy, discover its large satellite, Charon. The moon and planet are so close to each other, only 19,640 kilometers (12,200 miles) apart, that through ground-based telescopes they blur together. But through HST's new optics, the two appear as separate worlds.

HST observations show that Charon is somewhat bluer than Pluto, suggesting that their surfaces are of different compositions. The bright highlight on Pluto may be a reflection off a smooth surface layer. Detailed analysis of this image reveals a bright equatorial region, also detected with ground-based photometric techniques. Future HST observations will show if this feature is real.

This image was taken on February 21, 1994, when the double planet was 4.4 billion kilometers (2.7 billion miles) from Earth. Image: R. Albrecht and NASA



URANUS, THE TILTED WORLD

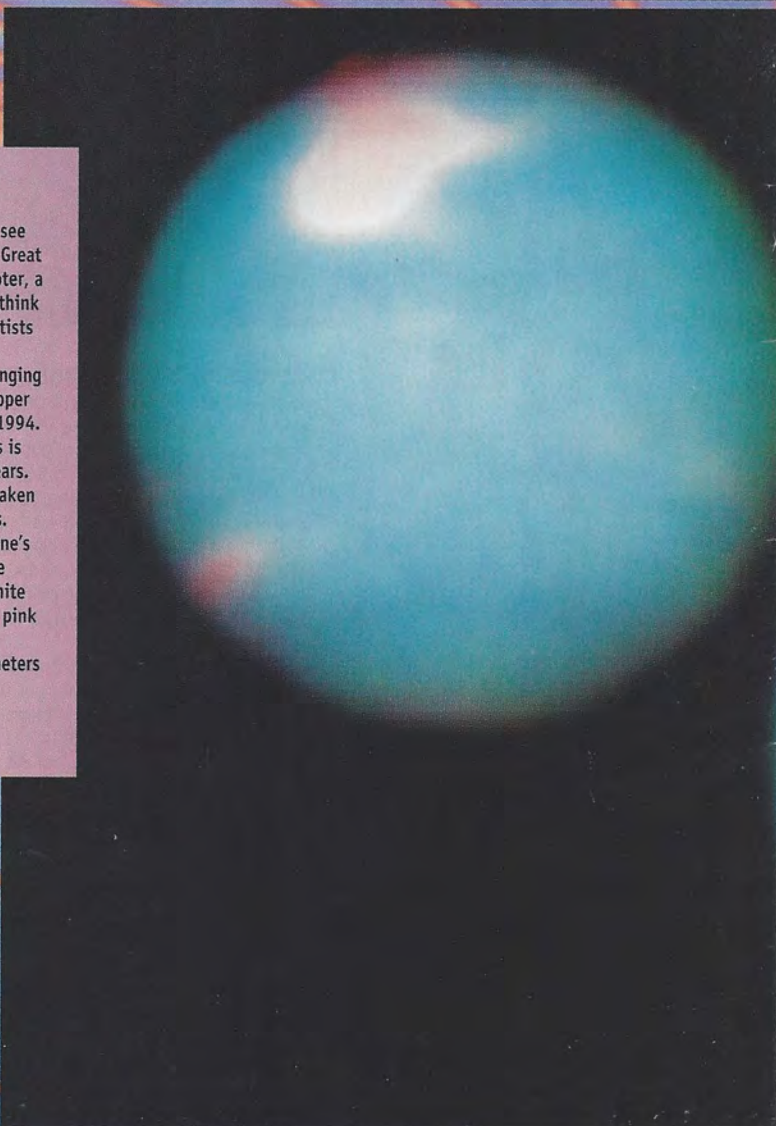
All the planets in our solar system spin around axes tilted relative to the poles of their orbits about the Sun, but Uranus is extreme—from our position on Earth, the planet and its system of moons appear to be lying on their side. Some errant body early in solar system history probably collided with the planet and knocked it out of its original alignment. This planetary system is now testimony to the violence that shaped our neighborhood in space.

In this view from the space telescope, we are looking toward the planet's south pole, and the rings appear nearly face-on. Uranus has 11 dark rings of dust, which had never been seen in visible light until the 1986 visit of *Voyager 2*. Even with HST's great power, only a few are visible here. The outermost is the Epsilon ring, appearing brightest in this image.

At least 15 satellites orbit Uranus, and three are visible here; from left to right, they are Cressida, Juliet and Portia. This image is a composite of three exposures, so each moon, because of its rapid motion about the planet, appears as three distinct dots.

Voyager 2 revealed Uranus' face to be bland and nearly featureless, but it did see a few hazes and clouds. HST picked out similar features: a polar haze and bright clouds at southerly latitudes.

The planet was 2.8 billion kilometers (1.7 billion miles) away on August 14, 1994, when the telescope took this image. Image: Kenneth Seidelmann and NASA



