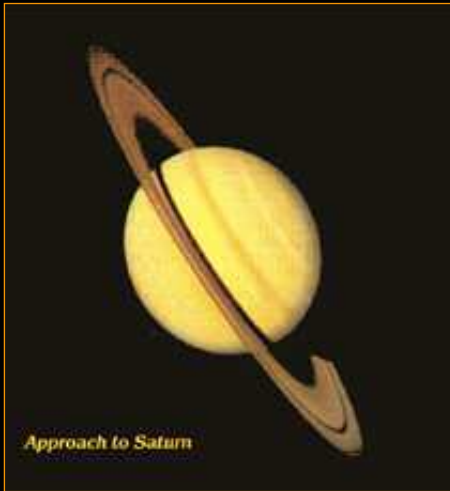


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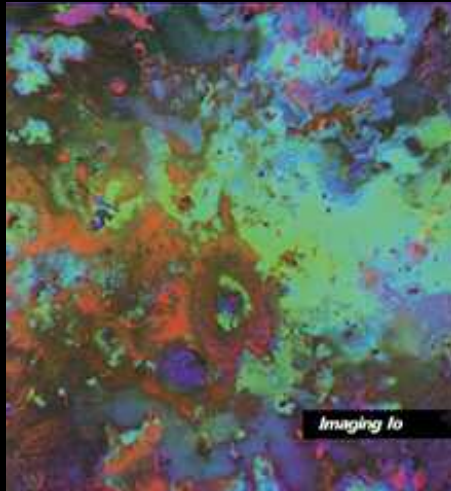
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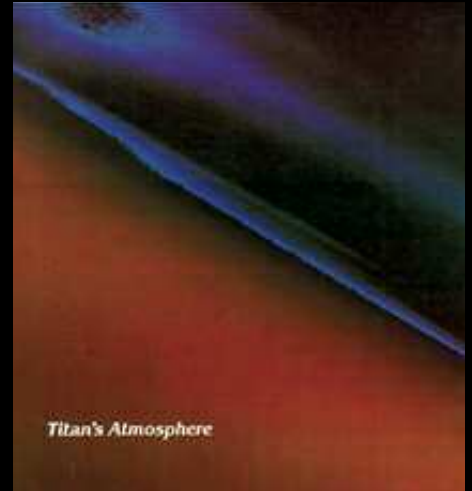
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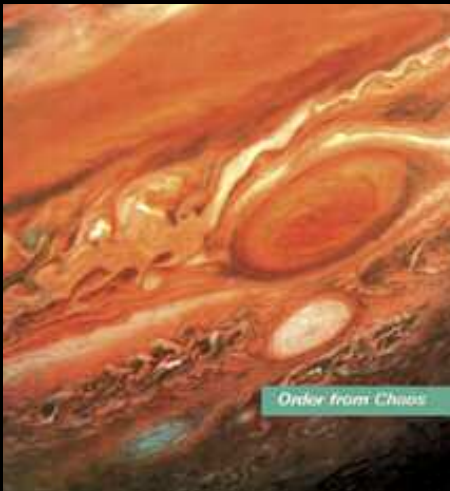
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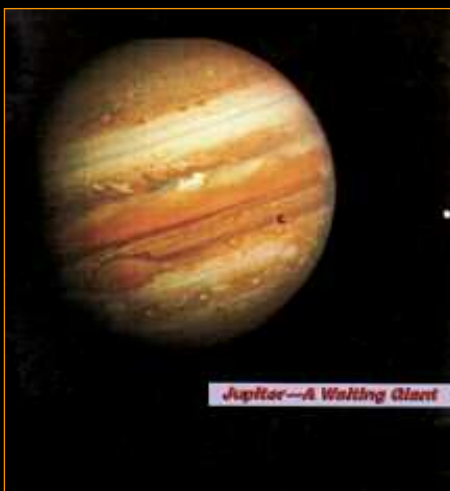


Voyager: To Neptune and Beyond



Voyager 2 at Neptune

Special Issue



Jupiter—A Waiting Giant



Voyager 2 at Uranus



Europa—Another Ocean?

**VOYAGER
SPECIAL ISSUE**



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From The Editor

Voyager is without doubt my favorite space mission. I know many others—writers, scientists, and engineers among them—who feel the same way. But I can't tell you for sure why these two spacecraft have inspired such deep affection.

The *Voyager* spacecraft don't look anything like the cute little robots for which humans usually develop affection. These hearty machines—all antennae, boxes, and booms—resemble nothing living. So, that's not the reason.

Nor was *Voyager* the first mission to reach the outer solar system; *Pioneers 10* and *11* blazed the trails to Jupiter and Saturn. *Voyager* was the first to reach Uranus and Neptune, but our unaccountable affection had already developed by then.

I have only one hypothesis about this affection phenomenon: *Voyager's* story fills our need for great sagas. *Voyager* gave us tales of cleverness, bravery, and perseverance that together formed a story of great adventure. Discovery after discovery astounded us, and we came to know the worlds of the outer solar system as distinct personalities, like characters in a saga.

Humans crave great sagas. We need to believe we can rise above the mundane and reach what once seemed unattainable. We want heroes like *Voyager*. And when we find them, we love them.

—Charlene M. Anderson

On the Cover:

The *Voyager* mission played a significant role in the founding of The Planetary Society. And, starting with our first issue 22 years ago, *Voyager's* images have graced many covers of *The Planetary Report*. Here are just a few of them.

Images: JPL/NASA. Painting (center): Paul Hudson

Features

4 *Voyager: An End and a New Beginning*

Bruce Murray has now retired to the relative peace of an emeritus professorship at the California Institute of Technology and the chairmanship of The Planetary Society's Board of Directors. However, during the first *Voyager* encounters with Jupiter and Saturn, he was not only directing the Jet Propulsion Laboratory but also working with Carl Sagan to create a truly public group dedicated to exploration: The Planetary Society. Here, he reflects on the golden days of exploration and discovery, explaining *Voyager's* significance today.

6 *Voyager: A Grand Mission*

Voyager's discoveries will stand as hallmarks of the great age of space exploration. At each new planet encounter, the spacecraft surprised us with unanticipated wonders: a ring around Jupiter, "spokes" in Saturn's rings, the baffling face of Miranda, nitrogen geysers on Triton. The daunting task of summarizing all that *Voyager* taught us is here undertaken by Ellis Miner, who served as deputy project scientist for *Voyager*.

14 *Voyager: A Message From Earth*

The two *Voyager* spacecraft carry a remarkable message to the future: a record containing the sounds and sights of our home planet. Renowned science writer Timothy Ferris, who was part of the team that developed the record, recalls the experience here. Among his fellow record producers were Planetary Society cofounder Carl Sagan, Board of Directors member Ann Druyan, and Advisory Council members Frank Drake and Jon Lomberg. Like nearly every story connected with *Voyager*, theirs is a tale of human achievement and faith in the future.

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Members' Dialogue

There's Still Time

I've been a member of The Planetary Society for a few years now, but the romance of planetary exploration captured my imagination many years before. I was introduced to the planets by my father, who installed a homemade telescope in our backyard and, more important, who helped bring to Earth the first close-up photos of Mars in 1965.

Perhaps it was my father's involvement in unmanned space exploration that has colored my views, but I feel strongly that the amount of money that's been dumped into manned space programs around the world has been a gigantic waste when compared to the paltry scientific insights gained. The unmanned probes have delivered much more information, have introduced us to a host of thrilling new worlds, and have given us a radically new view of our own planet—all at a fraction of the cost of the manned space missions.

Therefore, while I am shocked and saddened at the administration's axing of the Pluto, Kuiper belt, and Europa missions, I cannot bring myself to sign your petition because of the emphasis it places on manned space flight. I prefer to write my own e-mail to the powers that be.

Can you please tell me if there is still time to make a difference in this matter, or have the pertinent congressional votes already taken place?

Finally, let me thank you: first, for all your efforts in support of unmanned planetary exploration and, second, for the fine periodical you publish,

which I have enjoyed immensely over the years.

—ALAN LEIGHTON,
Bochum, Germany

There is still time for your voice to be heard. Meanwhile, we are doing well at winning back the Pluto mission. The issue will probably come to a full congressional vote in September. We will be sending our petition to Congress in late August, so if you want to write your congressional representatives, please do so as early in September as possible. For updates, continue to visit our website. And thank you very much for your kind remarks.

—Louis D. Friedman,
Executive Director

On "What to Tell Them?"

I would like to respond with the following statement to Charlene Anderson's invitation regarding James Walker's request (for 25 words or less to support space research) in the July/August 2002 issue of *The Planetary Report*:

It leads to understanding our place in the universe: revealing mysteries of our origin, the purpose of our being, and the promise of our destiny.

—RICHARD W. DAY,
Laguna Beach, California

It is inherent in humans that we know not only our past but also our future. Who knows? We may find God. We must explore.

—STEVE CHILDRESS,
Roswell, New Mexico

For freedom. For profit. For knowledge. For power. For safety. For our children. Just because.

Pick whichever reasons appeal to you. They're all true.

—ADRIAN TYMES,
Mountain View, California

To know that the universe exists in all its stupendous glory is to realize that one is intimately intertwined in the scheme of the cosmos.

—MIKE MARTINEZ
Lakeland, Minnesota

As flutterings of a butterfly's wings in India may affect rainfall in the Americas, so each exhalation of breath on Earth may affect the universe.

—RICHARD LAWRENCE
Corona, California

For conciseness, it's hard to beat Larry Niven's statement: "The dinosaurs became extinct because they didn't have a space program."

Any questions?
—ALLEN BROWN,
Corvallis, Oregon

The more we understand the universe, the closer we get to God.

—PHIL BRODSKY,
Methuen, Massachusetts

To know and to learn honors the eons it took to become conscious. To go through this evolution only to say "So what?" is ignorance.

