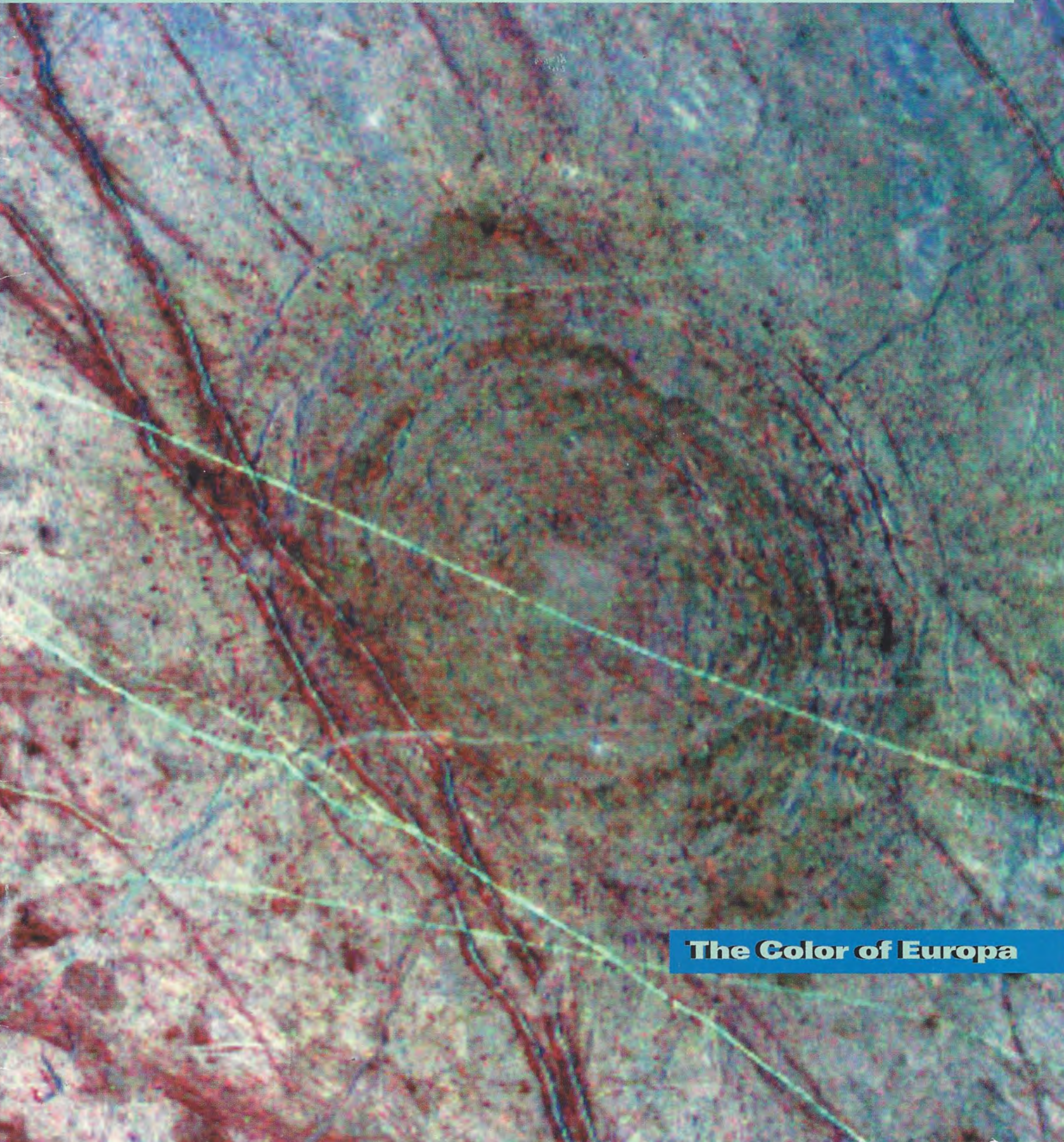
The PLANETARY REPORT

Volume XVII Number 5 September/October 1997



The Color of Europa

On the Cover:

Tyre, an ancient impact basin more than 140 kilometers (90 miles) across, grabs our attention in one of the highest-resolution pictures of Europa yet obtained by *Galileo*. In this false-color image, the bright blue, east-west ridges crossing the region are much younger than the crater, illustrating how the moon maintains its youthful appearance. Older, darker surfaces are covered over with clean, relatively coarse-grained ice that is extruded along the fractures in Europa's frigid crust. Coarse-grained ice, which forms at warmer temperatures, may be a sign of liquid water below.

Galileo imaged Tyre on April 4, 1997 from a distance of 703,776 kilometers (434,430 miles).

Image: NASA/JPL

From The Editor

As the editor of a bimonthly publication, I put together each issue knowing that there is no way we can compete in timeliness with daily newspapers and weekly magazines. Our readers sometimes have to wait two or more months before they read space mission results in *The Planetary Report*. At no time have I felt the pressure of this more keenly than now, as results pour in from the Near-Earth Asteroid Rendezvous (NEAR) at Mathilde and from *Pathfinder*, with its rover *Sojourner*, on Mars. And *Galileo* continues to funnel data back from its continuing mission around Jupiter.

We were already in production with this issue when NEAR passed Mathilde, and as I write this, *Pathfinder* and *Sojourner* are still exploring Mars. We have dropped in Mathilde images as a giant Factino in place of the usual Questions & Answers column. On the back cover, we've inserted an image from *Pathfinder*.

In place of timeliness, we have the luxury of waiting until things calm down and scientists have a chance to think about mission results. After the dailies and weeklies have lost interest, we continue to report on planetary missions and give our readers a fuller, more considered account of scientific discovery. In upcoming issues look for detailed reports from Mars, Mathilde, and the Jupiter system. We hope they'll be worth the wait.

—*Charlene M. Anderson*

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One thing that makes *The Planetary Report* different from most magazines reporting on scientific discovery is that we ask the people actually making the discoveries to write their own stories. In this article, William K. Hartmann recounts the leading theory of the Moon's formation—based largely on his research with Donald R. Davis. As you will see in the paintings that accompany this article, Bill is also a talented artist.

12 The Color of Europa

If one world has stolen the spotlight of *Galileo*'s mission to Jupiter, it's the icy moon Europa. *Voyager* gave us hints that this Moon-sized satellite might harbor an ocean of water beneath its shielding crust, and the continuing stream of data from *Galileo* makes it seem likelier than ever that Earth may not be the only world in our solar system with an ocean. On its way to Jupiter, *Galileo* made two passes by Earth, turning instruments on its home world and providing scientists with "ground truth" to compare with their findings in the Jupiter system. Here's a brief look at some of that comparative data.

14 On to Eros!

With Mathilde in its wake, the Near-Earth Asteroid Rendezvous spacecraft is now on its way to Eros. As scientists prepare for the rendezvous, it is possible that amateur astronomers could help the professionals gather the most complete information possible about the target asteroid. Clark Chapman gives some hints on observing this tiny nearby object.

18 Carl Sagan Memorial Station

When *Mars '96* crashed to Earth, we felt a particularly keen sense of loss at the Planetary Society: the spacecraft had been carrying a list of names of all our members (as of October 1993). But the Society has friends—very good friends—who surprised us with a special announcement as *Pathfinder* landed on Mars. The *Pathfinder* team honored the Society in another way when they named the landed craft after our co-founder and first president, Carl Sagan.

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Members' Dialogue

Eugene Shoemaker

I feel a great loss with the recent tragic death of Gene Shoemaker. It was from watching Gene explaining the origins of lunar rilles on TV during the *Apollo* missions of the 1970s that I first caught the planetary science bug. Since then, his works have pushed me on toward formal study. No doubt there are hundreds or thousands like me who have been inspired by Gene. My only regret is that I never got the opportunity to meet him.

The Planetary Society is in the best position to find ways of honouring so great a scientist. One idea would be to approach the right people at NASA to see if the next Mars station can be named for him after its successful arrival. It seems appropriate to have all future Mars landers named in the memory of planetary scientists from whatever nation. The naming of the Carl Sagan Memorial Station should just be the first.

—GARY EVANS,
London, England

Planetfest Praise

I have just been humbled. I do not know how the Planetary Society first came by my address to solicit my membership, nor do I know why I did not toss the letter into the trash as I do most of the unsolicited mail I receive, but something about the very name of the group piqued my interest and caused me to open the envelope. I read the letter and it fed my curiosity even more, so I decided the cost of membership was minimal and I could afford to lose the money if it was indeed a sham. I did recognize Carl Sagan's name from the *Cosmos* series, which helped me believe that I might not be throwing my money away.

Some weeks later I received my membership card in the mail. It was accompanied by the photos of the planets and a nice little sticker with Saturn on it, and was followed shortly by a copy of *The Planetary Report*, and I began to feel my money was not completely wasted.

Today I came back from day three of Planetfest '97. The awe I feel is beyond my ability to express in words. I have never been to anything so well managed, so well thought out and orchestrated, nor have I felt so proud to be able to call myself a member of the organizing body. I wish I could express, face to face, my heartfelt thanks to every member of the staff, and all the volunteers, for all their hard work and the dedication that was evident in the quality of the event. The membership fee is embarrassingly small and I am further embarrassed that I ever felt it might not be worth the money.

Thank you one and all.

—DEAN JOHNSON,
Ventura, California

Men or Machines?

In the July/August issue of *The Planetary Report*, Norman Horowitz opposed the idea of human missions to the planets. He stated that exploratory robots could do all that needed to be done. Not quite. Only human voyages can satisfy our insatiable curiosity. Only human voyages can bring about the joy and freedom of the indomitable human spirit, the exhilaration of having set foot on truly foreign soil and living to tell the tale. Human beings have always been explorers, seeking to experience firsthand what is unknown.

Let us not forget our Asimov: to allow machines to be substitutes is to allow the human spirit to shrivel and die. Yes, human voyages are dangerous, extremely expensive, and may not always be called for, but they are as necessary to our spirit as the air we breathe.

—ROSANNA SHAPIRO,
Cranford, New Jersey

Science and the Public

In the May/June 1997 issue of *The Planetary Report*, Clark Chapman addresses a critical shortfall in the scientific community. The inability to capture the imagination and spirit of the public with the wonderment of real science was overcome magnificently by Dr. Sagan. To continue his legacy, those of us in the Planetary Society need to take personal initiative to rescue American society from its recent disturbing, and growing, fascination with pseudo-science.

The answer is there on the page facing Chapman's article (see "Mars Link Evolves into Red Planet Connection" in Society News). Get the public on your side while they are young! Every Society member should go to their nearest elementary or middle school and give one of these educational packages to every teacher there. The $30 cost isn't much, but if a school has not budgeted for it, a teacher would have to use his or her very limited discretionary funds to get the materials. Don't wait for the teachers and school systems to come to us, take it to them from the member level. In addition, the Society should undertake a program to provide competitive scholarships for elementary and middle school children to programs like Space Camp.

