The PLANETARY REPORT

Volume XIX **Number 4** **July/August 1999**

Spiraling in to Io

On the Cover:

It's beautiful; it changes each time we see it. It's Io, the most volcanically active object in human experience. This look is from *Galileo*'s 10th orbit through the Jupiter system. On previous orbits, the red halo surrounding the volcano Pele was the most prominent feature in the southern hemisphere. On the 9th orbit, *Galileo* saw a gigantic plume, 120 kilometers (75 miles) high, from an eruption near Pele, from a volcanic center called Pillan Patera. On the next orbit, a large, dark feature, 400 kilometers (about 250 miles) in diameter, had broken Pele's red halo—one of the most dramatic changes seen on Io. *Galileo* took this image on September 19, 1997 from a distance of 500,000 kilometers (about 310,000 miles).

Image: JPL/NASA

From The Editor

Having a century and millennium end at the same time can addle the editorialist's brain. (And before sending me flaming messages about when the millennium actually ends, read the article that begins on page 4.) You look back across what you know of time and see that we humans have moved by fits and starts to reach this beginning of the Space Age.

For centuries, humans dreamed of flight, and we achieved it in 1903. Only 66 years later, a mere two-thirds of a century, we walked on the Moon. I remember those heady days of yesteryear when people believed that before the century was out, we would walk on Mars.

Instead, there are only 12 sets of footprints on the Moon. There are no plans to place any more footprints on that first stepping-stone into space. And the more time passes, the farther away Mars seems.

All I have to say is: "Thank heavens for robots." *Lunar Prospector* is about to crash itself into the Moon in a final search for water. *Galileo* is steadfastly maintaining its watch at Jupiter in hopes of "meeting" *Cassini* as the Saturn-bound spacecraft flies past. These and other robotic craft are keeping alive the dream of exploring other worlds.

We went from longships to spaceships in the last millennium, and from the *Wright Flyer* to Apollo's *Eagle* in the last century. How long until we talk ourselves onto another world?
—*Charlene M. Anderson*

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Owen Gingerich of the Harvard-Smithsonian Center for Astrophysics is one of Earth's preeminent historians of science. When he talks, other scholars listen. This question of when to mark the end of the current millennium is one of the most contentious we've heard at the Planetary Society. So, here it is, our unofficial final word on the subject.

8 In the Beginning

Since the Planetary Society began nearly 20 years ago, Jim Burke has been our resident "Moon man." The recent confluence of experimental results from *Lunar Prospector* and theoretical advances regarding the origin of Earth's natural satellite have placed Jim in the lunar equivalent of hog heaven. He reflects on Earth and Moon's shared story, and the history of humanity's attempts to understand their origins, in this essay that shares his passion with our members.

12 *Galileo:* On to Io and *Cassini*

Galileo's saga must be the most complex in the history of our explorations of other worlds. It began in the 1970s as designs for a mission called JOP, for Jupiter Orbiter and Probe. It evolved over the years into *Galileo*, one of the most complex and ambitious planetary missions ever planned. Approved in 1977 and scheduled to launch in 1982, the spacecraft waited while NASA's problems with the space shuttle forced postponement after postponement. Finally, in 1989, it set off for Jupiter and arrived in 1995. There, over the course of two years, it completed its primary mission, dropping a probe into Jupiter's atmosphere and studying the planet and its large satellites. In 1997, the spacecraft was hardy enough to carry out the *Galileo* Europa Mission for the next two years. And now, a bit doddery but still functional, *Galileo* undertakes another task: a rendezvous with *Cassini*.

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Members' **Dialogue**

Let's Save *Mir*

In a recent magazine, a reader proposed boosting *Mir* to lunar orbit, rather than "waste it" by allowing it to burn up in the atmosphere. I read in today's newspaper that Russia will cut off funding in August.

Notwithstanding the technical challenges involved, I think this reader may be on to something big, and I encourage the Society to immediately start a more detailed dialogue on this issue! *Mir* in lunar orbit could offer a giant leap toward a permanent human presence on the Moon. It could immediately pay dividends by acting as an equipment platform for a systematic human search for the best lunar base site and location of frozen water deposits on the Moon from lunar orbit instead of Earth!

Perhaps an aging space shuttle, unable to take the rigors of Earth-return gravity, could be used as a permanent Earth-Moon (orbit to orbit only) shuttle craft, carrying crew and cargo between the International Space Station and *Mir* in lunar orbit. It could provide a point for refueling and restock of human supplies for lunar construction activities without having to have crewed return-vehicles come all the way down the gravity well.

There's a billion-dollar civilization investment in the *Mir* station. I think saving *Mir* is a true test of, and challenge to, our commitment to making working technology reusable in space.

I urge you to network with the National Space Society, the Mars Society, and other pro-space organizations to investigate the technical feasibility of this concept. Or at least lobby to have *Mir* boosted higher into orbit for the next year (as opposed to months) while detailed discussions ensue.

—ED COOPER,
Moreno Valley, California

Pluto's Place

Clark Chapman's News and Reviews on the planetary standing of Pluto (see the March/April 1999 *Planetary Report*) was quite amusing. Why do seemingly intelligent people waste precious time arguing about such mundane matters as whether Pluto should retain planetary status?

The whole question is a moot point, because by very definition of the word *planet*, even Earth doesn't qualify. To the ancients, the word planet meant "wandering star." That means none of the bodies circling the Sun are planets. These bodies do not wander—they have remarkably stable orbits. They are not stars for they do not generate nuclear fusion.

I suppose we will have to simply refer to all of these bodies as rocks. We are the third rock from the Sun (which is really a star).

—RANDY W. MURRAY,
Clearwater, Florida

Solar System Ices

The compounds methyl hydroxide and hydrogen carbonyl mentioned in the "Ices" article by Wendy Calvin will be more familiar to most people by their common names: methanol and formaldehyde. Rotatable images of methanol and some other common molecules can be viewed with a Java-enabled browser at **http://DSNra.jpl.nasa.gov/IMS/molecules.html**.

These are just some of the compounds that the primordial solar nebula probably inherited from its ancestral molecular cloud. For a current list of interstellar molecules, see **http://www.cv.nrao.edu/~awootten/allmols.html**.

—TOM KUIPER,
Los Angeles, California

"Methyl hydroxide" and "hydrogen carbonyl" were inserted into the "Ices" article because of our policy of using names of molecules rather than formulas. (Dr. Calvin's original manuscript referenced these molecules as CH_3OH and H_2CO.) Thanks to Tom Kuiper for bringing the common names to our attention, plus two highly interesting Web sites.

—Charlene M. Anderson,
Associate Director

The True Story

James Pinkham's letter in the March/April 1999 issue isn't quite correct on one point: for once the United States Patent Office cannot be blamed! I never attempted to patent the communications satellite, largely because I never dreamed it would happen in my lifetime. (I was also helping to finish a war . . .)

Pinkham may be referring to an amusing spoof by patent lawyer Ted Thomas called "The Lagging Profession" (by Leonard Lockhard) in the January 1961 issue of *Analog*. This described an attempt by me to do just this, which had the results he mentions.

—ARTHUR C. CLARKE,
Colombo, Sri Lanka

Erratum

In the Questions and Answers section of the March/April *Planetary Report*, it was reported that sungrazing comets could reach speeds of 1,660 kilometers (about 1,030 miles) per second at the Sun's surface, when in fact their top speed would be 618 kilometers (384 miles) per second—also the escape velocity from the Sun. I regret this copying error.

As reported, comet 1996 S3 SOHO could theoretically have reached a top speed of 1,088 kilometers (676 miles) per second but to do so would have had to survive to its perihelion—well below the Sun's surface.

—DON YEOMANS,
Jet Propulsion Laboratory

OPINION:

Why Is the Day 24 Hours, and When Will the Millennium Begin?

by Owen Gingerich

The Death of Time

Painting: Courtesy of the artist, Tina York

This is the ceiling of the tomb of the pharaoh Ramses VI. The Egyptians divided the sky into 36 time-keeping parts called decans. The figures in this photograph are the northern constellations, and in the grid below are the star clocks related to the decans.

Photograph: Owen Gingerich

The intricate dance of the Sun, Moon, and Earth, but especially the Moon, provides the unexpected link between the two questions in the title of this article. For the first question, there are two entirely different kinds of answers, the first related to the history of science, to the rather arbitrary way that 24 happened to be chosen as the dividing unit, and the second related to planetary dynamics, to the spin the Earth has ended up with after some billions of years of tidal friction.

Most of our time units come from the ancient Babylonian sexagesimal system. Thus we have 60 minutes in an hour and 60 seconds in a minute. The 24-hour day is a curious exception, deriving from ancient Egypt. The Egyptians divided the sky longitudinally into 36 time-keeping parts called *decans*. These 36 configurations of stars are attested on calendrical coffin lids from the New Kingdom. Successive sets of decans could be used over 10-day intervals to mark the passage of time at night.

Why 24 hours from 36 decans? In Lower Egypt, the shortest summer night is only 10 hours long, allowing 15 decans to cross the meridian, the north-south circle that passes directly overhead. Only an inconvenient 13 decans are visible, as two are lost in twilight. That leaves 12 as a safe limiting number for the minimum number of time intervals on a midsummer night, and eventually this basic measure was generalized into 12 nighttime intervals and 12 daytime intervals. The day and night intervals were of different lengths and changed with the seasons. Convoluted as this explanation may sound, it is our best answer to the question as to how we have ended up dividing our day into 24 hours.

As the World Turns

As our blue planet hangs in space, spinning on its axis, we ask, "Why is the day just this long" and not twice as long, as we might sometimes wish, or even half as long? Where does Earth's particular rate of spin come from?

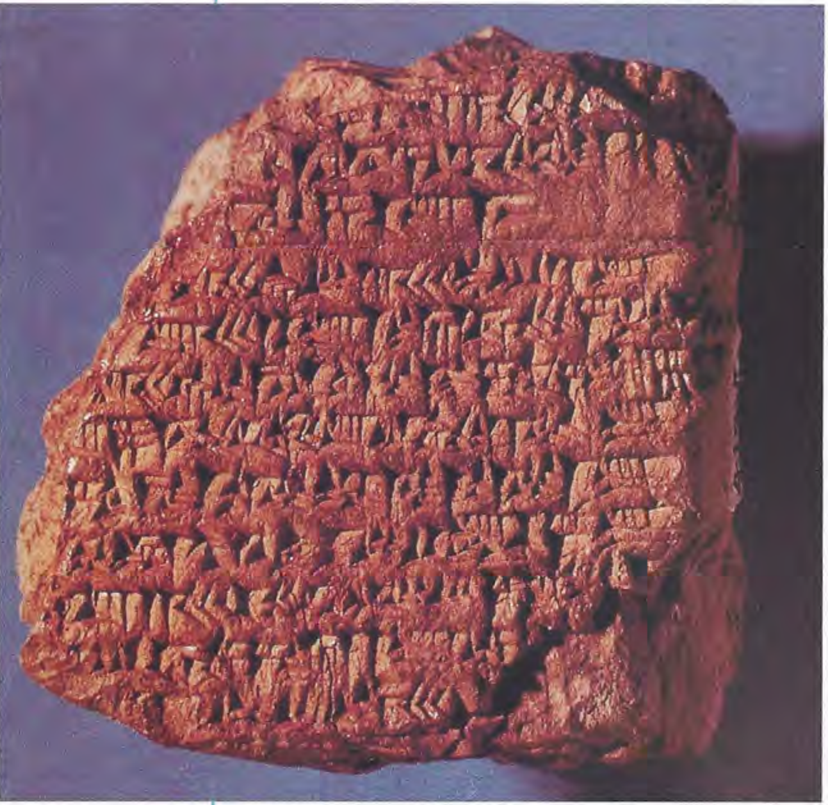
The Earth was formed by the accretion of smaller bodies in the early stages of the solar system, and the random impacts from these smaller bodies must have influenced our planet's spin, as it would be extremely unlikely for all the collisions to balance out perfectly. Among the most significant contributors to our current spin was the collision, between the proto-Earth and a Mars-size object, that gave rise to the Moon. I must add a caveat: none of us was there to see that such a Moon-creating collision took place. Nevertheless, this scenario seems the most plausible of the various ideas that have been proposed to account for the Earth's comparatively large companion. Once the Moon was formed, its gravitational drag acted to slow Earth's rotation and thus gradually increased the length of our days.

