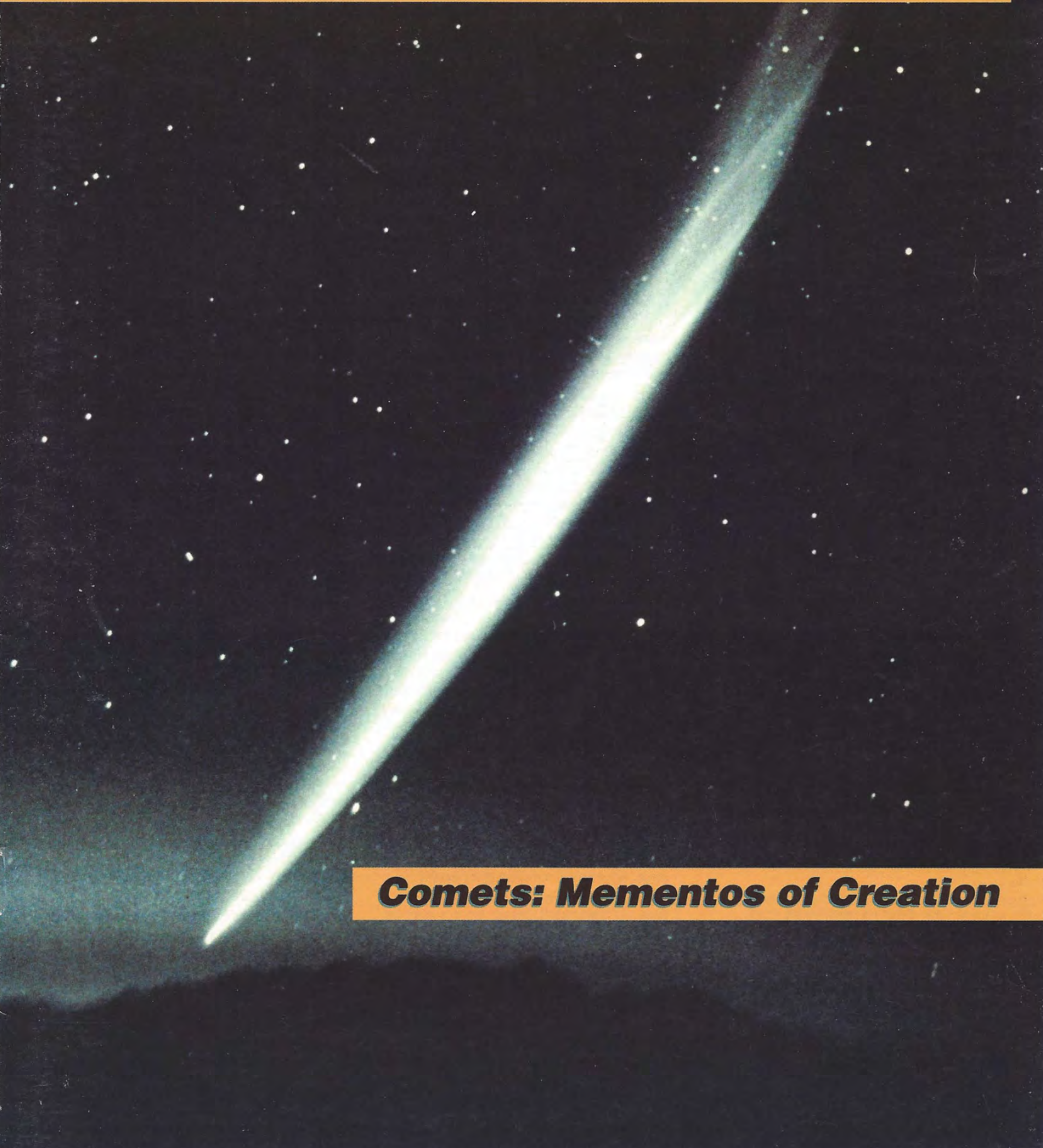
The PLANETARY REPORT

Volume IX Number 2 March/April 1989



Comets: Mementos of Creation

A Publication of
THE PLANETARY SOCIETY

The Planetary Report (ISSN 0736-3680) is published six times yearly at the editorial offices of The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106, (818) 793-5100. It is available to members of The Planetary Society. Annual dues are $20 in the US, $25 in Canada, and $30 outside the US or Canada.