—CHRIS ELDRIDGE,
Harrisburg, Pennsylvania

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VOYAGER: AN

BY BRUCE MURRAY



On August 20, 1977, Voyager 2—the first of two spacecraft comprising the Voyager mission—launched from NASA's Kennedy Space Center at Cape Canaveral, Florida. (Voyager 1 launched just 16 days later on September 5.) For 25 years, the two spacecraft have been on an extraordinary journey touring the outer planets, discovering dozens of moons, and now gliding toward the very edge of our solar system. Photo: JPL/NASA

We remember and pay tribute to *Voyager* for the same reason that more than two centuries later, we commemorate Captain James Cook's voyages to the South Seas, Antarctica, and Hawaii. Just as Cook transformed our geographic knowledge of Earth, *Voyager* revolutionized our geographic and geometric perceptions of our solar system.

Voyager also revolutionized our sense of what humans can accomplish. The *Voyager* team was an extra-

ordinarily gifted and talented one—otherwise this great mission of exploration would never have happened. There were times during the planning and execution of the mission when the team was forced to improvise. In many ways, it was superb judgments made on the spot by these men and women that got us to our goal. Like the success of all great exploratory missions, *Voyager's* was the result of excellent planning, quick thinking, and luck.

ARMCHAIR EXPLORERS

Given the state of communications in the 18th century, the public learned details of Cook's voyages well after the fact, not to mention secondhand. *Voyager*, however, brought distant planets and satellites directly into our living rooms—and quickly, too. *Voyager's* steady stream of images and other data, combined with the technological advances (and competitiveness) of media outlets, enabled the public to follow along with the mission in near real time. We—the scientists and engineers involved with the mission, as well as the general public—were in the envi-

able position of witnessing great moments of exploration as they happened and without leaving home.

Moreover, most of the people alive when *Voyager* launched were alive for the entire mission. *Voyager* sailed into space in 1977 and visited Jupiter in 1979, Saturn in 1980–81, Uranus in 1986, and Neptune in 1989. That's a remarkable adventure in a relatively short time.

VOYAGER AND THE PLANETARY SOCIETY

The extraordinary significance of *Voyager* (and *Viking*, which had landed on Mars just a few years earlier) resonated with Carl Sagan and me. We appreciated these missions of exploration and discovery while, at the same time, agonizing that NASA was moving away from such endeavors.

As *Voyager* was sending home spectacular images of the outer planets, NASA was bogged down in developing and selling the space shuttle. *Voyager* was, in many ways, the apex of the golden age of planetary exploration in the 20th century. Yet, by then, NASA was vigorously cutting back the means to advance such exploration because it conflicted with the agency's overriding commitment to the shuttle.

Carl and I both encountered NASA's conflict firsthand. We also knew of the public's enormous interest in the planets and the universe beyond. Carl and I felt we had to do something to keep that interest and enthusiasm alive. In late 1979, we decided to form The Planetary Society—a truly public group dedicated to planetary exploration and the search for extraterrestrial life, free of the then self-serving political agenda of NASA or any other government agency, or of associated aerospace companies. From the beginning, the Society was built as a public enterprise, supported largely by member donations and voluntary efforts. And we still continue with that mandate.

In many ways, *Voyager's* success and enormous po-

END AND A NEW BEGINNING

Nearly 12 million kilometers (7.5 million miles) from home, Voyager 1 looked back at its planet of origin and captured this image of a crescent-shaped Earth and Moon—the first image of its kind ever obtained by a spacecraft. The image was recorded on September 18, 1977, 13 days after the spacecraft launched. Voyager 1 was directly above Mount Everest (on the night side of the planet at 25 degrees north latitude) when the image was taken. The Moon, seen at the top, is beyond the Earth as viewed by Voyager. Image: JPL/NASA

tential parented The Planetary Society through Carl and me: Carl was just finishing the *Cosmos* television series and was serving as an investigator on the *Voyager* mission; I was the director of the Jet Propulsion Laboratory, with administrative responsibility over the entire endeavor. We were both deep into the enterprise of space, and The Planetary Society was born from our shared devotion to that enterprise.

Over the years, NASA wisely outgrew its failed objectives of the 1980s. Indeed, the NASA of today has assimilated many of the exploratory objectives first advocated by The Planetary Society. Yet, the Society's advocacy role remains clear—we must steadfastly urge the space agencies of the world to get out there and explore.

WHERE DO WE GO FROM HERE?

My personal reaction to *Voyager* may seem surprisingly downbeat considering how upbeat the times were. After all, we were shooting for Neptune, the very edge of our solar system. Yet, privately, I asked myself: where is *Voyager* leading us? Are we on our way to the stars? I gradually came to the somber conclusion that the stars are so distant that no one has even conceived of a feasible way to get there. The far reaches of our solar system, the outer limits of *Voyager*'s mission, dramatically emphasized for me the vast gulf between us and the stars.

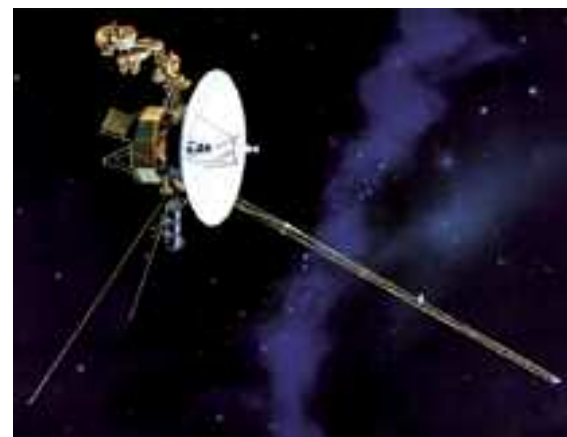
Furthermore, even with the most powerful telescopes, we're limited in how far we can see by what is known as the red shift. (The expansion of the universe means light appears to slow down—it gets redder and redder until you can't see any farther.) Ironically, at the grandest moments

of *Voyager*'s journey, I found myself feeling claustrophobic, trapped inside a soap bubble immersed within a giant red balloon—the soap bubble being the distance between the stars and the red balloon being the red shift. Having been in the midst of a period of such extraordinary outward expansion of human consciousness, I found it difficult to reconcile myself to the intrinsic physical limitations of our rather ordinary piece of the cosmos.

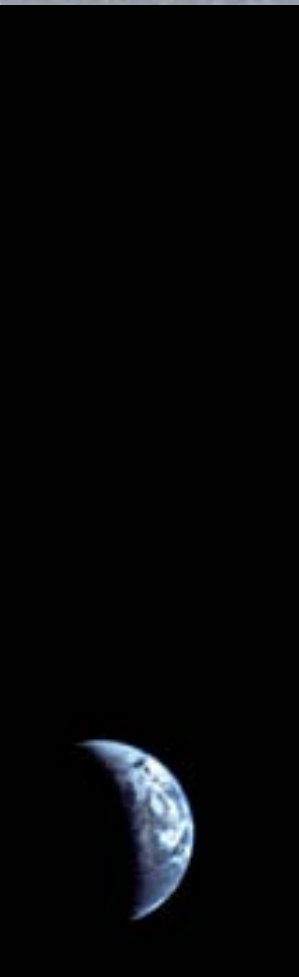
And nothing seems to have changed in the two and a half decades that separate us from those grand times. It still looks to me as difficult to venture much beyond our native solar system as it probably would have looked to Captain Cook to sail to the Moon—yet we did go to the Moon. It took two centuries from Cook's time for the first robots to reach the Moon, followed quickly by the first human to walk on the lunar surface. How long will it be until human creativity produces the breakthrough enabling interstellar flight?

With mind-numbing speed, we have reached a vast gulf, and we're probably going to be stuck at our end gazing across the expanse for a while, just as people once eager to go to the Moon were once stuck. But still, we know—looking back at *Voyager*—that amazing things can happen in a remarkably short time. That is *Voyager*'s message for our times.

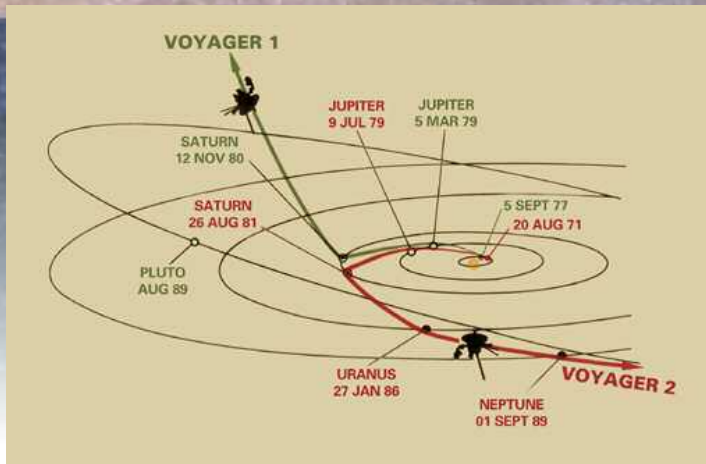
Bruce Murray is cofounder, and chairman of the Board of Directors, of The Planetary Society.



Today, more than 12 billion kilometers (7.5 billion miles) from Earth, Voyager's odyssey is far from over. The twin spacecraft continue to silently travel in space. We don't know exactly when the spacecraft will glide beyond the heliopause, crossing the boundary into interstellar space, but it could happen within the next 30 years. Then, they'll be off to the stars. Painting: JPL/NASA



VOYAGER:



Rarely do the planets line up in such a way that a single spacecraft could travel from Earth to Jupiter and then use Jupiter's gravity to move on to Saturn, Uranus, Neptune, and beyond—but Voyager 2 was able to do just that. Voyager 1 took a shorter tour, visiting just Jupiter and Saturn, but then it began its extended voyage to interstellar space.

Illustration and all images: JPL/NASA

August and September 2002 mark the 25th anniversary of the launches of *Voyagers 1* and 2. While that alone generates waves of nostalgia in the hearts of the author and a host of other veterans of the *Voyager* mission, there are far more important reasons for recounting the legacy of this remarkable pair of spacefaring robotic explorers. Consider the following:

- With *Voyager*, we accomplished something few had ever imagined possible: the exploration of the four largest planets in our solar system.
- For our generation, the *Voyager* mission data transformed Jupiter, Saturn, Uranus, and Neptune from astronomical oddities into familiar neighbors, each with its own distinct characteristics.
- *Voyager* discovered three of the eight known regular satellites (moons in near-equatorial, prograde, nearly circular orbits) of Jupiter, four of the eighteen known regular satellites of Saturn, ten of the fifteen known regular satellites of Uranus, and six of the eight known satellites of Neptune, as well as divulged the amazingly complex geologies of the satellites we already knew.
- *Voyager* found rings around Jupiter and revealed the startling complexity of Saturn's fabled rings. The ring systems of Uranus and Neptune are barely detectable from Earth, but *Voyager* revealed details that showed us the distinct characteristics possessed by each system.
- *Voyager* gave us our first detailed look at the magnetic fields and charged particle environments of the giant planets, following up on the first glimpses of Jupiter's by *Pioneers 10* and *11* in 1973 and 1974 and

of Saturn's by *Pioneer 11* in 1979.