—ROBERT L. BYERS,
Jacksonville, Florida

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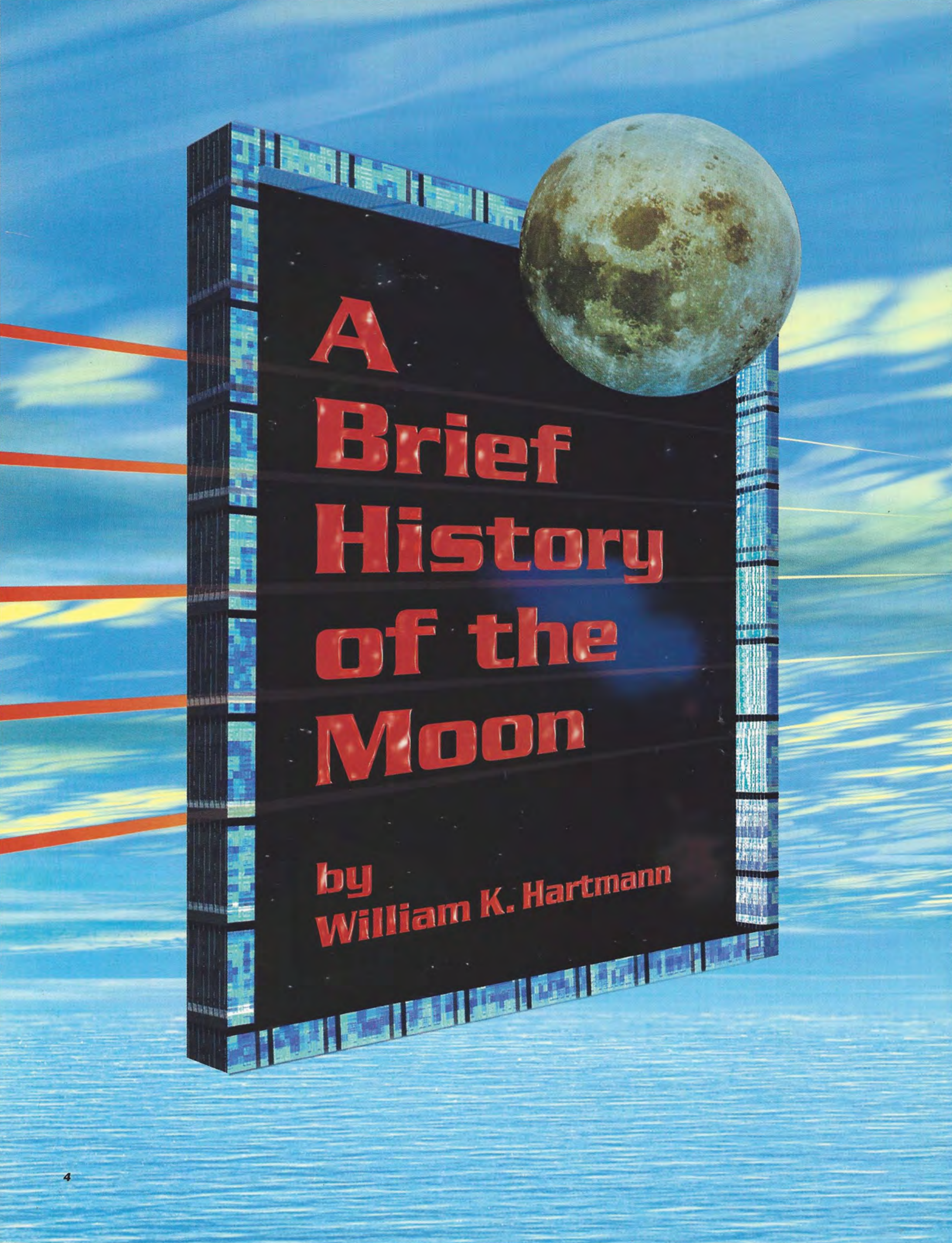
A Brief History of the Moon

by William K. Hartmann



We planetary scientists often find ourselves asked by journalists, "What positive results came from the *Apollo* lunar missions?" For those of us who watched the epic lunar voyages live on TV, it is a shock to realize that some of the earnest young reporters who ask the question were not even born at the time of the landings.

In my own answers, I stress something that is an underlying principle of the Planetary Society and an ideal of its co-founder, Carl Sagan: when we speak of our environment, it is no longer just the meadow next door or even the global ecosystem, but a larger cosmic environment. We can no longer speak of the history of our own planet without speaking of the history of its sister world, the Moon, because the two are linked. We live in a double-world system, moving within the larger system of planets. Before *Apollo*, geologists understood little of the Moon's history, and essentially only the last 10 to 20 percent of the history of Earth—the portion revealed clearly by the fossil record. Before *Apollo*, geologists discounted asteroid/comet impacts as a significant process in Earth's history. The *Apollo* missions revealed the story of the Moon and, by doing so, filled in many chapters missing from the first half of our planet's story. *Apollo* set the stage for awareness that we live in a larger cosmic environment.

We can divide the history of the Moon into rough intervals, admitting that interval boundaries are not hard and fast: some processes overlapped or tapered off gradually; for clarity, we round off numbers here and there.

Origin of the Moon: 4.5 Billion Years Ago

The Moon formed 4.5 billion years ago, probably from debris blown out of the newborn Earth by the most colossal impact in the history of the inner solar system. This hypothesis, derived in part from *Apollo* data, explains several mysteries that had puzzled scientists. For example, the double-world system of Earth/Moon, with a satellite one-fourth the size of its planet, is unique or nearly unique among planets. Pluto/Charon is a similarly double system, but Pluto is

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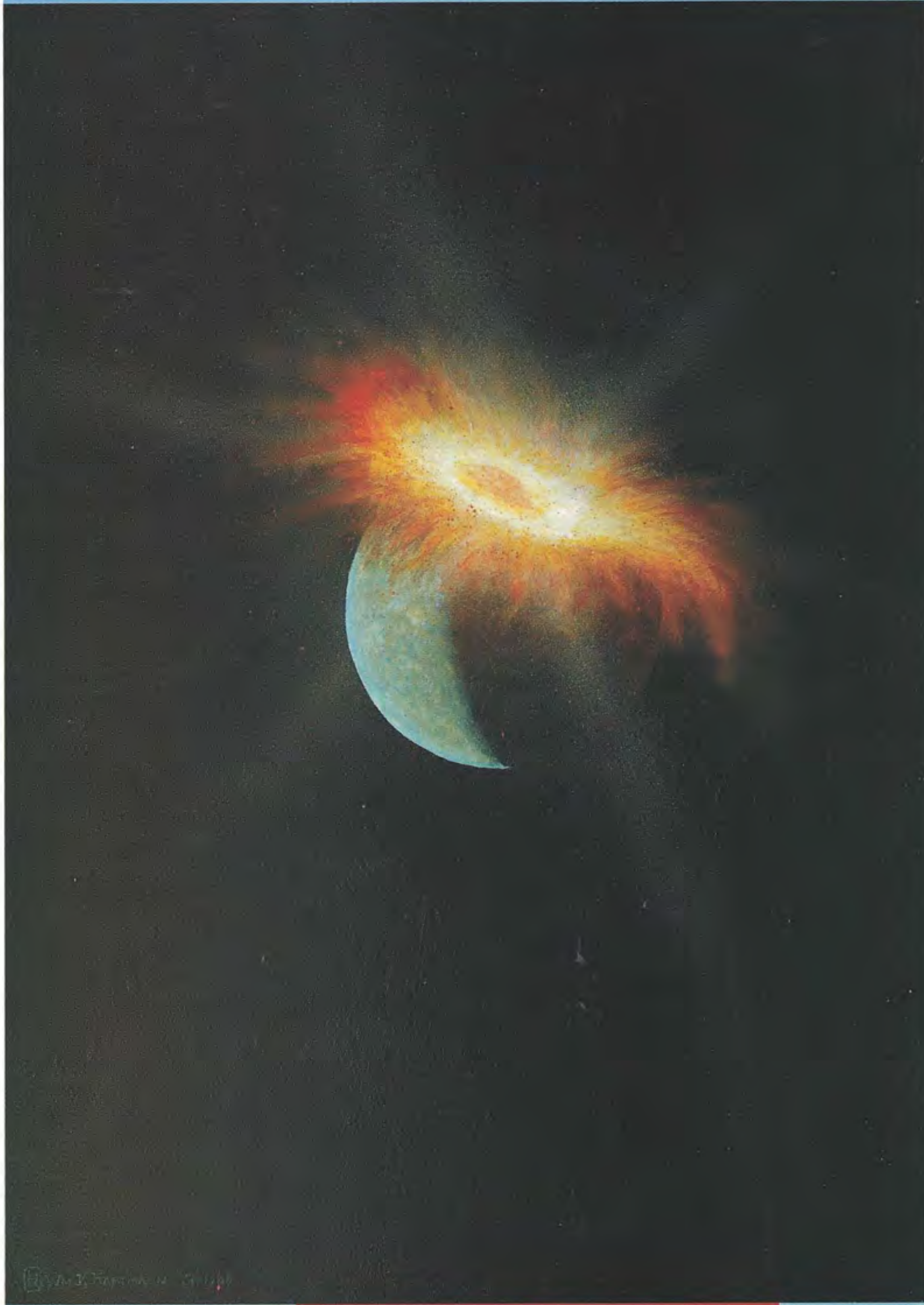
Illustration: B. S. Smith



One half-hour after the impact that spawned the Moon:

In this view, based on computer reconstructions by University of Arizona scientists Willy Benz, Jay Melosh, and others, the Mars-sized impactor has slammed into the Earth at a grazing angle and is blowing vaporized rock and white-hot material into space.

Painting: William K. Hartmann

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smaller than our Moon and its system is in some ways more like a large double asteroid. Either way, the impact hypothesis, by giving statistical reasons to expect that a moon-forming collision would happen to only one or two planets out of eight or nine, explains why our Earth/Moon pair is unusual.

A second pre-*Apollo* mystery explained by the giant-impact hypothesis was that the Moon has very little iron compared to Earth's bulk composition; the Moon has a mean density and rocky composition that resembles not the Earth as a whole but rather the material of Earth's rocky mantle. Suppose the impact happened *after* Earth's core formed. Then an impact blew rocky mantle material, from both Earth and the impactor, into a debris swarm around Earth. According to the giant-impact hypothesis, the Moon formed from this debris, which explains why it is made of mantle-like material.

A third mystery: the Earth is rich in water and other volatiles, but the Moon is not. This difference is explained by the giant-impact model: the ejecta were heated to extreme temperatures, so water and other volatile materials escaped from the debris into space as gases.

Lunar rocks revealed that the lunar material has exactly the same oxygen-isotope composition as Earth (that is, the different oxygen isotopes exist in the same relative proportions in both bodies), whereas rocks from other parts of the solar system (Mars rocks and meteorites of different types) have different oxygen-isotope compositions. The oxygen-isotope data thus ruled out earlier theories that the Moon formed elsewhere and then was captured whole into an orbit around the Earth. The oxygen data suggest that the Earth and the impactor had similar oxygen-isotope chemistry and that the impactor that hit infant Earth was a planetesimal that had formed at about Earth's distance from the Sun.

Aggregation of Consensus

Is a giant impact plausible? A personal note may be in order to explain the answer. During the 1960s the Russian scientist Victor Safronov, studying the idea that planets formed by aggregation from countless small planetesimals, inferred that many planetesimals had grown in each planetary zone. A cosmic "survival of the biggest" rule operated, with the big ones sweeping up the smaller ones to make single planets in each zone. Safronov suggested that the axial tilts of planets might be the result of this process; for example, a collision with a large planetesimal might have caused the odd tilt of Uranus, whose axis is nearly horizontal compared to the "north-south" axis of other planets in the solar system. Though Safronov's work was little known in the West, my colleague Donald R. Davis and I studied it and went on to make calculations of relative growth rates of planetesimals. We presented a paper at a meeting in 1974 proposing that there had been bodies in Earth's zone large enough to blast out enough mantle to make the Moon.

As a young scientist giving the paper, I was apprehensive when the famous researcher A. G. W. Cameron raised his hand after my talk. Would he make some point that would demolish our ideas? Instead, he said that he and William Ward had been working on the same idea but coming at it from considerations of angular momentum, or total spin rates in the system. A giant impact could solve certain puzzles about the angular momentum of the Earth/Moon system. Combining models of the total angular momentum brought into the system by a glancing blow, Cameron and Ward called for an even larger impactor than we had—they suggested that Earth had been hit by something about the size of Mars!

Davis and I published our work in 1975, and Cameron and Ward published the next year. However, the ideas received little attention because other researchers—who had been taught to abhor catastrophes as a mode of explanation in geophysics—felt that the giant impactor had literally been conjured up out of the blue. Other theories should be explored, they said, before this "ad hoc" explanation could be permitted. Years later, researchers became more comfortable with the idea that catastrophic impacts helped shape the solar system. Big impacts could not be dismissed as "ad hoc" just because they were random. The giant-impact model emerged as the dominant hypothesis in a 1984 conference on the origin of the Moon.

A new consensus has developed since then: you can't form planets without a hierarchy of impacts. Small impacts, trillions of them, act to produce generally similar properties of planets, such as circular orbits, prograde rotations (in the "normal" direction), and low axial tilts. The few large impacts, depending on their timing and the collision angles, impose "finishing touches" on the planets: quirky individual personalities like Uranus' high axial tilt and Earth's unusual satellite.

