The PLANETARY REPORT

Volume XIV Number 3 May/June 1994

Remembering *Apollo*

On the Cover:

The Genesis Rock was one of the great prizes returned to Earth by project *Apollo*. Here we show a magnified view of individual crystals within the rock. Analysis of this piece of anorthosite fixed its age at about 4.4 billion years—a rare find in a solar system only 4.6 billion years old. Scientists infer that the Genesis Rock formed from the original magma ocean that once covered the surface of the forming Moon.

Photograph: Graham Ryder, Lunar and Planetary Institute

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From The Editor

July 20 of this year will mark the 25th anniversary of *Apollo 11*'s landing on the Moon. It's hard to write or say anything about this achievement that hasn't been repeated into triviality.

For what it's worth, this is how I remember *Apollo:* As a success shared by all on Earth who were able to see it as a triumph of the human will to accomplish the impossible, and who could believe that "We came in peace for all mankind." As an accomplishment of a group working toward a goal that could only be reached through the coordinated work of thousands. As a benchmark for all who seek to measure the limits of human achievement.

Celebration, this year, seems to be mostly confined to individual reminiscing. In planning Planetary Society Jupiter Watch events in Washington, DC, which serendipitously will coincide with the *Apollo* anniversary, we were surprised to find so little being planned in the way of public celebration.

Why has *Apollo* been nearly forgotten? Has the world changed so very much? Such questions bear upon the reasons for the Society's existence, and our members' feelings about the *Apollo* anniversary could be important to us. Please write and share your ideas.

—*Charlene M. Anderson*

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Members' Dialogue

A Broader Scope?

I am responding to "Broaden Our Scope?" in the March/April 1994 Members' Dialogue. I feel that The Planetary Society should focus on increasing its membership and funding for more ambitious projects. I do not believe it should broaden its scope.

Many well-funded organizations, both private and governmental, deal with social, environmental, and a wide range of technological problems. The cost of doing anything worthwhile in space exploration is high. Spreading our resources and efforts to projects in which we have little expertise will only ensure that we spend too little on those things we can accomplish, and fail to accomplish anything worthwhile in the peripheral projects.

The best advice I was given as a graduate student, which I now give students and other scientists, is to focus on a project and finish it. That is the advice I am giving the Society today. Focused, ambitious projects are also the ones that I am most likely to contribute to the funding of.
—WILLIAM L. ROTH,
Wheaton, Maryland

Don't do it! Don't turn The Planetary Society into a liberal activist social organization. There are plenty of them around already, and if we members wanted to be in them we would have joined them already. We joined The Planetary Society because we are interested in promoting the exploration of other planets, not in trying to achieve "continued life, adventure, prosperity, happiness, harmony, knowledge, hope, freedom and time."

The very fact that this proposal has been made indicates that The Planetary Society is in grave danger of losing its way; that is, of losing its focus on the very reason for its existence. I sense that the general malaise toward space affecting America today is close to infiltrating our group.

Repent, I say! Leave environmental issues to the Sierra Club, economic issues to economists and international cooperation to the State Department. The Planetary Society is about the exploration of space. Let's get back out there!
—JOSEPH D. ANDREW, JR.,
Colorado Springs, Colorado

I think broadening your scope to include environment, international cooperation, advanced technology and cosmology is actually the best way to gain support for space programs. This would bring the subject of space to a much larger segment of the general population than you reach now. And the more paths you take to the public the better. As long as people feel isolated and that space is a hobby for the "elite," you'll never get their support.
—CAROL SHANE,
Richlandtown, Pennsylvania

Nix Wade

With all due respect, Nicholas Wade's article in the March/April issue of *The Planetary Report* is one of the more self-contradicting pieces this writer has ever read.

Wade waxes poetic about moving humanity to other planets. Where does he propose that humanity gain the experience needed to support travelers for long periods in space? To understand how to build large structures in microgravity? How will the nations of the world learn to work together on large projects in space? Canceling the space station would not move humanity toward Wade's lofty goal; it would set it back.

What would the reason be for "saving" the funds going to NASA? If $25 billion (the cost of *Apollo*) would not solve the United States' problems in the 1960s, will $15 billion do so today? Hardly.

If The Planetary Society is dedicated to exploration, to seeing humans working together in space, to seeing them explore Mars and the other planets, it should fight the attitude of people like Wade. To wait now, when the time is ripe to bring together the nations of the world in a single effort to explore and possibly expand into space, will be to fail utterly. That cannot be allowed to happen.
—ANDREW REYNOLDS,
Rochelle, Illinois

I can understand the apparent frustration that Nicholas Wade is voicing; however, his argument for abandoning the human portion of space exploration in favor of a program centered on robotic exploration is naive. I don't believe that Congress or the public would fully support a space program without a human component. People in space humanize the entire space effort, something a robotic program could never do.

As for his comment on viewers tiring of astronauts' weightless, and often witless, antics in space, I believe Wade needs an education regarding the purpose of NASA's human orbital missions. If humans are ever going to work efficiently in space, they must know what is involved in performing tasks in a weightless environment, and how prolonged weightlessness affects human physiology.

I will agree with Wade that for the last 20 years NASA has been sorely neglected by our elected leaders in the White House and Congress. We can indeed have an exciting robotic exploration program coexist with a viable and exciting human one. We had one in the 1960s through the mid-1970s.We can have one in the 1990s and beyond.
—KEVIN J. COLE,
River Forest, Illinois

Please send your letters to Members' Dialogue, The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106.

The Gift of *Apollo*

by Carl Sagan

The gates of Heaven are open wide;
Off I ride . . .

— Ch'u Tz'u (China, ca. 3rd century BC)

It's a sultry night in July. You've fallen asleep in the armchair. Abruptly, you startle awake, disoriented. The television set is on, but not the sound. You strain to understand what you're seeing. Two ghostly white figures in coveralls and helmets are softly dancing under a pitch-black sky. They make strange little skipping motions, which propel them upward amid barely perceptible clouds of dust. But something is wrong. They take too long to come down. Encumbered as they are, they seem to be flying—a little. You rub your eyes, but the dreamlike tableau persists.

Of all the events surrounding *Apollo 11*'s landing on the Moon on July 20, 1969, my most vivid recollection is its unreal quality. Yes, it was an astonishing technological achievement and a triumph for the United States. Yes, the astronauts—Neil Armstrong, Buzz Aldrin and Mike Collins, the last keeping solitary vigil in lunar orbit—displayed death-defying courage. Yes, as Armstrong said as he first alighted, this was a historic step for the human species. But if you turned off the byplay between Mission Control and the Sea of Tranquility, with its deliberately mundane and routine chatter, and stared into that black-and-white television monitor, you could glimpse that we humans had entered the realm of myth and legend.

We knew the Moon from our earliest days. It was there when our ancestors descended from the trees into the savannahs, when we learned to walk upright, when we first devised stone tools, when we domesticated fire, when we invented agriculture and built cities and set out to subdue the Earth. Folklore and popular songs celebrate a mysterious connection between the Moon and love. Especially when we lived out-of-doors, it was a major—if oddly intangible—presence in our lives.

The Moon was a metaphor for the unattainable: "You might as well ask for the Moon," they used to say. For most of our history, we had no idea what it was. A spirit? A god? A thing? It didn't look like something big far away, but more like something small nearby—something the size of a plate, maybe, hanging in the sky a little above our heads. *Walking* on the Moon would have seemed a screwball idea; it made more sense to imagine somehow climbing up into the sky on a ladder or on the back of a giant bird, grabbing the Moon and bringing it down to Earth. Nobody ever succeeded, although there were myths aplenty about heroes who had tried.

Not until a few centuries ago did the idea of the Moon as a *place*, a quarter million miles away, gain wide currency. And in that brief flicker of time, we've gone from the earliest steps in understanding the Moon's nature to walking and joyriding on its surface. We calculated how objects move in space; liquefied oxygen from the air; invented big rockets, telemetry, reliable electronics, inertial guidance and much else. Then we sailed out into the sky.

The Moon is no longer unattainable. A dozen humans, all Americans, have made those odd bounding motions they called "moonwalks" on the crunchy, cratered, ancient gray lava—beginning on that July day in 1969. But since 1972, no one from any nation has ventured back. Indeed, none of us has gone *anywhere* since the glory days of *Apollo* except into low Earth orbit—like a toddler who takes a few tentative steps outward and then, breathless, retreats to the safety of his mother's skirts.

Once upon a time, we soared into the solar system. For a few years. Then we hurried back. Why? What happened? What was *Apollo* really about?

The scope and audacity of John Kennedy's May 25, 1961, message to a joint session of Congress on "Urgent National Needs"—the speech that launched the *Apollo* program—dazzled me. We would use rockets not yet designed and alloys not yet conceived, navigation and docking schemes not yet devised, in order to send a man to an unknown world—a world not yet explored, not even in a preliminary way, not even by robots—and we would bring him safely back, and we would do it before the decade was over. This confident pronouncement was made before any American had even achieved Earth orbit.

As a newly minted PhD, I actually thought all this had something centrally to do with science. But President Kennedy did not talk about discovering the origin of the Moon, or even about bringing samples of it back for study.

After parking the lunar rover on the rim of Plum crater,* Apollo 16 *astronaut Charlie Duke collects samples of the Moon for return to Earth. The image captures both the glory and the unfulfilled promise of* Apollo: *Humans achieved the seemingly unattainable, then abandoned the quest. ***Photograph: NASA***

All he seemed to be interested in was sending someone there and bringing him home. It was a kind of *gesture*. Kennedy's science advisor, Jerome Wiesner, later told me he had made a deal with the president: If Kennedy would not claim that *Apollo* was about science, then he, Wiesner, would support it. So if not science, what?

The *Apollo* program is really about politics, others told me. This sounded more promising. Nonaligned nations would be tempted to drift toward the Soviet Union if it was ahead in space exploration, if the US showed insufficient "national vigor." I didn't follow. Here was the United States, ahead of the Soviet Union in virtually every area of technology—the world's economic, military and, on occasion, even moral leader—and Indonesia would go Communist because Yuri Gagarin beat John Glenn to Earth orbit? What's so special about space technology? Suddenly I understood.

Sending people to orbit the Earth or robots to orbit the Sun requires rockets—big, reliable, powerful rockets. Those same rockets can be used for nuclear war. The same technology that transports a man to the Moon can carry nuclear warheads halfway around the world. The same technology that puts an astronomer and a telescope in Earth orbit can also put up a laser "battle station."

Even back then, there was fanciful talk in military circles, East and West, about space as the new "high ground," about the nation that "controlled" space "controlling" the Earth. Of course strategic rockets were already being tested on Earth. But heaving a ballistic missile with a dummy warhead into a target zone in the middle of the Pacific Ocean doesn't buy much glory. Sending people into space captures the attention and imagination of the world. You wouldn't spend the money to launch astronauts for this reason alone, but of all the ways of demonstrating rocket potency, this one works best. It was a rite of national manhood; the shape of the boosters made this point readily understood without anyone actually having to explain it. The communication seemed to be transmitted from unconscious mind to unconscious mind without the higher mental faculties catching a whiff of what was going on.