- *Voyager* data forced us to revise our earlier, simpler notions of the processes that formed and altered the solar system, giving birth to the science of comparative planetology.
- *Voyagers 1* and 2 continue to operate, now at the greatest distances ever achieved by human-made objects, and may soon reach the outer limits of the Sun's magnetic influence, becoming the first spacecraft to enter the interstellar environment.

Let's examine each of these accomplishments in more detail, recognizing that there are many other kudos due this extraordinary mission. Space constraints do not permit us to recount the whole story of *Voyager* here. We can do little more than hit the high points of this mission, which changed how humankind views the solar system.

THE HUMAN ENDEAVOR

Only those most intimately involved with the *Voyager* mission are aware of the behind-the-scenes heroics of the *Voyager* staff at the Jet Propulsion Laboratory (JPL) and its team of enthusiastic scientists. While meeting the challenge of designing and preparing complex sequences to control the spacecraft, then receiving and decoding the returned data, these personnel were also faced with overcoming the hundreds of mechanical and electrical problems experienced by the two *Voyagers* between launch in 1977 and the conclusion of the Neptune encounter in 1989.

The spacecraft team, with help from others, devised reliable means of communicating with a tone-deaf backup radio receiver on *Voyager 2*—the primary receiver had failed shortly after launch. They also designed a method to combine *Voyager 2*'s data stream received by the Deep Space Network and other radio telescopes to amplify the weak signals from distant Uranus and Neptune. In addition, they diagnosed and effectively repaired the jammed scan platform motor on *Voyager 2*.

The navigation team threaded the needles through which the spacecraft had to fly in order to complete their designated missions on target and on time, even

A GRAND MISSION

BY ELLIS D. MINER

adjusting for last-minute knowledge of the target positions. They even launched an effective “anti-smear campaign” (a means of reducing the spacecraft rotation rate during data taking to eliminate image smear), thus enabling *Voyager 2*, with its mid-1960s technology, to return volumes of crisp images of objects as dark as coal illuminated by the equivalent of a first-quarter moon.

The science team then took these newly acquired data and explained their meaning and significance to an information-hungry world, usually within 24 hours of receiving them. Even more startling, most of those early interpretations of the data have withstood the test of time.

THE PLANETARY LEGACY

Before *Voyager*, no other mission had ever sent spacecraft to all the giant planets of the solar system—nor is there likely to be another such mission within any of our lifetimes. These four planets take between 12 and 165 years each to orbit the Sun, and their near alignment on one side of the solar system will not happen again soon.

Following this fortuitous trajectory, *Voyagers 1* and *2* were able to map the shapes, masses, gravity fields, rotation rates, wind patterns, compositions, and temperatures of each of the four giants. They found winds of up to 500 meters per second (1,100 miles per hour) in the clouds of Saturn and Neptune. (Earth’s winds rarely reach one-tenth that speed.) Additionally, they saw cloud-top superbolts of lightning in Jupiter’s atmosphere and “northern light” glows in the atmospheres of all four planets.



One of my favorite images came from *Voyager 1*'s approach to Jupiter in late February 1979, as we began to see our first detail on the inner Galilean satellites *Io* and *Europa*. These were not drab Moon-like objects but instead appeared as magnificent planetlike worlds, the detail from their surfaces blossoming with each picture as *Voyager* neared Jupiter. I became captivated and driven by the desire to see each and every image thereafter so that nothing would escape my eyes—and my imagination. There was a wonderful diversity among the dozens of worlds we saw on the 12-year voyage. It gives one the sense of how the great explorers felt as they made each new landfall.

—Charley Kohlhase, Mission Design Manager for *Voyagers 1* and *2*, Planetary Society Adviser

For Saturn and Jupiter, the relative fraction of helium was found to be less than that of the Sun; these two planets, within their interiors, are now believed to undergo gravitational separation of liquid helium from liquid hydrogen. (Because these giant planets were undoubtedly formed from the same disk of gases that formed the Sun itself, this finding may hold important clues about their origins and evolutions.) Jupiter and Saturn also have Earth-size molten rocky cores, whereas Uranus and Neptune may have little or no rocky materials within their cores.

All the giant planets except Uranus radiate back to space substantially more heat than they receive from the Sun; this excess heat is generated by processes in the interiors of these enormous planets. In addition, all have extremely hot upper-atmospheric temperatures



After more than 12 years in space that took her some 4.5 billion kilometers (2.8 billion miles) from Earth, Voyager 2 looked back at Neptune and Triton as she prepared to leave the solar system. During Voyager's odyssey, distant planets and their tiny moons were transformed into real worlds. Together, the two Voyagers wrote a unique page in human history. And it was a wild ride for us all.

—Brad Smith, Voyager Imaging Team Leader

(600 to 1000 kelvins), and all are circled by bands of electrons above their atmospheres that are similar in nature to Earth's Van Allen radiation belts.

THE SATELLITE DISCOVERIES

When *Voyagers 1* and *2* were launched, we knew of 13 moons around Jupiter; *Voyager* discovered Metis, Adrastea, and Thebe. Saturn had 10 known moons; Earth-based astronomers discovered Telesto, Calypso, and Helene between the *Voyager* launches and the Saturn encounters. *Voyager* discovered Pan, Atlas, Prometheus, and Pandora orbiting Saturn and revealed that a 1966 observation by R. Walker, once supposed to be Janus, was in fact a separate satellite, later named Epimetheus.

At Uranus, *Voyager* added Cordelia, Ophelia, Bianca, Cressida, Desdemona, Juliet, Portia, Rosalind, Belinda, and Puck to the five previously known satellites. Neptune's lone two satellites were augmented by Naiad, Thalassa, Despina, Galatea, Larissa, and Proteus.

Satellites we had once known only as points of light became distinct worlds to the keen eyes of *Voyager*. We discovered volcanic activity on Jupiter's Io. Europa was revealed to be an ice-covered world possibly harboring an ocean beneath the surface. Ganymede was

accorded the honor of being the solar system's largest satellite.

We learned that Saturn's Titan possesses a thick nitrogen atmosphere, something unparalleled among solar system satellites. Tiny Hyperion was found to be spinning chaotically as a result of frequent gravitational tugs from Titan. Enceladus was seen to have an extremely bright and geologically young surface. Mimas had a huge crater on one face that gave it an appearance similar to the Death Star featured in the movie *Star Wars*.

Among the Uranian satellites—which we once supposed to be frozen, inert worlds—was an amazing variety of landforms, including the three strange coronas, multiringed features on the surface of Miranda. On Miranda, we also saw cliffs that jut up to 20 kilometers (12 miles) above the surrounding terrain! In Miranda's low gravity, a rock thrown from the top of these cliffs would take a full ten minutes to reach the bottom.

Even distant Neptune's satellites were not without surprises, as Triton was seen to possess a thin nitrogen atmosphere and an extensive ice cap composed of frozen nitrogen, through which occasional geysers spewed dusty material that was carried downwind to form black streaks across the ice.



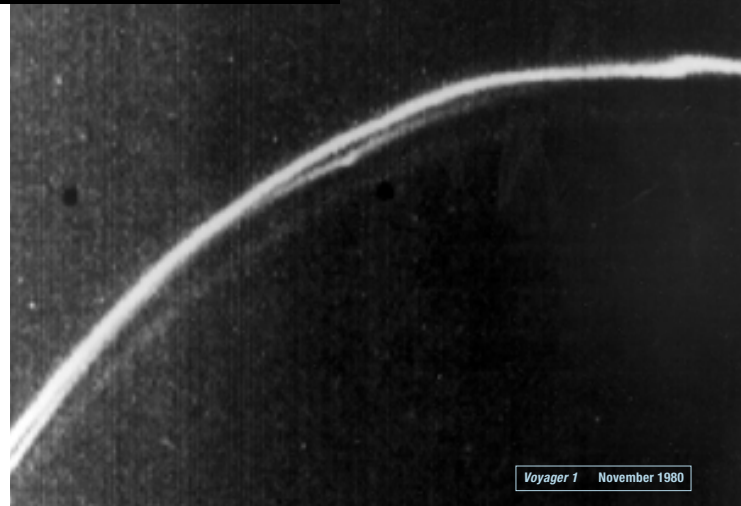
Voyager 1 November 1980

Beautifully composed, subtle, and deeply profound—this image of Saturn is, without question, my favorite from Voyager. Notice the shadow cast on the planet by its rings, indicating the rings are transparent. That's subtlety! Now, notice the perspective: we're looking at Saturn from behind the planet. Saturn itself is dazzling, but to travel beyond it and look back at it—that, to me, is incredible.

—Bruce Murray, Director of the Jet Propulsion Laboratory 1976–1982, Cofounder and Chairman of the Board of Directors of The Planetary Society

What the philosopher George Santayana said of wit—that a sense of humor is a sense of proportion—might be said of science, too. Scientific investigations help us comprehend our place in the wider scheme of things, as this Voyager far-side view of Saturn illustrates with wordless eloquence.

—Timothy Ferris, Producer for the Voyager Interstellar Message



Voyager 1 November 1980

The twisted rings of Saturn are beautiful as a work of nature, in part because of form but more so because of the story they reveal. To see the interplay of gravitational forces in the rings—leading us to a new understanding of the ring particles and the nature of planetary ring formation—took me by surprise, and I was someone schooled in celestial mechanics.

—Louis D. Friedman, Planetary Society Executive Director

THE GIANT PLANET RING SYSTEMS

We found that planetary rings, once thought to be unique to Saturn, were typical of all the giant planets. Before *Voyager 2* arrived at Jupiter, Earth-based astronomers had accidentally discovered Uranus' rings as they measured the light of a star occulted (blocked) by the planet. Then other astronomers detected hints of rings around Neptune. *Voyager 2* would confirm these discoveries and reveal the detailed appearance of the ring systems.