THE CHANGING FACE OF NEPTUNE

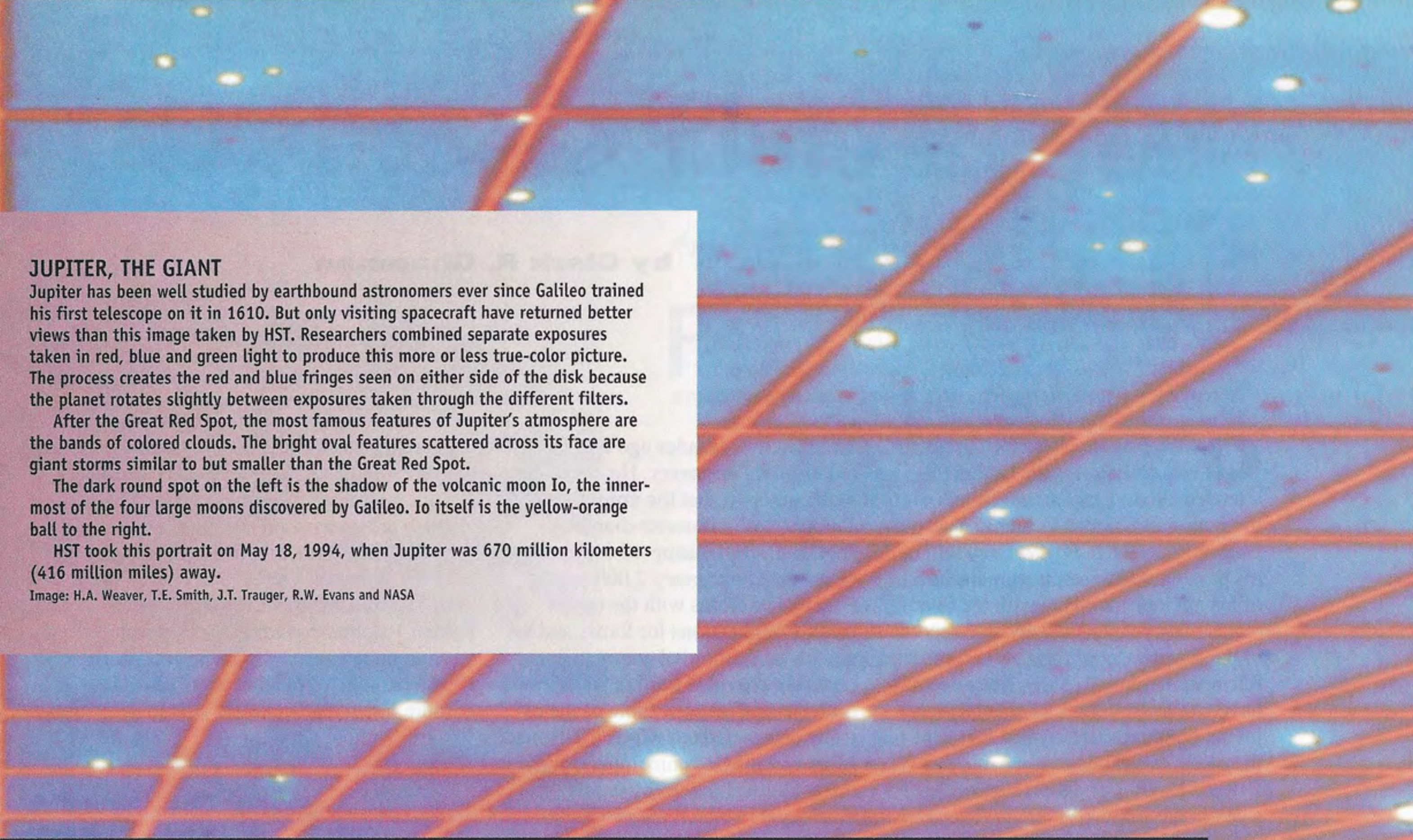
After Uranus' bland, blue face, *Voyager* scientists were happy to see the storm-swept, aqua-tinted face of Neptune. Features like the Great Dark Spot, similar to the Great Red Spot on Jupiter, and the Scooter, a smaller, fast-moving storm, gave atmospheric scientists a lot to think about. But *Voyager*'s encounter lasted only a few days, and scientists were unable to study how the planet changed over time.

Now, with HST's resolving power, scientists can study the changing weather on Neptune. These images were taken on October 10 (upper left), October 18 (upper right) and November 2 (lower center), 1994. They show that the weather can change over just a few days. This is different from Jupiter, where a storm can last for hundreds of years.

The colors in these images were reconstructed from a series taken through different filters at visible and near-infrared wavelengths. The distinctive blue color appears because the methane in Neptune's atmosphere absorbs red light. The pink features are high-altitude clouds made of methane ice crystals. The clouds would appear white if seen by human eyes on a passing spaceship, but here they are pink because they were recorded in the near-infrared.

These images were taken when Neptune was 4.5 billion kilometers (2.8 billion miles) from Earth.

Images: Heidi Hammel and NASA



JUPITER, THE GIANT

Jupiter has been well studied by earthbound astronomers ever since Galileo trained his first telescope on it in 1610. But only visiting spacecraft have returned better views than this image taken by HST. Researchers combined separate exposures taken in red, blue and green light to produce this more or less true-color picture. The process creates the red and blue fringes seen on either side of the disk because the planet rotates slightly between exposures taken through the different filters.

After the Great Red Spot, the most famous features of Jupiter's atmosphere are the bands of colored clouds. The bright oval features scattered across its face are giant storms similar to but smaller than the Great Red Spot.

The dark round spot on the left is the shadow of the volcanic moon Io, the innermost of the four large moons discovered by Galileo. Io itself is the yellow-orange ball to the right.

HST took this portrait on May 18, 1994, when Jupiter was 670 million kilometers (416 million miles) away.

Image: H.A. Weaver, T.E. Smith, J.T. Trauger, R.W. Evans and NASA

News and Reviews

by Clark R. Chapman

On the first anniversary of fragment A's collision with Jupiter, I attended David Levy's benefit talk at the Flandrau Science Center in Tucson. Elegantly and engagingly, Levy told of his passionate interest in comets, and of his anxious moments with the Shoemakers last year as they awaited reports of the first impact of their broken comet, Shoemaker-Levy 9 (SL9). They needn't have worried: A week of spectacular jovian bombardment ensued that kept the world enthralled.

Read David Levy's account of that week in the August *Scientific American,* coauthored with his SL9 codiscoverers, Gene and Carolyn Shoemaker. A sidebar traces the final chapter of SL9's 4.5-billion-year life, from 1929—when it most likely was captured into Jupiter orbit—through its violent demise. Yet the article says little about what was learned from the impacts, for scientific knowledge takes time to attain.