When President Kennedy formulated the *Apollo* program, the Defense Department had a slew of space projects under development—ways of carrying military personnel up into space, ways of conveying them around the Earth, robot weapons on orbiting platforms intended to shoot down satellites and ballistic missiles of other nations. *Apollo* supplanted these programs. They never reached operational status. A case can be made then that *Apollo* served another purpose—to move the US–Soviet space competition from a military to a civilian arena. There are some who believe that Kennedy intended *Apollo* as a substitute for an arms race in space. Maybe.

Six more missions followed *Apollo 11*, all but one of which successfully landed on the lunar surface. *Apollo 17* was the first to carry a scientist. As soon as he got there, the program was canceled. The first scientist and the last human to land on the Moon were the same person. The program had already served its purpose that July night in 1969. The half-dozen subsequent missions were just momentum.

Apollo was not mainly about science. It was not even mainly about space. *Apollo* was about ideological confrontation and nuclear war—often described by such euphemisms as world "leadership" and national "prestige." Nevertheless, good space science was done. We now know much more about the composition, age and history of the Moon and the origin of the lunar landforms. We have made progress in understanding where the Moon came from. Some of us have used lunar cratering statistics to better understand the Earth at the time of the origin of life. But more important than any of this, *Apollo* provided an aegis, an umbrella under which brilliantly engineered robot spacecraft were dispatched throughout the solar system, making that preliminary reconnaissance of dozens of new worlds. The offspring of *Apollo* have now reached the planetary frontiers.

If not for *Apollo*—and, therefore, if not for the political purpose it served—I doubt whether the historic American expeditions of exploration and discovery throughout the solar system would have occurred. The *Mariners, Vikings, Voyagers, Magellan, Galileo* and *Cassini* are among the gifts of *Apollo*. Something similar is true for the pioneering Soviet efforts in solar system exploration, including the first soft landings of robot spacecraft—*Luna 9, Mars 3, Venera 8*—on other worlds.

Apollo conveyed a confidence, energy and breadth of vision that did capture the imagination of the world. That too was part of its purpose. It inspired an optimism about technology, an enthusiasm for the future. If we could go to the Moon, what else was now possible? Even those who were not admirers of the United States readily acknowledged that—whatever the underlying reason for the program—the nation had, with *Apollo*, achieved greatness.

When you pack your bags for a big trip, you never know what's in store for you. The *Apollo* astronauts on their way to and from the Moon photographed their home planet. It was a natural thing to do, but it had consequences that few foresaw. For the first time, the inhabitants of Earth could see their world from above—the whole Earth, Earth in color, Earth as an exquisite spinning white and blue ball set against the vast darkness of space. Those images helped awaken our slumbering planetary consciousness. They provide incontestable evidence that we all share the same vulnerable planet. They remind us of what is important and what is not.

We may have found that perspective just in time, just as our technology threatens the habitability of our world. Whatever the reason we first mustered the *Apollo* program, however mired it was in Cold War nationalism and the instruments of death, the inescapable recognition of the unity and fragility of Earth is its clear and luminous dividend, the unexpected final gift of *Apollo*. What began in deadly competition has helped us to see that global cooperation is the essential precondition for our survival.

Travel is broadening.

It's time to hit the road again.

Carl Sagan, President of The Planetary Society, received NASA's Apollo *Achievement Award in 1969. This article is adapted from a chapter in his forthcoming book,* Pale Blue Dot: A Vision of the Human Future in Space *(Random House).*

While We Weren't Watching: *Apollo*'s Scientific Exploration

by Andrew Chaikin

If you went around and talked to the men who have been to the Moon, one of the most remarkable stories you would hear is *Apollo 15* astronaut Dave Scott's description of the view he had as he stood next to his lunar rover, high on the slopes of a mountain called Hadley Delta. Beyond Hadley Delta's sweeping flank, 90 meters (300 feet) below, lay the bright, undulating volcanic plains of Palus Putredinis, the Marsh of Decay. Everywhere the land was scarred by impact craters, some worn and smooth, others sharp-rimmed and brilliant white. At the horizon, the rounded peaks of the Apennines, one of the Moon's great mountain ranges, cradled the black dome of the lunar sky.

On the airless Moon, the entire scene was rendered in startling clarity. And out in the middle of this pristine, ancient wilderness, Scott could see a tiny speck: his lunar module, *Falcon*, more than 5 kilometers (3 miles) away. The view was so breathtaking, Scott says, that for a moment it distracted him from the real reason he and Jim Irwin were there: to hunt for geologic treasure.

Aside from the awe-inspiring view, Scott's story conveys the extraordinary heights *Apollo* reached during its brief lifetime. Just two years earlier, in July 1969, *Apollo 11* astronauts Neil Armstrong and Buzz Aldrin had stayed for 31 hours on a bland acre of moonscape after history's first human lunar landing. In their single moonwalk, which lasted about as long as a feature-length film, they never ventured more than 60 meters (200 feet) from their lander. By the fourth lunar landing, Scott and Irwin were living in a lunar valley for three full days. Improved space suits and backpacks allowed them to take three moonwalks, each lasting as much as seven hours. And, most significant, their battery-powered rover gave them the capability to range miles across the surface and visit spectacular features, including a canyon 1.5 kilometers (1 mile) wide called Hadley Rille. In two short years, NASA had greatly extended the reach of human activities on another world, and it had done so in the name of scientific exploration. But it had happened despite some long odds.

The Premise, and the Promise, of *Apollo*

With *Apollo 11*, NASA had met John Kennedy's challenge to land a man on the Moon and return him safely to Earth by decade's end. Television commentators and editorial writers proclaimed that 500 years in the future our century would be remembered for those footsteps on the Sea of Tranquility, when human beings left their home planet to explore the universe.

Within the space agency, there were some who considered *Apollo 11* an engineering demonstration, and they urged that it was time to move on to new challenges. You wouldn't ask Lindbergh to fly the Atlantic again, they said; why go back to the Moon?

The answer was that *Apollo* had given the country the ability to explore other worlds. To the geologists who, with almost childlike excitement, began to study the *Apollo 11* lunar samples, the Moon was a 4.6-billion-year history book waiting to be read. Future missions could discover clues to the earliest history and even the origin of the Moon—and, by implication, of our own world.

At NASA headquarters, Administrator Tom Paine needed no convincing. He believed that there was another message implicit in Kennedy's challenge, beyond its words: that America should become a spacefaring nation. With *Apollo 11*, the country had achieved that status; it had only to use it. In Paine's mind, *Apollo* was just the beginning.

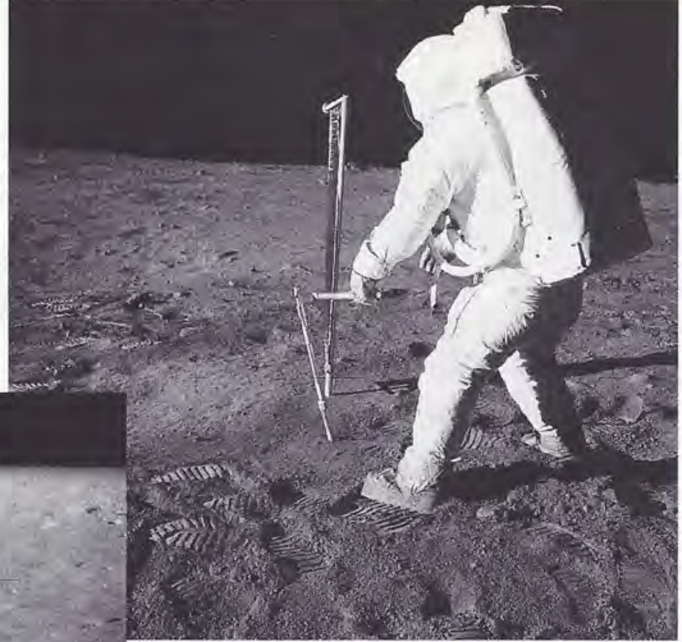
The Exploration Unfolds

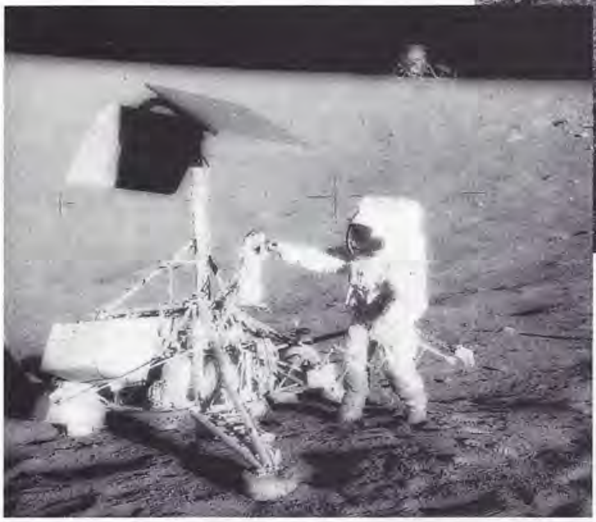
So it was that in November 1969 *Apollo 12*'s Pete Conrad and Alan Bean touched down on the lava plains of the Ocean of Storms. The samples they collected gave geologists a valuable comparison with *Apollo 11*'s volcanic rocks. Conrad and Bean also deployed a nuclear-powered scientific station designed to measure seismic activity and analyze the Moon's environment. And, most important for future missions, they touched down within walking distance of the robot *Surveyor 3* probe, which had landed on the Moon in 1967. With this pinpoint-landing capability, the way was now clear to visit more difficult and more geologically interesting locales.

Apollo 13 astronauts Jim Lovell, Jack Swigert and Fred Haise left Earth in April 1970, bound for the Moon's Fra Mauro highlands in what was to have been *Apollo*'s first true science mission. The mission was lost when the command ship was crippled by an explosion 200,000 miles from Earth. Using their lunar lander as a lifeboat, and with a heroic effort by mission controllers, the men barely made it back to Earth.

In February 1971, *Apollo 14*'s Alan Shepard and Ed Mitchell picked up the torch from Lovell and Haise, exploring Fra Mauro in two moonwalks totaling more than nine hours. They found a landscape much rougher than the lava plains visited by previous moonwalkers; instead it was like an airless, rock-strewn Sahara, with undulating ridges that reminded the men of sand dunes. This roughness was probably due to the presence of material ejected from the giant

of the Moon





Apollo 11 ***(above): Buzz Aldrin drives a core tube into the lunar soil and retrieves a sample for return to Earth. In the background is the Solar Wind Composition experiment, which he had just deployed. Even on this first mission to land humans on the Moon, astronauts completed several scientific experiments.*** **Photograph: Neil Armstrong, NASA**

Apollo 12 ***(left): A human explorer visits a robotic predecessor. Here Pete Conrad removes the television camera from*** **Surveyor 3,** ***which had landed 2½ years earlier on the Ocean of Storms. The astronauts returned several pieces of the robot to Earth, where scientists examined them to learn about the effects of the lunar environment on terrestrial equipment.*** **Photograph: Alan Bean, NASA**

Imbrium impact basin, 550 kilometers (340 miles) to the north. Finding the date of Imbrium's formation—one of the most significant events in lunar evolution—was *Apollo 14*'s main geologic objective.