Editor, CHARLENE M. ANDERSON;
Technical Editor, JAMES D. BURKE;
Assistant Editor, DONNA STEVENS;
Copy Editor, SUSAN JUNDANIAN;
Art Director, BARBARA SMITH

In Canada, Second Class Mail Registration Number 9567

COVER: Comets are frequent visitors to the skies of Earth. Since we reside in the inner solar system, as these small bodies of ice and dust pass us by they are heated by the Sun and pummeled by the solar wind, sometimes forming spectacular tails that can stretch out millions of miles behind them. Comets may be clumps of matter left over from the creation of the solar system, so by studying them we learn about our own origins. Seen here is Comet Ikeya-Seki, which graced our skies in 1965.

Photograph: Science Graphics

FROM THE EDITOR

As we go to press, the *Phobos 2* spacecraft is orbiting Mars, preparing to rendezvous with the moon Phobos. This complex craft will send two landers to Phobos' surface, irradiate it with a laser to measure its composition and conduct many other experiments that should greatly expand our understanding of this strange, asteroid-like satellite.

As our readers know, *Phobos* is the first mission in an ambitious Soviet program to explore the Red Planet. Mission planners are hard at work on a *Mars '94* mission that may carry balloon probes partly designed by The Planetary Society (see the September/October 1988 *Planetary Report*). A rover/sample return mission may follow later in the decade. Soviet space leaders make no secret of their desire to send humans to Mars, preferably in a joint mission, early in the next century. This has been the goal of Soviet dreamers since the early decades of this century, when rocket pioneer Konstantin Tsiolkovsky first visualized travel between our planet and Mars.

The *Phobos* mission is bringing Tsiolkovsky's dream one step closer to reality. We will keep you up-to-date as the mission progresses, and when the science results have been analyzed, you can look forward to a special issue of *The Planetary Report* with all the discoveries.

In this issue you'll read about:

—*Charlene M. Anderson*

Members' Dialogue

As leaders of a membership organization, The Planetary Society's Directors and staff care about and are influenced by our members' opinions, suggestions and ideas about the future of the space program and of The Planetary Society. We encourage members to write us and create a dialogue with us on topics relating to the planetary program, such as the space station, the lunar base and the exploration of Mars.

Send your letters to: Members' Dialogue, The Planetary Society, 65 N. Catalina Avenue, Pasadena, CA 91106.

In spite of all the stirring words and fervent appeals to our sense of adventure, I'm not very inspired by the prospect of further exploration of the Moon or Mars. It seems irresponsible to even think of extending our attitudes and actions to other worlds when we are so thoughtlessly in the process of destroying our own, not to mention the enormous expense and uncertain return.

On the other hand, a greatly increased commitment to SETI would be inspiring. If successful, it would be far more than a giant leap for mankind; it would be a new existence with our horizons instantly extended to the limits of the galaxy. We need to analyze and overcome our doubts, even fears, of success and failure and understand that contact and communication is the very essence of development for all forms of life. How much progress could there have been in the history of life on Earth, particularly intelligent life, without it? The stakes are high and the results could be traumatic, but now that we have the technical capability, SETI is the only reasonable way forward for the human race.
SUSAN SALAMAN, *Cambridge, England*

May I express my thanks, and, I am sure, that of millions of others in the United Kingdom and throughout the world for the way the American people have not only paid for the exploration of space but have also shared with the rest of us so much of the excitement and the breathtaking pictures of the planets and their satellites.

Those of us in nations who cannot contribute to this enterprise really do appreciate the way the American people have shared with us the results of this endeavor whilst taking the cost entirely to themselves. Membership in The Planetary Society is but a small way of expressing that appreciation.
PETER H. LLOYD, *Dunstable, England*

In your "World Watch" column from November/December 1988, an error appears regarding the orbital locations of the Tracking and Data Relay Satellites (TDRS). It states that "the US will have three TDRS equally spaced in geosyncronous orbit, enabling continuous contact between orbiting satellites and Earth stations." In fact, only two of these satellites will be used at any given time, and they will be placed at geosynchronous altitude at east and west longitudes in direct view of the associated ground station at White Sands, New Mexico. The third TDRS in orbit will be a spare, midway between TDRS East and West, so that it can be moved to replace either in case of failure. The position of the two operational satellites will be such that low orbiting spacecraft will be in view of one or the other except while they're in a small region over the Indian Ocean called the "Zone of Exclusion."