Also, *Voyager* revealed a totally unexpected wealth of detail in the structure of Saturn's rings, which had been observed from Earth for centuries. Details included ra-

dial structure (reminiscent of the grooves in a record) with sizes down to the limit of visibility of the measuring instruments. We still can't explain radial spokes of fine dust within the B ring of Saturn. *Voyager* saw vertical and horizontal waves that seem to propagate within the rings, and we found that the region previously



On Valentine's Day in 1990, Voyager 1, out beyond the orbits of Neptune and Pluto, looked homeward to reveal our little world in its cosmic context. Here is the fulfillment of T. S. Eliot's prophecy that

*"the end of all our exploring
Will be to arrive where we started
And know the place for the first time."*

This photograph is both a stunning technological achievement and evidence that we are beginning to attain some philosophical maturity as a species. It takes a degree of self-confidence to accept that our whole world is but a speck in the immensity. It was not so long ago that this affirmation of our lack of centrality in the universe would have been forbidden by the authorities. I cherish this image as the spiritual punch line of the first golden age of space exploration. It is a visual imperative to awaken from our collective stupor and learn how to care for our tiny planetary home and the precious life that it sustains.

—Ann Druyan, Creative Director of the Voyager Interstellar Message and CEO of Cosmos Studios

called the Cassini division, instead of being empty space, is filled with structured ring material.

One of *Voyager*'s first big discoveries was a diffuse, dusty ring circling Jupiter, apparently the result of meteorites bombarding the small moons Metis, Adrastea, Amalthea, and Thebe.

Uranus' rings were confirmed as dark, narrow bands of material accompanied by a surprising amount of dust—all in sharp contrast to Saturn's bright, icy rings. *Voyager 2* discovered an additional narrow ring of Uranus not noted by the Earth-based observers.

By the time *Voyager* reached Neptune, we naturally expected that Neptune would also have rings. Earth-based measurements of stellar occultations of Neptune were inconclusive. Certainly no continuous rings had been detected, and those brave souls who'd predicted strange, discontinuous ring arcs about the planet were proved right. *Voyager* imaged at least three narrow rings, the outermost of them (Adams ring) containing five discontinuous ring arcs occupying about 10 percent of the total circumference of the ring. The arcs are now known as Courage, Liberté, Egalité 1, Egalité 2, and Fraternité.

Among the giant planets, no two of the ring systems are alike; the story these differences tell has yet to be fully disclosed.

THE MAGNETOSPHERIC STUDIES

In 1977, Jupiter was the only giant planet we knew to have a magnetic field. Before the *Voyager* encounters of Saturn, *Pioneer 11* made the first measurements of Saturn's magnetic field. *Voyager* enhanced and extended the *Pioneer* measurements of both the Jupiter and Saturn magnetic fields and then, exploring virgin territory, found and measured the highly tilted and offset magnetic fields of Uranus and Neptune.

Each planet is surrounded by a magnetosphere, a region dominated by internally generated magnetic fields. And each magnetosphere contains trapped radiation in the form of charged particles. The population density of the radiation decreases from Jupiter to Saturn to Uranus to Neptune.

The distinctiveness of the planets' magnetic fields lies primarily in the differences among the tilts of their magnetic poles of rotation. The magnetic pole of Saturn has essentially zero tilt, while the magnetic

poles of Uranus and Neptune are tilted dramatically. The low tilt of Saturn's field is problematic because current theories of the origins of magnetic fields require an offset of at least a few degrees between the rotation axes and the magnetic axes of a planet. Earth's more familiar magnetic field has a tilt of 11 degrees, whereas Jupiter's massive magnetic field has a tilt of 10 degrees.

THE EFFECT ON PLANETARY STUDIES

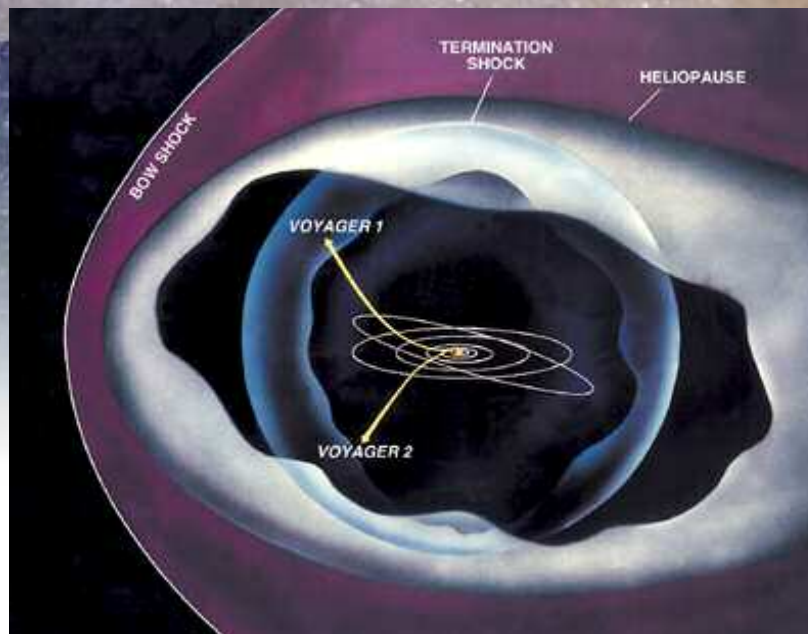
As *Voyagers 1* and *2* approached their planetary encounters, Earth-based observers turned their instruments on the planets, their rings, and their satellites. Such enhanced efforts helped increase our science return: they provided better characterizations of these worlds so we could fine-tune *Voyager's* measurements, and their scientific predictions gave *Voyager* something to either prove or disprove.

The *Voyager* encounters also gave a marked impetus to spacecraft that followed to the giant planets: *Galileo* to Jupiter and *Cassini-Huygens* to Saturn. In a very real sense, the *Voyager* mission changed studies of the outer planets from the realms of astronomy and orbit determination, practiced at great distance, to the realms of geology, meteorology, and other sciences that require data taken up close. For the first time, researchers could use the *Voyager* data to do comparative planetology and draw on the similarities and differences among planets, their rings, and their satellites to deduce the reasons for those characteristics.

While the *Voyager* data about Jupiter have been largely supplanted by the *Galileo* data, as the *Voyager* Saturn data will likely be supplanted by the *Cassini-Huygens* results in 2004 and beyond, the data from Uranus and Neptune are likely to remain the premier sources for studies of those planets for decades to come. Furthermore, the *Galileo* and *Cassini-Huygens* missions would not have been possible without the information provided by *Voyagers 1* and *2*.

THE INTERSTELLAR MISSION

I have been referring to the *Voyager* spacecraft as if their missions were entirely behind them. Yet these



Voyagers 1 and 2 have left the neighborhood of the outer planets and are headed for the heliopause—the outer limits of the Sun's magnetic field and outward flow of the solar wind and the beginning of interstellar space. Before penetrating the heliopause, the spacecraft must pass through the termination shock (where the million-mile-per-hour solar wind slows to about 250,000 miles per hour). While the exact location of the termination shock is not known, current estimates predict that Voyager 1 might complete the termination shock phase of its journey by 2003. Illustration: JPL/NASA

hardy spacecraft continue to collect data on charged particles and magnetic field strengths and orientations in the far reaches of the solar system.

At the beginning of 2002, *Voyager 1* was 83.3 astronomical units (AU; 1 AU is the mean distance between Earth and the Sun) from the Sun. The slower *Voyager 2* was 66.1 AU from the Sun. (For reference, *Pioneers 10* and *11* were 79.0 AU and 59.0 AU from the Sun, respectively.) *Voyagers 1* and *2* continue to move outward at respective rates of 3.50 and 3.13 AU/year. We anticipate, on the basis of the data being received, that soon (perhaps as early as 2004) *Voyager 1* will reach the boundary where the solar wind flowing rapidly outward from the Sun will slow from supersonic to subsonic speeds. That transition is called the termination shock. A few AU or tens of AU beyond the termination shock, the outward flow of the solar wind will cease altogether, and *Voyager 1* will cross the outer reach of the solar wind (the heliopause) into true interstellar space. Such is the destiny of these remarkable explorers!

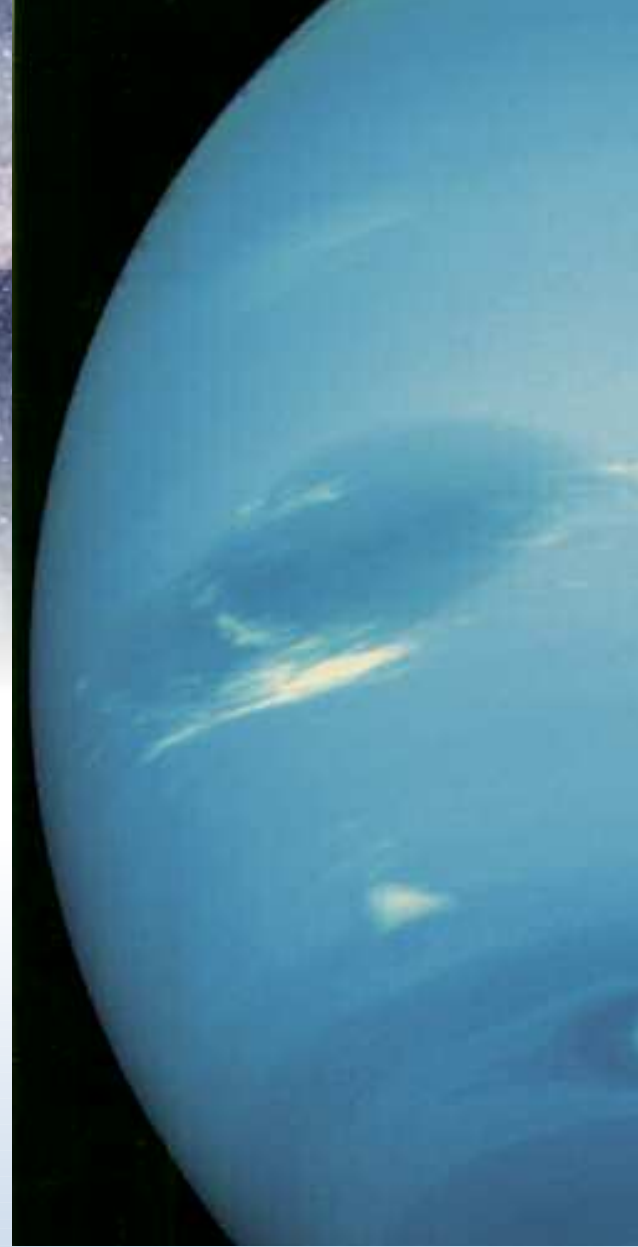
Ellis D. Miner, a planetary scientist at the Jet Propulsion Laboratory, served from 1978 to 1990 as assistant (or deputy) project scientist for Voyager.