But that turned out to be more difficult than Shepard and Mitchell had anticipated. Like their predecessors, they found it difficult to navigate on a surface devoid of trees and other familiar landmarks, without even the atmospheric haze that serves on Earth as a visual cue of distance.

On their second excursion, Shepard and Mitchell struggled to find the rim of the 335-meter-diameter (1,100-foot) Cone crater, where the samples of Imbrium ejecta were most likely to be found. Tired, and cutting into their reserves of oxygen and cooling water, the men were called back just short of their goal—which lay, unbeknownst to them, only 20 meters (65 feet) away. Nevertheless, the *Apollo 14* samples gave geologists a shaky but usable date for Imbrium's origin: 3.85 billion years.

Prior to *Apollo 11*, one researcher had stated that if so much as a single gram of lunar material was brought to Earth the scientific understanding of the Moon would increase a millionfold. Now, after three *Apollo* landings and one robotic sample return mission by the Soviets (*Luna 16*), there were 98 kilograms (216 pounds) of lunar rocks and soil in NASA's Lunar Receiving Laboratory and in laboratories around the world.

Spurred by the presence of lunar rocks on Earth, researchers had developed extraordinary techniques for analyzing the samples, using only tiny amounts of material at a time, able to detect individual atoms within a sample. Seismic data from the *Apollo 12* and *14* scientific stations were allowing geophysicists to probe the Moon's interior. And for astronomers, lunar dust was teeming with subatomic particles emitted by the Sun, and tracked with the trails of high-energy cosmic rays.

An Interrupted Quest

But even as *Apollo*'s explorations were bearing fruit, they were curtailed. In January 1970, faced with the leanest budget in nine years, NASA canceled the final lunar mission, *Apollo 20*, and assigned its *Saturn 5* booster to the *Skylab* Earth-orbit space station. The following summer, two more missions—*Apollo 18* and *19*—fell under the budgetary ax. And Tom Paine's vision for the post-*Apollo* era—which included space stations in Earth orbit and in lunar orbit, a base on the Moon, and human missions to Mars—had been rejected by the Nixon administration; only plans for a reusable space shuttle survived.

Ironically, the cancellations came just as NASA was planning its most ambitious lunar explorations. *Apollo 15* was the first of the extended lunar expeditions, called J-missions, that finally began to realize *Apollo*'s scientific potential. *Apollo 15*'s climactic moment came on August 1, 1971, as Scott and Irwin, prospecting on the slopes of Hadley Delta, found a small white chunk of rock, of a type called anorthosite, that proved to be a piece of the Moon's primordial crust.

For the astronauts, who had spent months training with geologists for their lunar fieldwork, it was a moment of triumph. For the scientists themselves, this find—which reporters nicknamed the Genesis Rock—confirmed that the Moon had once been covered by an ocean of liquid rock, or magma, which later solidified. The magma ocean concept was to become a key element in scientists' scenarios for the early evolution of Earth and the other terrestrial planets. Meanwhile, in lunar orbit aboard *Apollo 15*'s command

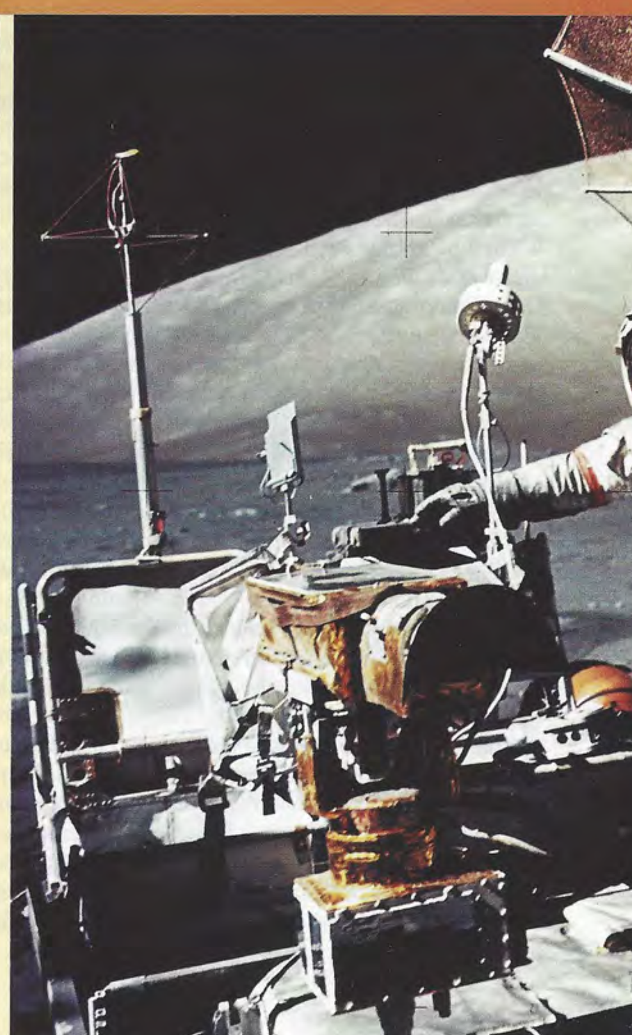
Apollo 15 *(left): Astronaut Dave Scott searches for geologic treasure high on the side of Hadley Delta mountain. Here he photographs a sample in situ before collecting it. Partly visible in the background is the lunar rover. Beyond that lie the volcanic plains of Palus Putredinis, and on the horizon are the peaks of the lunar Apennines.* Photograph: James Irwin, NASA

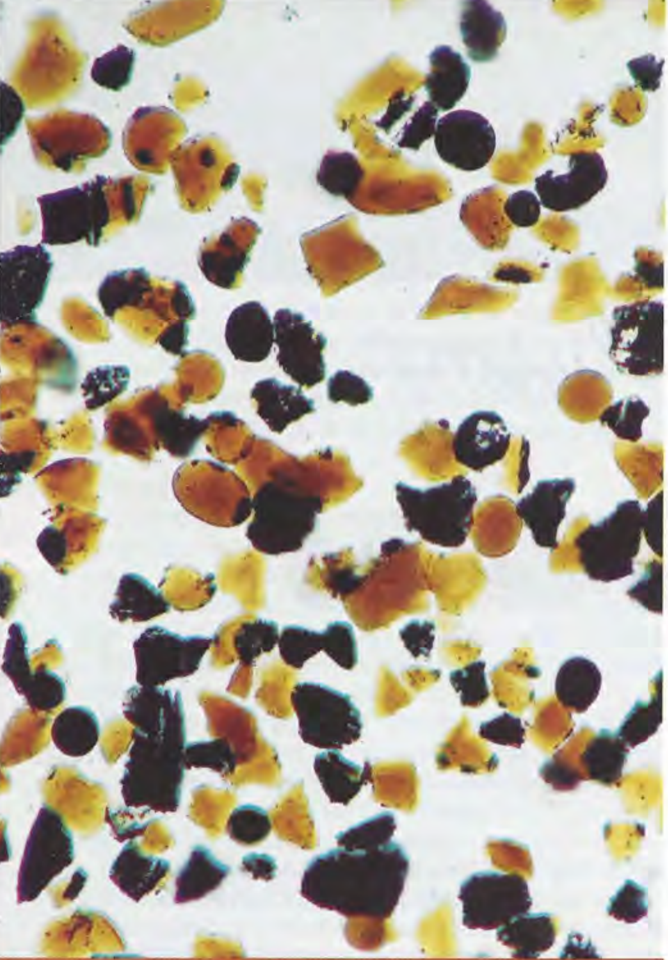
Apollo 17 *(right): These particles of "orange" soil, collected at Shorty crater by Jack Schmitt, are among the finest ever brought back from the Moon. They range in size from 20 to 45 microns (about 1/1000 of an inch), making them about the same size as terrestrial silt particles. Analysis suggests that they were formed by volcanic activity early in the Moon's history.* Photograph: NASA

Apollo 15 *(below): Dave Scott visits the Genesis Rock in the Lunar Receiving Laboratory on Earth. This piece of anorthosite is one of the oldest rocks ever studied by scientists, who dated it at about 4.4 billion years old. Scott and Jim Irwin collected it on the flank of Hadley Delta mountain.* Photograph: NASA

Apollo 16 *(above): Using a rake and tongs, John Young collects geologic samples near North Ray crater. Near the horizon sits the lunar rover in a field of large boulders.* Photograph: Charles M. Duke, Jr.

Apollo 17 *(right): Gene Cernan poses with the lunar rover during the last Apollo mission to the Moon. With Jack Schmitt, the first scientist to walk on the Moon, Cernan explored the Taurus-Littrow Valley and brought back to Earth a rich harvest of samples that still have not been completely studied.* Photograph: Harrison H. "Jack" Schmitt, NASA





module, Al Worden surveyed the Moon with a battery of high-powered cameras and sensors, amassing a haul of data that almost eclipsed the discoveries by his two crewmates on the surface.

A Last Hurrah, and a Distracted Nation

The final lunar landings bettered even *Apollo 15*'s extraordinary success. On *Apollo 16*, in April 1972, John Young and Charlie Duke became the first astronauts to explore the Moon's ancient central highlands. Expecting to discover evidence of volcanic activity, they found instead a landscape shaped by almost unimaginable violence: the meteorite and asteroid impacts that battered the Moon during its infancy and youth.

Finally, in December, *Apollo 17* saw Gene Cernan and geologist–astronaut Jack Schmitt, the first scientist to walk on another world, exploring a canyon at the rim of the Serenitatis basin. There they found rocks that dated almost all the way back to the formation of the Moon, 4.6 billion years ago, along with tiny beads of orange, red and black glass that had been ejected from deep in the lunar interior by spectacular eruptions called fire fountains.

Thanks to a remotely controlled camera on the rover, Cernan and Schmitt's activities were broadcast to Earth live, in color and with remarkable clarity. *Apollo 17* was nothing less than a space spectacular: It epitomized the boldness, ingenuity and above all the extraordinary human impact of the first visits to another world.

But by that time, most of us had stopped watching. Even before *Apollo 11*, the nation's attention had been divided. Concerned over the war in Vietnam, the endangered environment and the deteriorating inner cities, we no longer paid much attention to yet another team of astronauts exploring the Moon. By the time of *Apollo 17*, television networks had stopped covering the moonwalks in their entirety. The scientists working on the lunar samples had long accepted the Moon program's premature end. And at NASA, planners were already looking ahead to the space shuttle. Few mourned *Apollo*.