We don't know how fast the world spun 4 or 5 billion years ago. The configuration of oceans and continents has changed radically several times over, so the slowing effect of tidal friction has varied drastically. However, it has been possible to get direct evidence of the length of the month over the last 20 percent of geological time, and conservation laws give further constraints. From Utah limestones that contain occasional extraordinary strata of daily tides, and from the pattern of spring and neap tides also recorded in the sediments, paleontologists and stratigraphers have deduced that 900 million years ago the length of the sidereal month, measured against background stars, was 23 1/2 days —4 days shorter than at present—and that the day was little more than 18 hours long.

In the past 2,500 years, during which there have been scattered observations of eclipses to reckon by, the lengthening of the day amounts to 2.3 milliseconds per century. The slowing now typically adds about 1 second per year

The length of a "moonth" in Earth's distant past can be deduced from limestones bearing strata of daily tides. This stone shows the twice-daily tides, which squeeze together at neap tide and spread apart at spring tide. From spring tide to spring tide is one month, or one revolution of the Moon. The count of daily tides shows how many days the "moonth" was about 400 million years ago.

Photograph: Owen Gingerich



The Babylonians divided time into units of 60: 60 minutes to an hour, 60 seconds to a minute, and so on. They documented their time-measuring system on mud tablets inscribed with cuneiform, one of the earliest writing systems. *Photograph: Courtesy of the British Museum*

compared to the standard year, 1820. That is, our days are now each about 4 milliseconds longer than they were nearly two centuries ago, in 1820, and in the 365 days of a year this lengthening adds up to something over a second. On December 31, an extra second will be added before midnight, so don't celebrate early!

Scientists have determined that much of the friction that slows Earth's rotation takes place along oceanic mountain ridges, continental shelves, and especially the Bering Strait. Indeed, today's geophysical methods are sufficiently accurate to detect the change in the Earth's rotation brought about by El Niño warming of the Pacific Ocean. As the warmer atmosphere expands and the winds change, Earth's moment of inertia increases slightly and our planet slows by several tenths of a millisecond per day (a large random effect compared to the slow but continuous deceleration). As the Earth decelerates, conservation of angular momentum in the Earth-Moon system requires that the Moon move farther from Earth, currently at a rate of 3.8 centimeters (1.5 inches) per year.

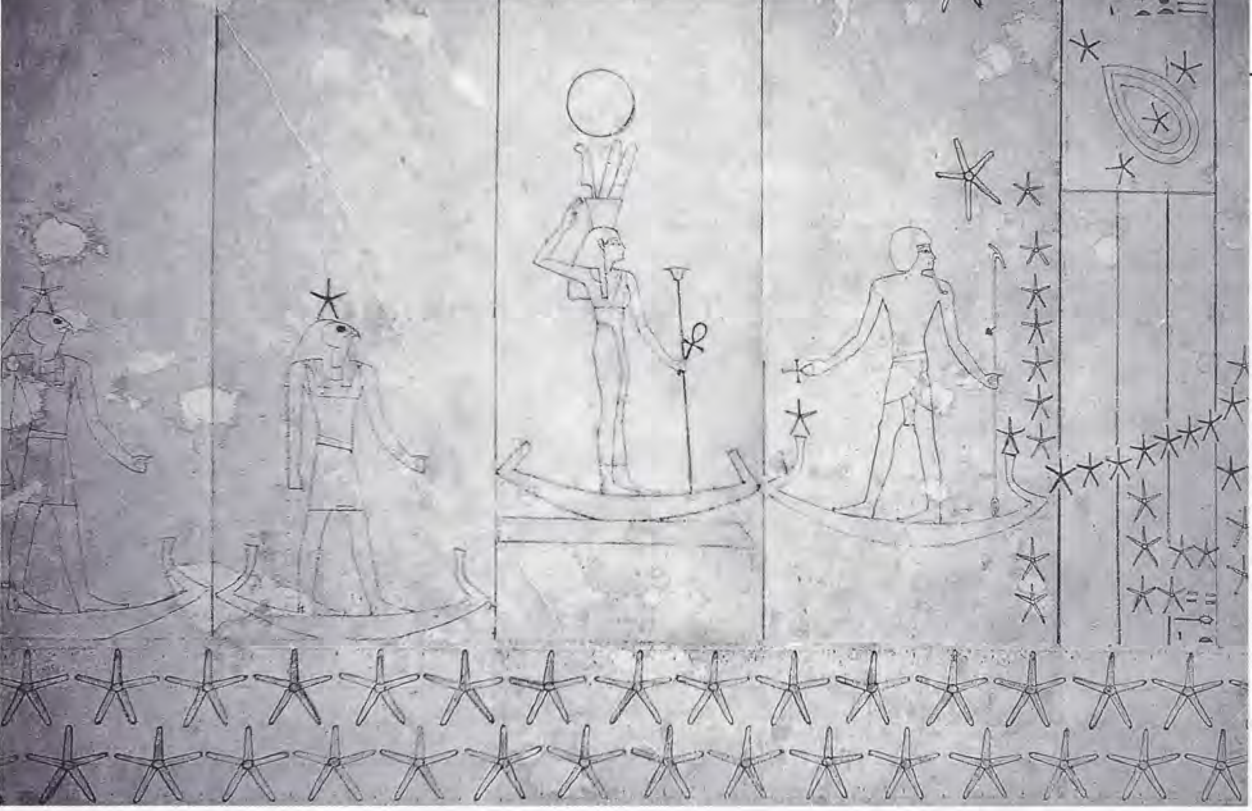
Millennia and the Moon

Our second question—when does the millenium begin?—is bound up with the motion of the Moon, which most primitive societies have used for basic time-reckoning. With the onset of agriculture, a seasonal and therefore solar calendar becomes essential. Unfortunately, with a solar calendar the number of "moonths" in a year does not come out even.

There are 12 lunar months per solar year with roughly 10 days left over. In order to keep a lunar calendar in step with the solar calendar, it is necessary to add a 13th month every two or three years. Two millennia ago, to keep the Jewish calendar in line with the seasons, a committee of the Sanhedrin used to examine vegetation in the spring to determine if the extra month should be added. I have investigated various calendar-calibration strategies, from observing cherry blossoms to tracking bird migrations. According to tradition, the swallows return to San Juan Capistrano (California) each year on March 19, St. Joseph's Day, but two years ago newspapers reported that the swallows had arrived five days early. Apparently, the best date-keeper from natural history is the spotted redshank, a bird that returns for the short nesting season in Finland on May 4 (give or take two days).

Because Easter is timed according to Passover, early Christians depended on the annual report to the Sanhedrin to know when to celebrate. As Christianity spread throughout the Roman Empire, it became increasingly inconvenient to wait for the word from Jerusalem, so at the Council of Nicaea the bishops agreed to regularize the calculation of Easter. This calculation could be done with reasonable accuracy because lunar months and solar years get back in step every 19 years if precisely seven extra months have been added beyond the usual 12 per year. This 19-year pattern, recognized by astronomers of ancient Babylon, is known as the Metonic cycle, after a Greek astronomer who discovered it independently in the fifth century BC. The Athenians liked the idea of the Moon-Sun cycle so much that they erected a statue in Meton's honor, though they failed to reform their lunar calendar!

After the Council of Nicaea, Cyril, a bishop of Alexandria, provided a 95-year table (five Metonic cycles) for calculating



The tradition of dividing a day into 24 hours seems to have evolved, via a convoluted path, from the 36 decans of the Egyptian day. This is the tomb of Senmut in Thebes. The ceiling seen here shows the decans that include Sirius and the constellation we call Orion.

Photograph: Owen Gingerich

the date of Easter. His table ended on the year we now call 531 AD, and the task of extending the table was assigned to a monk named Dionysius Exiguus—that is, Dennis the Short. Dionysius realized that to get a repeatable cycle of the to-and-fro Easter dates he had to multiply together three different cycles: 19 for the Metonic cycle, 7 for the days of the week, and 4 for the leap-year cycle of the Julian calendar, yielding the number 532, the basis for the paschal or Dionysian cycle. Starting his cycle just where Cyril's table left off, Dionysius discovered that 532 years earlier the vernal equinox had coincided with a new moon, which seemed propitious (as pointed out by E. G. Richards in his recent book, *Mapping Time: The Calendar and Its History*).

Marking Off Millennia

It was customary in those days to date events according to the reign of an emperor, and the year 1 was always counted not from the date of coronation but with the first full year of the reign. Dionysius felt that it was inappropriate to count years from the ascension of the Roman emperor Diocletian, a notorious persecutor of Christians, and suggested that his Easter cycle might provide a better starting point. Assuming that Jesus was born on Christmas of the first year of the Dionysian cycle, the new era would start counting with the next year, being the first full year of Christ's life. Whether or not Dionysius believed that Jesus was born precisely then I have not been able to establish, but he knew that his Easter cycle, arranged so that the second cycle would begin where Cyril's table left off, started during Christ's lifetime.

It took two centuries for the Dionysian epoch to begin to be adopted. The Venerable Bede, a redoubtable English calendrist, helped popularize it through his use of the expression *annus Domini* ("year of the Lord") in *De temporum ratione* (*On the Calculation of Time*, 725 AD). Not until the 16th century did Western scholars appreciate that the beginning of the AD epoch did not accurately tally with Christ's birth. In 1583, Joseph Scaliger published his huge treatise on chronology, arguing that Jesus was born at least two years earlier, and a couple of decades later Johannes Kepler proposed a still earlier date.

This brings us to the present controversy of when to celebrate the arrival of the new millennium. Please note that the presence or absence of a year 0 has nothing to do with it and that the absence of zero from the mathematical vocabulary of sixth-century Europe is irrelevant. To clarify the issue, suppose you have 100 dictation cassettes and want to use them in serial order repeatedly. You number them 1 to 100, and when you have used all 100, then you are ready to start again with 1. By similar logic, the third millennium begins with 2001.

But then again, we have the odometer syndrome. The transition from 1999 to 2000, with a row of nines giving way to zeroes, is impressive visually. (If I were the language maven William Safire, I would pause to say that the word *odometer* comes from the Greek *hodos*, meaning "way," and *meter*, meaning "measure," and that the first citation in the *Oxford English Dictionary* is from none other than Thomas Jefferson, who paid $10 for one in 1781.) And then there is the Y2K brouhaha: predictions of chaos—to ensue when computer systems sputter on the millennial zeroes—promise to make January 1, 2000 a highly memorable date. With anticipation building, it is easy to overlook that, in light of modern corrections for the year of Christ's birth, January 1, 2001 will be the 2,000th anniversary of a nonevent. So my bottom line is: why not celebrate twice?

In the complex dance of the Earth and Moon, the length of the month doesn't fit nicely into the length of the year, but this dance, with the partners pulling farther and farther apart, has brought the Moon to just the right distance for full solar eclipses, with the Moon just covering the Sun's disk. Eventually, the Moon will be too far away for this beautiful event to be seen from the surface of the Earth. I've polled the experts, and there's reason for cheer. At 3.8 meters of lunar regression per century, the final total solar eclipse is still 600 million years in the future.

Owen Gingerich is Professor of Astronomy and History of Science at the Harvard-Smithsonian Center for Astrophysics.