Forming the Highland Crust: 4.4 Billion Years Ago

The aggregation of the Moon from the debris cloud around the Earth involved so much infalling debris that the Moon's surface was

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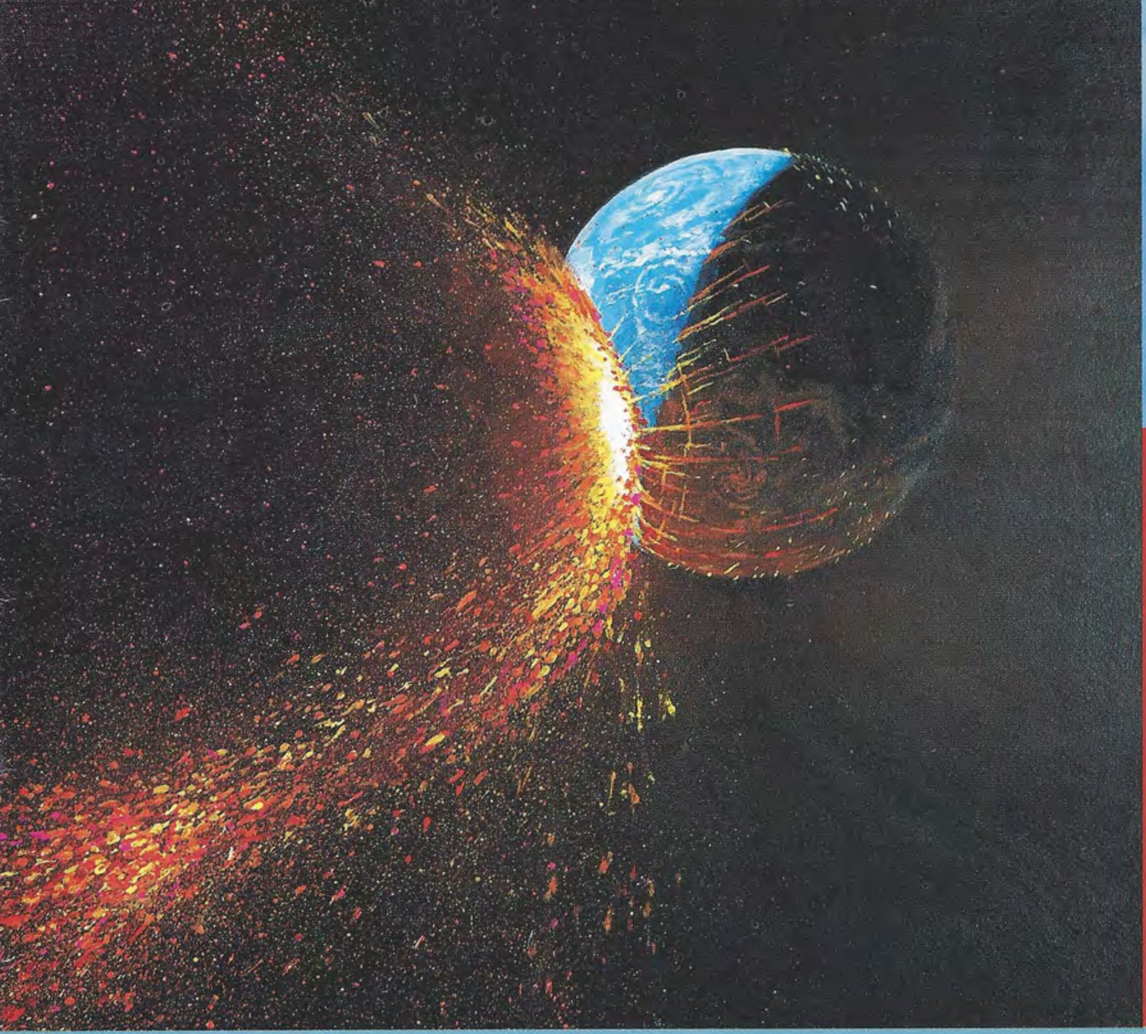

Five hours after the impact that formed the Moon:

According to computer reconstructions, a long streamer of debris was thrown into space. Much of the debris fell back to Earth, but a small fraction, enough to make the Moon, remained in orbit.

The aggregation of the Moon:

Dynamical studies show that the debris blown off Earth settled into a ring and that the Moon would have aggregated from material in the outer part of the ring. The inner ring eventually dissipated. In this view, the early Moon casts a large shadow on the Earth. Interplanetary debris in the form of comets was still common at this time, and distant nebulae in the star-forming region that spawned the solar system are seen in the background.

Paintings: William K. Hartmann

Early days on the Moon:

In the first few hundred million years, as the Moon's crust formed, the Moon was much closer to Earth than it is today. Earth dominates the sky in this lunar nighttime view. The bright spot at Earth's center is the reflection of a (giant) full Moon in Earth's oceans.

The last gasps of lunar geologic activity:

In this view, the Moon has receded near its current distance from Earth, and one of the last volcanic calderas is actively erupting. Blue earthlight contrasts with the orange volcanic glow.

Paintings: William K. Hartmann

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strongly heated by the impacts. This heating kept the surface molten, at least during the late stages of the Moon's growth, forming a global ocean of magma. In such a magma, low-density crystals float to the top like ice slush on water. The magma ocean cooled and solidified into a low-density crust that grew in thickness. This explains why the ancient highlands of the Moon—the initial crustal surfaces—are composed mostly of rocks formed from crystals of a common low-density silicate mineral called feldspar. Feldspar is also a major rock-forming mineral on Earth, but not as concentrated at the surface. Rocks formed from feldspar aggregates are called anorthosites, and astronauts brought back many anorthosites, which seem to make up most of the lighter-colored regions of the Moon.

By perhaps 4.45 billion years ago the anorthosite was forming, though it was continually blasted, pulverized, and even remelted locally by the rain of impactors and flooded by local eruptions of fresh lava. Despite all this havoc, lunar soils contain telltale rock chips dating back beyond 4.4 billion years.

Recession of the Moon: 4.4 Billion Years Ago

At the time of its formation, the Moon was much closer to Earth than it is today, probably only a few Earth-radii away (perhaps 24,000 kilometers, or 15,000 miles, out from Earth's center, instead of the present-day 380,000 kilometers, or 240,000 miles). Tidal forces between the Earth and Moon caused it to move outward, away from its parent. Tidal forces, which arise from gravitational interaction between a planet and its satellite, are very much stronger when a planet and moon are close to each other. As a result, the recession of the Moon was fast at the beginning and slow later. By the first few hundred million years, the Moon had moved out to an orbit over half of its present distance from Earth. The proof of all this is that the Moon is still receding from Earth, and the rate of recession has been accurately measured, using radar reflectors left on the lunar surface by *Apollo* astronauts and Soviet *lunakhod* rovers.

Intense Bombardment: 4.4 to 4 Billion Years Ago

Impacts are crucial in understanding the infancy of the whole Earth/Moon system. Counts of the numbers of craters at *Apollo* landing sites, which had different measured rock ages, revealed that the impact rate 4 billion years ago was hundreds of times the rate today. In fact, it is hard to trace the rate farther back than 4 billion years because the cratering was so intense that it obliterated older surfaces.

This early bombardment fits beautifully with our understanding that planets grew by sweeping up the interplanetary debris. Isotopic studies show that Earth grew to most of its present size 4.5 billion years ago, within a short interval of about 50 million years. To accumulate an Earth-mass of material in 50 million years requires roughly a billion times the present impact rate. In other words, the initial impact rate dropped from around a billion times today's rate to a value a few hundred times today's rate by 4 billion years ago. This decline is roughly consistent with the calculated rates for planets to sweep up interplanetary flotsam and jetsam during their statistical dance of chance among the terrestrial planets. In short, the Moon's ancient, cratered surface shows the final stages of the collision processes that gave rise to the whole planetary system.

This realization has affected our understanding of Earth and other planets. Earth itself was affected by the intense early bombardment, a fact not known until the *Apollo* expeditions. For example, giant basin-forming impacts may have thinned the crust in some regions and piled up continent-like masses of crustal ejecta in other regions. Such a process has been suggested as the origin of Mars' striking asymmetry, with an old, cratered crust in one hemisphere and massive volcanic plains in the other. The intense impact rate may also have made Earth's initial climate so unstable and the surface so precarious that the establishment of stable life forms could have been delayed. Everyone has heard of the impact that wiped out the dinosaurs and 75 percent of then-existing species 65 million years ago; with an impact rate 10,000 times the present value, primordial impacts comparable to that one were happening every few thousand years.

Was There a Catastrophe 4 Billion Years Ago?

When astronauts were sent to the Moon, they were supposed to look for "genesis rocks," rocks that might date back to the origin of the Earth/Moon system. However, there seemed to be a cutoff at about 4 billion years ago. The geochemists who measured the first *Apollo* samples, especially a team involving Gerald Wasserburg and others at the California Institute of Technology, theorized that a temporary spurt in the impact rate 4 billion years ago destroyed most of the earlier surface and most earlier rocks. This hypothetical burst of cratering came to be called the terminal cataclysm—implying a sudden event at the end of planet formation. Various theories were spun as to the source of this burst of impactors.

On the other hand, the cutoff in rock ages around 4 billion years ago might be explained not by a cataclysm but simply by a steep decline in the impact rate. In this scenario, any rocks formed in the surface layers 4.2 billion years ago would have been exposed to intense cratering and pulverized quickly, while similar rocks formed 3.8 billion years ago would have experienced impact rates so much lower that they survived to the present.

These two ideas—steady decrease versus a sudden spike in the cratering rate 4 billion years ago—continue to be debated today. Houston researcher Graham Ryder points to the absence of impact melt-glasses from the ancient period to support the terminal cataclysm. Impact melt-glasses are formed from rock melted and sprayed out from impact sites and rapidly cooled into glassy shards and droplets. Does the paucity of these glasses older than 4 billion years mean the impact rate was lower before the proposed cataclysm or just that the primordial glass fragments were pulverized by the intense cratering? A terminal cataclysm, if it happened, would have strongly affected geological and biological developments on Earth during the same epoch.

Forming the Lava Plains—4 to 3 Billion Years Ago

While cratering proceeded from the outside, geological structuring of the Moon continued from the inside. Like most worlds, the Moon followed a law promulgated by workers as diverse as Isaac Newton in the 1600s, Georges Buffon in the 1700s, and Percival Lowell in the 1800s: small planets tend to cool off faster than big planets, all other things being equal. By the same principles, small baked potatoes cool faster than big ones. The subsurface regions of the Moon retained their heat only for the first one or two billion years, and then volcanic activity on the Moon tapered off.

During the period of volcanic activity, pockets of molten material existed in the Moon at depths of a few hundred kilometers, just as Earth today has regions of molten material below the surface. Whenever large impactors fractured the surface layers, these deeper lavas gained access to the surface and erupted into giant pools that filled the available depressions. The types of rocks produced were lavas darker colored than the light crustal anorthosite rocks. Generally they are in the rock family known as basaltic lavas and are similar to basaltic lavas that still erupt from many volcanoes on Earth today.

Basaltic lava patches that formed before 4 billion years ago were rapidly obliterated, or at least buried under ejecta debris, by the violent impact cratering. Evidence of ancient basalts is revealed in certain dark-halo craters, which are the result of impacts that punched through the light-colored debris and ejected dark-basaltic debris, as shown in recent spectroscopic observations by University of Hawaii researchers B. Ray Hawke, Jeff Bell, and others. Additional evidence for very ancient basalt flows comes from *Galileo* multispectral images of the Moon's far side, where traces of basaltic material were found in ancient, heavily cratered basins.

Lava patches that formed after 4 billion years ago were better preserved because the cratering rate had declined. They appear as the dark-colored, broad lava plains of the Moon. Dated around 3.8 to 3 billion years ago, they make up the features variously known as the "man in the Moon" or the "rabbit in the Moon," as identified by diverse cultures down through the ages. These lava plains, mistaken for seas by the first telescopic observers, were given the Latin name for seas, *maria* (MAH-ree-a; singular *mare*, pronounced MAH-ray).