A Challenge More Than Met

Today, across the span of 25 years, it is difficult to comprehend how quickly we accomplished the first human explorations of the Moon—or how readily we gave them up. No one who participated in *Apollo*—least of all the astronauts themselves—thought it had accomplished all it was capable of. But even in its short life, *Apollo* gave us our money's worth. The *Apollo* lunar samples, totaling 381 kilograms (838 pounds), along with thousands of photographs and other data, are still yielding clues to the world that has been our Rosetta stone for deciphering planetary evolution.

In retrospect, *Apollo* stands out as a bright spot in a troubled era in our history, perhaps the last great act this country will ever perform out of a sense of optimism. What we did on that July night in 1969—and five more times in the 41 short months that followed—is still worth remembering: We touched the face of another world, and became a people without limits.

Andrew Chaikin writes about space science and exploration. His forthcoming book, A Man on the Moon: The Voyages of the *Apollo* Astronauts*, will be published in June by Viking.*

Observing a Cataclysm: The Last Days *of Comet* Shoemaker-Levy 9

by John R. Spencer

Between the 16th and the 22nd of July, a remarkable thing will happen: Every few hours, a piece of a broken comet will plunge into the atmosphere of Jupiter. All of these fragments, collectively called Shoemaker-Levy 9 after Eugene and Carolyn Shoemaker and David Levy, the astronomers who discovered them in March 1993, are parts of the same original comet, torn into 20-odd pieces by its unseen close approach to Jupiter in July 1992.

One of the great truths revealed by the planetary exploration program is that collisions in the solar system are common (geologically speaking) and can have enormous consequences. In addition to the nine planets, the solar system is swarming with smaller pieces of metal, rock and ice having much less regular orbits: the asteroids and comets. From time to time, they blunder into one another or into one of the planets, liberating enormous amounts of energy.

These impacts have excavated the craters that dominate the landscape of the Moon and a dozen other worlds—indeed, they probably created the Moon itself. They have likely changed the course of life on Earth, they can create and destroy atmospheres and they can deliver fragments of one planet to the surface of another. But until now we have had to rely on the aftereffects of impacts (such as craters), or on computer simulations, to learn anything about this fundamental process. Having the opportunity to watch a large-scale impact as it occurred seemed too unlikely to hope for.

However, Jupiter's enormous size and powerful gravity make it a much easier target for random celestial marksmanship than tiny Earth and the other terrestrial planets. Something the size of Shoemaker-Levy 9 probably hits Jupiter once every 50 to 500 years: a common event for the 4-billion-year-old solar system, but rare for us decades-old humans, so we are very lucky to see this happen.

We are unlucky, though, in the comet's choice of impact site. All the fragments will hit Jupiter just out of sight from Earth, a few degrees beyond the horizon on the far side of the planet. Only the *Galileo* spacecraft now approaching Jupiter will see the impacts directly, and it will be able to return only a very limited number of pictures and other data to Earth. For the most part, we must make the best of our indirect view from Earth.

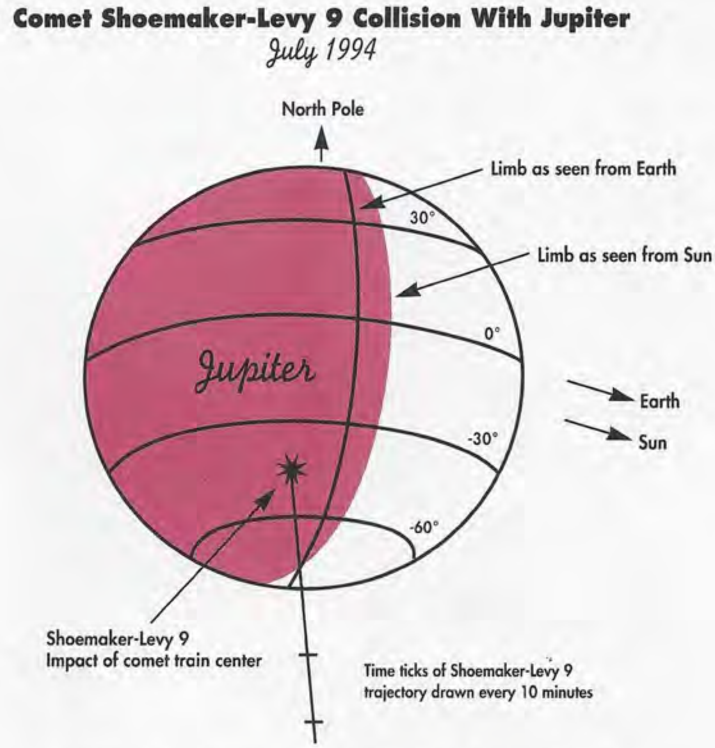
As soon as the impact was predicted, theoreticians scrambled to apply our limited knowledge of impact physics and predict what might happen in July. There is some agreement on what is likely to happen, but very little when it comes to putting numbers on the predictions. Something along the following lines seems likely, however. Each step in the story will be repeated 20-odd times—by each fragment of the comet in turn, over a period of six days.

One Likely Scenario

A few days before impact, each fragment enters the jovian magnetosphere, the region of space dominated by Jupiter's magnetic field. The fragment consists of a nucleus made of rock, ice and carbon-rich material, anywhere from a few hundred meters to a few kilometers in size, surrounded by a tenuous cloud of dust driven off the nucleus by evaporating ices suddenly exposed to space by the original breakup in 1992.

The high-speed electrons that fill the magnetosphere collide with the dust grains, producing a strong negative electrical charge on the grains. Electrostatic repulsion (the same effect that makes your hairs repel each other and stand on end when you pick up an electric charge after taking off a sweater) may tear the dust grains into even smaller pieces, increasing their surface area and possibly producing a visible brightening of the dust. The electrically charged dust grains may also be torn away from the nucleus by Jupiter's magnetic field. This may give us a brief dust-free view of each nucleus in the last few days of its life, and by measuring the brightness of the bare nucleus and assuming a plausible surface reflectivity, we may be able to improve our

Left: The repaired Hubble Space Telescope has given us a clearer view of comet Shoemaker-Levy 9's fragments than we had last year. We can see 20 pieces of the comet in this mosaic of images taken by the telescope's Wide Field and Planetary cameras.
Image: H.A. Weaver and T.E. Smith, Space Telescope Science Institute, NASA



Unfortunately for us observers watching from Earth, the pieces of comet Shoemaker-Levy 9 will strike Jupiter on its dark side, which faces away from us. Within minutes, however, the impact sites will rotate into view, and we may be able to see whatever effects are generated by collisions at 60 kilometers per second (134,000 miles per hour). ***Chart: D. Seal, JPL/NASA***

estimate of its size and mass, critical for predicting and understanding what happens when the nucleus hits Jupiter.

The comet fragment approaches Jupiter from the south, curving over the south pole and, to our frustration, disappearing behind Jupiter just before impact. As it falls toward the planet, the nucleus accelerates, finally plowing into the atmosphere at 60 kilometers per second (134,000 miles per hour). At this tremendous speed, atmospheric resistance doubles in strength every second. While still above the cloud tops, the nucleus is crushed into a mass of broken pieces, surrounded by an intensely hot, glowing envelope of superheated air.

Retaining most of its speed, the rubble of the nucleus plunges on, down below the cloud decks and out of sight. An observer watching this from a safe distance would see a sudden brilliant flash of light on Jupiter's dark side, for a few seconds rivaling the brightness of Jupiter itself and perhaps illuminating the jovian ring and the inner satellites and giving those on Earth a chance to "see" the flash by its reflected light.

Fireballs and Shock Waves

As the light disappears below the clouds, our observer might assume that the show is over, but not so. Below the clouds, the ever-increasing atmospheric pressure finally overcomes the speed of the nucleus and brings it to a screeching halt. Its energy is converted to heat, producing a bubble of superheated air very much like a nuclear fireball but much bigger, with an energy approaching a million megatons. The hot, buoyant fireball rises rapidly, punching up through the clouds and reemerging as a second brilliant light on Jupiter's dark side, this time lasting a minute or more before it cools and dissipates. This should also illuminate the ring and nearby satellites.

Meanwhile, shock waves from the detonation of the nucleus spread out from the impact site, some penetrating deep into Jupiter's interior before they reemerge at the surface, where they show up as perturbations in the upper atmospheric temperature. By detecting and measuring these expanding temperature ripples, which will spread rapidly onto the visible side of Jupiter, we can hope to learn about Jupiter's deep interior, just as our studies of seismic waves on Earth tell us about Earth's interior. Other ripples will spread more slowly through the upper atmosphere and, if we can detect them, will tell us about atmospheric conditions.

Only 15 to 20 minutes after impact, the rotation of Jupiter will carry the impact site into direct view from Earth. In the normally clear air at very high altitudes, we may see clouds produced from material thrown up from the lower atmosphere, and we may observe additional heat radiation from the cooling site of the impact. We may be able to detect chemicals created by the heat of the fireball, or blasted into the upper atmosphere from below, or injected by the comet itself, giving us a unique way to learn about the composition of the comet, or Jupiter, or both.