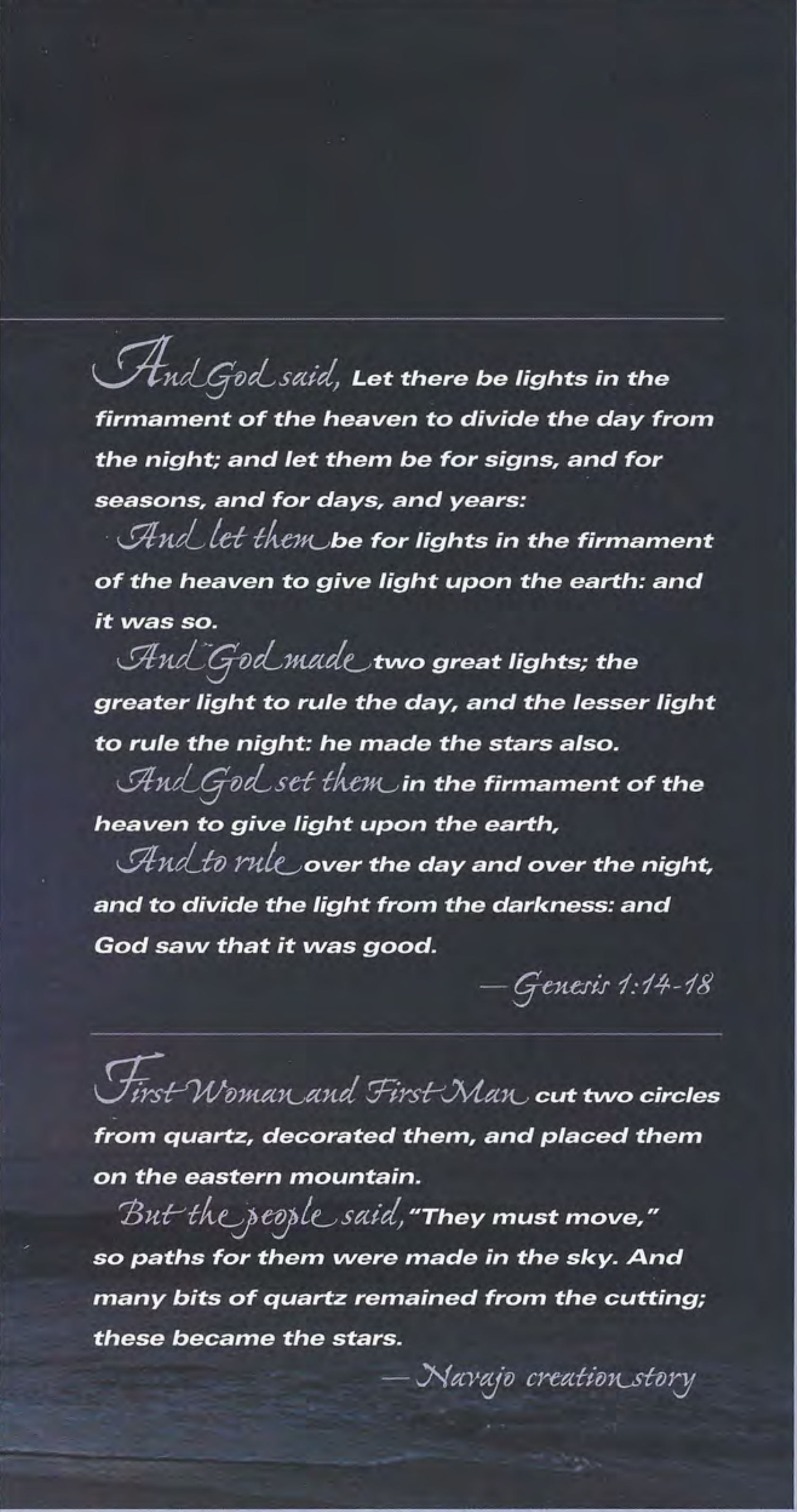
In the Beginning

by James D. Burke

In ancient scriptures rendered into immortal English by the scholars of King James I, in the lovely legends of the Navajo, and in countless other tales spoken and written in every human culture, origin accounts come down to us. Our vision ever evolves as people observe present nature and drive imagination deep into the past.

Even now, commanding a mighty science, we do as our forebears did. We look around us, then look back and wonder about what may have happened . . . in the beginning.

During the reign of James I (1603–1625), a new science was awakening. Galileo raised his telescope to the night sky, exploring the solar system, and saw a miniature solar system—Jupiter and its moons. René Descartes, perhaps observing leaf bits circling on small whirlpools in a brook, with the inner ones moving faster, guessed that the planets



> *And God said,* **Let there be lights in the firmament of the heaven to divide the day from the night; and let them be for signs, and for seasons, and for days, and years:**
>
> *And let them* **be for lights in the firmament of the heaven to give light upon the earth: and it was so.**
>
> *And God made* **two great lights; the greater light to rule the day, and the lesser light to rule the night: he made the stars also.**
>
> *And God set them* **in the firmament of the heaven to give light upon the earth,**
>
> *And to rule* **over the day and over the night, and to divide the light from the darkness: and God saw that it was good.**
>
> *—Genesis 1:14-18*

> *First Woman and First Man* **cut two circles from quartz, decorated them, and placed them on the eastern mountain.**
>
> *But the people said,* **"They must move," so paths for them were made in the sky. And many bits of quartz remained from the cutting; these became the stars.**
>
> *—Navajo creation story*

Our Earth and Moon, two worlds that would not exist as they are without each other, have been locked in their cosmic dance for billions of years. Photograph: B. Kurosaki/InStock Photography

might somehow be caught in vortices around the Sun. Later in the same century, with the discoveries of Isaac Newton, J. D. Cassini, and others, astronomy grew from its mathematical roots into a flourishing observational discipline. Yet always the origin question remained: How old is Earth? How old the stars, the Sun and Moon? How did they come to be?

Let us leap past the rich scientific history of the eighteenth and nineteenth centuries, when motions of bodies in the cosmos were the main subject of astronomy and when geology was born, and arrive now, when at last it is possible to determine the age and provenance of a rock.

A Primordial Disk

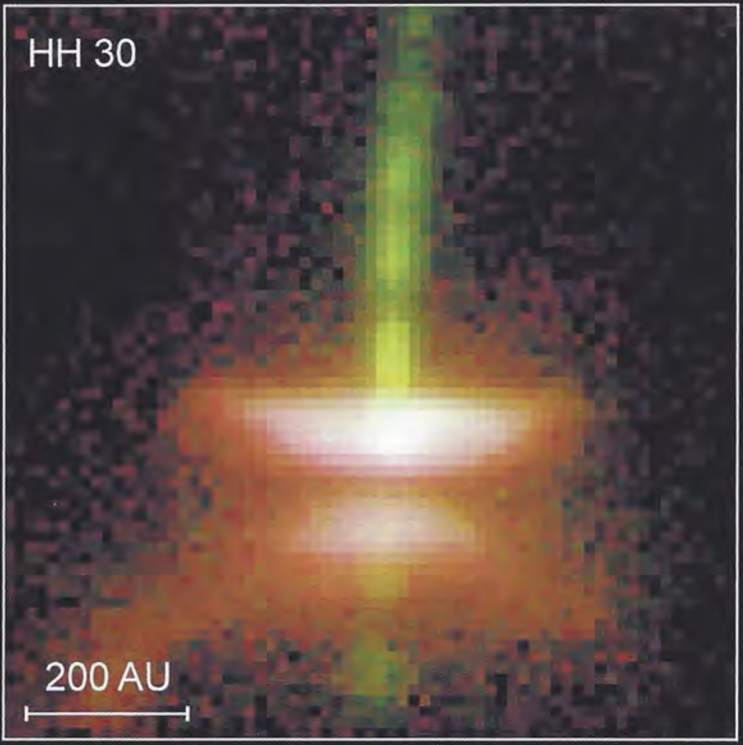
As radioactive elements decay, each at its own characteristic rate, they leave traces in time. By carefully measuring the ratios of certain isotopes as they are found today, one can ascertain how long ago their parent substances entered the structure of a mineral. Over decades of diligent research, much of it involving primeval meteorites, scientists have framed a history of the solar system. Though many questions remain, a general outline is clear: around 5 billion years ago, a rotating cloud of gas and dust began to condense into a disk, called the solar nebula, surrounding the nascent Sun. Very quickly, in terms of cosmic time, objects agglomerated within the disk, gravitationally sweeping up nearby material.

By about 4.6 billion years ago, certain radioactive clocks were set. Some meteorites contain tiny mineral grains whose isotopes are products of the radioactive decay of elements implanted in that ancient past. (Indeed some of these microscopic objects are even older than the Sun.) Mineral textures in certain meteorites show a complex history of assembly, from substances that melt at very high temperatures to others that would not have survived if they had ever been heated.

Why did the nebula take the shape of a disk? Why not a formless blob? In a turbulent cloud, one plane of spin eventually begins to dominate. Objects in orbits inclined to that plane, crossing it from above and below, suffer collisions, losing their up-and-down motion but preserving the component of motion that is in the plane. Reality is far more complex. Particles need not hit each other; they can interact by gas drag, mutual gravity, and electromagnetic forces. But the result is the same. Disks are the natural outcome in systems as disparate as Saturn's rings and the majestic spiral of a galaxy.

In the solar nebular disk, the forming planets went through a complicated adolescence. As scientists assemble the long story, they are weaving a tapestry of ideas from various disciplines, using threads of many colors. From chemistry, we have a model that fits the observed elemental compositions of the inner and outer planets. Bodies of rock and iron, materials which have high melting points, formed in the hot regions close to the proto-Sun. Farther out, where the nebula was cool, great gas balls accumulated.

From the study of minerals, we see the ubiquitous effect of planetary differentiation. Dense substances in a forming planet sink to the core while lighter substances rise, producing a



AU = astronomical unit, the average distance between Earth and the Sun

For over two centuries, the nebular hypothesis has been a leading explanation of how our solar system might have formed. But recently the Hubble Space Telescope has turned hypothesis to fact. In this image, we see the young star Herbig-Haro 30 surrounded by a thin, dark disk, just as predicted in theory. The disk is 40 billion miles across and divides the nebular form in two. We can't see the central star, but its light reflects off the disk, illuminating the reddish nebula. Gas jets blowing out from the young star appear as green streaks. *Image: Chris Burrows and NASA*

layered structure. From studies of electromagnetism, we conclude that the Sun and several planets contain dynamos supporting magnetospheres and driving vast, tangled skeins of solar-wind plasma past the planets. And using the powerful techniques of nuclear physics and mass spectrometry, we can follow the isotopic record of atmospheres, oceans, and rocks into the distant past.

Still, the nebular disk was only a theoretical concept. Then, at a scientific meeting, with the latest mathematical version of the nebula projected on a screen, the speaker called for the next slide (see image above). A gasp, a *frisson* of awe and delight, passed across the audience. There, in an image from the Hubble Space Telescope, was the real thing. Now dozens are known.

Simmering, Writhing, Crackling

Through all of this wonderful scientific progress, though, a grand mystery has remained: what does observation tell us about the origin of Earth and the Moon? From the time of the King James Bible till now, scientists have been exploring Earth, carefully observing the Moon, and building theories about how they came to be.

We have become aware of the enormous time span of geologic history. Mountains wear down, sediments are deposited, then mountains are thrust up again. Living systems have cycled the Earth's inventory of carbon through the atmosphere and oceans, building up an excess of oxygen in the atmosphere. Watery magmas belch from volcanoes and mid-ocean ridges, giving scientists clues to the planet's global tectonics.

Earth is a living planet, not only in the biological sense but also in its vigorous evolution, driven by internal heat. The dense core seethes with electromagnetism, the mantle overturns, continents slide and collide, earthquakes hit and volcanoes erupt, the climate oscillates. Meanwhile, the Moon drives ocean tides that brake Earth's rotation, lengthening our day. Those same tides drive the Moon outward in its orbit, lengthening the month.