Unprecedented Data

The sheer volume of SL9 data is unprecedented in the history of astronomy. Indeed, observations continue: The new black band of impact debris, although dispersed widely in Jupiter's stratosphere, is still visible a year after the comet crash. (Amateur astronomers: Look particularly at longitudes opposite the Great Red Spot.)

Astronomers are just beginning to reduce and publish some of their data. Early Hubble Space Telescope results are in the March 3, 1995, issue of *Science* magazine. Forty 4-page papers appeared in two issues (June 15 and July 1) of the technical journal *Geophysical Research Letters (GRL)*. Visit your state university library to find *GRL;* your efforts will be repaid by Gene Shoemaker's introduction, which sets the comet crash in its broader historical and scientific contexts. Shoemaker, who first proved Meteor Crater's extraterrestrial origin, organized the telescopic searches two decades ago that finally led to SL9's discovery. He calculates, with authority, that the impact onto Jupiter of a 2-kilometer-diameter Jupiter-orbiting disrupted comet should occur only once every 2,000 years. Shoemaker closes with the comet crash's implications for Earth, and for ourselves. Primordial comet impacts probably provided Earth's watery environment and perhaps some of the organic compounds of which life is made. More recently, cosmic impacts opened the ecological niche (by eradicating dinosaurs) in which the evolution of mammals thrived. SL9-like impacts pose potentially deadly hazards today if we do not pay heed.

Puny Comet Bits

Computer modeling of SL9's tidal breakup by Eric Asphaug (NASA Ames Research Center) and Willy Benz (University of Arizona), and by other researchers, shows that SL9 was originally just 1.5 to 2 kilometers across. Even its largest fragments, whose "bruises" in Jupiter's stratosphere exceeded the size of Earth, were only 700 meters across. Considering the enormity of Jupiter, how could such puny comet bits do so much damage?

Planetary physicists and chemists are just beginning to understand how. In May, the Space Telescope Science Institute in Baltimore hosted the world's SL9 researchers. Astronomers intercompared their *GRL* data and other late-breaking results. They finally began to understand *what* had been observed—at every stage of each impact, at every wavelength from X-ray to long-wave radio, and from every major observatory in the world and in space.

But researchers remain unsure whether the huge black spots were primarily made of comet debris or, instead, of jovian atmospheric gases, forged in million-megaton explosions. Preliminary accounts of the Baltimore meeting will soon appear in *Sky & Telescope* and other magazines. But we must be patient until the deeper meanings of SL9's crash are understood and reported. A special SL9 issue of *Icarus* will appear in the spring of 1996.

The Shoemakers have terminated their Palomar-based search; several other underfunded search projects are also ending. Without new efforts, it is more likely that an object will strike Earth without warning. As I write, the report of the Shoemaker committee, commissioned by Congress during Comet Crash Week, is in NASA's hands, awaiting release. Whether its recommendations to mount a major search for dangerous comets and asteroids will be heeded is anyone's guess.

Silly Season

Before we worry about whether Earth will survive cosmic bombardment, we have more pressing concerns. Despite the public's enthusiasm at reliving the drama of *Apollo 13* on the big screen, NASA's future is in jeopardy. Indeed, the entire culture of science and technology is under attack.

After all, this is "silly season." One week, Congress pretends that it will close down three NASA centers, cancel the US–European *Cassini* mission to Saturn and forget about projects that would revolutionize infrared studies of the cosmos. The next week, it threatens, instead, the Earth Observing System.

It is, perhaps, through the efforts of David Levy, and such science education causes as the one his SL9 anniversary talk benefited, that we may hope to inspire young people to pick up where the generation inspired by *Sputnik* and *Apollo* has left off. That may be SL9's most important legacy.

Clark R. Chapman is preparing for Galileo*'s long-awaited tour of Jupiter's satellite system, which begins this December.*

Society News

The Rover Gets a Name

The winning name in the Mars *Pathfinder* Microrover Contest has been selected. It is "Sojourner," named after Sojourner Truth, a former slave and abolitionist. Thirteen-year-old Valerie Ambroise of Bridgeport, Connecticut, chose "Sojourner" because "she [the microrover] is on a journey to find truths about Mars." Valerie will receive an all-expenses-paid trip to Florida for the December 1996 launch of *Pathfinder* and its microrover.

The contest was sponsored by The Planetary Society with the cooperation of the Jet Propulsion Laboratory. Over 3,000 entries were received from students born on or after January 1, 1976. Their task was to choose a heroine from mythology, fiction or history (not living) and describe, in 300 words or less, how she would explore Mars. The Society recommended names to NASA, which made the final selection.

Eighteen-year-old Deepti Rohatgi of Rockville, Maryland, won second prize (a $500 scholarship) with her selection, "Marie Curie." Third prize (also a $500 scholarship) was won by 16-year-old Adam Sheedy of Round Rock, Texas, for "Judith Resnik."

Also winning prizes (an Explorer's Guide to Mars poster and a $100 gift certificate for Planetary Society merchandise) were these students:

- Joshua Barnett (13 years old) of Visalia, California, for "Athena"
- Morgan Flubacker (13 years old) of Barrington, Illinois, for "Amelia Earhart"
- Rebecca Kastner (7 years old) of Columbus, Indiana, for "Sacajawea"
- Sarah Laub (14 years old) of Cresco, Iowa, for "Minerva"
- Courtney Nocera (14 years old) of Steubenville, Ohio, for "Thumbelina"
- Brian O'Leary (13 years old) of Plandome, New York, for "Harriet Tubman"
- Virginia Skelton (13 years old) of Senatobia, Missouri, for "Atalanta"

Although most of the contest entries were from students in the United States, essays came to us from Canada, India, Israel, Japan, Mexico, Poland and Russia. A book containing 100 of the essays will be produced. Each entrant whose essay appears in the book will receive a Mars *Pathfinder* T-shirt from the Jet Propulsion Laboratory. Everyone who entered the contest will receive pictures of the *Pathfinder* microrover and the surface of Mars.
—Louis D. Friedman, Executive Director

The Great (On-line) Space Place!