Last Gasps and New Beginnings

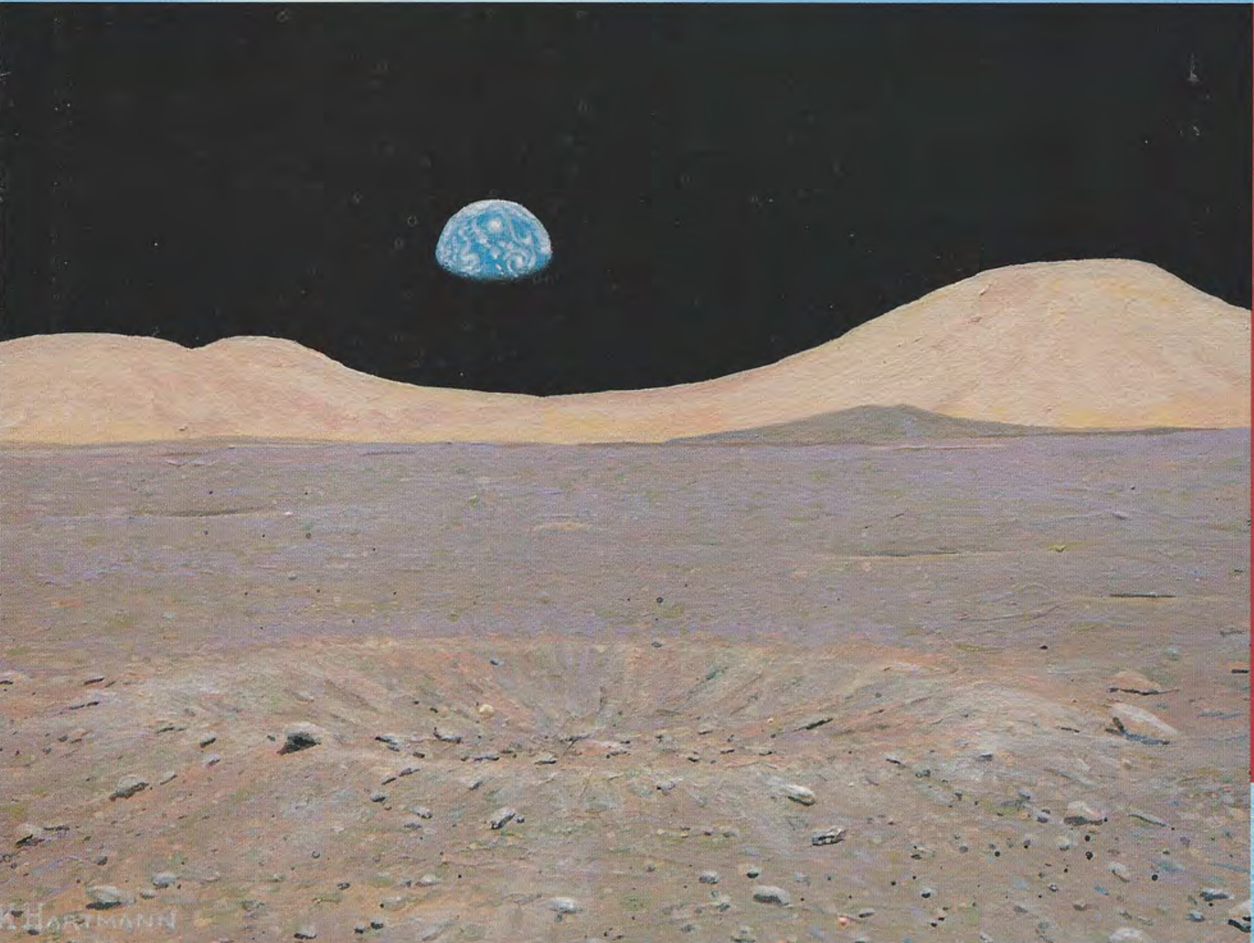
By 3 billion years ago, the Moon looked much as it does today. Probably a few local lava flows erupted here and there until about 2 billion years ago. Half the history of the Earth/Moon system was over as the Moon became dormant. On the blue Earth, high in the sky over the lunar plains, the landscapes were barren, but multicellular life was organizing itself in the seas. The Moon's history was nearly over, whereas the exciting story of life on Earth was still in its opening chapters.

Early telescopic observers proclaimed that "nothing ever happens on the Moon," although sporadic, unconfirmed gas emissions have been reported. Something important—at least in our human scheme of things—finally happened in 1969, when a spindly spacecraft allowed the first humans to leap across the void from the parent world to the daughter world. The sparsely cratered basaltic plains were the sites chosen for the first two lunar landings, because they afforded relatively flat terrain—hence the famous landing site of Mare Tranquillitatis, or the Sea of Tranquillity.

Tranquility persists on the Moon, but we may soon return, not only to develop our capability of voyaging the cosmic ocean but to tie up some loose ends in our understanding. One project for future explorers would be to measure the dates of, say, 5,000 impact craters near a lunar base. Such a count would allow us to plot a chart of the bombardment rate versus time, showing detail or structure in the curve at a resolution of a few million years. This level of precision might allow us to establish once and for all whether there was a catastrophe 4 billion years ago. We could also determine whether the impactor that wiped out the dinosaurs was a single, random event or part of a wave of impactors that repeats every 30 million years or so, as some have proposed. Making this determination would be a worthy goal for a return to the Moon—a goal that would unite planetary geologists, dynamicists, and biologists in a broad effort to fill in more pages in the biography of our double planet and its hesitant march toward intelligent life.

William K. Hartmann is a Senior Scientist at the Planetary Science Institute and an accomplished space artist. His first novel, Mars Underground, *about Mars exploration, was published this year.*

Family: *A view from 54,000 kilometers (34,000 miles) beyond the Moon reminds us that the Earth is a double planet and that the histories of Earth and its satellite are closely linked.*

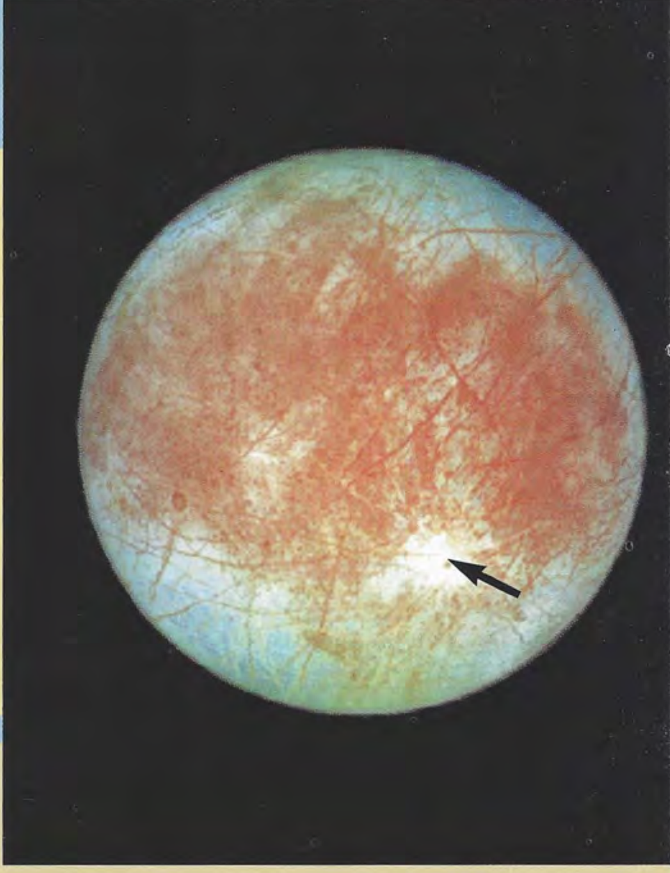


The Moon in the last billion years:

Except for visitations by humans, the Moon has been lifeless and relatively still. Microimpacts continue to sandblast the surface soils, and sporadic bigger impacts make scattered, modest-size craters, such as this one shown at high noon.

Paintings: William K. Hartmann

THE COLOR OF EUROPA



BY PAUL GEISSLER

Galileo has seen two worlds that have ice with a distinctive blue tinge—a subtle coloring associated with the ebb and flow of an ocean underneath. Finding a similarity like this in widely separate parts of the solar system commands attention, especially since variety is the lesson we learned so well from *Voyager* imaging, which ranged in unexpected wonders from the yellow burst of a volcano on Io to the black sprays of geysers on Triton. *Galileo*, too, has amassed a heterogeneous gallery of planetary images. Along its winding path to the Jupiter system, the spacecraft encountered Venus, the Earth and Moon, and asteroids Gaspra and Ida. It was at Earth that *Galileo* got its first glimpse of blue ice.

Arriving at Jupiter in December 1995, *Galileo* swung into orbit around the giant planet for repeated encounters with the large Jovian moons. From left to right, Figure 1 (above) shows Europa, Ganymede, and a slice of Callisto. These composite images were made by combining images taken through violet, green, and infrared filters. Given this combination of filters, these are not the colors you would see with the naked eye. We use false-color images and enhance contrast to get a better look at the details in a distant surface.

White in these images indicates fine-grained, fragmented ice, as seen in recent craters such as Pwyll on Europa, Osiris on Ganymede, and Burr on Callisto (black arrows). Looking around these comparatively young features, you'll notice that older terrains on Europa have a bluish cast, much bluer than terrains on Ganymede and Callisto, even allowing for darkening of their surfaces by non-ice contaminants. These color differences reflect the varied geological histories of the moons. Callisto's life has been relatively dull apart from a gradually diminishing bombardment by impactors; Ganymede experienced an episode of tectonism, probably associated with core formation, that disrupted its surface and produced its bright groove lanes—but that was over and done with long ago. Europa is clearly different, however, and the clue is its distinctive hue.

Now compare Figure 2 (below), which is a *Galileo* image of Antarctica from the spacecraft's second Earth flyby in December 1992, made from the same false-color filter combination as in Figure 1. The cyan (blue-green) color of the Ross Ice Shelf is due to coarse-grained sea ice, contrasting against the white clouds and continental snow. Sea-ice

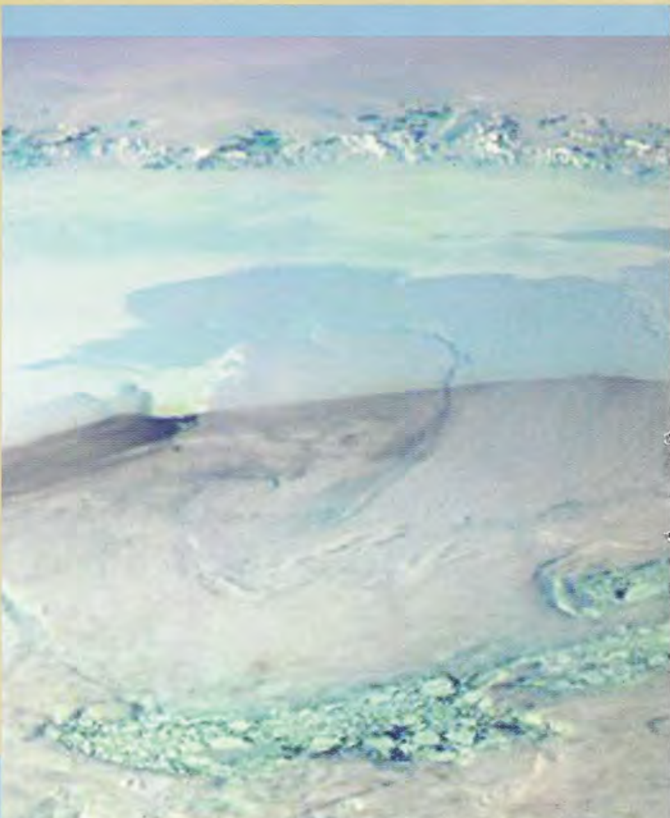


Figure 1, left: Europa, Ganymede, and Callisto (left to right) have been imaged repeatedly by the* Galileo *spacecraft, which has served us as a latter-day Audubon of the Jupiter system. False-color imaging imparts a characteristic blue to ice on Europa, a shade not seen on the other Jovian moons.

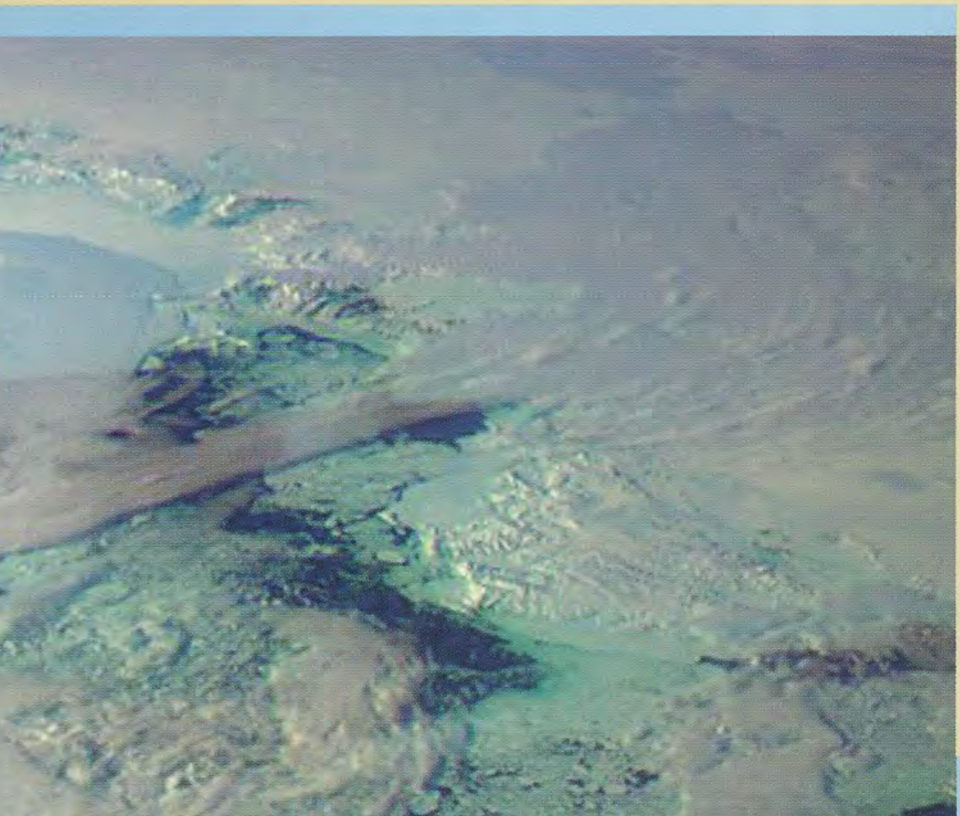
Figure 2, bottom: Sea ice underlying Antarctica's Ross Ice Shelf emerges as a blue-green hue in this false-color image from* Galileo*'s Earth flyby in December 1992. The striking resemblance to the blue ice in similarly processed images of Europa adds to evidence that Earth may not be the solar system's only watery world.