It's hard for me to pick a favorite photo or image because there were four planets, tens and tens of moons, and thousands and thousands of rings, each with its own character and attractiveness. But Neptune—so unknown, so far away, so cold—was expected to have been a rather dreary place, and it turned out to be incredibly beautiful. This was, for me, the prettiest photograph from a purely artistic point of view.

There is no doubt in my mind that the Voyager project was the most epic journey in the history of our species.

—Jurrie van der Woude, Photo and Imaging Coordinator for the Jet Propulsion Laboratory



Voyager 2 August 1989

We discovered what we believe to be nitrogen-greenhouse-driven geysers at the south polar cap of Neptune's moon Triton. The Voyager mission taught us that no matter where we go in the universe, no matter how cold or low-energy the planetary environment, nature will find a way to put on an exotic display of active natural processes. This lesson has taught us to anticipate the bizarre and the unexpected.

—Larry Soderblom, Voyager Deputy Imaging Team Leader





Voyager 2 August 1989



Voyager 1 March 1979

As our first Voyager spacecraft approached Jupiter, the astonishing structure of the planet's atmosphere came into focus. No scientist had ever predicted that Jupiter's clouds would be so sharply defined, so colorful, or so beautiful. The almost organic flow of clouds around the Great Red Spot shattered our preconceptions of how the outer solar system would look. At every world the Voyagers encountered, we gave the same gasp of surprise at what we saw. But Jupiter was where this revelation happened first. We would never look at the solar system the same way again.

—Jon Lomberg, Design Director for the Voyager Interstellar Message, Planetary Society Adviser



Voyager 2 August 1981

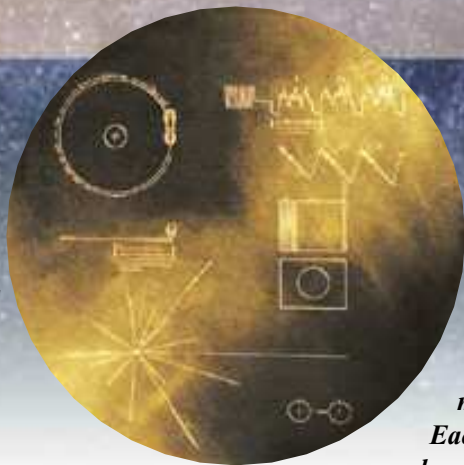
In the Von Karman Auditorium at the Jet Propulsion Laboratory, each day of an encounter, the sometimes raucous press from around the world would gather, waiting for the first look at what Voyager had discovered the day before. When the lights went down, all squirming stopped, and we held our collective breath, anticipating what new wonders we would see. My strongest memory is of the first photopolarimeter (PPS) image: a graceful sweep of red and yellow arcs representing the finest detail of Saturn's rings. These images were not "real" in that they represented a single track of data taken across the rings and then projected to simulate the rings' appearance. The PPS Instrument measured the dimming of light from a target star as it passed through the rings, giving scientists a measure of particle density. From such arcane data, the Voyager team produced images of astounding beauty, such as this.

—Charlene Anderson, Editor of The Planetary Report, Associate Director of The Planetary Society

VOYAGER:

The Voyager record jacket.

Photo: JPL/NASA



As both Voyager spacecraft reach the edge of our solar system, poised to cross the boundary into interstellar space, each carries a carefully crafted message from Earth. The message—consisting of 116 images, greetings in 55 languages, 19 sounds of Earth, and 27 musical selections—was intended to capture and, it is hoped, one day communicate the diversity of life and culture on our planet. This message is encoded on a phonograph record: a 12-inch, gold-plated copper disk.

Each disk is encased in a gold-colored aluminum jacket and packaged with a cartridge and a needle. Line drawings etched into the jacket explain the origin of the spacecraft and indicate how the record is to be played. (The images are encoded in analog form, while the remainder of the record is in audio designed to be played at 16 2/3 revolutions per second.)

In “A Message From Earth,” science writer Timothy Ferris recounts his part in developing the record’s profound and complex message: whittling down centuries of the world’s music to a 90-minute compendium. Illustrating his article is a sampler from the 116 images on Voyager’s *Interstellar Message*, with captions adapted from those written by the record’s design director, Jon Lomberg, in the book *Murmurs of Earth*. —Jennifer Vaughn, Managing Editor

Having presumed, in my youth, to produce a recording intended to last a billion years, I may reasonably be held accountable for how well it holds up as a work of art and craft today, a mere quarter century later: is it a hit or a miss?

The Voyager record contains many things—a montage of natural sounds of Earth, ranging from volcanic eruptions and brain waves to crickets chirping and a kiss, spoken greetings in 55 languages representing 87 percent of the human population, and 116 encoded photographs—but three-quarters of its two-hour length is devoted to music. So, when I took it off the shelf and played it recently, I concentrated on the music.

I don’t know whether music is a universal language, but it certainly is a potent abridger of time, and as the first tracks wafted out of the speakers—Bach’s second *Brandenburg Concerto*, followed by a Javanese gamelan piece, a rousing Senegalese percussion session, and the bell-like tones of pigmy girls singing in the deep forests of Zaire—I was carried back to the hectic, exciting months when we put the record together.

Time was short, our deadline inexorable: if you miss the launch of an interstellar space probe, you cannot very well catch it at the next bus stop. Not until seven months before launch did Frank Drake—who, with Carl Sagan, had created the engraved plaques carried by two prior probes, *Pioneers 10* and *11*—realize that much more information could be placed on *Voyager* (for the benefit of any extraterrestrials who might one day snare the spacecraft) by turning the plaque into a phonograph record. Weeks more elapsed while Sagan sold NASA on the plan. As Frank writes in the official account of the Voyager record, “By then it was very late, and the construction of the record became a crash

project” (*Murmurs of Earth*, by Carl Sagan, F. D. Drake, Ann Druyan, Timothy Ferris, John Lomberg, and Linda Salzman Sagan).

When Carl invited me to produce the record, my initial response was to ask John Lennon of the Beatles to take on the job instead. He knew far more about working with sound than I did, and the project would have benefited from his incisive creative vision. But Lennon, under harassment by the Internal Revenue Service at the behest of the Nixon White House, was obliged to decamp for Japan. He left us two valuable tips, however. First, he recommended that I use his engineer, the talented Jimmy Iovine, who proved to be a great help. Second, Lennon’s trick of etching little messages in the blank spaces between the “take-out grooves” at the end of his vinyl records inspired me to do the same on the Voyager record—a useful stunt, though one that was to create unforeseen problems with NASA.

Drake’s original outline, drafted when he met with Sagan in Hawaii in January 1977, envisioned 14 pictures—among them a rocket launch, human figures, the DNA molecule, and a map of our galaxy—accompanied by a few snatches of music and ambient sounds recorded on one side of a 33 1/3 rpm LP. By using both sides of the disk, cutting the speed in half—to the 16 2/3 rpm of the “talking book” recordings I’d listened to as a child—and encoding the pictures discretely on each side of the grooves, in stereo, I was able to quadruple the record’s bandwidth, clearing fully 90 minutes for music.

Astronomy and music are two brightly intertwined threads in the history of human creativity. Their interaction dates from at least as far back as those prehistoric nights when shepherds traced constellations while soothing their flocks by playing the first bagpipes—fluted sheep’s

A MESSAGE FROM EARTH

BY TIMOTHY FERRIS

bladders that reassuringly reminded lambs of their mothers' bleatings. It was already an old story by the time that Kepler wrote of the "music of the spheres" to Galileo, a musician's son. We relived it nightly, playing stacks of records in Carl's living room in Ithaca by the soft light of a John Lomberg model of the Milky Way, and on the refrigerator-size speakers in my Manhattan apartment, seeking to carve out slivers of the world's music that could both stand on their own and somehow do justice to the whole.

From the outset, we had two main objectives: to make a recording of enduring musical merit and to represent many cultures, not just those of the West.

Meeting the first criterion was to some extent a matter of taste, although perhaps less so than one might assume. In practice, it mainly meant sticking to genuinely great music and excluding, as the writer James Salter puts it, everything that's merely "good enough." We turned a deaf ear to entreaties that we include second-rate tunes aimed at gratifying particular constituencies. One such offering was "Moscow Nights," a song said to appeal to the spacefaring Soviets, which deserved Carl's characterization as "a kind of Soviet Mantovani, the blandest, least controversial and also least interesting music imaginable." Omitted, too, was "Danny Boy," which a NASA official maintained would gladden the heart of then Speaker of the House Tip O'Neill. (I happen to like "Danny Boy," but we weren't about to start auctioning off songs in return for putative political favors.) As when doing any creative work, we had our hands full just making something we'd be proud of, without also trying to make it what others might want it to be.

In the service of our pancultural criterion, we tried hard to find strong pieces unknown to most Western listeners. At the prompting of the musicologist Robert E. Brown, Ann Druyan exhumed copies of Surshri Kesar Bai Kerkar's superb recording of the raga "Jaat Kahan Ho" from a dusty brown box under a card table in a Manhattan appliance store. The ethnomusicologist Alan Lomax—whose historic collections have inspired contemporary records ranging from Moby's *Play*, which has sold more than 10 million copies, to the Grammy-winning *O Brother, Where Art Thou?* soundtrack—fished, from a mass of unjacketed disks stacked on his living room sofa, what was probably the only copy in the Americas of the stirring Georgian chorus "Tchakrulo." Thanks to the help of many such dedicated professionals, we were able to navigate wine-dark

waters from our cultural home, winding up with a record on which the majority of selections are non-Western. Opinions may differ on how successfully the Voyager record reflects the incredible diversity of Earth's musical realms, but parochial it's not.