The Society's on-line resource center for space exploration is now available on our new World Wide Web home page. Check it out at http://planetary.org/tps/. The new page features Spacegate, a gateway to all space resources on the Internet. New features are added weekly.

Is there a link you'd like us to add? Let us know: Send e-mail to tps.km@genie.geis.com. *—Kari Magee, Resource Center Manager*

Galileo Updates

Beginning in November, the Society will work with the Jet Propulsion Laboratory to provide the latest mission updates as *Galileo* approaches Jupiter, with *Galileo* team members answering questions on-line on the World Wide Web. To find out how to participate and to receive an information packet on the mission, call Society headquarters at 818-793-5100. Details are also available on our Web home page and on our GEnie RoundTable. *—KM*

Help Turn BETA On

In late October, 1995, the Society will launch Project BETA, the Billion-Channel Extraterrestrial Assay that will scan the universe for signs of intelligent life on other worlds. The project was funded by our members with a matching grant from Micron Technology, Inc.

Be in on this at the beginning—join us at the opening ceremonies for BETA at the Oak Ridge Observatory in Harvard, Massachusetts. If you're there, you'll have a chance to take part in the actual turning on of BETA. The names of all members attending the opening ceremonies will be entered in an on-site drawing. The person whose name is drawn, along with any accompanying family members, will help throw the switch that will turn BETA on.

For more information on the opening of Project BETA, including the exact date, please write to me at Planetary Society headquarters. Or contact me via e-mail at tps.sl@genie.geis.com.
—Susan Lendroth, Manager of Events and Communications

On-line Adventure

Teachers, take your students on a real-time, on-line adventure aboard the Kuiper Airborne Observatory! *Passport to Knowledge,* a public television project whose earlier multimedia ventures included *Live From Other Worlds* and *Live From Antarctica* (see the November/December 1994 *Planetary Report*), will be linking students and Kuiper scientists as part of the new *Live From the Stratosphere,* beginning this fall.

Some highlights: Glimpses of Saturn and its mysterious moon Titan are on the agenda during a five-hour flight on October 13, and information on how to follow *Galileo*'s December 1995 encounter with Jupiter will also be given on-line.

For recorded information, call 800-626-5483. You may also call producers Geoff Haines-Stiles and Erna Akuginow at 908-273-4108, or write to *Live From the Stratosphere,* P.O. Box 1502, Summit, NJ 07902-1502.
—Charlene M. Anderson, Director of Publications

Keep in Touch

Our mailing address:
The Planetary Society
65 North Catalina Avenue
Pasadena, CA 91106-2301

General calls: 818-793-5100

Sales calls only: 818-793-1675

E-mail: tps@genie.geis.com

World Wide Web Home Page:
http://planetary.org/tps/

Questions and Answers

How do scientists calculate an incoming comet or asteroid's orbit? And how do they figure out what areas on Earth will be best for observing the body? How is it all timed so perfectly?
—Gary L. Brown,
Sandoval, Illinois

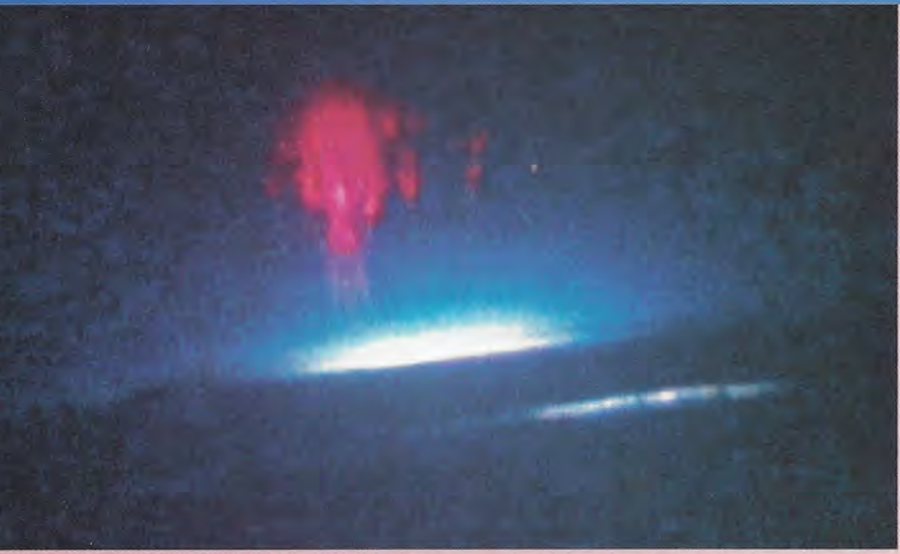
We track incoming bodies the same way we track all asteroids and comets. The method is a perfect example of how we are still indebted to Copernicus, Kepler and Newton and their works of the 1500s and 1600s. Before that time, when Earth was seen as the center of the planetary system, planets could be a degree or more out of the position predicted by the old Ptolemaic theory. The measurement of a degree at the distance of Mars, for example, could correspond to a million miles, or a couple of hundred planet diameters. That means that astronomers of that day could not track objects very precisely. The breakthrough made by Kepler and Newton was to show that all planetary bodies move in ellipses around the Sun.

Today, if we detect an asteroid—either out in the main asteroid belt or approaching Earth—we need only fit its observed position onto an elliptical path, with the Sun at one focus of the ellipse, and then we can project where it will go. In principle, as few as three precisely observed positions—at three different times—are adequate to determine the ellipse. In practice, observations have errors, so dozens or hundreds of observations may be used to tie down the orbit.