The TDRS Space Network is, therefore, not directly related to NASA's Deep Space Network, which maintains continuous contact with distant spacecraft through the use of three ground communications complexes that are almost equally spaced apart in longitude.
LARRY N. DUMAS, *Pasadena, CA*

I have no quarrel with the Society's stated policy of trying to stimulate a Mars mission. On the other hand, it seems apparent that until someone finds a way to make money in space, the space program is not going to go anywhere. Without getting into value judgments as to whether this is a good or a bad thing, I believe the Society should focus an effort on convincing people that there are profits to be made in space. I do not see the United States government in the near future acknowledging the intrinsic value of a space program.
LAWRENCE L. LANGLEY, *Wagoner, Oklahoma*

As any research scientist knows, the easy (fun) part of any project is doing the research. The hard (ugly) part is talking the boss into paying for it. Unfortunately, research scientists

(continued on page 27)

NEWS BRIEFS

NASA and the National Oceanic and Atmospheric Administration launched an airborne expedition to study ozone loss in the Arctic. Last year scientists were disturbed to find that the Arctic also has elevated levels of the same chlorine compounds that are responsible for the ozone hole over Antarctica.

The project sent aircraft into the stratosphere over the Arctic polar vortex, a region around the North pole that becomes isolated from the rest of Earth's atmosphere during a two-month period each winter. Ozone depletion is not expected to be as bad in the Arctic, partially because Antarctica's vortex lasts for five months instead of two.
—from Breck W. Henderson in *Aviation Week & Space Technology*

Dr. John V. Atanasoff, father of the modern electronic computer, has been honored by Bulgarian astronomers (Bulgaria is the country of his "roots") with the naming of an asteroid for him. Asteroid 3546, now "Atanasoff," was discovered by Vladimir Shkodrov and Violetta Ivanova with Eleanor Helin of the Jet Propulsion Laboratory.

Dr. Atanasoff, who is better known for his achievement in Bulgaria than in the US, put the "ABC" computer together in the late 1930s. This computer established all the principles used in the development of modern electronic computers.
—from Ron Helin

NASA has a new policy regarding space shuttle "passengers." Shuttle crews will range in number from five to seven members and will be limited to professional NASA astronauts and payload specialists. The agency will review shuttle operations annually to decide when the first

(continued on page 27)

Comets: Mementos of Creation

by Carl Sagan and Ann Druyan

If there is a ceiling above you, step outside. Cast your eye upward. Concentrate on the smallest piece of sky you can make out. Imagine it extending in a widening wedge far out into space, to the stars. In that little patch of sky are a hundred thousand worlds or more, worlds unseen, unnamed, but in some sense known. These distant cousins of Earth are the cometary nuclei —cold, silent, inactive, slowly tumbling in the interstellar blackness. But when they are induced to fall into our part of the solar system, they creak and rumble, begin to evaporate and jet, and eventually produce the tails so admired by the inhabitants of Earth.

An Evolving Solar System?

In the eighteenth century, observational astronomy was making remarkable progress. Immanuel Kant and Pierre Simon, Marquis de Laplace, were intrigued by the structure of the rings of Saturn as had been revealed through the discoveries of Galileo, Christiaan Huygens and their successors. Here was a planet with a flat disk of particles surrounding it in its equatorial plane. Did the Sun once have a much larger ring system, from which the planets somehow condensed?

The Kant-Laplace hypothesis for the origin of the solar system involves the interplay of rotation and gravitation. Imagine some irregular cloud of interstellar matter made of gas and dust and destined to form the solar system. All such clouds known today exhibit slow rotation. If the cloud is sufficiently massive, the random molecular motions are overwhelmed by self-gravity—the mutual attraction of the atoms and grains in the cloud. The cloud then begins to contract, the distant provinces falling inward; the density of the cloud increases as a fixed amount of matter squeezes itself into progressively smaller volumes. As it contracts, the cloud spins faster, for the same reason that a pirouetting ice skater does as she brings her arms in. (The experiment can also be done with a small person, seated on a rotating piano stool, holding a brick in each outstretched hand, and then rapidly drawing them in. This demonstration must be performed with caution.) The principle of physics involved is called the conservation of angular momentum and can be derived from Newton's laws of motion.