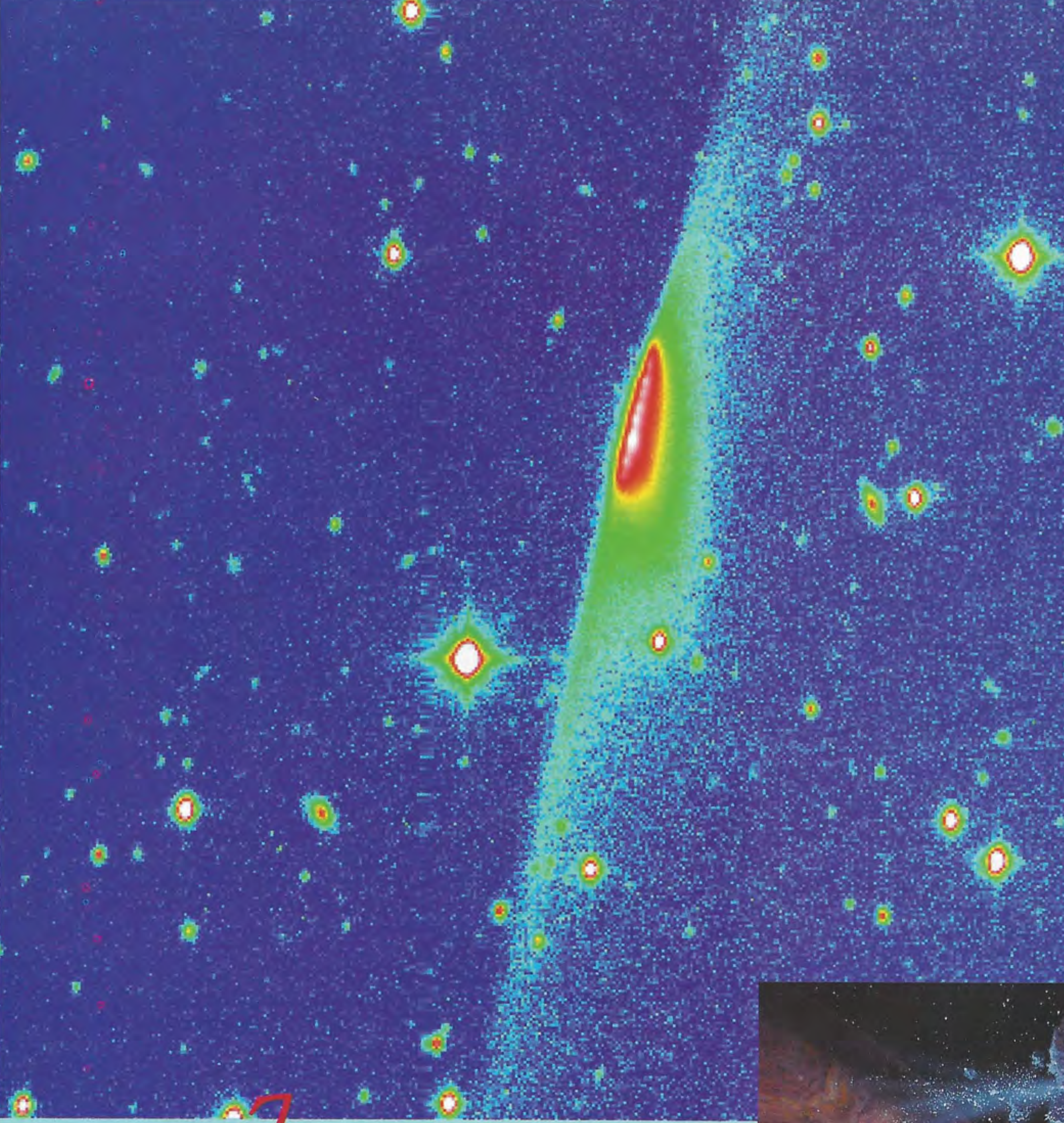
Not all of the comet's dust will hit Jupiter. Some of it may collide with the small satellites near Jupiter's ring, kicking up dust that will become part of the ring and visibly brighten it. It is even possible that some dust may eventually settle into a temporary new ring.

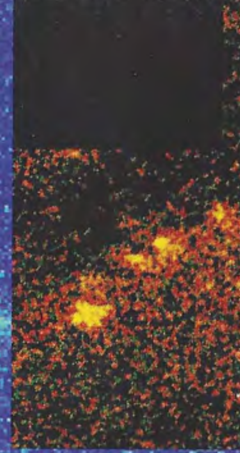
High Stakes for Comet Watchers

So these are some of the things that earthbound astronomers will be looking for during the comet impact: the brightening or stripping of the dust from around each nucleus; the flashes

By combining six images from the Spacewatch camera at Kitt Peak in Arizona, astronomers produced this wide-angle view showing 16 to 17 pieces in the comet train. You can also see faint dust trails extending off both ends of the train. The three straight streaks to the left of the comet are the trails of satellites traversing the telescope's field of view.

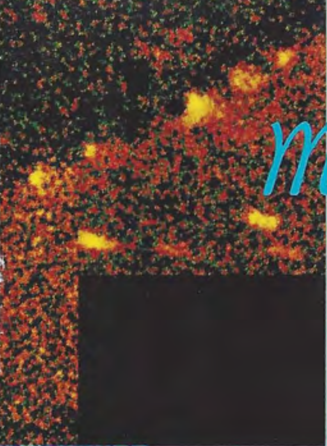
Image: Robert Jedicke, Travis Metcalfe and J.V. Scotti





This spectacular image of the comet chain was taken by the Spacewatch camera at Kitt Peak in Arizona. Although this camera is not able to resolve the individual nuclei as finely as the Hubble Space Telescope can, it still can show us much about the comet. About 11 pieces are visible here, spread out over 170,000 kilometers (105,000 miles). The tails of small particles blown off the comet by the solar wind stand out distinctly in this color-enhanced image.
Image: J.V. Scotti, University of Arizona

No one was there to watch it when the comet passed too close to Jupiter in July 1992. But artists can imagine what the scene might have looked like as the ice-and-rock body was ripped apart by its encounter with the planet.
Painting: Michael Carroll



Many different instruments around the world have been observing comet Shoemaker-Levy 9. This composite image of the fragments as they appear in the infrared was taken at NASA's Infrared Telescope Facility on Mauna Kea in Hawaii.

Image: Michael A'Hearn and Philip Esterle, University of Maryland; Tom Greene, Infrared Telescope Facility

In these computer-generated images, we see some possible effects of the impact of a fragment of comet Shoemaker-Levy 9, as seen from a volcanic caldera near the south pole of Jupiter's moon Io. Before the impact (top), the nighttime scene is dimly illuminated only by the sunlit crescent of the planet and the glow of an eruption in the caldera. As the comet fragment hits Jupiter (bottom), it creates a bright flash on the planet's dark side, which lights up Io's surface and also illuminates some of the dust trailing the comet. If we are lucky, during the impacts this July, Io will be illuminated brightly enough for us to see it from Earth.

Image: John Spencer, Lowell Observatory

from the atmospheric entry and the subsequent fireball reflected off the ring and satellites; ripples spreading out from the impact site; new clouds and new chemicals created by the impacts; and the brightening of the ring or the creation of a new ring.

The sharp pictures of the Hubble Space Telescope will give us our best chance to observe the formation of new clouds, and the *Galileo* spacecraft, with its unique viewpoint, may measure some of the impact flashes directly. It's unlikely that amateur astronomers with small telescopes will see anything, but it's certainly worth a look.

If we see any of these phenomena, we will learn a lot about how impacts into atmospheres occur, what the interior of Jupiter is like and how Jupiter's magnetosphere works. But precisely because we have so much to learn, we cannot tell beforehand if any of these various effects will be big enough to see. We will go to our telescopes knowing that perhaps we will see nothing but a faint string of cometary fragments disappearing into the glare of Jupiter, never to emerge again on the other side. But perhaps we will see astonishing things that no one has ever seen before.

John R. Spencer is an astronomer at Lowell Observatory in Flagstaff, Arizona. He will be traveling to the Cerro Tololo Observatory in Chile for his own observations of the comet impact.

The Comet Is Coming: *The Planetary Society Revs Up for* Jupiter Watch

by Charlene M. Anderson

Looking through its repaired optics, the Hubble Space Telescope was able to see the fragments of comet Shoemaker-Levy 9 more clearly than before. In this image, astronomers discovered that the pieces of the comet seem to have broken into even more pieces since they observed it last summer. Some of the pieces (bottom right) are straying from the main strand of the "string of pearls."
Image: H.A. Weaver and T.E. Smith, Space Telescope Science Institute, NASA

Comet Shoemaker-Levy 9 is now slowly accelerating toward Jupiter, moving toward its final rendezvous. As the pieces of the fragmented comet collide with the planet over a six-day period in July, The Planetary Society will be intensifying its Jupiter Watch program, orchestrating events around the world to share the excitement of this once-in-a-thousand-lifetimes astronomical event with as many people as possible. Here's a guide to what's in store during the impact period (July 16 to 22) and in the weeks leading up to it.

Capital Events

Washington, DC, will be the site of several special Society events during the period of impact. On the evening of July 21, we'll be throwing a Jupiter Watch party at the United States Naval Observatory. Party-goers will tour the observatory's facilities, hear talks by experts and take turns viewing Jupiter through a telescope, weather permitting. For more information on this event, contact Susan Lendroth at Society headquarters.

On July 22, Society President Carl Sagan, along with the comet's discoverers, Eugene and Carolyn Shoemaker and David Levy, will deliver lectures, sponsored by the Society, at the Stouffer Mayflower Hotel. Levy and the Shoemakers will talk about discovering the comet in March 1993, and, by this time, they should have the latest information on how the comet impacts have affected Jupiter. For tickets to this event, contact Carlos Populus at Society headquarters.

Somewhat serendipitously, the largest chunk of Shoemaker-Levy 9 should hit Jupiter on July 20—the 25th anniversary of the *Apollo 11* landing on the Moon. We'll take advantage of this coincidence by holding a gala dinner that week to celebrate the *Apollo* achievement and to present the Society's first annual Thomas O. Paine Award for the Advancement of Human Exploration of Mars. Tom Paine was the administrator of NASA at the time of the *Apollo 11* landing, and he was a Director of The Planetary Society. (See the September/October 1992 issue of *The Planetary Report.*) Society President Carl Sagan and other leaders of space exploration will be at the dinner to celebrate with our members.

This dinner is being cosponsored by the National Space Society and is being held in cooperation with the Spaceweek organization's events in Washington, DC. For tickets, contact Cindy Jalife, Jupiter Watch coordinator, at Society headquarters.

Keeping Informed Electronically

The Planetary Society is now on the Internet through the Diaspar Virtual Reality Network, operated by Digital Expeditions. Our "Planetary Society Online" service will carry a special Jupiter Watch section that will be updated weekly or as quickly as events demand. Information on other Planetary Society activities and services will also be provided.

Planetary Society Online is virtual network number 3 on Diaspar. You can access it at (714) 376-1234 or via Internet at telnet diaspar.com. As a one-time offer, your first five hours of access are free; after that, the cost is $1.00 per hour, paid in advance.

The Society will maintain a toll-free telephone hot line, 1-800-9-WORLDS, for information on the impact and our activities. More detailed updates on the comet's progress will be regularly posted on 1-900-88-IMPACT; this service costs $3.00 per call for a two-minute message.

Read All About It

The Society has produced a 16-page booklet on the coming collision. You'll be able to read the discoverers' own story of finding the comet, short articles on the nature of comets and Jupiter, instructions for viewing the collisions and an essay on the significance of the event. The booklet is available for $5.00. Ask for the *Jupiter Watch Guide* when you contact our headquarters.

We have also produced educational materials to help teachers excite students about the coming comet collision: Comet codiscoverer David Levy has written a short guide, complete with activities for children. To get copies of this guide, write to our headquarters and ask for *Comets, Crashes and Collisions*. Please enclose a check for $3.00 for each copy.

Watching With the Experts

The Society is working with planetariums and observatories around the world to involve as many people as possible in this exciting happening. If we are cosponsoring events in your area, you will receive a special notification from us. However, we can't reach every astronomical facility, so if there is one in your area, call it to see if anything is planned. You may want to contact Carlos Populus for a calendar of regional events, which lists many of the special lectures and programs that astronomical facilities will be putting on in the weeks before the collision.