We also fine-tune the calculated orbit to adjust for the gentle tug of various planets, which may nudge an asteroid out of a perfect Keplerian ellipse. In this way, we know the position of asteroids in three-dimensional space to accuracies of a few tens of miles, and we can project along the orbit to see if it will intersect our own planet, Earth.

This in turn answers the second question. If you (or rather your computer) know where an asteroid is at any instant in time, within tens of miles, then you know whether California, France or Borneo is facing that way and hence who may have the best view

Factinos



Hundreds of spectacular red and blue flashes like these have been observed in Earth's upper atmosphere, and recorded by researchers from the University of Alaska's Geophysical Institute. Called "sprites," these electromagnetic displays occur above thunderstorms. This is the first true-color image of a sprite, observed over a midwestern thunderstorm on the night of July 3, 1994. The image was captured using a low-light-level color television camera from an airplane. The top of this large sprite is higher than 85 kilometers (53 miles); the blue, root-like tendrils beneath it are as low as 60 kilometers (37 miles). Below the sprite is a blue-white area that is an overexposure of normal lightning on the storm's cloudtop, which is about 17 kilometers (10 miles) high.
Image: Daniel Osborne, University of Alaska Geophysical Institute, Fairbanks

Last year was literally a "shocker" for atmospheric scientists. According to Davis Sentman, a geophysicist at the University of Alaska, they had thought that Earth's upper atmosphere was a "quiet, calm, tame, almost boring place." Instead, Sentman and his colleagues found it to be alive with brightly colored electromagnetic displays. In 1994, Sentman and colleague Eugene Wescott and Walter Lyons, a meteorologist from Mission Research Corporation in Fort Collins, Colorado, caught some of the flashes on videotape. Scientists from Pennsylvania State and Stanford universities joined the research effort last summer. Between June 28 and July 12, 1994, they captured dozens of video and still images of the flashes.

There are two types of flashes, sprites and blue jets. Sprites are described as looking like red jellyfish with faint blue tendrils. They appear as high as 100 kilometers (60 miles) and are not always connected to storm clouds. The blue jets reach about half as high, and shoot up from thunderstorms in geyser-like streams that flare out on top. Although both types seem connected with thunderstorms, there is no established theory to explain what happens.
—from Robert Cowen in
The Christian Science Monitor

of the asteroid. This is why astronomers can predict *roughly* where to go to see an asteroid pass in front of a star—occultations that let us detect shapes and possible satellites of asteroids.

The key here is to imagine a universe consisting only of the distant star, the asteroid and Earth. As the asteroid passes between the star and Earth, it casts a shadow across Earth. Only in the shadow can the observer see the occultation (think of a solar eclipse). Thus, if we know the asteroid's position within 1,000 miles, we can say only that the shadow will cross Earth somewhere in North America or Europe, for example. But if we know the asteroid's position within tens of miles, we can say that the shadow will cross southern Arizona or northern Illinois or some other local region.

—WILLIAM K. HARTMANN,
Planetary Science Institute

In 1983, Planetary Society members were invited to help track and map an asteroid, Pallas, from the ground. For the methods used, see "Help Examine a Mysterious Asteroid: The Planetary Society Pallas Project," by Clark Chapman, in the March/April 1983 issue of The Planetary Report. *For a detailed account of what they found, see Chapman's "Pallas Report" in the July/August 1984 issue. —Editor*

From what I read in "Basics of Spaceflight: Getting There" (see the March/April 1995 issue of* The Planetary Report*), I get the impression that launches from Earth to the inner planets must occur during the day, while launches to the outer planets must happen at night. Is that so?
—João Miguel Matos,
Setúbal, Portugal

Your conclusion is basically correct: To take best advantage of Earth's motions, generally the time for a spacecraft to depart from Earth on its final interplanetary trajectory will be when it's over the nighttime side for a flight to the outer planets, and over the daytime side for a flight to the inner planets. However, the time of liftoff from Earth's surface can actually vary widely.

"Getting There" oversimplified the concept of launch to "pretend that the launch process doesn't take much time." It didn't make much of a distinction between liftoff from Earth's surface and injection on an interplanetary trajectory (departure from Earth's vicinity). In reality, the time of liftoff from Earth's surface would vary according to how long it will take until the final injection stage can be ignited, how long it will take the injection stage to burn and how many separate impulses there will be. Both *Voyagers* lifted off from Earth's surface in the local daytime, but by the time their rocket engines placed them on trajectories to the outer planets, they had traveled along an arc eastward around to Earth's nightside.

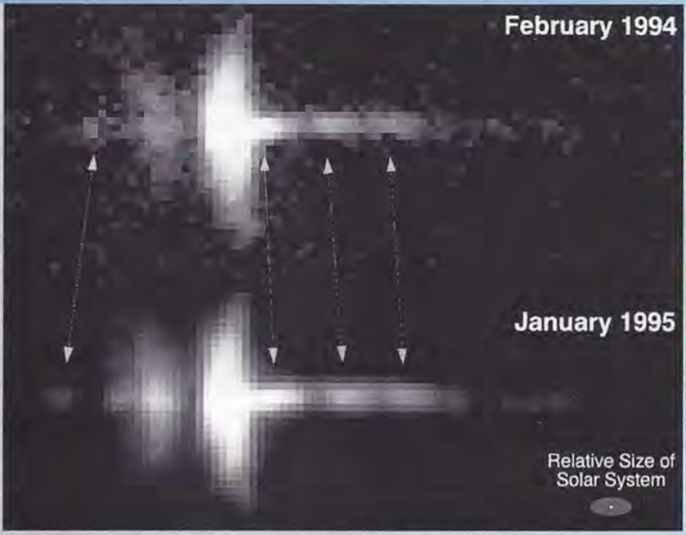
When interplanetary spacecraft have been launched via the space shuttle (*Magellan*, *Galileo*, and *Ulysses*, for example), there have been additional tasks to undertake while still in Earth orbit, including opening the shuttle's payload bay doors, deploying the spacecraft and moving the shuttle a safe distance away. The shuttle's liftoff time therefore bears little resemblance to the time the spacecraft finally departs from Earth orbit.