But as the gas and dust and occasional condensations that make up the cloud spin faster around their common axis of rotation, they experience an increasing reluctance to continue falling inward, sometimes called centrifugal force (centrifugal means "fleeing the center"). A pail of water on a rope whirled sufficiently fast around your head does not spill—at least not until you stop whirling. The centrifugal force balances gravity.

The contracting cloud also will experience centrifugal force, which will slow it down and eventually stop the contraction—but only in the plane of rotation. If you are standing on a small lump of matter falling toward the center of the cloud but along the axis of rotation, rather than in the equatorial plane, you do not feel any centrifugal force. The result is that matter in the equatorial plane stops collapsing, while matter along the axis continues to fall in. As a result, an initially irregular cloud in time becomes a flattened disk. The fur-

Nearly five billion years ago the solar nebula condensed from a conglomeration of gases, ices and dust to form our solar system. The planets and their moons have evolved over many millennia, erasing evidence of their primordial selves. But the much smaller comets have spent most of their time drifting at the edge of the solar system, where they have remained relatively unchanged since their births. Thus by studying comets, we study mementos from our solar system's creation.

Painting by Jon Lomberg from *Comet* by Carl Sagan and Ann Druyan (Random House, NY, 1985).

ther the disk collapses, the more rapidly it rotates and the denser it becomes at the very center. The collapse stops, or at least slows, when the disk starts spinning so fast that matter spews off at the periphery.

The Kant-Laplace hypothesis proposes that an irregular, rotating interstellar cloud collapsed in this manner long ago, with the central condensation forming the Sun. There is no doubt today that interstellar matter compressed to the density and temperature of the Sun will initiate thermonuclear reactions and begin to shine like a star. But it was a daring hypothesis for the eighteenth century. Other, smaller nearby condensations, Kant and Laplace proposed, formed the planets, each sweeping out a wide swath of adjacent debris as it grew in size. The result would be a regular spacing of the newly formed planets, something like the layout of the solar system today. Still smaller condensations near the planets would form their moons. The general idea behind the Kant-Laplace hypothesis is more important than the precise details: The solar system, they proposed, *evolved* from a very different primordial state and with no outside intervention, natural or supernatural.

Because the word nebula means "cloud," and out of analogy with the spiral nebulae (which are, of course, of much larger, galactic dimensions), the contracting cloud that formed the Sun and the planets is traditionally called the solar nebula. Today we know a much larger variety of flat rotating clouds around the nearer stars. They are called accretion disks.

Laplace suggested that during the formation of the solar system, the Sun's atmosphere once extended far out into space, perhaps in consequence of an enormous explosion in the Sun. Or perhaps it was the residuum of the original solar nebula. Laplace's interstellar comets were, he imagined, falling in toward the Sun. The material in the solar nebula slowed comets down in the inner solar system, altered their orbits and induced them to impact the Sun. The drag of the solar nebula cleaned the inner solar system of comets with nearly circular orbits but left the comets at much greater distances unaffected. Through gravitational perturbations by the jovian planets, an occasional comet can be induced to visit the inner solar system.

The idea is remarkable in several respects. It indicates a kind of natural se-

Once lords of Earth, these Tyranosaurus Rex cower before a force of spectacularly immense power—an asteroid striking the planet. The impact of an asteroid or one of its cousins—a comet—may have caused the extinction of the dinosaurs and so made possible the rise of the mammals. From the mammals evolved the human species.

Illustration by Don Davis

lection in the physical world well before Darwin, it proposes that there were once many more objects in the solar system than there are now, and it hypothesizes a large repository of comets beyond the most distant planet known.

The Problematical Planets

Why, then, were the planets not similarly disturbed and induced to collide with the Sun? Laplace proposed that the planets had formed by successive condensations in the early solar nebula. A tube of empty space, centered around the orbit of each new planet, was formed as the planet, growing at the expense of adjacent material, swept its surroundings clean of nebular debris. Perhaps he toyed with the idea that many dark breaks should exist in the rings of Saturn if there are moons among the rings. However, he urged caution in accepting his hypothesis. Probably because of his flirtation with a possible interstellar origin of comets, it seems not to have occurred to him that comets as well as planets might condense out of the solar nebula.