Images: NASA/JPL and Lunar and Planetary Laboratory, University of Arizona

crystals grow much larger than snow crystals because sea ice forms at higher temperatures, being in contact with the warm ocean below. By analogy with Antarctica, scientists believe that the blue in the older regions of Europa probably indicates resurfacing by ice crystallized from a warm liquid to form a relatively coarse-grained surface, similar to the blue sea-ice seen on Earth. The bright blue ridges seen in the Tyre region (see front cover) illustrate this process at work, showing how older, darker surfaces are replaced with clean, relatively coarse-grained ice extruded along fractures in Europa's frigid crust.

Impacting comets and asteroids, along with the intense radiation from Jupiter's magnetosphere, tend to disrupt Europa's surface over time, fragmenting the ice crystals and making Europa appear less blue and more like its sister satellites, which we believe are geologically dead. However, it appears Europa is shaped also by heat from within, probably generated within a warm ocean not far below the surface. It seems internal heat keeps pace with the destructive processes of radiation and impact cratering to maintain the blue tinge of a world that is geologically active, perhaps with an ocean.

The possibility of a water ocean, first suggested in previous *Galileo* imaging of Europa, made headlines earlier this year. Water is a precursor of life, when combined with carbon-based molecules and energy to drive chemical reactions. Having learned from *Voyager* the lesson of variety, we may be on the verge of an even greater discovery, coming more clearly into view through the eyes of *Galileo*.



Paul Geissler is a Senior Research Associate at the Lunar and Planetary Laboratory in Tucson, Arizona.

On to Eros! How you can get personally

Using radar echoes bounced off Eros during a close approach in 1975, scientists produced this approximation of the asteroid's shape, seen in these images as if it were rotating about its axis.

NASA's new, smaller planetary spacecraft have started returning dividends. *Mars Pathfinder*'s landing and *Sojourner*'s rovings across the surface of Mars brought unprecedented public attention to the Red Planet, after two decades of neglect. What is next on the horizon? How can YOU become involved?

By getting to know Eros! The "erotic" adventure I have in mind has little to do with the god of love, however. Asteroids, especially those discovered in the nineteenth century, were often named after gods and goddesses. In 1898, G. Witt of Berlin found the object we know as 433 Eros, one of the so-called Amor asteroids that orbits far inside the asteroid belt, crossing the orbit of Mars and—in fact—coming quite close to Earth. It is not (at least not yet!) an Apollo, a class of Earth-orbit-crossers.

Eros is among the largest Earth-approaching asteroids, and that is why it is the chief target of the Near-Earth Asteroid Rendezvous mission (NEAR). The Volkswagen Beetle-sized spacecraft had a remarkably successful encounter with the larger, black, main-belt asteroid 253 Mathilde on June 27 (for encounter details, see page 20). Next January 23, NEAR will fly just 500 kilometers (300 miles) above the Earth's surface to gain a final trajectory change from our gravity so that the spacecraft can nuzzle up to Eros a year later.

During 1999, NEAR will maneuver around the asteroid, using sensitive instruments to map its surface, measure its chemistry, and generally investigate Eros like no asteroid has ever been investigated before.

Back in 1975, Eros came very close to the Earth (within 22.5 million kilometers, or 14.0 million miles), the closest pass since the asteroid was discovered, and astronomers responded with an observing campaign. Telescopes around the world scrutinized the object at visible, infrared, and radio wavelengths. Radar signals were bounced off Eros as well. Now NEAR will study it up close for a full year. And you can come along for the ride.

NEAR Is Headed Our Way

The most fun way to get involved would be to watch the little NEAR spacecraft when it sails close by in January. Unfortunately, that happens roughly over Baghdad in daytime. Perhaps well-equipped astronomers in Hawaii and the western United States can watch NEAR approach a few hours earlier . . . but most of us will just have to use our mind's eye.

There will be times when you can study Eros yourself—if you are an amateur astronomer or if you can lay hands on a telescope and learn the tricks of backyard astronomy. The NEAR camera-spectrometer science team welcomes interesting observations of Eros by amateur astronomers and will add their data to the existing database in support of the mission.

Asteroid orbits aren't so nicely circular and don't hug the ecliptic as closely as planetary orbits (the ecliptic is an imagined plane from the center of the Sun passing through the center of the Earth). The good news is that Eros' elongated orbit periodically brings it in from well beyond the orbit of Mars to good visibility from Earth.

The bad news for northern observers is that at closest approach next April, the inclination, or tilt, of Eros' orbit sends it far south of the ecliptic. It will be doing an epicycle (an apparent looping motion as seen against the background of stars) along the fringes of the Milky Way in the constellations Lupus and Centaurus. Observers in the US, unless you live in southern Texas or Florida, will have difficulty spotting Eros low in the southern sky from March through May 1998.

Using a slightly different model to interpret the data, scientists produced a body more concave on one side. Which is closer to the actual shape of the asteroid probably won't be known until NEAR approaches its target in 1999.

Images: David L. Mitchell, R. Scott Hudson, Steven J. Ostro, and Keith D. Rosema; NASA/JPL

INVOLVED WITH THE NEAR MISSION

BY CLARK R. CHAPMAN

But there are times of good visibility, especially if you use a telescope 6 inches or more in diameter. You can start looking for Eros in the morning sky. As October begins, Eros is in Gemini; it moves through Leo in November and is near the bright star Spica as 1998 begins, brightening from 13th magnitude to 12th. Eros will brighten to 11th magnitude (100 times fainter than the unaided eye can see) when it is far south in Lupus.

SPACECRAFT MEETS ASTEROID

Next summer, Eros climbs higher in the sky—and is visible during more convenient evening hours—while it fades to 14th magnitude (fainter than Pluto!), as the Earth's faster orbital motion propels us ever farther away from Eros. During autumn 1998, it will take a larger telescope (8- or 10-inch aperture) and sharp eyes to follow the small asteroid's path through Scorpio, Sagittarius, and then into the evening twilight.

In January 1999, NEAR reaches the vicinity of Eros. A series of rocket burns slows the spacecraft down until it hovers about 500 kilometers (300 miles) away from Eros. The spacecraft instruments will map the global properties of the oblong object. Engineers at NEAR's home base (The Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland) will gain confident knowledge about Eros' shape and gravity field. Then they will lower NEAR to orbit just 35 kilometers (22 miles) from the center of Eros, which is indeed close, given that Eros is 35 kilometers long (at its elongated end, the surface sticks out only half that far from the center). The sharpest pictures and best compositional measurements will be made from the close-in orbit. Through these maneuvers, NEAR fans will have to watch over the Internet, for the asteroid will be lost in the Sun's glare until about November 1999.

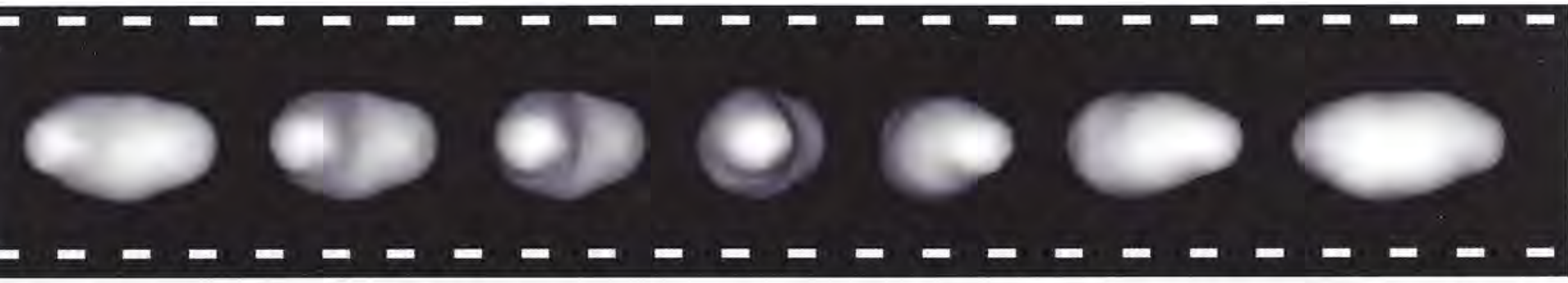
As the NEAR mission draws to a close, early morning observers may again find a faint, 14th magnitude Eros shifting amid the stars south of Spica.

Finding a faint asteroid in a telescope is tricky but rewarding. You need good coordinates for Eros (interpolated at hourly intervals) and a good star map, showing stars at least as faint as Eros. Eros will be the one that is "out-of-place" and that visibly moves from hour to hour. You will then want to monitor Eros' brightness as it spins, with its broader and narrower faces alternately reflecting more or less sunlight. Eros typically varies about a magnitude in brightness (compare it with nearby stars), showing two maxima and two minima during its 5 hour, 16 minute "day."

For star charts showing Eros' path through the stars, check out the NEAR project's Web site, where non-telescope-owners too can follow NEAR's progress. There are links to NEAR's recent pictures of Mathilde, as well as an educator's guide that introduces the spacecraft, its instruments, its trajectory, and some of the issues that NEAR was designed to investigate. During most of 1999, with Eros behind the Sun and new pictures and data being posted almost daily, NEAR's Web site will become the place to be.

Clark R. Chapman is a member of the NEAR camera-spectrometer science team. He is also the regular "News & Reviews" columnist for The Planetary Report.

Visit the NEAR home page on the World Wide Web at:
http://sd-www.jhuapl.edu/NEAR/



Basics of Spaceflight:

ATLO: Assembly, Test, and Launch Operations

by Dave Doody

The acronym ATLO is used so frequently throughout space flight operations it might as well be a valid English word. ATLO stands for Assembly, Test, and Launch Operations—the period of gestation and birth for a robotic spacecraft. In this installment of Basics, we'll look in on *Cassini*'s ATLO, since it's typical of ATLO for many spacecraft now plying the depths of the solar system.

ATLO in Overview

A spacecraft's conception in the minds and computers of planners, designers, and scientists covers a lot of ground. It begins with studies of the concept for a mission and includes planning and obtaining funds, which in the case of NASA's interplanetary robots come from the congressional budget. The spacecraft's design proceeds until metal is cut and bent and electronic circuits and mechanisms are fabricated and individually tested. This whole process may take the better part of a decade for the larger missions, such as *Galileo* and *Cassini*. *Mars Pathfinder*, one of the faster-development, lower-cost Discovery missions, took only about four years from startup to its bouncing, spectacular stop on Mars.

ATLO ends after launch, and a spacecraft then enters its cruise phase, freefalling toward its destination and giving its ground operations crew some valuable flying lessons. Encounter is the next phase, when all the science observations are carried out. Most interplanetary missions then enter an extended-mission phase, when the last bits of data are squeezed from the spacecraft. The extended-mission phase is a good time to take some risks in search of new data, as was done with *Magellan*'s aerobraking adventures (see the March/April 1994 *Planetary Report)* and will be done in *Galileo*'s repeat encounter with Io, deep within the dangerous Jovian radiation belts.

ATLO is the phase when a spacecraft takes recognizable shape. Early in this period the spacecraft's computers come alive, and they communicate almost constantly with the people working on the craft. Most of the time this communication, which includes telemetry and command (see the November/December 1995 *Planetary Report),* passes through support equipment operated by engineers who specialize in particular spacecraft components. A Command and Data Subsystem (CDS) engineer, for example, uses CDS support equipment to monitor and operate the CDS. An Attitude and Articulation Control Subsystem (AACS) engineer uses a different set of hardware and software for the AACS support equipment.