—DAVE DOODY,
Jet Propulsion Laboratory

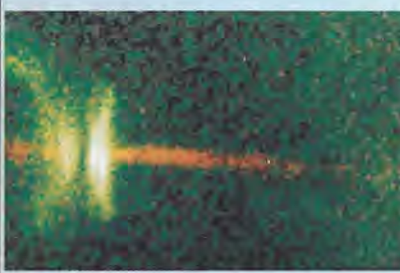
The Hubble Space Telescope (HST) has returned these images showing unprecedented detail of a newly forming star called HH30. This is the first time HST has shown an accretion disk around a forming star. When this star becomes hot enough, it will stop accreting material and blow away much of the disk—but perhaps not before planets have formed around it. Scientists generally believe that our solar system formed from such a disk and that the orbits of the planets are the skeletal remnant of the disk. This also explains why all the planets orbit the Sun in the same direction and in roughly the same plane.

These exposures, taken about a year apart, show the motion of high-speed blobs of gas (arrows) that are being ejected from the star at about 800,000 kilometers (half a million miles) per hour. These jets emanate from the center of a dark disk of dust.

—from the Space Telescope Science Institute



***Above:** These Hubble Space Telescope images show the formation of a new star, called HH30, in detail not seen before. The arrows in these images, taken about one year apart, point to high-speed blobs of gas that are part of jets being ejected from the center of a dark disk of dust that encircles the star and hides it from view. The presence of the blobs suggests that the star formation process is fitful and episodic as chunks of material fall onto the newborn star. The relative size of our solar system is shown at lower right.*



***Upper right:** In this color view of HH30, the HST shows for the first time that the jet (red) expands for several billion miles from the star, but then stays confined to a narrow beam. This protostar is 450 light-years away in the constellation Taurus.*

Images: C. Burrows, Space Telescope Science Institute and European Space Agency; the Wide Field/Planetary Camera 2 Investigation Definition Team and NASA

Basics of Spaceflight: Attitude Control

by Dave Doody

Picture yourself flying along with the *Voyager* spacecraft in the far reaches of the outer solar system. During much of its flight, *Voyager* must keep its large, dish-shaped antenna facing Earth so it can send back data, and so it can receive commands. It must also be able to aim its instruments in precisely the desired direction.

If you have ever looked through a telescope, you know how important it is to point it in exactly the right direction and to keep it that way while you observe, moving it slightly to adjust for Earth's rotation. The same principle holds true for every modern spacecraft, whether it's a weather satellite orbiting Earth, a radar mapper at Venus or an interstellar cruiser like *Voyager*. Its attitude—that is, its orientation in space—must be controlled and stabilized, and its instruments' pointing may have to be adjusted for the relative motions of the targets they observe.

There are other reasons for controlling a spacecraft's attitude. It enables convenient use of the heating and cooling effects of sunlight and shadow for spacecraft thermal control. It is necessary so propulsive maneuvers can be executed in just the right direction. Images and other scientific data can be properly interpreted only if the spacecraft's attitude is known precisely.

To discuss attitude, we should first describe roll, pitch and yaw. In a sailboat, roll is the motion tilting the deck over to the left or right—excuse me, port or starboard. Pitch is the motion of the bow up and down. In yaw, the bow moves to starboard as the stern moves to port, and vice versa.

The roll, pitch and yaw axes of a spacecraft are always orthogonal (at right angles to one another) and they pass through the spacecraft's center of mass. In *Voyager*, *Galileo* and *Magellan,* the roll axis (more properly, the longitudinal axis) extends straight through the focus of their large, dish-shaped antennas, so that rolling the spacecraft turns the antenna dish like a wheel.

For the purposes of our discussion, we can ignore the speed of the spacecraft and its trajectory (its path through space). All we're talking about is the way a spacecraft changes attitude, rotating slightly left or right, or back and forth. For example, you don't care that your airline coffee cup is speeding along at 650 miles per hour. What you do care about is whether it's right-side-up while you hold it, and that it tips just so as you sip.

Spinning to Stability

Probably the simplest way to stabilize a spacecraft is to set it rotating, so that its spinning mass acts as a gyroscope; if it rotates in roll, for example, the spinning mass keeps the yaw and pitch from changing. If you throw a Frisbee well, you'll see this gyroscopic principle in action. The disk stays flat and stable as it spins.

If you could see *Galileo* moving toward Jupiter, you'd be looking straight "down" its longitudinal axis, and you'd see it rolling clockwise about three revolutions per minute. This spinning action not only keeps the spacecraft stable, but also allows certain instruments to sweep around, which is ideal for making measurements of fields and particles in the spacecraft's immediate vicinity. *Galileo* has a motor-driven section that keeps its cameras pointed properly while the rest of the craft rotates. *Pioneer 10* and *11*, still operating in the outer solar system, are also spin-stabilized craft.

Typically, a spacecraft's human controllers will command the propulsion-system thrusters to fire once in a long while to make desired changes in the spin-stabilized attitude. For example, if you need *Pioneer*'s roll axis to point exactly to Earth for communications, you may have to adjust the spacecraft's attitude a couple of times a year—because from the spacecraft's point of view, Earth keeps moving back and forth in its solar orbit.