We are investigating the possibility of having live video feeds from telescopes so that local cable television companies and facilities with satellite dishes can provide their audiences with front-row seats. If you can help, please contact Society Executive Director Louis Friedman.

Watching on Your Own

Our *Jupiter Watch Guide* (described above) does contain instructions for watching the collision, including what equipment is helpful. This guide contains all the information most people will need to get the most out of the experience.

For advanced amateur observers, the Association of Lunar and Planetary Observers (ALPO) has produced an in-depth observer's guide. If you plan to devote a lot of time and energy to tracking the events, this is the guide for you. It can be obtained from the Society by asking for the ALPO guide and enclosing a check for $5.00.

Help Fill In the Gaps

The Society's staff is cooperating with amateur and professional astronomers to form an observers' network to provide continuous coverage of the comet impacts. We would like to hear from people who live in areas far from professional observatories. Our goal with this network is to ensure that at any time during the six days of collisions a telescope somewhere on Earth is pointed at Jupiter. Nearly every major telescope is booked for the event, but there are still gaps in coverage, especially in the Southern Hemisphere. If you can help, contact Phillip Budine of ALPO, RD 3, Box 145C, Walton, NY 13856.

Jupiter Watch is turning out to be one of the largest public information projects ever undertaken by The Planetary Society. We're going all out to make sure that this once-in-a-thousand-lifetimes event is not missed by anyone who wants to witness planetary history in the making.

Join us!

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

Jupiter Watch Lectures

Here are a few of the lectures sponsored or cosponsored by The Planetary Society. Check with your local planetariums and museums for additional events.

May 21	*David Levy* *McMath Planetarium, Cranbrook Institute of Science, Bloomfield Hills, Michigan*
May 23	*David Levy* *Hayden Planetarium, American Museum of Natural History, New York, New York*
June 14	*David Levy* *H.R. MacMillan Planetarium, Vancouver, British Columbia*
June 23	*David Levy* *Koch Science Center and Planetarium, Evansville Museum of Arts and Science, Evansville, Indiana*
June 24	*David Levy* *Cleveland Museum of Natural History, Cleveland, Ohio*
July 9	*David Morrison* *Mount Tamalpais State Park, San Francisco, California*

News and Reviews

by Clark R. Chapman

When I was young, I believed that impacts made the lunar craters I saw through my telescope. For my first summer job after high school, at Gerard Kuiper's fledgling Lunar Lab in Tucson, I measured and counted craters on lunar photos, including early *Ranger* pictures. Later, *Mariner* revealed craters on Mars. Then, as a graduate student, I got to know how common asteroids are. More than once, on a cold mountaintop, I found myself measuring spectra of the wrong asteroid because it happened to be near the coordinates of the one I wanted to measure.

So I was hardly surprised by the idea, published in 1980 by Luis and Walter Alvarez and their collaborators, that an impact had caused the Cretaceous–Tertiary (K/T) mass extinction that ended the Mesozoic era 65 million years ago. After all, Nobel laureate Harold Urey and others wrote of impact catastrophes long before the iridium layer was found near Gubbio, Italy.

Most paleontologists come from a very different background. They have spent careers studying fossils winnowed from the countless rock layers formed from sediments accumulated over millennia and aeons. To them the layers and gaps seem naturally explained by transgression and regression of seas, erosion by streams, and other familiar processes. Rare volcanic explosions can be invoked, if need be, to explain any sudden changes in the fossil record. Why invoke an exotic extraterrestrial impact "when we have so much evidence of other processes in our own backyard?"

That was a question asked by Gary Landis, of the United States Geological Survey, at the February 9–12 Snowbird 3 meeting of astronomers, geologists, biologists and physicists (the first two Snowbird meetings were held at the Utah ski resort in 1981 and 1988, but the latest was at the University of Houston). Landis' question seemed odd to many participants, since the choice of venue was partly motivated by Houston's proximity to some of the best outcrops of debris from the gigantic (180–300 kilometers in diameter) 65-million-year-old crater, Chicxulub. Some sedimentologists previously not involved in the impact controversy went on field trips to see with their own eyes the giant tsunami (tidal wave) deposits along the Brazos River near Houston and in northeastern Mexico—and they agreed that the deposits were exceptional.

Chicxulub Crater

There is no denying it: There was a huge impact in Texas' "backyard." Moreover, asteroids and comets are in Earth's interplanetary backyard. Gene Shoemaker, of Lowell Observatory in Arizona, proposed that most large impacts on the Moon and Earth have been made by fragments of comets—just like comet Shoemaker-Levy 9—ripped apart during close passes by Jupiter. Other talks at Snowbird 3 reaffirmed that Chicxulub happened exactly at the K/T boundary. That marks significant progress since Snowbird 2, when Alan Hildebrand (of the Geological Survey of Canada) was just beginning to search the Caribbean region for the relict K/T boundary crater. Actually Chicxulub was first recognized in the 1950s and in 1981 was suggested to be the crater left by the dinosaur-killing impactor (see *Sky & Telescope*, March 1982, page 249), but it was then forgotten for nearly a decade. Now even die-hard paleontologists acknowledge the reality of Chicxulub. But many stubbornly refuse to credit it with killing off their favorite dinosaurs, or even their favorite plankton.

During Snowbird 2, blind tests were proposed to settle arguments about the suddenness of the great killing. Was the seminal iridium layer at Gubbio laid down all at once, or was it spread out over time? Did plankton species die out instantly, or did they decline over thousands or millions of years? Samples were collected, secretly coded and distributed (along with placebos and zingers) to different laboratories; antagonists and independent researchers both participated. The results, announced in Houston, were unambiguous: The iridium was deposited in an instant, and the Cretaceous fossils disappeared suddenly.

The impact theory continued its winning streak at Snowbird 3. But legitimate controversies remain. Dinosaur experts no longer say that the giant beasts lived into Tertiary times. But even the huge bone-counting projects done since 1988 cannot prove whether dinosaurs (as distinct from plankton) died out instantly or gradually. Maybe we will never know, although hope was held out by C. Pillmore of the US Geological Survey that we may yet find iridium-rich impact fallout filling a fossilized dinosaur footprint.

It remains elusive whether impacts caused the other mass extinctions in the geological record. Iridium has been searched for and not found. But neither is it found in tektites (the glassy, meteorite-like pellets ejected from terrestrial craters) or at the stratigraphic horizons of other large impact craters. More work than the partial efforts reported at Snowbird 3 will be required to find—or rule out—the presence of diagnostic impact-shocked quartz and glassy microtektites at times of other great evolutionary revolutions in the fossil record. Perhaps by Snowbird 4, in the year 2000, we will finally learn whether the K/T killings were the exception or the rule for the environmental challenges to species survival that have driven the evolution of life on our planet.

Clark R. Chapman is concluding his term as editor of Journal of Geophysical Research—Planets *this year.*

World Watch

by Louis D. Friedman

Washington, DC—In the new spirit of "smaller, cheaper, faster," NASA has proposed in the fiscal 1995 budget an exploration program—Mars Surveyor—that would send a series of spacecraft to the Red Planet. Beginning in 1996, both an orbiter and a lander would be launched at every two-year launch opportunity.

The missions of the first two new orbiters, to be launched in 1996 and 1998, would be to recover the science lost with the *Mars Observer* spacecraft.

The new spacecraft are to be small, with a maximum mass at launch of under 500 kilograms (1,100 pounds). For comparison, *Mariner 9* weighed 975 kilograms (2,145 pounds) at launch; the *Viking* orbiter, 2,324 kilograms (5,113 pounds); and *Mars Observer*, 2,565 kilograms (5,643 pounds).

The funding for the program is estimated to be $100 million–$130 million per year, including launch and mission operations.

For the 1996 launch, the lander will be the already approved *Pathfinder*, carrying the microrover being built by the Jet Propulsion Laboratory.

Pathfinder was to have been a technology demonstration for the Mars Environmental Survey (MESUR) network of landed stations. MESUR was large and complex, and the concept never really got off the ground. Now *Pathfinder*, with a launch weight of 700 kilograms (1,540 pounds), will be a precursor of even smaller concepts.

As for the 1996 and 1998 Surveyor orbiters, each will carry duplicates of some of the instruments from the lost *Mars Observer*. Between them, the two smaller orbiters should be able to accommodate most of the instruments.

Each orbiter will carry a communications relay to aid the transmission of data from the small scientific stations, penetrators, balloon and rover that the Russians are planning to launch to Mars this century. The relays will serve as a replacement for the Mars Balloon Relay, which was lost with *Mars Observer*.

The Planetary Society has long advocated an evolutionary Mars program leading to sample return and surface exploration with robots and humans. The proposed Surveyor program could be the beginning of that evolution. But NASA must overcome severe financial and technical challenges if the program is to succeed in an era of tightly constrained federal budgets.

Congress is now considering this new program. The Society will be a voice of advocacy as the Mars Surveyor makes its way through the budget process.

Moscow—The bad news has been officially given: *Mars '96* has been delayed to 1998. Now called the Orbiter, Rover, Balloon (ORB) mission, its launch has been postponed because all available money from the Russian Space Agency has been directed to the *Mars '94* mission.

Mars '94 is now in the final stages of testing and assembly, but if those processes don't go perfectly the mission may have to slip to 1996. As I write this, the mission is still officially on schedule, but the schedule is incredibly tight and the resilience to problems is very low.

Ironically, the slip of *Mars '96* to 1998 may actually help Russia's international partners. The French suffered some setbacks in their tests of the Mars Balloon, and the financial demands for all the European participants in the *Mars '94/'96* missions were becoming extreme. NASA is just beginning to consider participating in the Russian Mars Rover program, and the extra two years afforded by the 1998 launch date could make it easier and more affordable for NASA to get involved.

Laurel, Maryland—The Near-Earth Asteroid Rendezvous (NEAR) is now scheduled for launch in February 1996. Along with *Pathfinder*, this mission will kick off NASA's Discovery program of low-cost planetary missions.

The mission plan calls for a rendezvous with the asteroid Eros in February 1999. During the rendezvous, the spacecraft will fly alongside the asteroid, training five instruments on its target.

NEAR is managed by Johns Hopkins University's Applied Physics Laboratory in Laurel, Maryland.

Pasadena—*Magellan* has received additional funding of $1.7 million in the current fiscal year to finish its gravity-mapping mission at Venus. (See the March/April 1994 *Planetary Report*.)

Magellan had been scheduled to be shut down in April, but it can now keep operating until October. By then, the spacecraft should have obtained gravity data for over 97 percent of the planet.

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

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Stardust to Planets: A Geological Tour of the Solar System

By Harry Y. McSween, Jr.;
St. Martin's Press, New York, 1994,
241 pages.
Retail price: $22.95
Member price: $20.00

Not so long ago, astronomers who ruled solar system science classified the heavenly bodies according to how and what they orbited. But in the wake of space exploration, much of the scientific stewardship of the planets passed to geologists. Now Harry McSween, who heads geological sciences at the University of Tennessee, suggests organizing the planets, moons, comets and asteroids in different ways: by their composition, density, shape—attributes that may help explain their evolution.