At times the spacecraft power is turned off to allow mechanical engineers (the "mechanics") to attach this flight computer or that science instrument. They perform electrical measurements with the power still turned off to be sure all the connections were properly made. When power comes back on, the new components are put through their paces. Component developers send commands to the newly installed equipment, load it with any operating software it needs, and scrutinize all the telemetry that comes back "down" to them. They have to check out all the commands their piece of the spacecraft is designed to recognize, and they have to make sure the telemetry it returns truly reflects its operational states—typically, both hardware and software states.

At certain points during ATLO, the spacecraft is treated just as though it were flying through interplanetary space. The spacecraft's radio transmitter and receiver are connected to a special antenna, and the Deep Space Network (DSN) talks to the spacecraft using a station near the grounded spacecraft. The DSN uses these opportunities to measure the minute amount of time the spacecraft takes to receive and re-transmit signals—a key piece of information when DSN people use the ranging technique (see the July/August 1995 *Planetary Report)* to precisely measure the spacecraft's location in the solar system.

Cassini in Particular

Early in 1997, eight years after the *Cassini* program's startup, a thermal-engineering model of the *Huygens* probe was attached to *Cassini* at the Jet Propulsion Laboratory (JPL), just as the real *Huygens* probe, bound for Titan's atmosphere, will be attached prior to launch. Then the assembled spacecraft was carried slowly up the hill at JPL on a truck, flanked by engineers and technicians on foot. Atop the hill, the spacecraft was subjected to the most torturous tests of all. During this phase of ATLO, affectionately called "shake and bake," the spacecraft received vibrations that simulate the rough, noisy ride it will have atop its Titan IV-B launch vehicle.

Then the spacecraft was placed in a huge vacuum chamber—85 feet tall and over 25 feet wide, the Solar Thermal Vacuum chamber gave *Cassini* a taste of space. The inner walls of The Chamber were lined with panels containing liquid nitrogen. A hot simulated Sun shone down from a large mirror above. The thermal engineers tested all the extremes of heating and cooling the spacecraft would have to endure for its 12-year primary mission.

One cold, rainy night as I stood outside The Chamber, a tanker truck pumped liquid helium to a special and very cold target plate inside. Only a handful of degrees above absolute zero, this was as cold as it gets. The target plate simulated the extremely cold, dark space in which some of *Cassini*'s infrared-sensitive instruments would have to work. I realized how balmy the rain was by comparison.

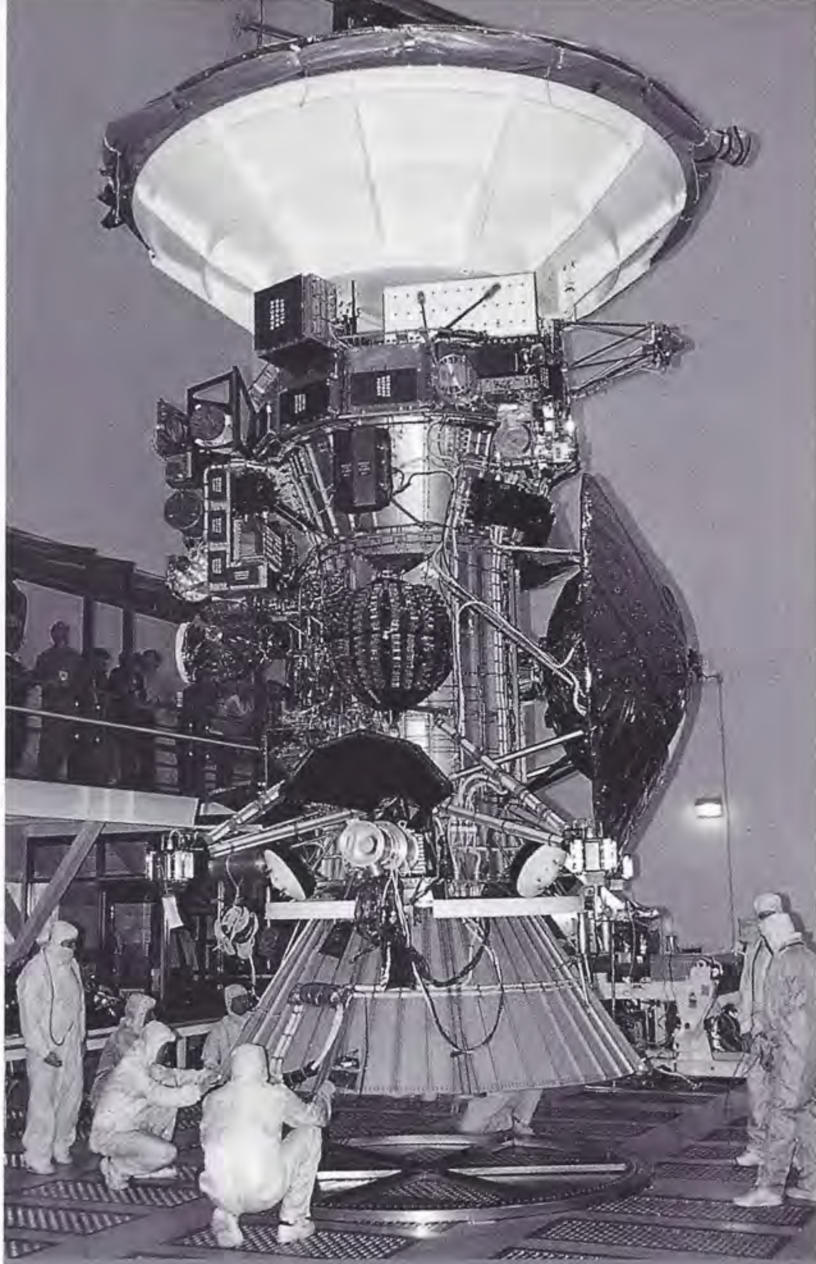
Having passed shake-and-bake with flying colors, the *Cassini/Huygens* pair was trucked back down the hill to the clean room. With all the scientific instruments and other components installed, we carried out a "science end-to-end test." Science teams around the world, without leaving their home institutions, used their local computer workstations to develop sequences of commands to operate their instruments. This is how the science teams will operate when *Cassini* is in flight. Once their individual command sequences were completed and checked, the commands were sent to JPL and assembled into one file of command data.

The DSN established a two-way radio communications link with the live spacecraft, still in its "hangar." Finally, the Ace (see the November/December 1996 *Planetary Report)* radioed the command data aboard *Cassini*, checking to make sure every bit arrived intact. Over the hours while the command sequence clocked away, all the results flowed back through the DSN as telemetry and out to the scientists worldwide. Once the scientists analyzed the data from their instruments, it was clear that *Cassini*, *Huygens*, and the ground-based operations system were alive and very well!

Final Steps to Launch

At this writing early in July, *Cassini* is in a clean room at the Kennedy Space Center, Cape Canaveral, Florida. Telemetry flows daily to JPL from the spacecraft, where it is stored for the life of the mission. ATLO telemetry is extremely valuable during cruise, encounter, and later, because it helps engineers and scientists interpret the ways in which the spacecraft responds to actual flight conditions deep in interplanetary space.

The propulsion module has been loaded with propellants, amounting to over half the spacecraft's launch mass—most of the fuel will be needed for the spacecraft to slow down and enter orbit at Saturn. The upper parts of the spacecraft have been stacked onto the propulsion module. Stacking was a major step, taken only after a careful review, because the ATLO team cannot reach some parts of *Cassini* once stacked. The *Huygens* probe has arrived in Florida from its home in Germany and awaits its turn to join *Cassini*. The Titan IV-B launch vehicle is sitting on the launch pad, ready to accept a Centaur upper stage and, finally, the *Cassini/Huygens* payload. Back in Pasadena, the operations team joins in launch rehearsals with Florida colleagues.



Visitors look on from within the glass-enclosed viewing gallery as ATLO engineers lift the **Cassini** *spacecraft in a clean room at JPL. The* **Huygens** *probe engineering model is within its gold shield, attached to* **Cassini**'*s side.* Photo: JPL/NASA

As you read this, Earth and the other planets are moving into positions identified by *Cassini* mission planners years ago, positions that will offer the spacecraft gravity assists on its looping flight past Venus, Earth, and Jupiter. The launch window opens October 6, 1997, and ATLO will rocket to a close. *Cassini/Huygens* will begin its seven-year cruise phase.

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.*

Be sure to visit the *Cassini* site on the World Wide Web for all the latest news: http://jpl.nasa.gov/cassini. The site even offers a *Cassini/Huygens* spacecraft scale model that you can download and build.

Carl Sagan Memorial Station: *Pathfinder* Carried Members' Names

by Louis D. Friedman

The *Pathfinder* landing on Mars will continue as a source of special joy and pride to Planetary Society members, because we are there! Planetary Society names made it to the Red Planet in two surprising ways.

First, the memory of Carl Sagan, our late president and co-founder, was honored in the naming of the *Pathfinder* lander station. NASA Administrator Dan Goldin announced at Planetfest '97 that the spacecraft on Mars would be known as the Carl Sagan Memorial Station, acknowledging Carl's lifelong devotion to the exploration of Mars, including scientific participation and public education in every US Mars mission from the *Mariners* to *Mars Global Surveyor*. This gesture is deeply appreciated by Carl's family and by all of us at the Planetary Society. The Carl Sagan Memorial Station follows a precedent set in the naming of the *Viking 1* lander, called the Thomas A. Mutch Memorial Station after the NASA Associate Administrator who led the imaging team on that mission.

Roll of Society Names Survives Loss of *Mars '96*

Members of the Planetary Society (including Carl Sagan) made it to Mars in another way—aboard *Pathfinder*. You may remember "Visions of Mars," the compact disc (CD) containing works of science fiction that flew with the ill-fated Russian mission *Mars '96*. Accompanying the CD was a "documentation chip" that included the names of the 100,000 members of the Planetary Society at the time the CD was prepared. This documentation chip was included in MAPEX—the microelectronics and photonics experiment—devised by the Jet Propulsion Laboratory (JPL) as a passive recorder of incoming radiation at the Martian surface. The Society enabled inclusion of MAPEX on *Mars '96* with the idea that when the first human explorers came to Mars, it would be there to provide information about the radiation environment on the planet.

JPL's Microdevices Laboratory made several MAPEX spares—on the chance they might be useful for future missions.

It came as a wonderful surprise when we learned, shortly before the July 4 landing, that the *Mars Pathfinder* Project Team, under the direction of Manager Anthony J. Spear, had put MAPEX aboard their spacecraft. Our members' names and names of project personnel and others associated with the mission are all there together on a little chip—inscribed by electron-beam lithography.

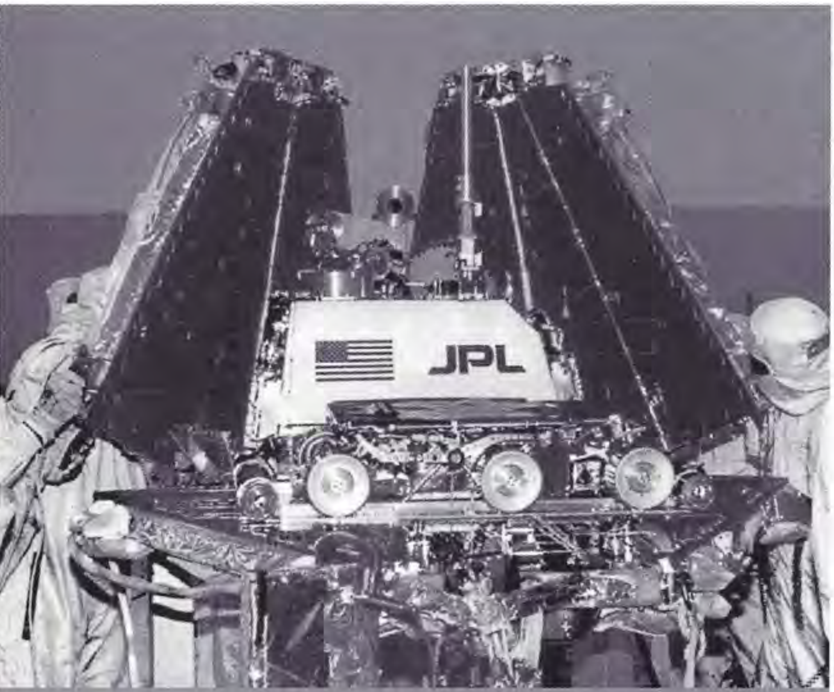
To read these names on Mars would require a scanning electron microscope, not to mention an intelligent life form on site to do the reading. That may happen someday, but for now I am sure our members agree: it's nice to be there.