Three-Axis Stabilization

Unlike *Galileo* and *Pioneer*, *Voyager* doesn't spin. It is constantly rocking around a little, though, changing its attitude (see sidebar). The amount of rocking in each axis is controlled by an onboard computer—known as the attitude and articulation control subsystem (AACS) computer—that commands tiny, liquid-fueled rocket thrusters to fire a short burst and reverse the direction of rocking every so often, in a constant effort to dampen it out. Each thruster burst lasts only a few milliseconds, pushing with less than 1 newton of force (about as much reaction as you'd get from "firing" spray paint from an aerosol can).

To know when to fire the thrusters, the AACS computer normally processes input from attitude sensors. *Voyager* uses a Sun sensor to measure the Sun's apparent excursions while the spacecraft slowly rocks in pitch and yaw. To sense roll motion, the AACS computer uses the Canopus tracker, which keeps its "eye" on Canopus or another bright star, watching it appear to move if the spacecraft rolls.

Input from sensors that watch the Sun or other stars is called celestial reference. *Galileo*'s celestial reference, by the way, normally comes from a star scanner that is mounted on the rotating body and recognizes the moving star patterns as it sweeps around.

Voyager's class of attitude control is called three-axis stabilization. The amount of "rock-and-roll" permitted before the thrusters fire is called the deadband. During each of *Voyager*'s planetary encounters, the AACS computer was commanded to make the deadbands much narrower so the optical instruments could be pointed more precisely.

Another method of three-axis stabilization uses electrically driven reaction wheels, also called momentum wheels, mounted in orthogonal axes. To rotate the whole spacecraft in one direction, you spin the proper momentum wheel in the opposite direction. To rotate the vehicle back, you just slow down the same wheel.

Spacecraft momentum wheels are generally about a foot in diameter. They're convenient for use in a spacecraft that changes its attitude a lot. This was the case with *Magellan*, which was constantly adjusting its pointing while it was radar mapping the surface of Venus, and also had to turn frequently to communicate with Earth.

This kind of system isn't perfect, since there is friction in the mechanism. Also, there are constant small forces acting from outside to rotate a spacecraft, such as the slight pressure from sunlight, and the very slight difference in the strength of a planet's gravity, felt at the different points on the spacecraft that happen to be facing toward or away from the planet (this is called gravity gradient). All these factors cause excess momentum to build up, and the momentum wheels end up spinning faster and faster. So the spacecraft must occasionally use its rocket thrusters to slow the momentum wheels down.

The Hubble Space Telescope (HST) uses momentum wheels to control its attitude, too, but it can't use rocket thrusters for momentum desaturation because their exhaust clouds might condense on the sensitive optical components and contaminate them. So Hubble uses four electromagnets called magnetic torquers, which, when selectively energized, react with Earth's magnetic field to apply the desired torque to the spacecraft.

Trade-offs

There are advantages and disadvantages to all the various attitude control schemes, of course. Spin-stabilized craft provide a simple means of stability, and the continuous sweeping desirable for fields and particles instruments, but they sometimes require complicated systems to de-spin antennas or optical instruments that must be pointed at targets. Three-axis controlled craft can point optical instruments and antennas without having to de-spin them but may have to carry out special rotation maneuvers to best utilize their fields and particles instruments. Also, they have to carry enough propellant to keep the craft stable over the life of the mission. Among three-axis stabilizing systems, it may be preferable to carry propellant, as in the case of *Voyager*, rather than attempt to operate electromechanical momentum wheels throughout a flight lasting decades. And magnetic torquers are only operable in the vicinity of a planet that has a substantial magnetic field to "push" against.

Small gyros, and sometimes accelerometers (acceleration sensors), provide attitude reference (called inertial reference) for those periods when celestial reference is not being used. Some spacecraft use their inertial reference nearly continuously. *Magellan,* for example, checked its celestial reference only once every orbit or two, to update the attitude information provided by its gyros. Other spacecraft, such as *Voyager*, use celestial reference nearly continuously. They rely on gyros (inertial reference) only during relatively short maneuvers when celestial reference is dropped.

In either case, gyro data must be taken with a grain of salt. Most of today's gyros are electromechanical units, so they precess and drift as a result of internal friction. Great pains are taken to monitor and measure their drift rates so the AACS may compensate as best it can when it computes its knowledge of the spacecraft's attitude.

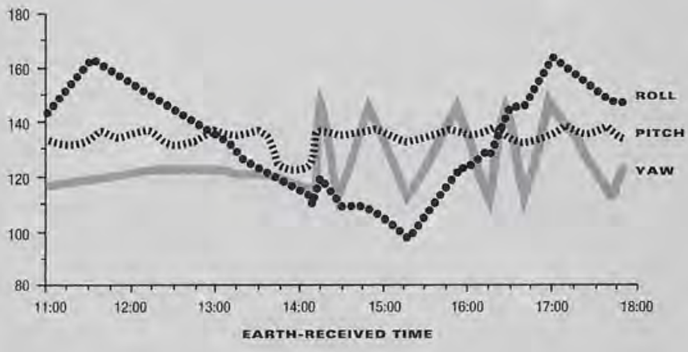


Chart by Dave Doody, redrawn by B.S. Smith

Seven Hours in the Life of Voyager 1

Here's a plot that shows the actual pitch, roll and yaw motion of *Voyager 1* over a seven-hour period on Thursday, June 1, 1995. In the plot, the fact that the lines are not straight and flat reveals that the spacecraft is moving in all three axes.

The values on the left side of the plot are arbitrary units called data numbers, which translate into different numbers of degrees for each axis. The roll-reversal points, where the thrusters fire, are set to plus and minus 0.25 degree; this means that the spacecraft is free to roll a total of half a degree before a thruster fires. The total allowed for pitch is 0.10 degree, and for yaw it is 0.20 degree.