Calculating these Earth-Moon changes back in time, scientists were driven to conclude that billions of years ago the Moon must have been very close to Earth—so close that enormous rock tides would have heated the surfaces of both bodies far past their melting points.

Differentiated Moon

There the matter stood until about 15 years ago. Some people believed that the Moon might have been ejected centrifugally from a fast-spinning Earth, and textbooks suggested that the Pacific Ocean basin was the resulting scar. Others held that Earth and Moon accreted independently in the solar nebula and then became gravitational partners. But then a third hypothesis gained acceptance, because it gave a better fit to observations: this was the idea of a giant impact (see the September/October 1997 *Planetary Report*).

In the giant-impact scenario, a body the size of Mars struck the early Earth a glancing blow, throwing out a huge cloud of vaporized material. Much of that material would have fallen back onto Earth, and some of it would have escaped into interplanetary space. A small fraction could have been delivered into Earth orbit, whence it could have formed a disk and then accreted into a hot, dry proto-Moon. Supporting this concept, *Apollo* and *Luna* samples and lunar meteorites reveal that the Moon's material was once molten and that repeated episodes of differentiation have sorted and zone-refined its minerals into a suite of enriched and depleted species. The compositions of Moon rocks betray a long history of complex heating and mixing events, overlain by aeons of destruction and recombination due to impacts.

Perhaps we have come to an agreed-on picture of the cataclysm that formed the Moon, and we have approached an understanding of how Earth gathered its substance out of the solar nebula. But wonderful mysteries remain: how did Earth acquire its oceans and atmosphere? What really controls its climate? Is there a "Gaia," a symbiosis between the biosphere and the rocky planet? What will be the ultimate fate of the Moon? When humans become a two-planet species, will we control nature or will it dominate us? Science has no answers to these questions now, but the never-ending quest lies before us.

And God saw ***every thing that he had made, and, behold, it was very good.***

James D. Burke is Technical Editor for The Planetary Report.

At the time of the big collision that formed the Moon, Earth may not have been fully grown. It may have been easier to blow the future Moon-material off a partially grown Earth. This painting, by the lead author of the original giant-impact hypothesis, shows Earth at that stage, still marked by craters and just beginning to form an atmosphere. Painting: William K. Hartmann

More About the Moon

After the collapse of Apollo and its huge Soviet competitor in the early 1970s, lunar exploration languished for two decades. Now a modest revival is in progress. The Clementine and Lunar Prospector missions returned a splendid harvest of global remote-sensing data, enabling scientists to map the whole Moon's topography, surface composition, and magnetic fields. Meanwhile, using these and ground-based observations, plus theoretical knowledge from a wide variety of scientific disciplines, the lunar scientific community has mounted a renewed attack on the questions posed in the accompanying article.

In December 1998, a conference at Monterey, California covered current thinking about the origin of Earth and the Moon. The program and abstracts for that meeting are on the Worldwide Web: **http://cass.jsc.nasa.gov/meetings/origin98/pdf/program.pdf** (see also **http://lunar.arc.nasa.gov**).

During the heyday of lunar exploration, the origins problem was discussed in the Gordon conferences, a series of summer meetings held in delightful settings in New England. Now, with new observations suggesting that planetary systems are common in the cosmos, a Gordon conference is scheduled for this summer with the title "Origins of Solar Systems" (see the Web site **http://www.grc.uri.edu/**).

While scientific discussions proceed, there is also a revival of interest in new missions. In Europe a consortium is developing Lunarsat (see **http://lunarsat.lrt.mw.tu-muenchen.de/**).

And in the United States, proposals are afoot to send rovers into the Moon's dark polar regions to look for the possible ice deposits indicated by *Clementine* and *Lunar Prospector* (see **http://frc.ri.cmu.edu/mrl/**).

Perhaps in the next few years humanity will again be en route to deeper understanding of our life-sustaining world and its mysterious, beckoning companion.

—JDB

GALILEO: I
Galileo: On to I

by Micha

Left: On December 7, 1995, Gali
600 miles) above the volcanic s
problems prevented the spacec
data from that close encounter.
mission, in February 2000 Galil
of only 200 kilometers (about 1

Right: Two volcan
by Galileo *on June*
kilometers (about 3
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center named after a
Near the termin
you can see the
in every image
Galileo *(since 19*
erupting

The *Galileo* spacecraft is running out of fuel. It is being bombarded by the energetic and penetrating particles of Jupiter's magnetosphere. *Galileo* is getting old. And yet there is growing excitement among mission planners: long-awaited scientific operations at Io and the prospect of joint maneuvers with *Cassini* loom ahead as the mission moves toward a dramatic conclusion. A mortal struggle to eke out the maximum scientific return from the *Galileo* enterprise will be played out over the next 17 months.

When the spacecraft first arrived at the Jupiter system in December 1995, it passed only 900 kilometers (about 560 miles) above the surface of Io, taking the full brunt of the radiation environment and demonstrating that it could operate in these extreme conditions. If there had been no other contingencies to deal with, we could have taken some great images and other readings of Io's volcanic vents and lavas—geologic processes at work on an alien world. Geologic, photometric, and spectroscopic measurements of the volcanic terrains, of gases and other effluents in the volcanic plumes, and of mountains would have been richly detailed. Because of a last-minute, almost disastrous malfunction of the tape recorder—just as the spacecraft began its final approach to Jupiter—we had to scrub camera operations so that they would not interfere with the return of critical data from the Jupiter atmospheric probe.

Now, after nearly four years of splendid discoveries from a safe distance near and outside the orbit of Europa, it is time for the spacecraft to return to the vicious environs of Io. Not one, as originally planned, but three close encounters with Io will provide a fitting climax to one of NASA's most technically challenging endeavors. We will push the spacecraft well beyond its design limits for radiation, so that every consumable resource on board is used to produce the best science possible.

In a gesture of support for future space exploration, the *Galileo* mission team is working out plans for cooperative

O CASSINI

o and Cassini

l J. S. Belton

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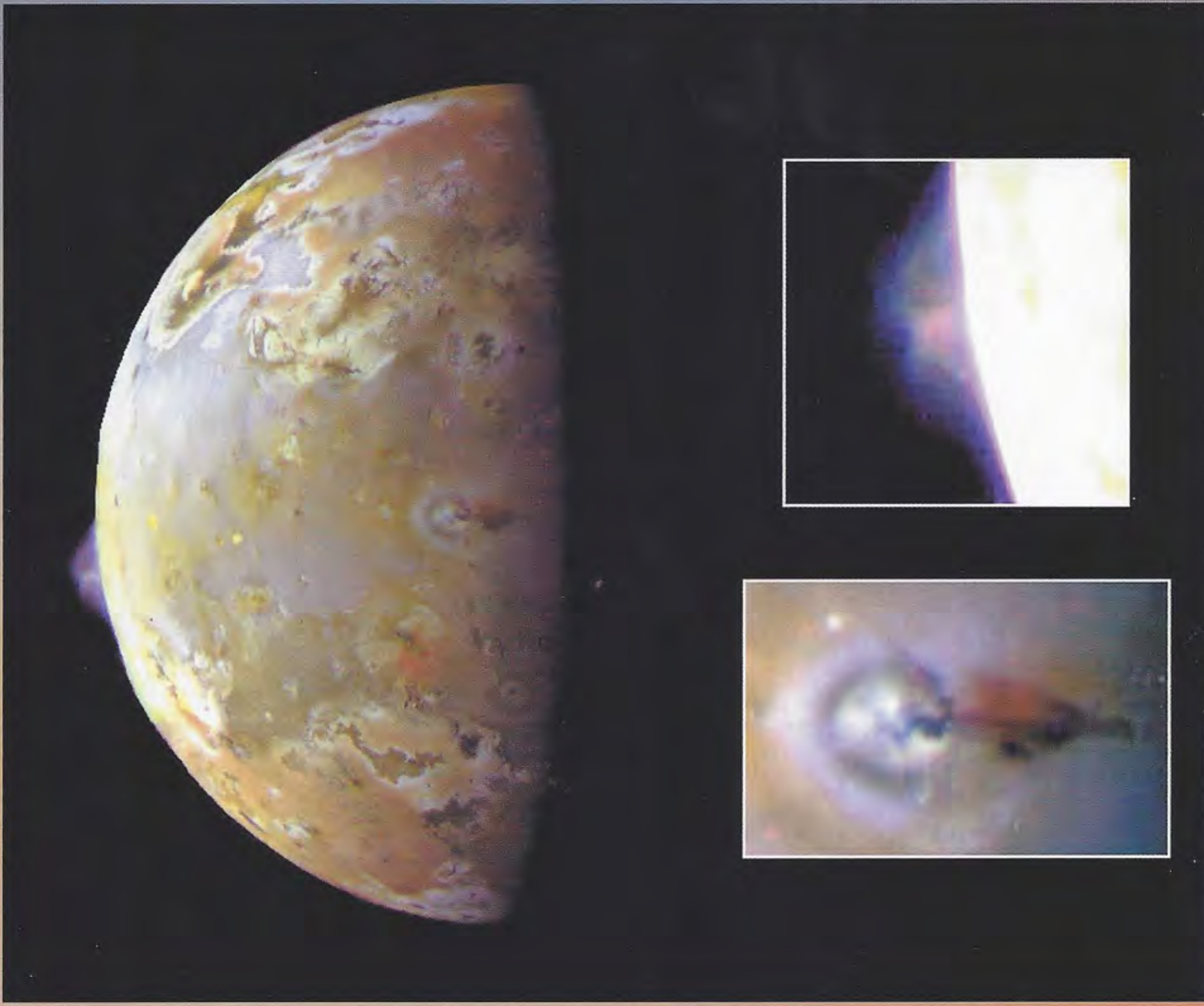
rface of Io. Unfortunately, technical
aft from collecting valuable scientific
As part of the final extension of its
could travel by Io at an altitude
5 miles). Painting: David A. Hardy



c plumes erupt from Io in this image taken
3, 1997 from a range of more than 600,000
73,000 miles). At center left, on the moon's
e the plume from Pillan Patera, a volcanic
South American god of fire and volcanoes.
tor (the boundary between day and night),
ume of Prometheus, which appears active
of the area taken by Voyager (in 1979) and
5). It's possible that Prometheus has been
continuously for 19 years. Image: JPL/NASA