Access to the Adventure

Getting everybody involved—at least those who care about the future—has been a goal of the Planetary Society since our founding in 1980. Carl Sagan's initiative in developing the *Pioneer* plaque and *Voyager* Record, with their messages on behalf of all humanity, pointed the way to the naming of individuals for the "Visions of Mars" CD. The name of the microrover *Sojourner* is an example in the same spirit from the *Pathfinder* mission. Valerie Ambroise of Bridgeport, Connecticut entered the winning name in an international student contest co-sponsored by the Jet Propulsion Laboratory and the Planetary Society.

Looking ahead, we have gathered more than half a million signatures in cooperation with the *Cassini* Project for delivery to Saturn. And we will continue to offer opportunities for expressions of human confidence in the future, because we hope, as Carl Sagan hoped, that humans from all nations will someday venture to Mars and throughout the solar system.

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



As Mars Pathfinder *was being assembled for launch, a microdot containing the names of all Planetary Society members as of October 1993 was attached to the spacecraft.* Photo: JPL/NASA

News and Reviews

by Clark R. Chapman

University of Arizona astronomer Tom Gehrels has hosted many scientific conferences over the years, often connected with plans for books in the seminal Space Science Series about the solar system. Following an early conference, Gehrels would invite participants to join him on a hike up to Seven Falls in the Catalina Mountains, and it was during one of these hikes that I met and chatted with an impeccably dressed European astronomer, walking up the trail in street shoes. Clearly, he was not prepared for a trek into the wilderness, but he nevertheless walked the several miles up the dusty, desert trail. This was Jürgen Rahe, the comet scientist from Bamberg, Germany.

Later, Rahe became responsible for NASA's planetary astronomy research programs, and, finally, he led NASA's whole Solar System Exploration Program. In June, unexpectedly, Rahe was again unprepared for a bout with nature: a violent thunderstorm and microburst blew over trees in suburban Washington, DC, near Rahe's home, one of which crashed onto his automobile, killing him instantly.

Amid Bureaucracy

Jürgen Rahe brought scientific integrity, excellence, and diplomacy to a federal agency that already stands above most government bureaucracies. I first worked with Rahe in connection with the International Astronomical Union's Commission 15, which coordinates comet and asteroid research programs. Later, I worked with him when he reorganized NASA's Planetary Astronomy research programs. In that capacity, he skillfully combined an objectivity in distributing the declining research funds, while still managing to care for the individual needs of each researcher supported by the program. He found pathways through the bureaucratic labyrinth to do what was right for science.

When Wesley Huntress was put in charge of all science in NASA, Rahe took over his responsibilities for solar system exploration—from the smallest theoretical research project to the largest deep-space missions, like *Galileo* and *Cassini*. Jürgen Rahe especially nurtured the new Discovery series of smaller missions; some say he was almost single-handedly responsible for making the Near-Earth Asteroid Rendezvous (NEAR) mission a reality. Regrettably, Rahe died only a week before NEAR achieved its first scientific triumph, returning pictures of the unexpectedly giant-cratered asteroid Mathilde. Officials at The Johns Hopkins University Applied Physics Laboratory, which built and operates NEAR, paid tribute to Rahe on encounter day.

A week later, *Mars Pathfinder* captured the front pages—and hearts—of America and the world, as it bounced onto Mars and its miniature rover explored nearby rocks, the first successful return to Mars since *Viking*, two decades ago. The coordination of programs like *Mars Pathfinder* was eased by Rahe's oversight, and it is again too bad that he did not live to witness the rebirth of popular excitement in NASA's exploration of the planets.

The Importance of the Improbable

Jürgen Rahe, more than any other NASA official, paid heed to the newly appreciated hazard of impacts by asteroids and comets. When Congress mandated, in 1990, that NASA evaluate the impact hazard, Rahe was assigned to get the studies accomplished. In order to establish the scientific context of the hazard, with full international participation (appropriate for a hazard that knows no national boundaries), Rahe asked me to organize—with the Planetary Society's assistance—the 1991 First International Conference on Near-Earth Objects. And he appointed two committees to investigate the matter—one to consider how we might detect possible impactors, the other to address what might be done should a dangerous projectile be found.

Rahe skillfully negotiated the tricky politics of the impact hazard. Vice President Quayle had been ridiculed for expressing concern about asteroids, Edward Teller (father of the H-bomb and the Star Wars program) wanted to blow up asteroids near the Earth, and few people could relate to the combination of extremely high consequences and extremely low probability that defines this hazard. It took a man with Rahe's diplomacy and quiet fortitude to handle these complex issues.

Most people succumb to cancer, heart attacks, automobile accidents, and similar causes. Almost nobody dies from cosmic impacts, and yet such events do happen, as the sorrow of Rahe's untimely death attests. When a freakish impact on a global scale happens, almost everyone might die. We live with capricious Nature. And Jürgen Rahe labored to help us to deal with that reality. I don't know how many people are killed annually by falling trees, but it is a rare occurrence. We must accept the fact that freakish events are part of the fabric of our existence. Rahe is survived by his wife, Hazel, and his daughter Isabell, near whose horse stable he was driving when he died.

Rahe was a co-investigator of the *Giotto* mission to Comet Halley long before assuming his management responsibilities for the NEAR and *Rosetta* missions to asteroids and comets. But someone got out to the solar system's tiny worlds before Jürgen Rahe—Saint-Exupery's *Little Prince*. In the penultimate chapter of the famous tale, the little prince departed for good: "He remained motionless for an instant. He did not cry out. He fell as gently as a tree falls."

Clark R. Chapman is an Institute Scientist in the Boulder, Colorado office of the Southwest Research Institute.

Factino:

NEAR Flyby Yields First Closeups of Mathilde

After a flawless encounter with asteroid 253 Mathilde, the Near-Earth Asteroid Rendezvous (NEAR) spacecraft sent back images revealing an intensely dark body that has survived a barrage of world-shaking impacts. The NEAR images of Mathilde provide our first detailed look at one of the C-type asteroids, which scientists believe to be leftover hunks of the primordial material from which planets formed. If so, the pictures you see here represent pristine remains from the early solar system.

The June 27 encounter lasted only 25 minutes, returning 534 images from the spacecraft's multispectral camera. Lighting conditions were a challenge, as NEAR intercepted Mathilde at twice Earth's distance from the Sun, with only 3 percent of available sunlight reflected from the target surface. Mathilde is about twice as dark as charcoal. With perfect timing and no unanticipated problems, the encounter proved successful for the NEAR mission team, headed by Robert W. Farquhar of The Johns Hopkins University Applied Physics Laboratory. In less modest terms, the flyby was a slam dunk.

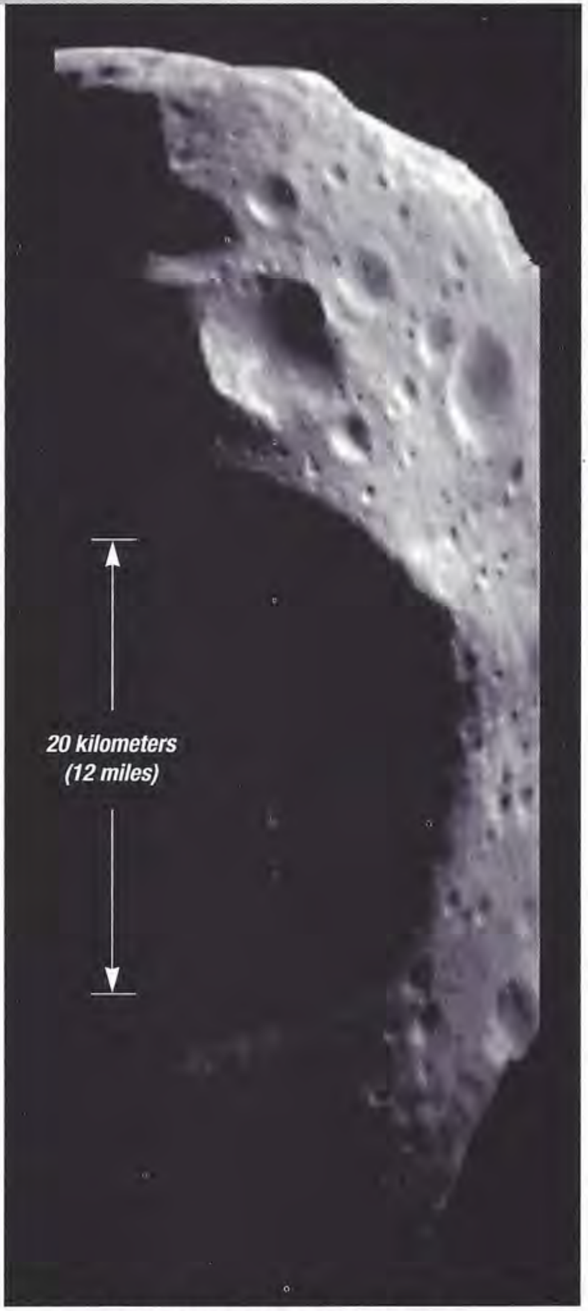
Mathilde is thoroughly cratered, like the *Galileo*-encountered asteroids Gaspra and Ida. However, NEAR scientists were surprised to find several craters on Mathilde that must have come close to blowing apart this tiny world, which has a mean diameter of only 52 kilometers (33 miles). One particularly deep scoop, penetrating an estimated 10 kilometers (6 miles), allows a cutaway view into Mathilde's interior. Joseph Ververka of Cornell University, head of the NEAR imaging science team, notes that slopes on this and other craters show no signs of differentiated rock types. Apparently Mathilde is made of the same dark material through and through. This observation is consistent with C-type asteroids being made of pre-planetary, carbon-rich material—rock so primitive it precedes the geologic processes that form the rocks we recognize on Earth.

The bulk density of Mathilde is remarkably low, according to preliminary analysis of the radio science experiment, which measured the slight tug from the asteroid's gravity on the trajectory of the spacecraft. Density gives a clue to Mathilde's origin, explains Donald K. Yeomans of the Jet Propulsion Laboratory. Low density suggests Mathilde may have accumulated as a loose conglomeration of material, a kind of rubble pile.

The heavy cratering may be responsible for at least part of the loose-conglomeration structure of Mathilde—if that is indeed the correct model. A solid, monolithic structure would probably have shattered as a result of the hits taken by Mathilde. If Mathilde is a rubble pile type of object, the shock of large impacts would be more easily absorbed without busting up the asteroid completely. As an analogy, if you hit a brick with a bullet, it shatters. A sand pile suffering the same hit will only form a crater.

Scientists continue to study the Mathilde images as NEAR heads on to its primary target, 433 Eros.

—from The Johns Hopkins University Applied Physics Laboratory/NASA



At closest approach (1,200 kilometers, or 700 miles), the NEAR spacecraft could resolve craters smaller than 500 meters across. Looking closely along certain crater rims, you can see sections that are curiously straight, perhaps indicating that faults or fractures have influenced crater formation. Raised crater rims suggest ejecta flew only a short distance before returning to Mathilde's surface.

Asteroid 253 Mathilde images from the NEAR spacecraft constitute the first science return from NASA's "faster, cheaper, better" Discovery program. At first glance, scientists are intrigued by two characteristics revealed in these images—the uniformity of Mathilde's rock and the asteroid's history of drastic impacts.

From this perspective, Mathilde measures 59 by 47 kilometers (36 by 29 miles), and the shadowed indentation at center goes to an estimated depth of 10 kilometers (6 miles). The wedge-shaped shadow at lower right defines the edge of another substantial crater, as does the diagonal at the top left. The mountain-shaped feature just left of the diagonal may mark the edge of a fourth large crater. Battered Mathilde is shown in this image mosaic at a distance of 2,400 kilometers (1,500 miles) with resolution of details as small as 380 meters.