Oddly enough, the track that provoked the most controversy in our little group—Chuck Berry's "Johnny B. Goode"—turned out to be our most popular selection. The song depicts a rural youth's dream that his music will win him fame:

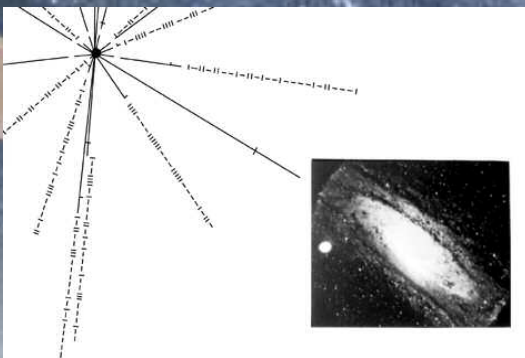
*He used to carry his guitar in a gunny sack
Go sit beneath the tree by the railroad track.
Oh, the engineers would see him sitting in the shade,
Strumming with the rhythm that the drivers made.
The people passing by, they would stop and say
Oh my, but that little country boy could play**

Druyan had championed the song on the grounds that we ought to include a selection of rock music and that this one was ably written and performed by a rock pioneer. Carl initially pronounced it "terrible" but later changed his mind and became one of its staunchest advocates. (When one of our consultants sniffed that it was "adolescent," Carl reminded him that there are, after all, millions of adolescents on planet Earth.) In the end, the fact that NASA sent rock music into the depths of space became part of popular culture, prompting a *Saturday Night Live* skit in which aliens respond to receipt of the record by demanding, "Send more Chuck Berry!"

With the deadline for delivery to NASA less than two weeks away, I staggered into the Columbia recording studios in New York City carrying two large cardboard boxes loaded with tapes and vinyl records from around the world. There, we remastered the recordings, mixed the sequence of Earth's natural sounds, and edited the "brief comments" of United Nations delegates—most of which were windy speeches—into a succinct collage.

Late on the last night of the session, I cut the master, etching the music, sounds, and encoded photographs into a 12-inch virgin vinyl platter to be cloned, in California, into the two gold-plated copper disks that would travel aboard the spacecraft. Near midnight, when the master was done, I took the hot needle employed to cut the grooves and with it rendered, in the blank spaces between the "take-out" grooves at the end, an inscription: "To the makers of

*"Johnny B. Goode," written and performed by Chuck Berry, courtesy Isalee Music Co.



We enlarged part of the solar location map shown on the cover of the record so that its binary code would be clear. Then, we added another reference point: the Andromeda galaxy in its position relative to the Sun at the time of Voyager's launch. Andromeda is our nearest neighbor in space, and millions of years from now its pattern of dust and stars will have changed only slightly. This may be the only picture in the entire collection that the people of Earth and any future recipients have seen firsthand. Illustration: Courtesy F. D. Drake

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	58x10 ⁶ km	108	150	228			
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$\frac{41}{100}$ d	$\frac{43}{100}$	$\frac{45}{100}$	$\frac{65}{100}$	$\frac{7}{10}$			

These diagrams of our solar system show the diameter, distance from the Sun, mass, and period of rotation for each body. The poor, TV-quality resolution of the images on the Voyager record made it necessary to split the diagram into two parts. The fact that the top section ends with Mars and the bottom begins with Jupiter indicates the inner solar system is composed of small rocky planets, while, except for Pluto, the outer system is composed of large gas planets. Diagrams: Courtesy F. D. Drake



We chose images of Mercury, Mars, Jupiter, and Earth to represent planets. This snapshot of Earth, what Carl Sagan called "the meadow in the middle of the sky," shows the planet from which the pictures were sent. The diameter and mass indicated below refer back to the solar system chart. Looking at pictures of objects (such as planets) that are somewhat familiar helps recipients calibrate their own system for reproducing images, which might then help them understand our concept of a picture—that is, how we represent reality on a two-dimensional surface. Image: NASA



One of Frank Drake's earliest ideas was to show different animal species around a waterhole. For all of us interested in interstellar communications, the concept of the waterhole has added significance. It represents the band of frequencies in the microwave region—a relatively quiet zone in the radio spectrum—that is bounded by the emission of hydrogen on one side and the hydroxyl radical (OH) on the other. This frequency has been nicknamed the "waterhole" because hydrogen and OH are the products of the breakdown of water. Just as living things on Earth have always gathered near water, so might water-based life from other worlds meet at the radio waterhole. Photo: Courtesy South African Tourist Corporation



The record carries a series of photos showing a variety of human dwellings such as houses and cities. Above is Oxford, England. Two pictures of the United Nations building were included, one taken during the day and one at night (right), which also demonstrated how we light our cities. Photos: Douglas Gilbert, from C. S. Lewis: Images of His World, William B. Eerdmans Publishing Company; United Nations

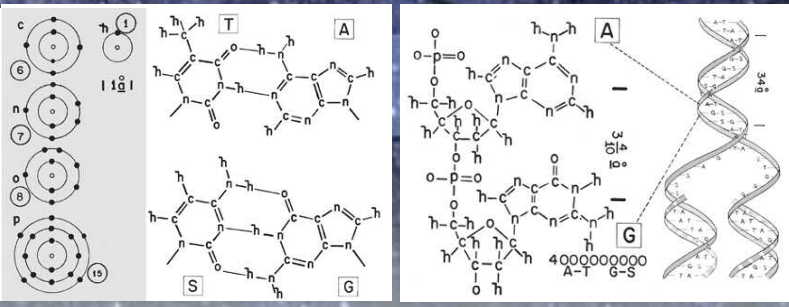


music—all worlds, all times." I tucked the master under my arm and took the red-eye to Los Angeles.

A few weeks later, when the finished gold-plated records reached the Kennedy Space Center at Cape Canaveral, Carl received an alarming phone call from NASA. An official charged with signing off on all parts of the *Voyager* spacecraft had examined the record and verified that its size, weight, composition, appearance, and magnetic properties were all to specifications—but not my handwritten inscription. Because there was no mention of the inscription in the specifications, the officer rejected the record. The space agency informed Carl that they were preparing to put a blank ballast disk in its place. Fortunately, Carl convinced the NASA administrator to sign a waiver, arguing that my

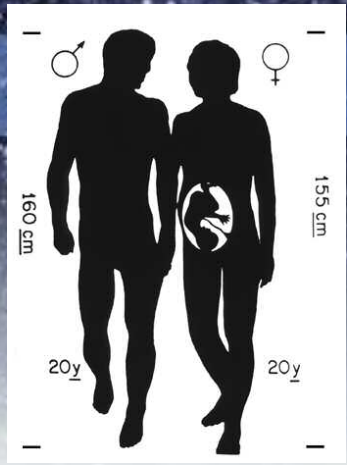
scribblings constituted the sole example of human handwriting to be found on the spacecraft, and thus added information content to it. And so, the record flew.

"I wasn't sure we'd actually get away with it," Carl confided as we stood on the sands of the Cape and watched the first of the two *Voyagers* rise into the blue Florida sky. We all felt a sense of elation and relief—mixed with a sense of regret over all the sounds, words, pictures, and music that wouldn't be going along for the ride. I was among those disappointed that Bob Dylan, the most important artist of our times, wasn't aboard. Others were dismayed by the exclusion of Claude Debussy, Aaron Copeland, George Gershwin, and John Coltrane. But perhaps, like any work, the *Voyager* record is better judged by what it contains than by what it omits.



Showing the structure of DNA seemed like a good idea because all life on Earth uses the DNA molecule to store and replicate the information that tells the organism how to grow itself from scratch. The shaded portion on the left side of the picture at top left is a schematic of the five atoms that comprise DNA. By indicating the size of the hydrogen atom as one angstrom (one ten-millionth of a millimeter), we hoped to make it obvious that we were talking about atoms. The right side of the illustration shows the four bases that connect the two twisting spirals of the DNA backbone. Here, we encountered a problem that cropped up throughout the project: eliminating sources of ambiguity. To avoid using the letter C to show two different things—carbon and cytosine—we had no choice but to represent cytosine with an S! This became an object lesson in the special problems of communicating with extraterrestrials.

The left side of the picture at top right shows the composition of the backbone of the DNA molecule with two of the bases attached. The right side of the illustration consists of a diagram of the entire molecule, showing how the backbone and base pairs form a helical structure capable of self-replication. At bottom, the legend "4000000000 A-T G-S" indicates that a molecule of DNA uses a large number of base pairs to code the information necessary to construct a living being (in this case, a human). Diagrams: Jon Lomberg



Our original proposal to NASA included a picture of two nude human beings: a man and a pregnant woman. However, NASA refused to include it. So, we substituted this silhouette of the pair in order to finish the series on human reproduction. The male and female symbols distinguish the father from the mother, and the typical sizes of human beings are noted in the margins. Illustration: Jon Lomberg



This image is of a human fetus after about two months of development. Photo: Frank Allen, George Washington University



The versatility of the human hand has played a large part in our cultural evolution, so we used photos showing hands performing a variety of tasks. We also wanted to show something of our medical technology. It occurred to us that an X-ray of a human body (or body part) might indicate that we could direct our technology toward our own biology. So, we went out to Thompkins County Hospital in Ithaca, New York and photographed radiology technician Teresa Cima comparing an X-ray of a hand to one of her own. Photo: Herman Eckelman, National Astronomy and Ionosphere Center



Astronaut James McDivitt is shown here on a space walk from a Gemini orbital flight. His hand is visible, helping recipients recognize the figure as human. One of the few pictures sent in color, this links to the other color views of Earth. Photo: NASA



Each Voyager spacecraft was launched into space atop a Titan Centaur rocket—like the one shown here blasting off from Florida's Cape Canaveral in 1975, sending Viking on its way to Mars. Photo: NASA



Next to the violin is a page of musical score. The score is the Cavatina from Beethoven's String Quartet No. 13, which is the last piece on the record. After the picture appears, a few seconds of the quartet play. These few seconds are the measures scored on the sheet music. If extraterrestrials figure that out, they will know that music is composed and written down. We hope this will give them some idea of what the rest of the sounds on the record are all about. Montage: Jon Lomberg

Unfortunately, few have ever heard it. Because the record's music, natural sounds, and photographs come from such a wide variety of sources, the prospective task of obtaining permission to reproduce them all proved daunting to those who considered putting it on the market. Fully 15 years passed before it was released—in a technically uneven version put together without my knowledge by a record company that soon went out of business—and it remains obscure to this day.