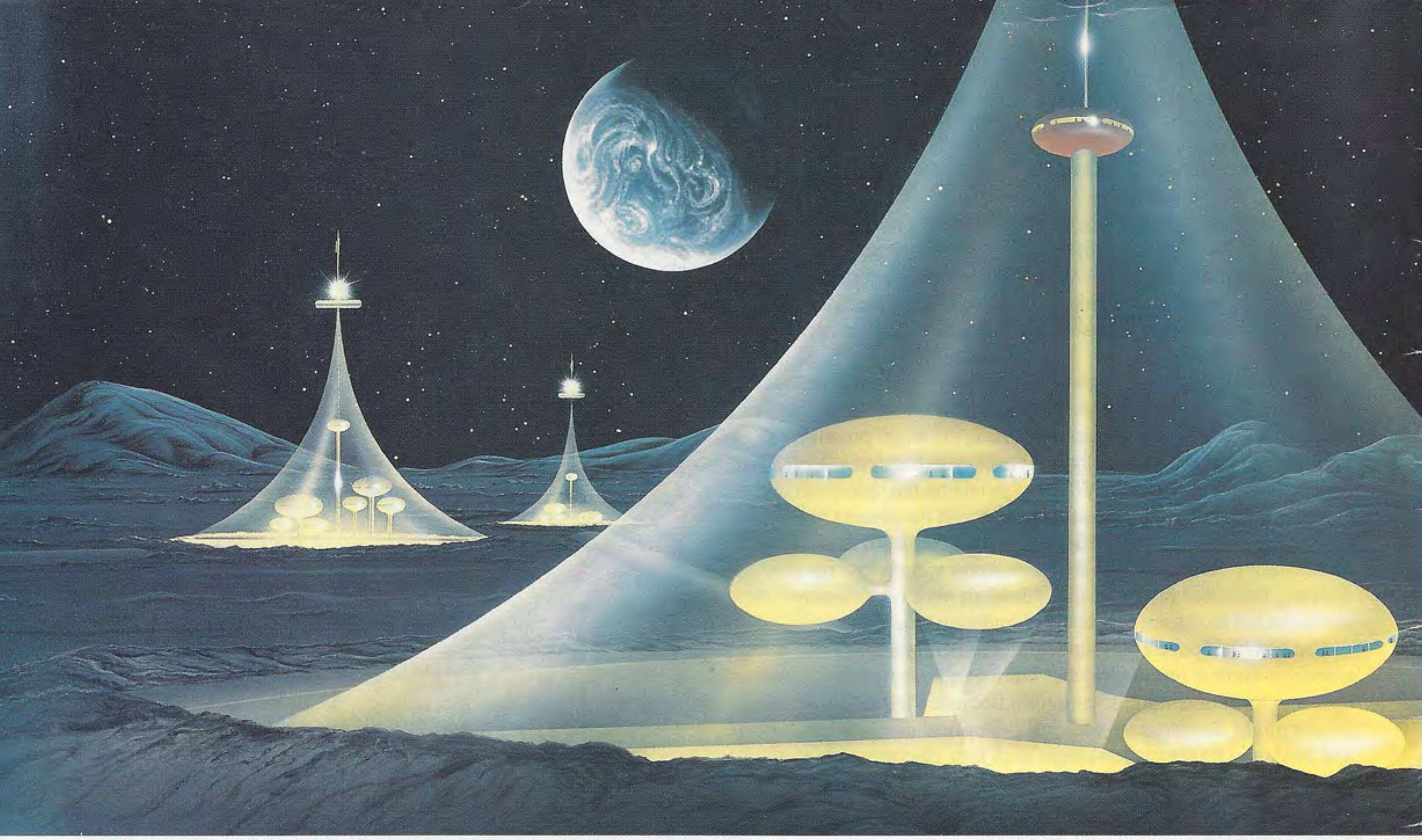
Roll, indicated by the dotted line, shows motion in one direction until it reaches a value of about 165 at a time of about 11:40, when a thruster fires. It reverses direction for about four hours, until the thruster fires again near a value of about 95.

While *Voyager*'s pitch attitude, indicated by the dashed line, is fairly steady, the most rapid changes occur in yaw, indicated by the gray line. The yaw axis passes through the spacecraft along its massive appendages, making movement in yaw comparatively easy, since it only involves a twisting of these masses, rather than swinging them around which is required for motion in pitch or roll. The pitch curve has a U-shaped feature in it at about 13:45; this was caused when AACS slewed the spacecraft's optical instrument platform to make an observation with the ultraviolet spectrometer. Pitch returned to normal when the slewing movement stopped about 14:10, but the abrupt stop started the spacecraft "bouncing" back and forth in yaw, as evidenced by the "mountain range" of peaks in the yaw plot. *—DD*

Next time, we'll take a look at telecommunications, the process of sending commands to, and receiving information back from, a distant spacecraft.

Dave Doody is a member of the Jet Propulsion Laboratory's Advanced Mission Operations Section and is currently working on the Cassini *mission to Saturn.*

For more information, check out JPL's *Basics of Space Flight* on the World Wide Web at Universal Resource Locator http://oel-www.jpl.nasa.gov/basics/bsf.htm.



What will human colonies on the Moon look like? In "Tent City on the Moon," Kazuaki Iwasaki envisions a plan where the walls of lunar craters are used as base supports for huge, round tents filled with the special mixture of oxygen, nitrogen and other gases that comprises Earth's atmosphere. In this scenario, the buildings inside the tents can be raised and lowered.

Kazuaki Iwasaki has been painting space scenes for 44 years. When he is not painting, Iwasaki works as an industrial designer. He lives in Yokohama, Japan.

THE PLANETARY SOCIETY
65 North Catalina Avenue
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