In *Stardust to Planets,* McSween introduces historical heroes, such as Nicolaus Steno, who as geologists may be new to readers of *The Planetary Report.* Steno was the 17th-century Dane who came up with some of the key principles of stratigraphy while working as court physician to the Duke of Tuscany. Roaming the Italian hills, Steno formulated the *principle of superposition*—that the oldest layers of rock lie at the bottom of the pile if nothing disturbs them—and the *principle of original lateral continuity*—that horizontal strata spread like pancake batter equally in all directions unless something stops them.

These simple concepts enabled geologists to trace a stratigraphic history of Earth. That these principles apply as well to extraterrestrial bodies was argued convincingly by geologists Eugene Shoemaker and Robert Hackman in 1962, when they proposed that "the geologic history of a portion of the Moon was decipherable using stratigraphic principles."

Proud of his calling, McSween reveals trade "secrets." One is the careful use of photographs, especially the crucial role of shadows in creating the impression of the third dimension. Another is the development of a seismic scan, analogous to the CAT scan used in medical imaging, to get 3-D slices of the interior of Earth. A third is the belief that, with patience, geologists who seek them will find extraterrestrial visitors in the form of isotopes embedded in meteorites.

McSween follows quirky questions (Could you eat a comet? Is it like a snowcone?) with clear, geologically sound explanations. *Stardust* includes memorable descriptions of Mars and the moons of Jupiter and Neptune. Each body has a special story to tell, but probably none that has so engaged our collective curiosity as much as the nature of our mysterious, shrouded neighbor, Venus.

"Planets, like babies, are born with unwrinkled skin and become gnarled with age," McSween tells us. Continuing the simile, he describes Venus as "pockmarked" by external forces, and adds that perhaps she once opted for a "face-lift" in the form of volcanic explosions that smoothed her surface, at least temporarily.

Then, conjuring up the image revealed by *Magellan,* he concludes that Venus is over the hill. "Her face is dirty, stained by long streaks of windborne dust. She runs a constant fever and has no water to slake her thirst or soften her rough edges. It is no wonder that she hides herself behind a veil of clouds."

In 15 essays peppered with personal anecdotes, McSween presents portraits of selected planetary bodies. The glimpses of the human side of the geologist—an air force pilot, McSween grew up in South Carolina where he developed a passion for homegrown tomatoes—help explain how an extrovert like the author came to devote his career to investigating what are for the most part uninhabitable, user-unfriendly worlds.

—Reviewed by Bettyann Kevles

Still Available: Newton's Clock: Chaos in the Solar System

By Ivars Peterson.This 2,000-year sweep of humanity's efforts to predict celestial movements gives us a look at chaos theory as applied to astronomy and raises the disquieting question of how stable the solar system really is.
(Reviewed January/February 1994.)
Retail price: $22.95
Member price: $20.00

Universe Down to Earth

By Neil de Grasse Tyson. Treasures abound in this entertaining and useful collection of essays exploring ideas of science rarely satisfactorily examined in the popular literature.
(Reviewed March/April 1994.)
Retail price: $29.95
Member price: $25.00

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Society News

Solve the Mystery of Dinosaur Extinction

The Planetary Society is working to help find out what killed the dinosaurs. From January 3 to 12, 1995, scientists Adriana Ocampo and Kevin Pope will be leading a geologic expedition to northern Belize to search for evidence supporting the theory that a massive meteorite impact ended the age of dinosaurs. Society members can join the expedition and help discover deposits that this cataclysmic impact may have left behind.

Ocampo and Pope will meet Society members in Belize City. The expedition team will stay in comfortable hotels on the coast of Belize and in the Rio Bravo rain forest reserve. Although the expedition will not be strenuous, participants must be in good health and should be prepared for work in a tropical environment. They will be assisting scientists in field mapping and collecting and recording samples.

Accommodations, meals, travel within Belize and field equipment will be provided, but participants will be responsible for travel to Belize City. No children will be included. However, accompanied students over 16 are encouraged to join.

The expedition team is limited to 10, and the deadline for applications is July 30, 1994. For more information, contact Planetary Society headquarters.— *CJS*

Attention, Students: Name the Mars Microrover for NASA's *Pathfinder* Mission

The Planetary Society is asking students to suggest names for the Mars microrover, the robotic vehicle that is scheduled to explore the surface of Mars in 1997 as part of NASA's *Pathfinder* mission.

To enter the contest, choose a heroine from mythology, fiction or history (not living), and tell, in 300 words or less, how she would explore Mars. You might consider these questions:

- What would the heroine you have chosen use for transportation?
- How would she compensate for Mars' thin air, which lacks enough oxygen to support human life?
- Why should the *Pathfinder* microrover carry her name?

The first-prize winner will receive a trip to the *Pathfinder* launch. The top 10 entries will be given to NASA for consideration, and the students who submit them will receive a $100 gift certificate for Planetary Society merchandise, an "Explorer's Guide to Mars" poster and a *Pathfinder* microrover T-shirt. Everyone who enters will get pictures of the *Pathfinder* microrover and Mars' surface.

Your essay should be in English, and your entry must include your name, address, phone number and proof of age (you must have been born on or after January 1, 1976). All entries must be received by March 1, 1995, at The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106, and become the property of the Society. For more information, contact Society headquarters.

—Carol J. Stadum, Manager of Education

Are We Ready for Interstellar Flight?

The Planetary Society and the British Interplanetary Society are sponsoring a conference called "Practical Interstellar Robotic Flight: Are We Ready?" The conference is scheduled for August 29 through September 1, 1994, and will take place at New York University in New York City. For more information, contact me at Society headquarters.

—Susan Lendroth, Manager of Events and Communications

Society Flies to Egypt to Promote Space Science

The Society is one of the cosponsors of the United Nations' and European Space Agency's Fourth Space Science Workshop on Basic Space Science for Developing Countries.

From June 27 through July 1, 1994, at the University of Cairo in Egypt, the workshop will cover topics such as solar system science, space astronomy, astrophysics and the search for life beyond Earth.

For members who wish to attend, the Society makes available some travel arrangements. Interested members can travel from Los Angeles to Cairo and stay in one of the city's three-star hotels. Travelers can also choose to go on a five-day cruise up the Nile. The number of participants will be limited. For more information, contact me at Society headquarters.—*SL*

A Visa for Space Travel

We would like to give a special thanks to US Planetary Society members who help support the Society by using a Planetary Society Visa card. Through this program, Society members have contributed more than $30,000 to planetary research simply by making purchases with the card. We have allocated these funds to seeding new missions in planetary exploration.

US members can apply for this special Visa card by calling 1-800-847-7378. We hope to make this same opportunity available to our non-US members in the future.

—Louis Friedman, Executive Director

Keep in Touch

Our mailing address:
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Pasadena, CA 91106

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Questions and Answers

Would it be possible to use some sort of slingshot to achieve escape velocity from a planetary surface, lessening the need for propellant on the spacecraft?
—Beth Rackley, Poquoson, Virginia

Surface-based slings and orbiting tether facilities may be useful in achieving this goal. The principal limitation in launching a system that incorporates a tether from Earth's surface is that the mass of the tether and the associated dynamical control grow exponentially with the square of the required velocity change. Thus, a tether system usable for interplanetary propulsion would have to be very massive, with strength requirements in excess of those currently available.

Nonetheless, it is theoretically possible that tethers used as orbital slingshots could reduce rocket propellant requirements and be practical in the future. The orbital slingshot concept, which was pioneered by Italian celestial mechanician Giuseppe Colombo, uses a tether to deploy a payload already in orbit into a higher orbit (e.g., outward from the shuttle away from Earth). The payload is then sitting in the higher orbit, but with the velocity associated with the lower orbit—that is, with an excess velocity.

Kepler's law gives a different energy for each orbit—and using the tether changes the orbit. Once the payload is released from the tether, that excess velocity puts it into a higher orbit without the use of rocket propellant. Of course, power (hence energy) must be used to deploy the tether. Depending on the implementation of the tether power system, this might be a more efficient approach than ordinary propulsion. A surface-based sling on the Moon (or on any other body for that matter—although, say, on Earth the much larger gravitational mass and large air resistance make the idea impractical) could put a payload into a low orbit where it could be caught by a lunar orbiter. Such applications are clearly far in the future.

A tether concept was tested on a space shuttle flight in early August, 1992. The deployment had only gotten started when a snag developed in the process. The experiment was still encouraging to tether advocates, and they are proceeding with development and further experiments.

—JOE CARROLL, *Tether Applications*

Clementine Spacecraft Lunar Images

The tiny spacecraft Clementine *(see the September/October 1993 issue of* The Planetary Report*) is now orbiting the Moon. The spacecraft captured these images of the Moon on February 19, 1994, with its ultraviolet (UV)/visible and high-resolution cameras.*

The large crater at the lower left of the UV/visible frame is Nansen, which is 105 kilometers (65 miles) in diameter. Nansen's central peak shows up well in this image. In the high-resolution image, small craters down to about 100 meters (109 yards) in diameter are visible peppering Nansen's rim. This heavily cratered surface is fairly typical of the lunar highlands. The arrow in the UV/visible image points to the rim of a small double crater on Nansen's edge. This is the same area pointed to in the high-resolution image.

These images were taken very early in the lunar phase of the Clementine *mission from an altitude of 1,572 kilometers (about 975 miles).* Images: Naval Research Laboratory


UV/Visible Image


High-Resolution Image

Mars has an axial tilt very similar to Earth's. But if the Moon acts as a gravitational gyroscope for Earth, as a "Factino" in the May/June 1993 issue of* The Planetary Report *states, then how is it that Mars stays almost upright (comparatively speaking) when it only has two tiny moons? The small bodies surely would have a negligible gyroscopic effect on the planet. Why hasn't Mars fallen on its side?
—P.J. Spencer,
Whangarei, New Zealand

The use of the phrase "gravitational gyroscope" in the original article was unfortunate. It did not give the real reason that the Moon stabilizes Earth's axial tilt. You had every reason to be left with questions. The explanation is complex, since it depends on the interaction between a planet's orbit and its spin.

A spinning planet itself acts like a gyroscope in that its spin axis will remain pointed in the same direction unless forces are applied. The spin axes of both Earth and Mars are influenced by the gravitational attraction of the Sun. Mars' spin axis direction moves over a broad range, while the additional gravitational force from the Moon keeps the motion of Earth's axis more restrained.

A spinning planet will have an equatorial bulge and its smaller polar dimension will be aligned with the spin axis. Centrifugal forces distort an otherwise spherical planet and the faster-spinning planets are distorted more. Without forces from outside the planet, there would be no change in the direction in space of its axis of rotation.