How does it hold up, one forty-millionth of the way into its long journey? Personally, I think it's a great record. The quality of the compositions and performances is uniformly high, and the contrast among them at least hints at the astonishingly rich and varied palettes of human artistry, from the

mathematical austerity of Bach to the vitality of rhythmic pieces like Mexico's "El Cascabel" and Bulgaria's "Izlel je Delyo Hagdutin" and the deep emotional currents of the ancient Chinese ch'in piece "Flowing Streams." I'm particularly fond of the record's ending—Blind Willie Johnson's "Dark Was the Night," followed by the Cavatina from Beethoven's String Quartet No. 13, Opus 130—two lost souls emerging from very different lives to arrive at a high and hard-won common ground. But mine is hardly an impartial judgment. The critics who ultimately will make that judgment lie far from us in time—and, perhaps, in space, too.

Timothy Ferris' latest book, *Seeing in the Dark*, has just been published by Simon & Schuster.

Society News

Voyager's 25th Celebrated on *planetary.org*

Voyager's fantastic journey forever changed the way we view our place in the solar system. Join us on The Planetary Society website, *planetary.org*, as we look back and share with you *Voyager's* inspirational journey. See the images, read about the people, and learn the history behind one of the most successful space missions ever.

We hope you join us in this anniversary celebration!

—Monica Lopez,

Web Marketing Coordinator

Society Scholarship Winner

The Planetary Society has recently awarded academic scholarships to three promising students interested in space and its exploration.

A \$1,000 fellowship went to Amanda Heiderman of Western Nevada Community College, now transferred to the University of California at Berkeley, and to Hillary Cummings of The University of Washington (UW). The 2002 Planetary Society Jim and Lin Burke fellowship for the International Space University's summer session in Pomona, California, was awarded to Bojan Pecnik, a 27-year-old doctoral student from Croatia.

Amanda impressed us with her drive to succeed, moving from a small community college to one of the leading research universities in the world. Hillary, in addition to her outstanding academic performance, is involved in several space-related projects, including the Space Student Design Competition in Houston, Texas, and the renovation of the historic observatory on the UW campus.

Bojan is working at the Max Planck Institute for Extraterrestrial Physics in Germany on developing a general model of the formation of giant planets

and planetary systems. In addition to his strong academic credentials, the committee was struck by Bojan's expressed fascination with the wonders of space and by his commitment to promoting public awareness of space exploration.

More information about Planetary Society scholarships and the 2002 winners is available on *planetary.org*.

—Amir Alexander, *Web Editor*

Shoemaker NEO Grant Winners Announced

The results are in! After a tough round of judging, we're proud to present the 2002 winners of The Planetary Society's Gene Shoemaker NEO Grants.

The winners are James McGaha from Tucson, Arizona; John Broughton from Reedy Creek in Queensland, Australia; Matt Dawson from the Roeser Observatory in Luxembourg; Roy Tucker from Tucson, Arizona; and Richard Kowalski from Zephyrhills, Florida.

These dedicated observers and their projects were selected from a group of 37 proposals The Planetary Society received from 13 countries. Each Shoemaker Grant proposal offered ways to better our understanding of NEOs (near-Earth objects), which couldn't have been more appropriate given the recent discovery of asteroid 2002 NT7 and the media attention it received.

Find out more about each of the winners on the Society's website, *planetary.org*.

—Melanie Melton, *Web Editor*

Expedition to Argentina

We are still planning an expedition to Argentina to study some interesting outcrops in Patagonia. We were hoping to depart in January or February 2003, but it now looks like we'll need to wait until later in the year. If you're interested in the expedition—even if you're just curious and want to know

more—please call Lu at (626) 795-5100, extension 234, or e-mail her at *lu.coffing@planetary.org*.

—Lu Coffing, *Financial Manager*

Society Participation at Devon Island

On July 17 to 24, The Planetary Society's science and technology coordinator, Emily Lakdawalla, traveled to Devon Island in Arctic Canada to join the NASA Haughton-Mars Project (HMP). The HMP, which is run by the SETI Institute, was established in 1997 to study Devon Island and its Haughton impact crater as a potential analog for Mars (see the January/February 2002 issue of *The Planetary Report*).

Lakdawalla joined a three-person team led by the NASA Ames Research Center (ARC) to fly an autonomous airplane set to capture video of the barren landscape of crater and gullies on Haughton Crater—just as we hope airplanes will one day be used to scout out new frontiers on Mars. Cooperative weather permitted a total of 14 flights at three different locations around Haughton Crater, during which more than 60 minutes of video were captured of the rocky landscape.

The team was led by Benton Lau, deputy project director of ARC's Bio-inspired Engineering for Exploration Systems (BEES) for Mars project. The goal of BEES for Mars is to develop aircraft that can autonomously explore Mars by mimicking the behaviors of simple creatures like bees or ants. This year, the exploration airplane was provided by MicroPilot, a private company specializing in autopilot hardware for small aircraft.

For more information about the Society's participation in the HMP, please visit *planetary.org/html/Devon_Island*.

—Emily Lakdawalla, *Science and Technology Coordinator*

World Watch



by Louis D. Friedman

Pasadena, CA—Twenty-five years ago, *Voyagers 1* and *2* left Earth and began a remarkable and memorable journey through the solar system. Now, the two explorers are gliding toward the heliopause, ready to cross the boundary into interstellar space.

As successful as the *Voyager* mission was, it was still a compromise—scaled back from earlier proposals for a more expanded Grand Tour mission. *Voyager* well exceeded expectations and accomplished almost all the Grand Tour goals. That said, *Voyager* still marked the Apollo era—from 1960 to 1980, each and every year saw a planetary encounter—but cutbacks and focus on the space shuttle meant that from 1980 to 1989, only *Voyager* sent home pictures from other worlds.

The dichotomy between enormous public interest in planetary missions like *Voyager* and *Viking* and political efforts to cancel future planetary exploration was the reason Carl Sagan and Bruce Murray hatched the idea of forming a public interest group to advocate for planetary exploration. Thus, The Planetary Society was born in 1979 (see “*Voyager: An End and a New Beginning*,” page 4).

This schism, between popularity and political perception, has been with us ever since. When we lobby, we always run into congressional representatives who tell us (in effect), “I know planetary exploration is good and valuable, but if my constituents ever knew how much we paid for these missions, they would vote me out of office.” Thus, our job—the job for which Sagan,

Murray, and I formed the Society—is to educate the politicians that planetary exploration is not merely valuable, it is popular, too.

We have our work cut out for us. While there is no plan afoot to cancel planetary exploration, there is one to cancel outer planets exploration—which is still an American-only endeavor. Europe, Russia, and Japan are not yet proposing missions to any of the scores of new worlds discovered by *Voyager* in the outer solar system.

This year, the Bush administration has proposed canceling the outer planets line item in the federal budget; the first two missions being developed in that line item are a Pluto–Kuiper belt flyby and a Europa orbiter. We have repeatedly engaged our members in fighting for these missions, and we twice have helped save the Pluto–Kuiper belt flyby mission from extinction. Still, the missions are not out of danger.

In July, both Pluto and Europa received high-priority endorsements from the National Academy of Sciences in a report commissioned by NASA to examine priorities in solar system exploration for the next decade.

The science community endorses missions to these worlds; the public supports these missions; NASA had already initiated mission development and, in the case of Pluto, even selected a science and engineering team for implementation; and Congress has supported the missions in past budgets. So, what went wrong?

What went wrong is that the White

House Office of Management and Budget opposes a Pluto mission. Despite science, public, and congressional interest, the administration’s interest is lacking. That is why Society members must fight in Congress for restoration of outer planets exploration.

The time is now. Please write to your congressional representative and your senators and tell them you want the NASA missions to Pluto and Europa restored to the budget.

Updated information is on our website, planetary.org, including to whom to write and the key issues in the upcoming vote.

Meanwhile, we at Society headquarters are sending a letter to *all* members of Congress, signed by the thousands of you who responded to our special appeal petition several months ago. Even if you signed that petition, we urge you to send in your own letter to Congress.

Paris—In the July/August issue of this column, I reported on the loss of *Venus Express* in the European Space Agency (ESA) program and opined that, contrary to the name of its plan, the program did not constitute a “Cosmic Vision.” We are pleased to note that ESA reversed its decision and has reinstated *Venus Express* development in the program. It does not yet have full funding for the mission but is at least working on it. Venus exploration has been a serious omission from space program plans—the ESA mission could correct that.

Louis D. Friedman is executive director of The Planetary Society.

Questions and Answers

Is it possible that matter inside of Saturn's rings could still be accreting to form new moons?

—Joao Miguel Matos,
Setubal, Portugal

To answer your question, let's start by building a small hypothetical satellite about 10 kilometers (6.2 miles) in diameter. Next, we'll place a ring particle on the surface. Assume our particle sits on the satellite's equator, on a line between the center of Saturn and the center of the satellite. There are now three major forces working on the ring particle: the satellite's own gravity, centrifugal force due to the satellite's rotation, and a tidal shear generated by the planet. The satellite's gravitational force tries to hold the particle on the surface of the satellite, while the centrifugal force and tidal shear try to remove it.

The region around a planet where all these forces balance each other out is called the Roche zone. Outside the

Roche zone, the satellite's own gravity wins; the ring particle stays on the surface and the satellite grows. Closer to the planet, however, the particle is removed. Consequently, a satellite cannot accrete new material in this region. The main rings of Saturn are well within the Roche zone, so it is unlikely that they can accrete to form a new satellite. In fact, each ring system in our solar system lies within its parent planet's Roche zone.