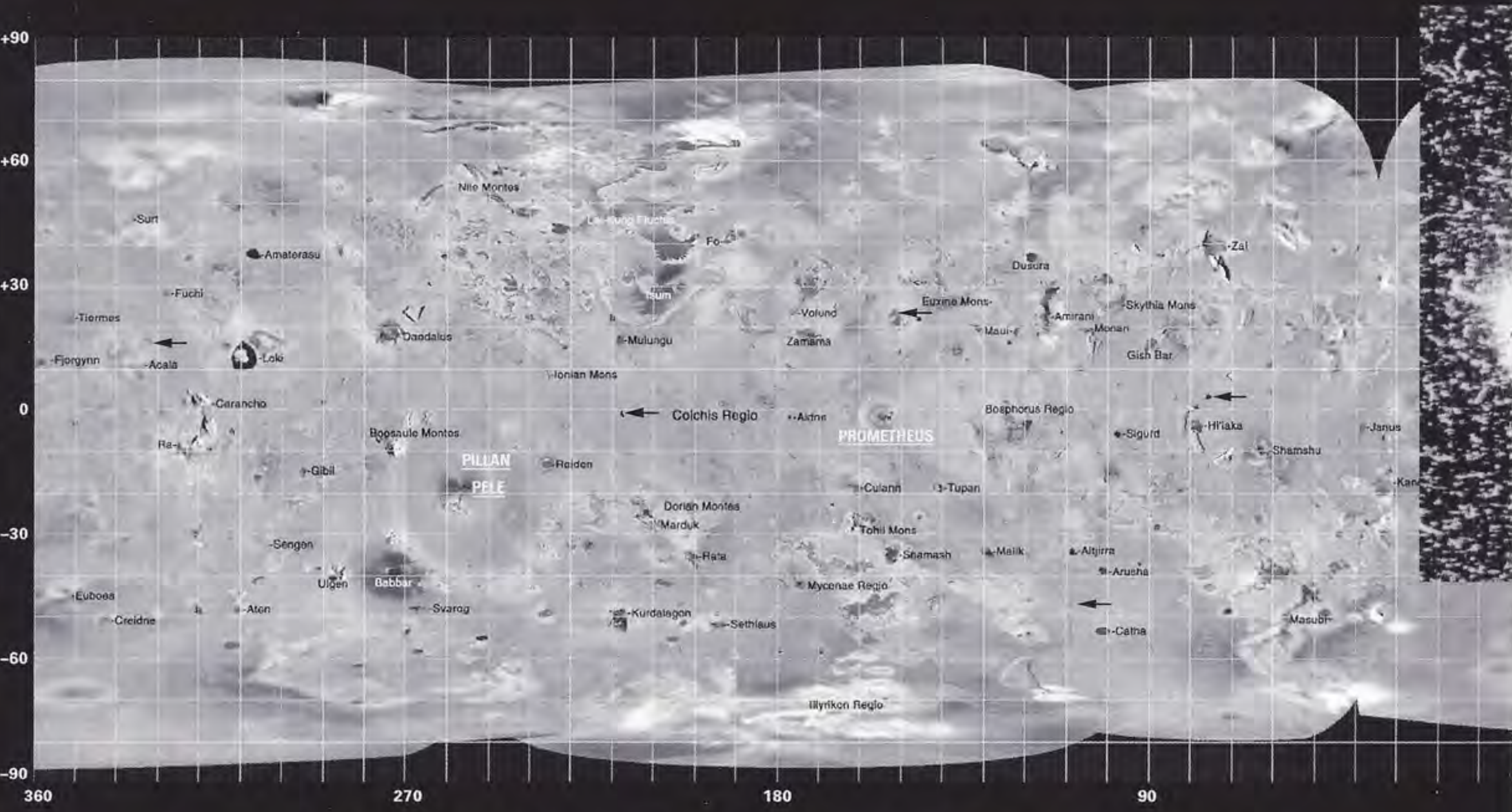
investigations with *Cassini*, which is en route to Saturn and Titan. In addition to producing good science, these operations will serve as a symbolic passing of the baton in outer-planet exploration.

Beyond the Primary Mission

Galileo completed its primary mission in December 1997, having successfully inserted a probe into Jupiter's atmosphere and carried out explorations of Jupiter's magnetosphere, rings, and satellites. The spacecraft now operates under a mission extension called the *Galileo* Europa Mission (GEM), also known as "Fire and Ice" (see the January/February 1998 *Planetary Report*). The "Ice" part of the extended mission, focusing on Europa and the liquid-water ocean that may lie beneath its frozen crust, ended in February with a flyby of the satellite during *Galileo*'s 19th orbit around Jupiter.

In the transition to "Fire," the spacecraft will execute four encounters with Callisto, the most massive of the Galilean satellites, which will send the spacecraft progressively deeper into Jupiter's radiation belts until it can again fly close to Io on orbits 24, 25, and 27. Akin to testing the water with one's toe, these transition orbits may well be the riskiest. With each orbit's perijove (closest approach to Jupiter), the radiation dose is predicted to rise steeply, increasing the level of noise in any measurements and increasing the probability of an abrupt failure of the spacecraft. Meanwhile, with every maneuver, the fuel tanks come closer to empty.

After the spacecraft was first injected into orbit around Jupiter, it had 110 kilograms (about 240 pounds) of hydrazine fuel left in its tanks. The primary mission used 50 kilograms (110 pounds), and after GEM, a mere 40 kilograms (about 90 pounds) remained. To reach the rendezvous with *Cassini*, we may use every remaining drop of this fuel. We cannot calculate fuel consumption precisely because there are always small, unpredictable errors in the spacecraft trajectory and satellite positions, and there are uncertainties in each firing of



Scientists made a mosaic of highest-resolution images of Io to produce this map of the volcanic moon. Io's main geologic features are called out by name, and several active but as-yet-unnamed volcanic centers are marked with arrows. *Map: University of Arizona*

the rocket engine. We cannot say for sure whether on the last orbit there will be fuel to spare or the tanks will run dry.

Radiation Environment

The spacecraft's ability to endure radiation is similarly unpredictable. High-energy radiation penetrates into the body of solid-state electronic components, creating electrical charges and, sometimes, causing dislocations in the atomic structure of their materials. The effects may range from transient noise in scientific data to physical damage that could disable electronic components, which could mean the loss of important spacecraft functions. It is possible that a damaged system could issue spurious signals, possibly endangering the spacecraft.

So far, *Galileo* has seen plenty of evidence of radiation noise in scientific data. For example, long-exposure images of Io taken during eclipse are speckled with its effects. This noise is proportional to the level of the ambient radiation, which may fluctuate significantly from one occasion to the next. At Io, the radiation is so intense that we expect that fully half the picture brightness will be due to radiation noise. If we are lucky, the radiation levels could be much lower than that and the close-up images will be of exceptional quality. If we are unlucky and the radiation is abnormally intense, the pictures could be entirely wiped out.

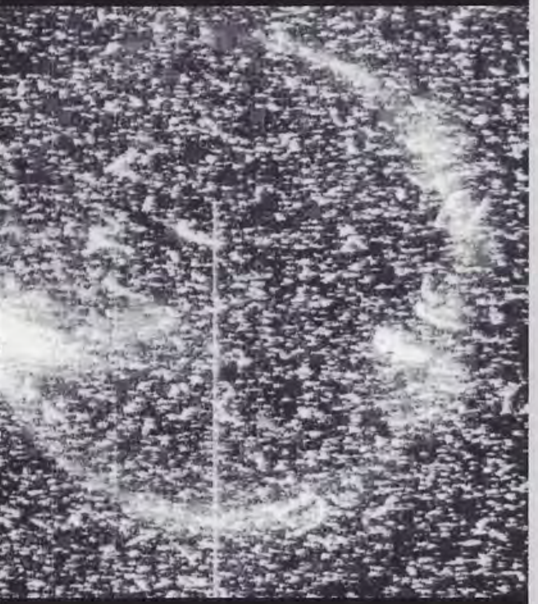
Instances of radiation damage to the spacecraft have been thankfully few. However, there is evidence of degradation in the attitude-control system. After 11 perfect orbits during the main mission, we began to see the spacecraft occasionally become confused and automatically "safe" itself, which resulted in the loss of scientific data from two encounters of the "Ice" orbits. Although it cannot be directly proved, the accumulating exposure to radiation is the most likely cause. And so, as the *Galileo* endeavor moves toward its conclusion, the spacecraft finds itself locked in a death struggle, as it were, with increasing effects of radiation, dwindling fuel, and pervasive uncertainties.

Flight Plan for Io and Europa

The challenge at Io is to return the maximum amount of high-quality data from three close encounters, each closer than the one before, at altitudes of 575, 300, and 200 kilometers (357, 186, and 124 miles). Two of the Io encounters, during *Galileo*'s 24th and 27th orbits around Jupiter, will be passes at low latitude, while the encounter on the 25th orbit will follow a trajectory over high latitudes near the moon's south pole.

The geometry of the flybys is difficult. The spacecraft will approach Io from the night side each time. The camera must "shoot through the booms" of the rotating part of the spacecraft to take images on approach. During close approach, the observing platform has to slew rapidly to pick up the prime volcanic targets at high resolution. As the spacecraft departs over the lit hemisphere, the pointing system must turn again near the direction of the spacecraft's rotation axis, an orientation where even small changes in angle can be difficult. While all of these problems can be overcome, the solutions usually require a trade-off in the quantity and possibly the quality of acquired data.

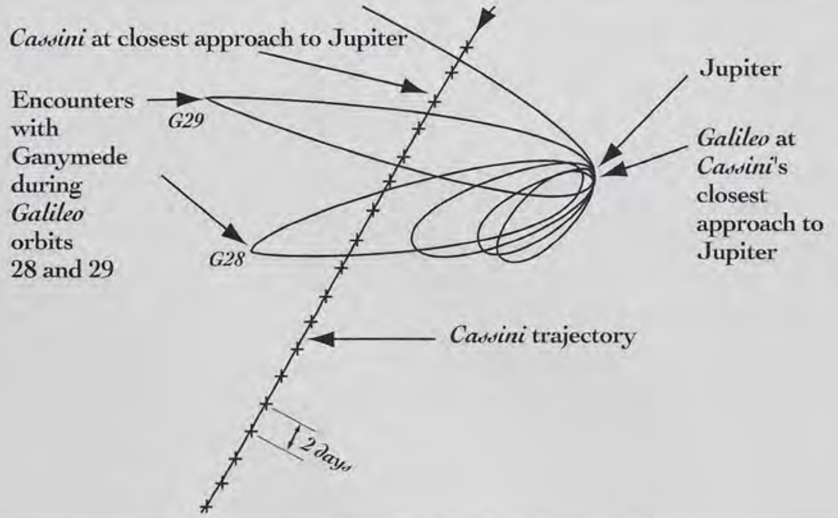
Getting the data back to Earth is another challenge. In the 25th orbit, the interval from the Io encounter to the next encounter is 38 days—only enough time to play back



Io in eclipse by Jupiter does not present a pretty picture. However, this 6.3 second exposure does show the dramatic effects of magnetospheric radiation on* Galileo*'s cameras. Because of the long exposure, the glowing volcanoes appear as shapes resembling check marks, as do stars outside the circle that is Io. But the rest of the glitches are due to radiation. During the coming close encounters with Io,* Galileo *will be exposed to even more intense radiation, which may dominate its images.

Image: Galileo Solid State Imaging Team

Galileo and *Cassini* Trajectories



Galileo's Encounters After GEM*

Orbit	Main Target	Date	Altitude Kilometers	Altitude Miles	Notes
C20	Callisto	May 5, 1999	1,315	817	Approach Io torus
C21	Callisto	June 30	1,047	651	Approaching Io's warm torus
C22	Callisto	August 14	2,295	1,426	Reaching outer torus
C23	Callisto	September 16	1,057	657	All magnetospheric observations
I24	Io	October 11	611	380	
I25	Io	November 26	300	186	Europa encounter included
E26	Europa	January 3, 2000	374	232	Europa magnetic field
I27	Io	February 22	200	124	
G28	Ganymede	May 20	900	559	
G29	Ganymede	December 28	1,000	621	In eclipse by Jupiter

Joint operations are proposed with *Cassini* as it encounters Jupiter on December 30, 2000.

*GEM = *Galileo* Europa Mission

a fraction of the data. To complicate matters, there will be Europa data on the tape competing with the Io data for precious playback time. The Europa data, gathered from a one-time-only opportunity to image the moon's Jupiter-facing hemisphere, are of high scientific interest, allowing us to test current models of how the moon's ice shell responds to tidal forces. The data-playback dilemma, yet to be resolved, may affect plans for the next encounter, which is at Europa.

The Europa encounter (coming later in orbit 25 than the Europa imaging just mentioned) has great significance for determining whether the moon has a subsurface ocean, because the unique geometry of the encounter should allow *Galileo*'s magnetometer to determine the strength of Europa's induced magnetic field (for details on magnetometer evidence in studies of Jovian moons, see the May/June 1999 *Planetary Report,* page 11). The magnetometer will certainly be the focus of the Europa encounter during orbit 25. Teams managing other instruments may decide to forgo observations so that data remaining from the Io encounter can also be returned.