The forces of the Sun and any satellites on the planet's equatorial bulge cause the direction of the spin axis in space to slowly precess, like the precession (wobble) of the axis of a spinning top. For Earth this precession takes 26,000 years. If the planetary orbits didn't change, the precession would have a uniform rate, and the tilt between the planet's equator and its orbit plane (this angle is called the obliquity) would be constant. Every 26,000 years the spin axis would trace out a cone.

The gravitational forces between the planets are small, but they cause slow variations in the planets' orbits about the Sun. The orbit planes change orientation and the elliptical orbits change elongation. These orbit "perturbations" are limited in size, but they influence each planet's precession rate and obliquity, causing them to vary about some mean value. Earth's obliquity stays within 1.3 degrees of its mean value of 23.3 degrees. If the precession period is near a period of the orbit perturbations, there can be a resonance between the orientation of the planet's equator (precession and obliquity) and the orbit variations.

A child's swing provides a familiar example of resonance. Pushing on the swing with the rhythm of its natural period causes increasingly larger motion. Similarly, if the period of an orbit perturbation is near the natural precession period, then the obliquity can change by large amounts in a few million years.

For Earth, the forces from the Sun are responsible for about one third of the precession rate and the forces from the Moon for the other two thirds. If the Moon were to suddenly disappear, the existing 26,000-year precession period would be tripled. In an article in the February 18, 1993, issue of *Nature*, J. Laskar, F. Joutel and P. Robutel state that this longer precession period would be in the range (roughly 40,000 to 300,000 years) where large changes in the obliquity would occur. Without a large satellite, and farther from the Sun than Earth, Mars has a longer precession period (170,000 years) than our planet. Laskar and Robutel report in the same issue of *Nature* that Mars has its precession rate in the range where large, chaotic obliquity changes can occur. Mars' obliquity varies from 0 to 60 degrees in a few million years.

On Earth, the obliquity gives rise to the seasons. Large changes in the obliquity would subject surface locations to large changes in sunlight, profoundly influencing climate. We can be thankful that our own Moon has restricted Earth's obliquity to small changes rather than subjecting our planet to large climate variations.

—JAMES G. WILLIAMS,
Jet Propulsion Laboratory

Factinos

Military spacecraft in orbit thousands of miles above Earth have collected data showing that our planet is being constantly bombarded by large meteoroids that explode like atomic bombs. The formerly secret data, from satellites meant to detect rocket firings and nuclear explosions, were declassified recently by the Defense Department.

From 1975 to 1992, the satellites spotted 136 explosions, about eight a year, high in the atmosphere. The blasts appear to have intensities roughly equal to 500 to 15,000 tons of high explosive or the power of small atomic bombs. Experts who have analyzed the data are publishing it in a book, *Hazards Due to Comets and Asteroids*, due out later this year. They say that the detection rate is probably low and that the actual bombardment rate might be 10 times higher, with about 80 blasts happening every year.

—from William J. Broad
in *The New York Times*

❖

This summer's collision between comet Shoemaker-Levy 9 (SL9) and Jupiter will likely result in a new ring around the planet within about 10 years, says Mihaly Horanyi of the University of Colorado in Boulder. He reports that dust from the breakup of SL9 near Jupiter last July, combined with dust now being produced along the comet's trajectory, will probably form a new ring that could be as bright or brighter than the current ring.

According to his calculations, the new ring will form in a region far outside Jupiter's existing ring. Pieces of SL9's original nucleus are expected to deliver large amounts of dust to the magnetosphere—the region around Jupiter permeated by the planet's magnetic field—during the comet's final approach to the planet. Some of the dust grains, those about 2 microns in diameter, will probably be captured by the magnetosphere to form the new ring.

—from the University of Colorado

Celebrations and Collisions!

One small step for a man . . . one giant crash for a comet.

Jupiter Watch!

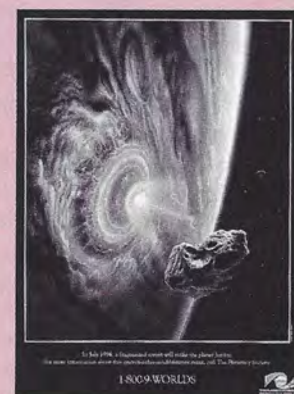
The Sky Is Falling

Comet Shoemaker-Levy 9 will plummet into the atmosphere of Jupiter and hit the planet with a force the equivalent of perhaps 100 million megatons of TNT—an amazing astronomical event the likes of which have never before been observed by humankind. Our special Jupiter Watch items make it easy for you to share the excitement of this momentous crash.

Jupiter Watch Guide NEW
This 16-page guide gives you definitive information about comet Shoemaker-Levy 9 and its upcoming collision with Jupiter. The guide includes instructions on how to observe this once-in-a-thousand-lifetimes event (soft cover). *(Not shown.)* 1 lb.
#680 $5.00

Jupiter Watch T-Shirt NEW
The colorful symbol of the collision is emblazoned across this comfortable 50/50 cotton/poly shirt, worn here by Cindy Jalife, the Society's Jupiter Watch coordinator. L, XL. 1 lb.
#681 $9.00

Jupiter Watch Button NEW
Same logo as T-shirt. *(Not shown.)* 1 lb.
#683 $1.00



Jupiter Watch Poster NEW
This striking reproduction of a painting by space artist Don Dixon depicts the comet plunging into Jupiter's atmosphere. 18" x 24". 1 lb.
#682 $5.00

Color Reproductions

Portrait of the Milky Way
40" x 27" poster. 2 lb. **#330 $15.00**

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Nine 8" x 10" mini-posters. 1 lb.
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16" x 20". 2 lb. **$8.00 each**
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#345 Night Launch
#348 Launch Pad

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The Starflight Handbook: A Pioneer's Guide to Interstellar Travel
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#538 *Magellan*
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#524 *Galileo*

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Set of 16 cards (envelopes included). 1 lb.
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Over a span of six days, from July 16 to 22, the largest planetary impact ever witnessed by humanity will occur. During this same period, on July 20, The Planetary Society and the rest of the world will celebrate the 25th anniversary of the Apollo 11 Moon landing. Whether you want to relive the excitement of Apollo or speculate about the comet–planet collision, we offer a singular selection of items to help you be a part of these historic events.

Remember Apollo!

25th Anniversary

Images taken by *Apollo* astronauts help us relive the exciting moments 25 years ago that changed forever our perspective on both the Moon and Earth.

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To walk where no one has walked before. Humanity's curiosity and thirst for new discoveries are momentarily satisfied by the adventures of the *Apollo* astronauts. 20" x 16". 1 lb.
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Earth

Home. A small, bluish planet floating in space. There's no place like it in our solar system. 20" x 16". 1 lb.
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$22.00

Atlas of the Moon

By Antonin Rukl; edited by T.W. Rackham. This book is a great source of information on the Moon, its surface, its origin and evolution and the humans and robots that have explored it. 224 pages (hard cover). 2 lb.
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By Don E. Wilhelms. An excellent history of lunar theory in the 20th century. 477 pages (hard cover). 2 lb. **#006 $24.00**

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VHS (US) #404 PAL (VHS-Europe) #405
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Planetary Society Sweatshirt
S, M, L, XL. 2 lb. **#664 $21.00**

Solar System T-Shirt
Children's S, M, L. 1 lb.
#668 $11.00
Adults' S, M, L, XL. 1 lb.
#667 $14.00

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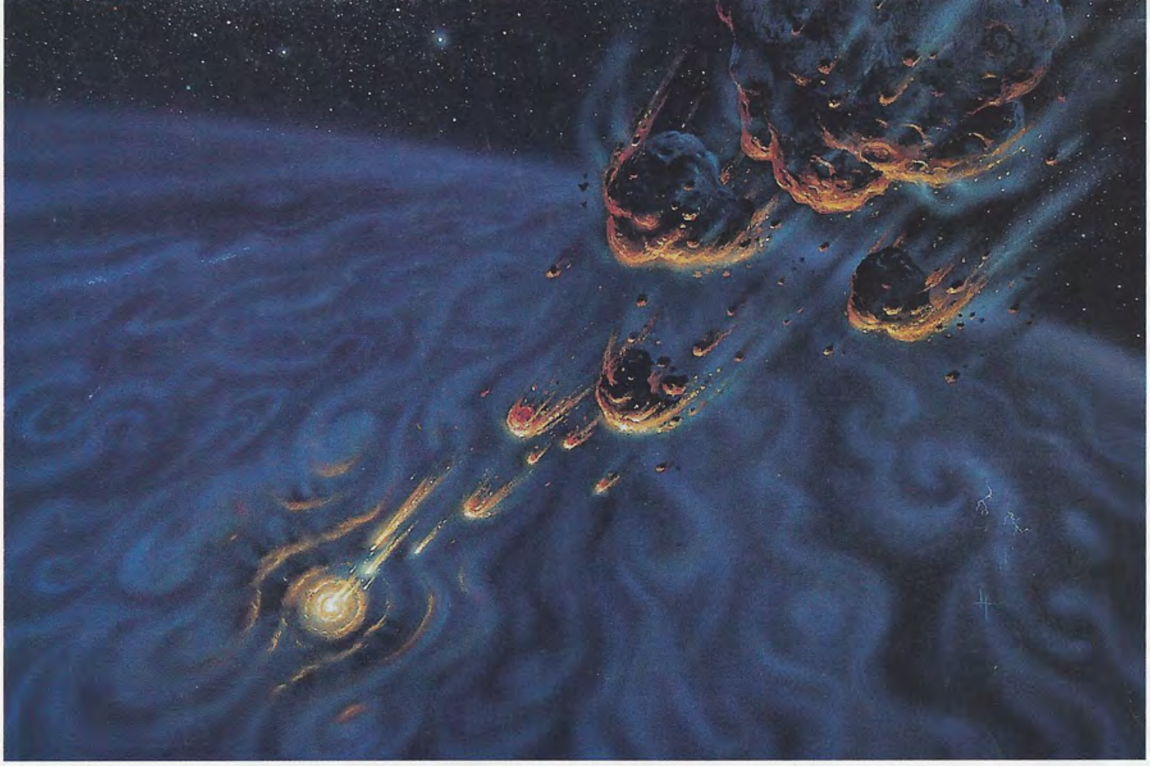

In "Comet Shoemaker-Levy 9 Impact," a stream of particles from the comet's nucleus (many of them too small to be seen from Earth) glow red, then white-hot as they enter Jupiter's atmosphere and plunge into the cloud layers. These impacts will create "ripples," which may become visible as the area rotates into view from Earth.

This year British space artist David A. Hardy will celebrate the 40th anniversary of his art first being published. His painting "Terraforming Mars" is included in the CD-ROM, produced by The Planetary Society, that will fly to Mars on the *Mars '94* probe. It also serves as the frontispiece for Arthur C. Clarke's new book, *The Snows of Olympus.*

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