—MITCHELL K. GORDON
NASA Ames Research Center

Editor's note:

In keeping with the theme of this special issue of the magazine, the following Voyager-related questions and answers have been reprinted from previous editions.

Assuming that Uranus once rotated in a more conventional alignment and that it was, indeed, "knocked on its side" by a collision, how can the

present orbits of its moons and rings be explained, since they are now in the plane of its equator? Had those orbits been there before the collision, or did they "migrate" to their present alignment?

—Gerry Bogacz,
Yonkers, New York

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

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

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

Because Saturn's rings lie inside the planet's Roche zone, particles in the rings cannot accrete to form new satellites. Voyager 1 took this picture of Saturn and two of its moons, Tethys (top) and Dione, on November 3, 1980 from a distance of 13 million kilometers (8 million miles). Shadows from Tethys and three of Saturn's rings are cast onto the planet's cloud tops.

Image: JPL/NASA



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

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

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

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

—WILLIAM B. MCKINNON,
Washington University

Could those mysterious spokes that appear in Saturn's rings be attributed to nothing more than a "stroboscopic slip effect," similar to the way the wagon wheels in a Western film beat in time with the movie camera's shutter speed to give an illusion of the wheel slowing down or even reversing?

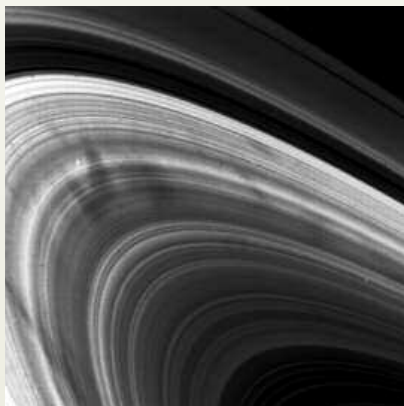
—Alistair Murch, Worthington,
United Kingdom

Before I answer your question, let me give you some background. *Voyagers 1* and *2* discovered a new form of brightness variation in the main rings of Saturn. These radially elongated, fuzzy-looking features

appeared dark against the bright rings. They quickly got the name "spokes" because they seemed to rotate like the spokes of a wheel. Shortly afterward, when *Voyager* viewed the rings from a different angle, the spokes appeared brighter than the background rings. Also, we then saw that they were actually wedge-shaped, being narrowest at the location where ring material orbits at the same rate as the planet's magnetic field.

These changes in relative brightness, and the observation that the spoke structure was tied to the motion and strength of Saturn's magnetic field, led us to believe that they were regions of abundant micron- and submicron-size ice grains, probably puffed up off the surfaces of the normal centimeter- to meter-size icy ring particles. Such small particles are easily affected by otherwise tiny magnetic forces, and their light-scattering properties agree with the observations. Several years after *Voyager's* flyby, it was suggested that such tiny particles could be produced in the sporadic fashion observed, with associated electrostatic charging, by interplanetary debris hitting the rings.

The meteorite impact trigger idea is supported by the fact that most of the



One of the most surprising discoveries from Voyager's encounter with Saturn was the dark "spokes" that seemed to rotate like the spokes on a wheel. Voyager 2 captured this high-resolution image of Saturn's rings on August 22, 1981, when the spacecraft was 4 million kilometers (2.5 million miles) away. Visible here are the numerous spoke features in the planet's B ring.

Image: JPL/NASA

spoke-creation episodes seem to occur in the region where the impact velocity and flux (the rate of particle flow) would be the highest. The huge cross section of the rings provides an impact rate that could agree fairly well with the observations, although the flux of projectiles is something we don't know much about.

Another theory describes a form of magnetic instability that can occur as a result of a meteorite impact, or even an unrelated fluctuation in the plasma surrounding the rings.

A strobe light works by freezing the motion of a very rapidly moving object; for repetitive patterns such as the spokes of a wheel, the speed can be measured by adjusting the light's flash rate to mimic the time it takes for one spoke to advance exactly to the position of another. This effect would not apply here because sunlight has no such regular (or even irregular) flickering. Neither are the *Voyager* cameras susceptible to this sort of effect.

There is surely a lot that we don't understand about Saturn's spokes and about the rings in general. When *Cassini* arrives at Saturn in 2004, it will observe the flux of interplanetary material with its dust detector, observe the changes in the magnetic fields near the rings with charged-particle detectors, and observe the structure, formation, color, and evolution of the spokes. It will discover whether the distribution of spokes varies with time and the tilt of the rings, as might be expected based on a meteoroid impact hypothesis.

Cassini will also answer many other questions about the rings: how the composition varies from dark, grayish material in the C ring and Cassini division to bright, reddish material in the B and A rings; whether small moonlets reside in the many empty gaps in the rings (other than the one 10-kilometer object discovered recently in the A ring's Encke gap); whether new ring features have appeared or whether some of the features *Voyager* saw have since evolved into different forms.

—JEFF CUZZI,
NASA Ames Research Center

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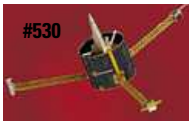
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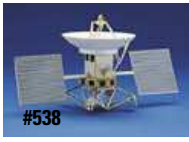
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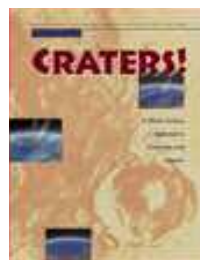
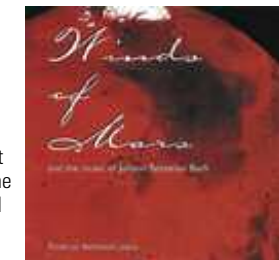


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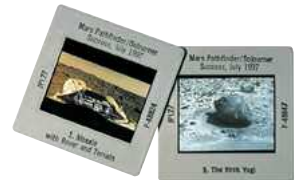


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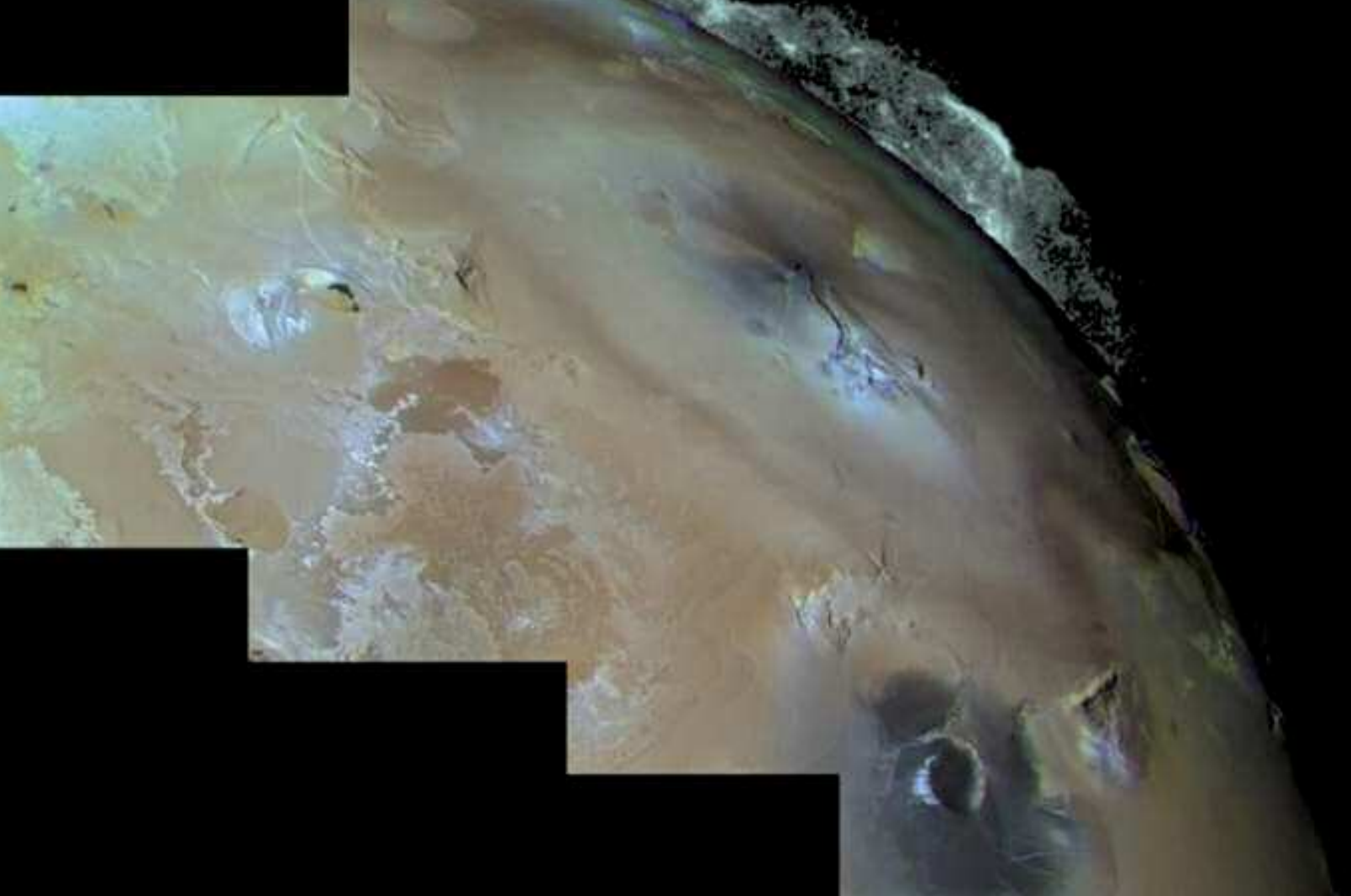
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The *Voyagers* revealed Jupiter's moon Io to be one of the most exotic worlds in our solar system. As *Voyager 1* flew past Io in March 1979, it made a surprising and spectacular discovery: not only was the innermost Galilean satellite covered with volcanoes, but many of those volcanoes were active. The plume seen off Io's limb at upper right was the largest *Voyager* saw, extending roughly 500 kilometers (about 310 miles) in all directions from its source, the erupting volcano Pele.

Editor's note: We chose to fill this space, normally reserved for paintings and prints, with one more beautiful image from the mission that was itself, in many ways, a work of art. Image: JPL/NASA. Image processing, United States Geological Survey, Flagstaff, Arizona

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