Io's Volcanic Terrains

The scientific opportunities during *Galileo*'s last encounters are awesome. At Io, the spacecraft will fly slightly north of the moon's most powerful volcano, Pele. Seen just before dawn, the source regions of its plume and lavas will glow incandescent against the dark surface, still in the shadow of night. Will we see fire fountains, sinuous flows of molten lava, and lava ponds and lakes? No one knows what answers we will find when *Galileo* begins to explore the volcanic vents of this fiery moon at high resolution.

Prometheus, a different type of volcano, will be seen in daylight and is scheduled to receive intense study. We know that massive changes in the distribution of lava flows and in the position of the main vent have taken place since *Voyager* times. From comparisons of new and old flows, there will be much to learn about how volcanoes resurface Io. As we fly over Io's south pole, we will have a special view of the plume emanating from Prometheus. It will be seen from the side, and we may be able to study the ways in which gas and solids in the plume leave the vent.

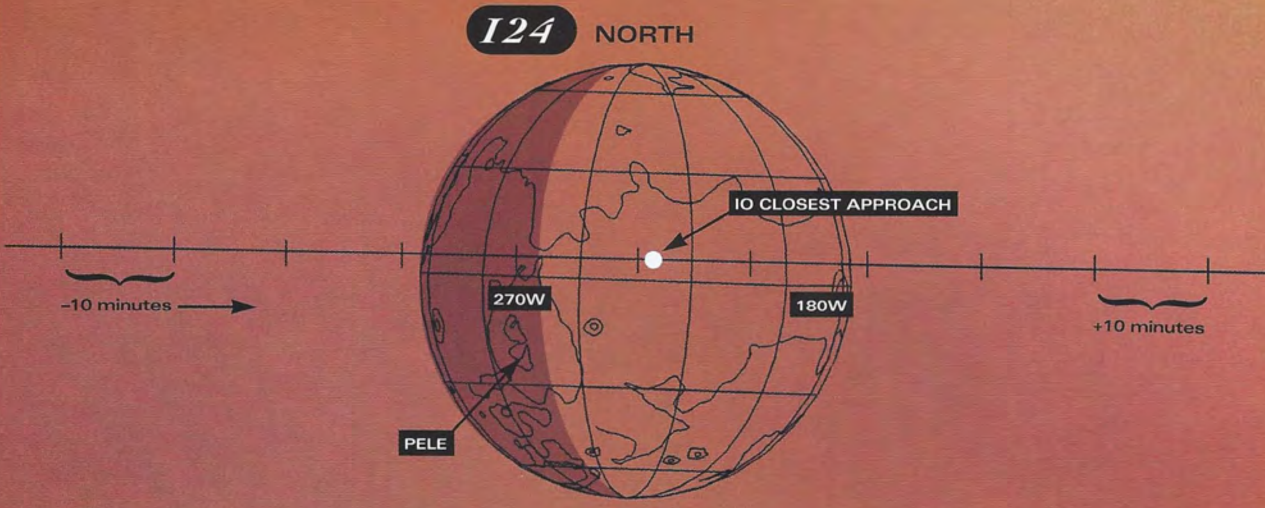
Between these two enormous volcanoes is a landscape littered

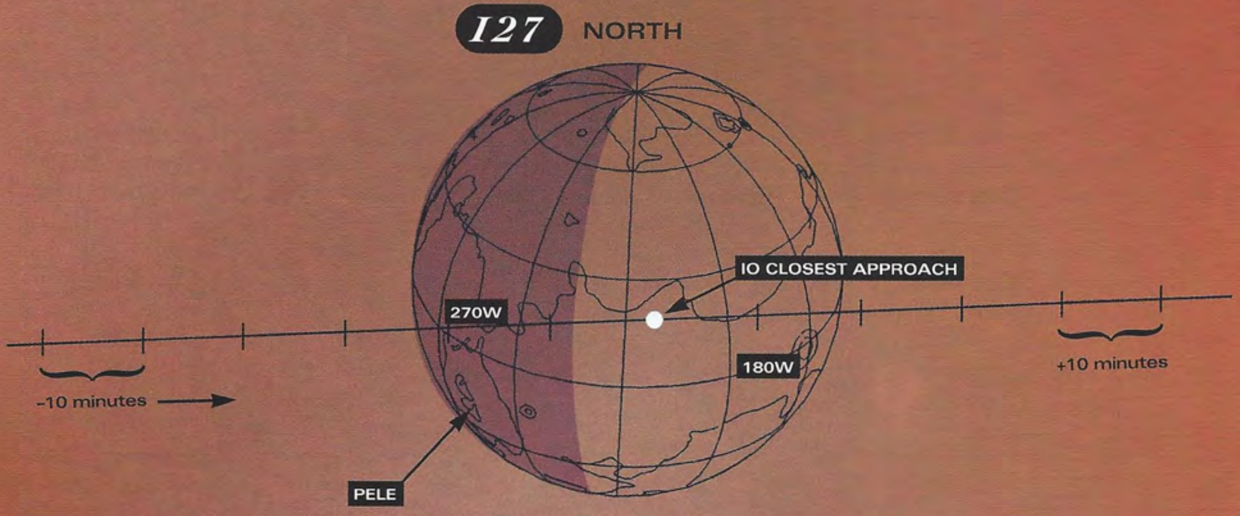
Galileo will have three close encounters with Io, designated I-24, I-25, and I-27. The numbers refer to the spacecraft's orbits around Jupiter. On October 11, 1999, Galileo will approach Io from its nightside and then pass 611 kilometers (380 miles) above its daylit surface. The lavas of Io's largest volcano, Pele, will glow in the predawn darkness. As the spacecraft recedes from the satellite, it will look down on the long-lasting eruptions of Prometheus.

Galileo's I-25 closest approach will be at an altitude of 300 kilometers (186 miles), traversing the moon's south polar ionosphere and offering views of uncharted terrain.

On February 22, 2000, Galileo makes the closest pass of the mission to Io. At only 200 kilometers (124 miles) above the surface, the spacecraft will be in position to return spectacular views of lavas and vents of the volcanoes Pele, Pillan, and Prometheus.

Diagrams adapted by B. S. Smith





with tempting geological targets, such as Pillan, a volcano that showed signs during orbit 10 of having erupted a few months earlier. Also of interest are mountains and layered and fretted terrain that have suffered some kind of large-scale erosional process. We would like to have a closer look at an unnamed region with a greenish tinge, known to members of the imaging team as Io's "golf course." The discovery that Io's lavas commonly have extremely high temperatures ensures that we are observing siliceous volcanism and that the crust of Io is some kind of basaltic rock. In the last encounters, we should be able to find out how these materials are laid on the surface and how the sulfur and sulfur-dioxide frosts that cover them are deposited and recycled.

Ganymede and Cassini

On its way to rendezvous with *Cassini* on December 30, 2000, *Galileo* will have two close encounters with Ganymede. We are fairly sure that this moon, not visited since *Galileo*'s eighth orbit, has a permanent magnetic field, a tenuous atmosphere, and a surface shaped by global tectonic processes, which were active when its interior differentiated and formed a metallic core. High-resolution studies on the 28th orbit will complement earlier examination of other regions, allowing us to test and extend our ideas of Ganymede's geologic history. Ganymede will be in eclipse by Jupiter at the final encounter of the mission, which presents an excellent opportunity for investigating any auroral phenomena that may occur in its atmosphere near the magnetic poles.

Meanwhile, *Cassini* is headed for Jupiter on its way to Saturn, and current plans call for the spacecraft to take measurements of Jupiter's plasma environment, atmospheric features, satellites, and rings. If all goes well, *Galileo* will carry out experiments in coordination with *Cassini*. During the proposed tandem operations, *Galileo* will be much closer to the planet most of the time. We expect these observations from the two spacecraft to be highly synergistic, producing knowledge we would not attain from either spacecraft alone. Early in the rendezvous, *Galileo* will make particle and fields measurements from deep within Jupiter's magnetosphere while *Cassini* samples the outer boundaries of the magnetosphere, which is buffeted and shaped by the solar wind. Later on, the two spacecraft will reverse these roles.

At Jupiter, *Cassini* cameras will take movies of changes in atmospheric features over extensive intervals, while the *Galileo* camera and other instruments will make appropriately timed measurements much closer in and extend the movies. Together these observations should help us understand how atmospheric features on Jupiter originate and evolve.

Begun in 1977, the *Galileo* mission has seen many trials: launch delays caused by the *Challenger* explosion, the failure of the main antenna, restriction in the operation of an ailing tape recorder, the risky establishment of new operating software in the flight computers. All of these challenges have been overcome, and the gallant spacecraft has carried on a brilliant campaign of scientific discovery—from Venus, the Moon, the asteroids Gaspra and Ida. From Jupiter, *Galileo* has reported back on the death of a comet, on the descent of the first probe into the Jovian atmosphere, on Jupiter's magnetosphere and Io's torus, and on encounters with the icy Galilean satellites. Now *Galileo* squares up to its final trials: the hellish environment of Io and the chance to do unprecedented investigations jointly with *Cassini*. One of the most spectacularly successful explorers ever to leave home, *Galileo* hastens to its destiny.

Michael Belton is an astronomer at the National Optical Astronomy Observatories in Tucson, Arizona. He has devoted a large part of his career to space exploration, participating in the Mariner Venus-Mercury *and* Voyager *missions. He has led the* Galileo *imaging team since its inception.*

On December 30, 2000, Cassini will fly by Jupiter in a final gravity-assist maneuver to gain the velocity it needs to reach the Saturn system. If all goes well, it will also "meet" Galileo, the spacecraft that has been exploring the Jupiter system since 1995.

Painting: JPL/NASA

News and Reviews

by Clark R. Chapman

Three years ago, following a dramatic Washington press conference, headlines blared that fossil life had been found in Martian meteorite ALH84001. Many scientists reacted skeptically and have since advanced contrary evidence. The proponents of life in the Mars rock have stiffened their stance, maintaining that their original arguments were sound. In fact, their article in *Science*, entitled "Search for Past Life on Mars: Possible Relic Biogenic Activity . . . ," was very cautious indeed. (Note the word "possible.")

Indeed, the concluding paragraph admitted that "None of these observations is in itself conclusive for the existence of past life" and that "there are alternative [that is, nonbiological] explanations for each" of the lines of evidence developed by the authors. It was only when the lines of evidence were taken together that David McKay of the Johnson Space Center and his colleagues concluded that "they are evidence for primitive life on early Mars." Note: "evidence for," not "proof of."

In the May 4 issue of *Eos*, a weekly newsletter of the American Geophysical Union, Allan Treiman of Houston's Lunar and Planetary Institute offers a fresh perspective on the controversy. Two years of follow-up studies by numerous research groups around the world have made ALH84001 the most intensively studied rock ever. How do the original conclusions of McKay and colleagues stack up? What has been learned about life on Mars?

Many people rejected the McKay group's conclusions from the outset, arguing that the reported evidence—even if it were 100 percent valid—failed to meet the test that extraordinary claims require ironclad proof. That Saganesque dictum is usually applied to hypotheses that run counter to accepted paradigms. Yet the existence of life on Mars at some time in that planet's history—while profoundly fascinating, if true—has been and remains generally accepted as a plausible possibility. Why shouldn't four independent, circumstantial lines of suggestive evidence permit McKay and colleagues to reach the qualified conclusion that they did? Many people have been convicted in courts of justice on weaker evidence.

Intense Scrutiny

After three years it is clear that the specific claim of the McKay group has failed to measure up. By their own criterion, that four intriguing phenomena *taken together* provide "evidence for primitive life," the proponents should be obliged to reassess their case.