In this group portrait of all asteroids imaged by spacecraft to date, Mathilde (left) is joined by tiny Gaspra and by Ida, both encountered by Galileo. *Mathilde and Ida are similar in number of impacts per unit of surface area and in number of impacts within size categories, with one conspicuous exception—craters larger than 20 kilometers (12 miles). Mathilde has taken at least 5 such hits. Gaspra and Ida are silicate-rich S-type asteroids, typical of the inner part of the asteroid belt. Mathilde is spectral type C, believed to be rich in carbon, predominating in the outer part of the asteroid belt.* Images: The Johns Hopkins University Applied Physics Laboratory/NASA

World Watch

by Louis D. Friedman

The following column was first published on the Opinion page of the Los Angeles Times, *the day before the* Mars Pathfinder *landing, and it cites the risk that we knew was inherent in that landing. Risk is an important consideration in making decisions. It must be weighed against the potential gain. In an earlier piece, entitled "Zero-risk, Zero-gain," I argued against those who opposed the* Cassini *launch because of risk related to the nuclear power sources on the spacecraft. The risk, analyzed exhaustively in an environmental impact report, was very small. The risk of anyone dying from* Cassini *was less than the risk of you, the reader, being struck by lightning. But the gain from sending an international mission to Saturn and its moons was very large, a rich cascade of new information about the worlds around us. Ultimately all risk and gain tradeoffs must be endorsed by the public, expressing their will in the political process.*

Houston—Do We Really Have a Problem?

What does the *Progress-Mir* collision mean to our future in space? First, let's be thankful there was no loss of life—we should not forget the praise and admiration due our Russian colleagues for building such a resilient system and devising procedures that maintain safety even when the worst happens. As in the earlier fire incident, *Mir* has proved remarkably robust.

The Russian space station has lasted 11 years in orbit—three years longer than it was designed for. It now carries American crews and has enabled the US to jump ahead five years in its human space program with long-duration flights and life science experiments. The experience of working and coping in space, being gained on *Mir*, will certainly help the crews of the international space station.

But these are technical details, and the space station is not about technology. It is about a vision—a vision of humanity moving off its island Earth to new worlds and new achievements. Will the accident, the potential loss of life, the delay to science experiments, and the extra money needed for repair and recovery cloud that vision? I heard a congressman proclaiming that we should stand down in our program until the Russians meet "American safety standards." This is confusing since the Russians operate the only space station and have done so with a perfect safety record for 11 years. The US has not yet matched that achievement. Such posturing is not a challenge to the space station's design, but it is a challenge to the vision.

The public—in this nation and others—will have to decide whether to view the *Mir* incident and the inherent risk of space exploration with clear or clouded vision. If the risk, the cost, and the uncertainty are too great, then we will remain bound to Earth. But with prudent risk, reasonable cost, and resilient planning, the public may support the continuing quest to go farther and faster to explore new worlds.

The space station itself cannot fulfill that quest. It leaves us still stuck in Earth orbit, doing experiments that for the most part could be done better and cheaper with robots. But as an international venture, the space station can fulfill significant objectives: training humans to live in space and cope with difficult engineering requirements, defining the effects of long-duration flights on human physiology, and building the partnerships necessary for a trip to Mars, the asteroids, or even a re-run to the Moon with human explorers. The *Mir* mission, the construction of the international space station, and even the *Progress-Mir* accident are doing just that.

Space is a difficult place—it is risky. We've outgrown the "routine access to space" nonsense promulgated by the NASA of the 1980s. We don't send teachers or members of Congress or journalists to space. We shouldn't be promoting space tourism—it, too, is nonsense. (It's hard enough to book a tour to the Antarctic or the Marianas Trench, far more benign and easy to reach environments.) A hundred reports remind us that someone will again die in space—some accidents will occur.

Robotic missions to Mars have had their difficulties; there were failures in 1989, 1993, and 1996. Still, we are on our way, with a national policy committed to launches at every opportunity—a real Mars program, leading to robotic sample return and then human flights early in the next century. This robotic Mars program and the human space station program converge in their common goal of sending human explorers to Mars. This is in the public interest. Indeed, it is the public's interest in the questions of life in the universe, evolution of planets, and the origins of our physical and biological world that fuels the space program.

If we want zero risk, we should stay at home (and even that isn't so safe). If we want to seek adventure, to explore and gain new knowledge of life in the universe—past, present, and future—then we must accept risk.

If the recovery goes well, perhaps the accident on *Mir* may be helpful. The engineering lessons learned will remind us both of the adventure and the risk, preparing us to take even bolder steps into the future.

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

Society News

Thousands Celebrate *Pathfinder* at Planetfest

Over the July 4 weekend, the Planetary Society's Planetfest '97 welcomed thousands of visitors to the Pasadena Convention Center to witness first-hand the unfolding of *Mars Pathfinder*'s landing and the release of *Sojourner*. Members of the Jet Propulsion Laboratory (JPL) *Pathfinder* mission team joined celebrants in the center's packed 1,800-seat Main Hall, offering updates, insights, and their own excitement as the weekend events developed. Images came to the center direct from mission operation headquarters at JPL in Pasadena.

Exhibit hall displays, discussions (led by some of the world's leading scientists and engineers), book signings, and films were well attended by the more than 8,000 people who joined in the event each day.

With the sponsorship of Sun Microsystems and NASA Integrated Network, audio feeds for many symposium discussions, as well as video feeds of major exhibits, were beamed to the world via the Internet. Sun Microsystems will archive many Planetfest events for viewing at their site on the World Wide Web and at the Society's award-winning home page. Watch for more information about events at Planetfest in the November/December issue of *The Planetary Report*.
—Bill McGovern, Production Editor

Society Attends UN/ESA Meeting

Planetary Society Executive Director Louis D. Friedman and Advisory Council member Adriana Ocampo led the Planetary Society delegation to the United Nations/European Space Agency's developing countries basic space science workshop in Tegucigalpa, Honduras in June. The Planetary Society has cosponsored these workshops for six years as a United Nations nongovernmental organization enlarging interest in planetary exploration and the search for extraterrestrial life.

Friedman presented Honduran President Dr. Carlos Roberto Reina Idiaquez with a copy of *Comet* by Carl Sagan and Ann Druyan, with a special inscription from Ms. Druyan. Friedman and Ocampo led several discussions at the workshop, which focused on encouraging developing countries to participate in worldwide efforts to increase near-Earth object observations.
—Louis D. Friedman,
Executive Director

Rover Roundup Papers Published

Selected papers from the Planetary Society's International Conference on Mobile Planetary Robots and Rover Roundup will be published in the September/October issue of *Space Technology*, which is dedicating a special section to the international conference. Professor Klaus Schilling of Steinbeis Transferzentrum in Weingarten, Germany, which has developed rovers for the European Space Agency, selected 12 papers submitted by conference participants. The first conference of its kind, the Rover Roundup took place in Santa Monica, California in January 1997 and brought scientists and engineers from around the world to demonstrate prototype rover technology for remote planetary exploration.
—BM

Order Your Mars Symposium Proceedings

Proceedings from the November 1996 Washington, DC symposium *Life on Mars, What Are the Implications?* (cosponsored by the Planetary Society and George Washington University) are now available to Society members. Organized by Society Advisory Council Chair John Logsdon, the symposium included a wide range of discussion topics from science to religion. Complete proceedings are available by sending $5 for shipping and handling to "Symposium" at the Planetary Society address.
—LDF

Neil Tyson Joins Board

Princeton University astrophysicist and acting director of the American Museum of Natural History-Hayden Planetarium in New York, Dr. Neil Tyson is the newest member of the Planetary Society's growing Board of Directors. A columnist for *Stardate* magazine, Dr. Tyson has authored two space science books geared toward nonscientists. Dr. Tyson's professional study focuses on dwarf galaxies and the "galactic bulge" at the center of the Milky Way.
—Charlene Anderson,
Director of Publications

Scholarship Created

The Dr. W. Reid Thompson of the Class of 1969 Memorial Science Scholarship has been established at Washington County High School, Springfield, Kentucky, where Reid graduated salutatorian of his class. Thompson's life and successful career in scientific research ended last year after a long and courageous battle with cancer.

The scholarship will go to the student with the highest grade point average of four or more high school science classes that include chemistry and physics or anatomy. The recipient must also have been accepted at any four-year college in the United States with an intended major in natural or physical science or medicine. The Planetary Society has contributed $500 to the scholarship.
—Donna Stevens, Assistant Editor

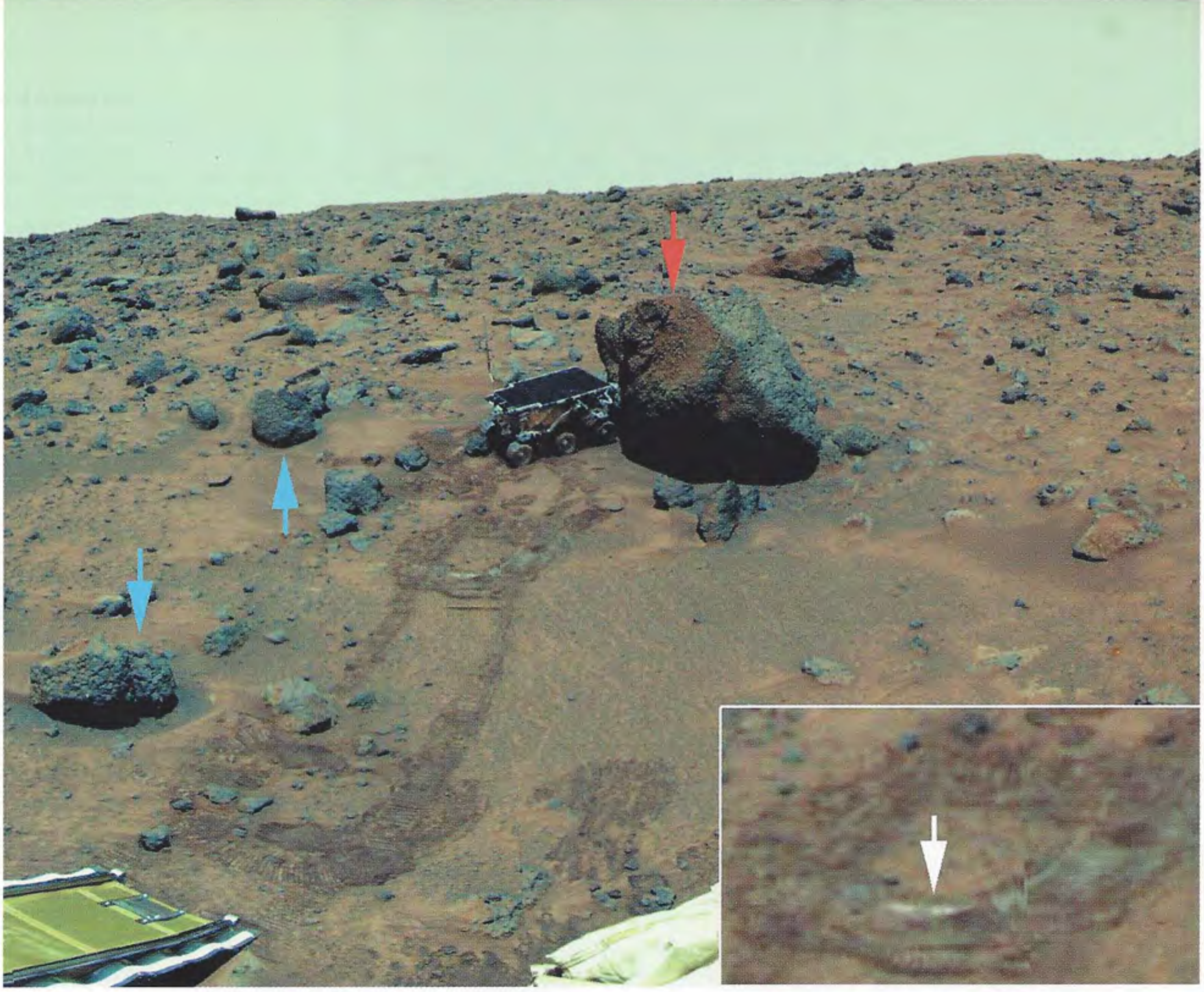
More News

Mars Underground News:
A photo essay of *Pathfinder*'s success and the newest images of the Red Planet.

Bioastronomy News:
Pathfinder and past life on Mars; ice and ozone on Jupiter's moons.

The NEO News:
CCD technology and the amateur astronomer.

For more information on the Society's special-interest newsletters, call (626) 793-5100.



Here we see the rover *Sojourner* in action as it visits the rocks of Mars. The image has been color-enhanced to make the differences between the rocks and soil more visible. The northeast face of the boulder Yogi (red arrow) is fresher than the rest of the rock. This may be due to eolian (wind-driven) scouring or simply because pieces broke off, exposing a newer surface. The blue arrows point to Barnacle Bill (left) and Cradle, both typical of the area's smaller, unweathered rocks.

As *Sojourner* turned to deploy the Alpha Proton X-Ray Spectrometer, its wheels dug particularly deeply and exposed white material (see inset), which may underlie much of the site. The lander's rear ramp, from which *Sojourner* drove down to the planet's surface, is visible at lower left. Image: JPL/NASA

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