As Treiman summarizes the situation, only part of one of the four lines of evidence remains strongly suggestive (*some* of the microscopic magnetite particles may be best explained as produced by bacteria; the associated evidence involving iron sulfides was always weak, according to Treiman). Polycyclic aromatic hydrocarbons (PAHs) in the rock, touted by McKay and colleagues as suggestive of life, are now widely regarded as common contaminants (on both Earth and Mars), often of nonbiologic origin. And there is controversy about whether the carbonate globules, in which the other evidence was found, were formed at temperatures conducive to life or instead under conditions that were much too hot for life; clearly McKay's conclusion about the implications of the carbonates has been weakened.

Finally, there are the intriguing "bugs" themselves: photographs, magnified 50,000 times, of "bacteria-shaped objects" in ALH84001. While these segmented ovoids appeal to the visually oriented public (more so than "wiggles on graphs," according to Treiman), few biologists ever took them seriously. They are much smaller than terrestrial bacteria, often with too little volume to contain even the minimal amount of DNA and proteins required for biological processes. Finally, it was demonstrated that similar features are produced unavoidably, by abiotic processes, during preparation of samples for analysis in the laboratory.

Science Evolves

All told, we're down to one or two items suggestive of life, not four. And few scientists now think that it adds up to convincing evidence for fossil life on Mars. But that doesn't mean that the original paper was "bad science," nor does it even lessen the case for life on Mars.

Few papers in the history of science have been subjected to such overwhelming scrutiny by researchers, armed with the most sophisticated laboratory instruments. Science is an evolving, self-correcting approach to understanding, so the 1996 *Science* paper could hardly have been expected to survive intact.

The specific evidence for past life in ALH84001 now seems less secure. But nothing learned from analysis of the rock rules out past life, in contrast to the *Viking* lander experiments of the mid-1970s, which were eventually interpreted as ruling out life in the surface soils of Mars.

If anything, renewed interest in Mars—spawned in part by the McKay group's announcement—has led to better understanding of the nature of microbial life and of the range of Martian environments. The chances for eventually finding Martian life (whether fossilized or still living) seems better than ever.

The Mars rock mainly has proved to be a mirror in which scientists and laypeople alike see reflected their hopes or doubts about the prevalence of life in the universe.

Clark R. Chapman is a planetary scientist in the Boulder, Colorado Department of Space Studies of the San Antonio-based Southwest Research Institute.

World Watch

by Louis D. Friedman

Washington—For fiscal year 2000 (which begins October 1, 1999), the US administration proposed a $13.6 billion budget for NASA. As we noted in the May/June *Planetary Report,* and in a letter to all our members, this is the eighth straight year in which NASA's budget has been reduced. Our letter to Society members called for action, asking you to tell Congress, "Enough! No more cuts."

Two programs at NASA appear destined for severe cuts no matter how good or bad the final congressional action. Under the budget knife are funding for research and technology and for science on the Deep Space Network. The latter is facing a 50 percent cutback, which will effectively cancel all radar observations by the tracking antennas, including observations of near-Earth objects (NEOs). Without radar tracking, there will be a huge gap in the world's capability to monitor NEOs.

The budget cuts to science will further decrease our ability to conduct data analysis and research and technology development, and there is real concern about the loss of national (and international) capabilities, which have been built up over the last several decades.

Discussion abounds in Congress and among space-interest groups about commercialization as a remedy for the NASA funding shortfall—letting the private sector do it. Whatever "it" is, it certainly is not long-range research and technology development, nor is it planetary exploration and science. In fact, the Deep Space Network's troubles relate directly to commercialization, as funds NASA hoped to generate from the private sector never materialized.

Many commercialization proposals remain illusory. After 40 years in space, only one area of enterprise—communications—has found a successful commercial market independent of government support.

On the other hand, international cooperation has proved a significant source of cost savings. Success in this area is under attack by commercial interests. Last year, the House Science Committee tried to pass legislation that would have impeded the launch of government space-science missions on non-US launch vehicles. The Planetary Society led a successful fight to block the provision, but now the same committee is trying once again to pass legislation that will impair international cooperation on NASA missions.

The new legislation would require NASA to publish all proposed international agreements and then wait 45 days before proceeding. With today's mission schedules increasingly limited, the notification process could be a bureaucratic kiss of death. We are fighting this proposal too, for fear it could destroy the international plan for a Mars sample return, which is based on a partnership among the US, France, and Italy (see "Building Toward Mars" in the March/April 1999 *Planetary Report*).

The House Science Committee did add $10.5 million for NEO observations. However, this funding is not really needed because of new and highly productive cooperative programs between NASA and the US Air Force, relying on existing facilities instead of building new ones. The boost in funding would be valuable if it could be directed to international programs. Additional resources are needed for observations of approaching NEOs in the Southern Hemisphere. There are many follow-up observations that scientists in developing countries could work on. However, the $10.5 million cannot be used for these purposes. Recognizing the need, the Planetary Society has emphasized international programs in its Gene Shoemaker NEO Grants program.

Members of the Planetary Society can make a difference on these issues and others by sending letters and e-mail to their representatives in Congress. Much work remains before NASA's budget is resolved. If you can't reach our Web site, call our office and we'll send you information by mail.

Brussels—The science ministers of the European Space Agency met in mid-May and provided good news for planetary exploration. The ministers positively endorsed the *Mars Express* mission, an orbiter scheduled for launch in 2003. However, they also continued the freeze on the space-science budget. Space science was singled out for the freeze—spending on the International Space Station and on nascent commercial applications increased.

Also supported was a space telescope, known as FIRST-Planck. FIRST is an acronym for Far-InfraRed and Submillimeter Telescope. It is scheduled for a 2007 launch. The funding for *Mars Express* and FIRST-Planck came from a one-time extra allocation of $43 million over the next four years.

Mars Express now looks secure, and development has started. It may include a lander, *Beagle II*, being developed in Great Britain. Proponents are seeking support from the British government and the private sector.

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

Questions and Answers

Venus has significantly more atmosphere than Earth although it has slightly less gravity and a much higher temperature. What determines the maximum atmospheric carrying capacity of a terrestrial planet? And then what determines how close a planet will come to that capacity? How close are Venus, Earth, and Mars to their maximum capacities?

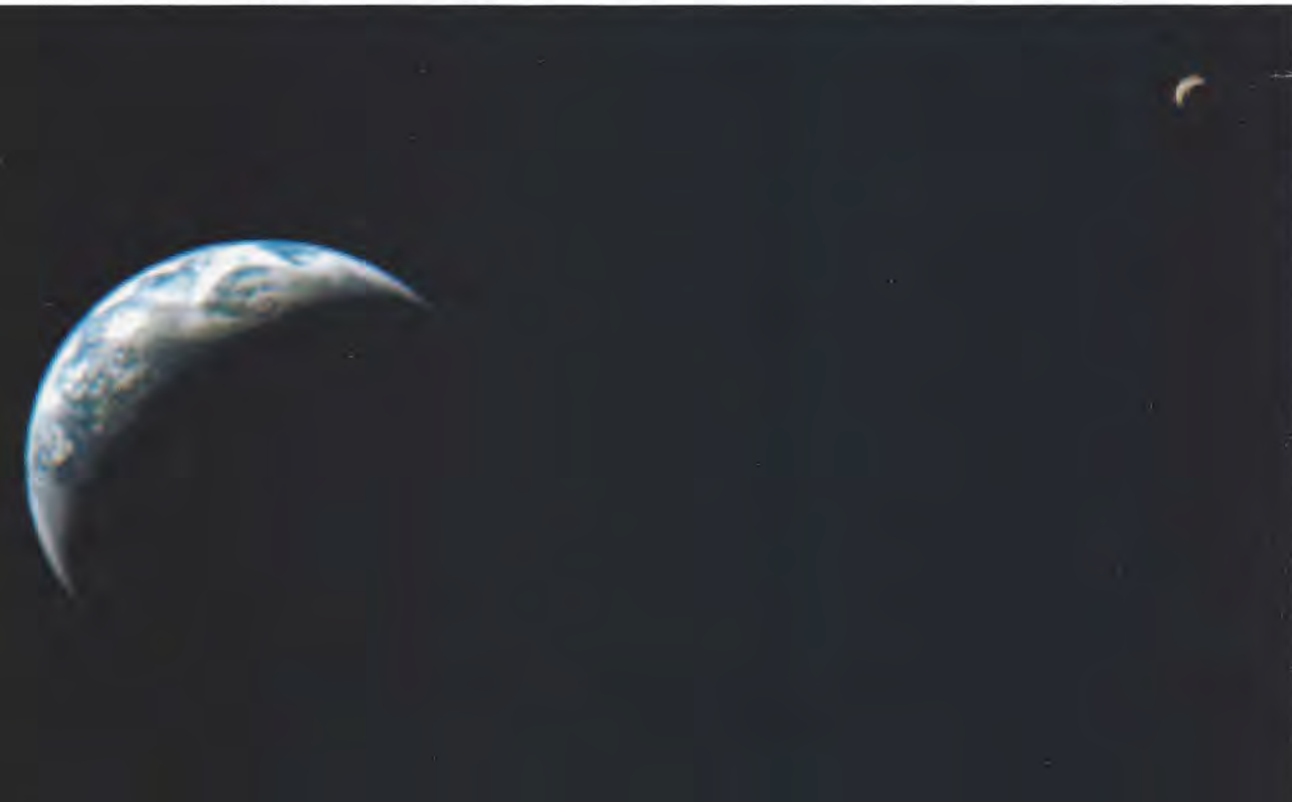
—Bob Barauskas,
Philadelphia, Pennsylvania

Everything else being equal, a planet with low gravity and high temperature will have less atmosphere. Mercury and the Moon are good examples. Gas molecules move faster when they are hot, so they are more likely to reach escape velocity—especially if the escape velocity is low, as it is for a small object with low gravity. Being near the Sun makes things hot, but it also exposes an atmosphere to erosion by the solar wind. Mercury and the Moon have thin, transient atmospheres that are probably supplied by comets and other things crashing into their surfaces. The molecules of such an atmosphere are eventually lost to space or trapped in cold, sunless craters at the poles.

But everything is not equal, and escape of individual gas molecules from the top of an atmosphere is not the whole story. Only some compounds are vapors at planetary temperatures, and the total inventory of these volatiles is important. So are the chemical reactions that link these volatiles to the planetary crust and interior. Each element is different and is controlled by a different process. So, even though the atmospheres of terrestrial planets are made primarily of the same four elements—hydrogen (H), oxygen (O), carbon (C), and nitrogen (N)—atmospheres differ enormously from planet to planet.

On Earth, the most abundant volatile is water. If Earth were as hot as Venus, we would have, instead of oceans, a water vapor atmosphere 300 times more massive than our present nitrogen/oxygen atmosphere. There may be a significant amount of water bound to the rocks in Earth's mantle and crust, but most of our water is probably in the oceans. The water may have come early, from the inner solar system, chemically bound to the grains that formed our planet. Or it may have come later, delivered by comets from the outer solar system.

Most of Earth's elemental hydrogen is that found in water. Light atoms like



Evidence continues to mount that the Moon formed when a Mars-size body plowed into Earth and blew debris into space—matter that accreted to form our lone satellite. Japan's Nozomi *spacecraft captured this portrait of Earth and Moon on July 18, 1998.*

Image: Institute of Space and Astronautical Science hydrogen move faster than heavy atoms and molecules, so this hydrogen can escape once it reaches the top of the atmosphere. Fortunately, very little does, since our upper atmosphere is quite dry. On Venus, the upper atmosphere may once have been wet. If Venus started out with an ocean's worth of water, conditions on that planet would have produced a water-vapor atmosphere rather than oceans, as we have on Earth.

Isotopes of hydrogen (variant forms of hydrogen, which occur in predictable proportions to ordinary hydrogen) provide evidence that early Venus experienced colossal global warming, a "runaway greenhouse," because of the planet's nearness to the Sun. Most of the hydrogen escaped, but deuterium, a heavy isotope, escaped more slowly and is now enriched relative to ordinary hydrogen by a factor of 100. There is little water on Venus today. Presumably the oxygen that was left behind when the hydrogen escaped is now bound to crustal rocks or to carbon in the atmosphere.

The second-most abundant volatile on Earth is carbon dioxide (CO_2), although very little of it is in the atmosphere now. A huge amount of Earth's CO_2, precipitated out of the oceans, has gone into forming the calcium carbonate shells of marine organisms. The CO_2 tied up in these marine deposits, if released, would create an atmosphere many times more massive than the present Earth atmosphere. The quantity is hard to measure, but the total inventory of CO_2 on Earth may be equal to that on Venus, which has a surface pressure 90 times that on our planet. With a hot, dry, lifeless surface, Venus has kept its CO_2 in the atmosphere, whereas the CO_2 on Earth has precipitated out.

Mars has both water and CO_2 in its perennial frost caps. The total inventory is hard to measure because more frost may be buried. The amount of these substances in the atmosphere is controlled by evaporation and condensation on the frost caps. Since the frost caps are cold, the amount of these gases is small. The surface pressure of the Martian atmosphere, which is largely CO_2, is less than one percent of the surface pressure on Earth.

All three planets have nitrogen in their atmospheres. The mass of N_2 on Venus is comparable to the mass of N_2 on Earth. Nitrogen is not a very reactive gas, so most of the inventory is probably in the atmosphere and not in the crust.

Oxygen, the second-most abundant gas in Earth's atmosphere, is only a trace gas on Mars and Venus. Earth is special because green plants release oxygen by photosynthesis. The amount reflects a balance between photosynthesis and oxidation of organic compounds. Without life, Earth's oxygen would combine with surface rocks and be buried in the crust.

The bottom line is that the atmospheres of the terrestrial planets reflect a complex history of interaction with planetesimal grains, with comets, with the crust and mantle, with life, and with space. These atmospheres are not close to their maximum capacities, and it is not certain that such a maximum even exists.
—ANDREW P. INGERSOLL,
California Institute of Technology

If the Moon was formed after a collision between Earth and a Mars-size body, what became of the Mars-size body? Is there any chance of finding leftover chunks, and where would we start looking for them?
—Phoebe Gorsuch,
Wiesbaden, Germany

The computer simulations of this impact event suggest that the material of the impactor merged with Earth and with the material that was to become the Moon. Much of the rocky mantle of the impactor got vaporized and either sank into the Earth or went into orbit around our planet, condensing into dust that later aggregated to form the Moon.

Interestingly, the computer models suggest that the iron core of the impactor plowed into Earth's interior, and under the resulting superheated conditions, the impactor's iron all sank to our planet's center and joined the iron core. Given these conditions, and the geologically rapid turnover of Earth's crust by plate tectonics, no "chunks" of unaltered rock would be left from the impactor.

In any case, the impactor rock might not have been dramatically different from Earth's rocks, because the oxygen-isotope data from Moon rocks suggest that the impactor was a body formed at the same distance from the Sun as Earth, from material of the same composition.
—WILLIAM K. HARTMANN,
Planetary Science Institute

Factinos

Recent data from *Mars Global Surveyor* (*MGS*) reveal surprising evidence of past movement of Mars' crust, adding credibility to the theory that the Red Planet was once more dynamic and Earth-like than it is today.

Scientists used the spacecraft's magnetometer to find banded patterns of magnetic fields on the Martian surface. The adjacent magnetic bands point in opposite directions, making these invisible stripes very similar to patterns in the crust of Earth's seafloors. On Earth, the seafloor spreads apart slowly at mid-oceanic ridges as new crust oozes up from the hot interior. The direction of Earth's magnetic field occasionally reverses, resulting in alternating stripes in the new crust. These stripes carry a fossil record of Earth's magnetic history, a finding that validated the once-controversial theory of plate tectonics.

"The discovery of this pattern on Mars could revolutionize current thinking on the Red Planet's evolution," said Jack Connerney of the Goddard Space Flight Center, an *MGS* magnetometer team member. "If the bands on Mars are an imprint of crustal spreading, they are a relic of an early plate tectonics on Mars. However, unlike on Earth, the implied plate tectonic activity on Mars is most likely extinct."
—from NASA Headquarters

◆

Erich Karkoschka, a researcher at the University of Arizona's Lunar and Planetary Laboratory, has discovered an 18th moon orbiting Uranus. Until now, Saturn was the only planet in our solar system known to have as many as 18 satellites. "The new satellite is about 40 kilometers [25 miles] in diameter, similar in size to comet Hale-Bopp, and it may also have similar composition as the comet," Karkoschka said. Although Karkoschka identified the tiny moon in 1999, it will be designated as S/1986 U 10 until it receives its official name from the International Astronomical Union.

Voyager 2 captured seven images of S/1986 U 10 during a flyby of Uranus in January 1986. However, nobody recognized the moon until Karkoschka compared the *Voyager* images with pictures of the Uranian satellites taken by the Hubble Space Telescope. "This discovery is very unusual," said Karkoschka. "Typically, satellites are found within days after the discovery image has been taken. In this case, the discovery image is more than 13 years old."
—from the University of Arizona

Society News

SETI@Home Starts Up

SETI@ home now has 550,000 participants, according to Dan Werthimer of the University of California at Berkeley, one of the creators of the innovative screen-saver program. SETI@home, enabled in part by funds from the Planetary Society, harnesses the power of personal computers from around the world to help crunch data collected by the Arecibo radio telescope. As of June—one month after the program became available—participants had contributed 7,500 years of their computing time. "By far the world's largest supercomputer," Werthimer said. The program works through facilities at Berkeley that send out bits of information to be analyzed by screen-saver programs around the world. It's not too late to be part of this historic project. To download the free software, visit the Planetary Society Web site and click on the link to SETI@home.

—Susan Lendroth,
Manager of Events and Communications

Membership Database Changes Take Effect

The Planetary Society's new membership system is now installed. The new system is year 2000 compliant and has many features that will help us speed membership requests. Members who joined prior to May 10, 1999 will retain their original membership number and receive a new membership number as well. You can use either number for any Society inquiries; however, we'll begin using new membership numbers on all future mailings. We apologize for any delay in processing your membership due to this changeover and look forward to the new system's serving you better.

—Melanie Lam, Membership Manager

Glenn Announces New Planetary Society Student Project

On May 6, 1999, John Glenn, along with Bill Nye the Science Guy and Louis Friedman, Executive Director of the Planetary Society, announced a revolutionary new project to involve students in a real planetary mission. The project, called Red Rover Goes to Mars, will incorporate the ideas and hands-on work of student astronauts and student scientists on the Mars Surveyor 2001 mission—the first education-oriented experiment on a planetary mission.

Organizations around the world are responding, as students in their countries prepare to enter the essay contest that will culminate in the selection of a student scientist team. In addition to the student scientist team, there will be a team of student astronauts, selected on the basis of their experience (recorded in a journal) with rovers and robotics in programs such as Red Rover, Red Rover. For more information about the project, visit the Planetary Society Web site.

—Linda Hyder,
Manager of Program Development

Torino Conference Focuses on Impacts

The Planetary Society cosponsored a major international workshop on near-Earth objects (NEOs) in Torino, Italy from June 1 to 4, 1999. The workshop—titled "IMPACT: International Monitoring Programs for Asteroid and Comet Threats"—brought together about a hundred NEO researchers and program operators to discuss discovery and tracking efforts and the manner in which information about close Earth approaches is made public.

The Planetary Society was widely praised at the workshop for its Eugene Shoemaker NEO Grant Program. Several observing groups—amateurs and professionals—are making useful observations thanks to grant funding. One of the most dramatic cases was that of Frank Zoltowski, an Australian amateur observer whose observations of asteroid 1999 AN10 are enabling researchers to better predict its orbit.

—Louis D. Friedman,
Executive Director

Put Your E-mail to Work

You can make your electronic voice heard in Washington, DC from the Planetary Society's Web site. In July, we added a Legislative Alert page that lists e-mail addresses for White House staff and all members of the House and Senate. Make sure you've signed up for the Society's e-mail list on our Web page, so we can let you know when important issues are coming to a vote.

—Cynthia Kumagawa,
Manager of Electronic Publications

Society to Cosponsor Mars Society Meeting

The Mars Society will hold its second International Mars Society Convention at the University of Colorado in Boulder, August 12 to 15, 1999. The Planetary Society will cosponsor a public event on August 12 in conjunction with the meeting and will also sponsor a panel discussion at the convention. To get more information or register on-line, visit the Planetary Society's Web site or write to the Mars Society, PO Box 273, Indian Hills, CO 80454. Convention registration rates range from $50 for students to $180. Mention the Planetary Society when you register, and the Society will receive a portion of the registration fees as a donation.

—SL

More News

Mars Underground News
Life-detecting experiments on Mars; *Mars Polar Lander* holds microphone.

The NEO News
NASA's NEO Office begins operating at JPL; LINEAR moves ahead.

Bioastronomy News
Astrobiology Institute searches for life on Earth and in the universe.

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

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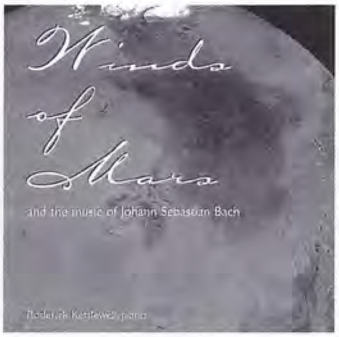
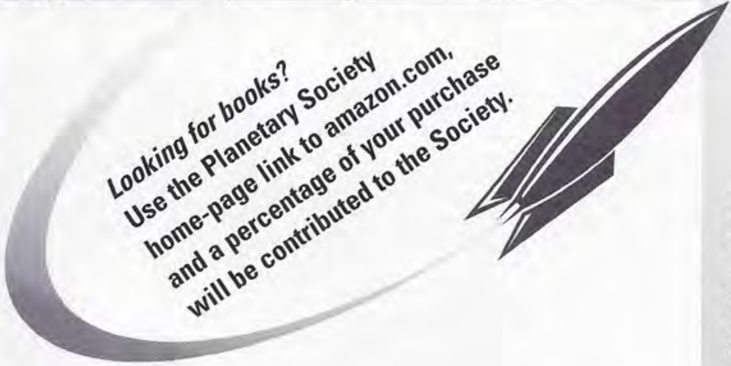


Winds of Mars and the Music of Johann Sebastian Bach

This audio CD features digitally simulated sounds of the winds of Mars between 17 of Bach's finest compositions, played on piano. The wind data were collected by an instrument on the *Mars Pathfinder* lander and were translated into wind sounds through a Musical Instrument Digital Interface (MIDI). CD includes extensive liner notes explaining the production of the Martian sounds and giving a general history of Mars exploration.
1 lb. **#785 $14.99**



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In *Savoring the Moment*, Harrison (Jack) Schmitt is taking a break to look in wonder and to appreciate just how fortunate he is. As the only professional geologist ever to study another world firsthand, he needs a little time to let the significance of the event sink in. Jack is living a dream that is almost as old as man himself: to voyage off this Earth and out toward the stars. As Jack said earlier, "Oh, what a nice day. . . there's not a cloud in the sky."

Alan Bean was the lunar module pilot on *Apollo 12*, the fourth person to set foot on the Moon (and the first to eat spaghetti there). In 1973, he served as spacecraft commander of the *Skylab II* mission. Bean had been studying art since his time as a test pilot, and in 1981 he retired from NASA to devote himself full-time to painting. His work has been exhibited in museums and galleries and is collected by people and institutions around the world.

Adapted from *Apollo: An Eyewitness Account by Astronaut/Explorer Artist/Moonwalker Alan Bean*, published by the Greenwich Workshop Press.

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