That the rotation and revolution of the satellites are in the same direction as the rotation of their planets; that the planets rotate in the same sense that they revolve; and that the orbits of the planets are close to circular, while the comets have highly eccentric orbits, all followed naturally if everything (including or excluding the comets) had condensed out of the same rotating and collapsing cloud.

Observations Offer New Evidence

In the last few years, groundbased and spaceborne observations have confirmed that many nearby stars are surrounded by accretion disks. The initial discovery was made by a space observatory called IRAS, the Infrared Astronomy Satellite, a joint Anglo-Dutch-US endeavor. Vega is one of the brightest stars in the night sky, only twenty-six light years distant, and it was a real surprise to discover that this well-studied star is surrounded by a previously unsuspected disk of debris. It showed up as an extended source of infrared radiation centered on Vega, a star considerably younger than the Sun. To find an accretion disk around Vega strongly suggests that most, perhaps even all, ordinary stars are surrounded by such a disk during and immediately after their time of formation. Something eventually tidies up the disk—perhaps a combination of radiation pressure, the stellar wind and planetary formation. But it takes time. And in that time, additional bodies may be condensing out of the nebula.

IRAS also provided infrared evidence of an accretion disk around a star called Beta Pictoris, among many others. Soon after, Bradford Smith of the University of Arizona and Richard Terrile of the Jet Propulsion Laboratory attached a special highly sensitive camera, developed for a forthcoming space observatory, to a groundbased telescope and were able to photograph the Beta Pictoris accretion disk in ordinary visible light.

The disk extends at least 400 Astronomical Units (1 A.U. is the mean distance of Earth from the Sun, about 150 million kilometers) from the central star. If this were a picture of the Sun in its early history, the accretion disk would extend much farther from the Sun than does the orbit of the farthest known planet (some 30 to 40 A.U. out).

Smith and Terrile deduce a relative absence of debris in the interior of the disk and suggest that this region has already been swept up by the condensation of planets that are much too small to be seen directly. Astronomers have recently sighted many other accretion disks around adolescent stars. They have also found accretion disks around infant stars formed only a million years ago.

Thus, it now seems that the Kant-Laplace hypothesis is in its fundamentals verified, and by a technology that would have delighted both of its authors. The Sun, the planets and their moons all condensed out of the same rotating and collapsing disk of gas and dust. This is why all the planets revolve in the same plane in which the Sun rotates.

Comets are best known in their dramatic and ethereal forms with spectacular tails streaming out behind them, as Comet West appeared as it passed by Earth in 1976. The small icy and dusty nucleus of a comet spends most of its time in the deep freeze of the outer solar system where the Sun's heat and the solar wind alter it little over the millennia.

Photograph by Dennis di Cicco

Interstellar Space Gives Birth

Let us now follow a modern rendition of the Kant-Laplace hypothesis, in which we pay special attention to the origin and evolution of the comets. From direct spectroscopic evidence, we know the interstellar gas to be composed mainly of hydrogen and helium, although it is rich in many other materials, including complex organic molecules. Besides the gas, the other chief constituent of interstellar space is an enormous number of dust motes. One of them, placed on a table before you, would be entirely invisible. They are, typically, a tenth of a micron across. But concentrate enormous numbers of them over hundreds or thousands of light years, and you can have enough dust to blot out the stars behind them.

We can also infer the chemistry of the grains. Most seem to be made of ices, silicates and organics—very roughly in equal proportions. Since this mix of gas and grains makes up the interstellar clouds everywhere in the Milky Way, it must also have constituted the early collapsing solar nebula. Since interstellar space ordinarily holds much more gas than grains, this should have been true for the solar nebula as well.

As the nebula contracts and its density increases, grains collide more frequently. In part because of the organic and icy content of these grains, when they collide they tend to stick. Big grains annex smaller ones. But all this does not go on in the dark. The primitive Sun has begun brightly shining. In the outer parts of the disk, it is still sufficiently cold that exotic ices such as methane or carbon monoxide are perfectly stable in the growing condensations of matter. But in the very inner solar system, it is too hot even for water ice. There the ices on the grains evaporate and dissipate, and what survives is made mainly of silicates. You have to carry a rock very close to the Sun, only a few million kilometers away, for it to boil. As a result of all this, the chemistry in the inner solar system must have been very different from the chemistry in the outer solar system—silicates predominating inside and ices with organics outside.

According to several calculations, a vast number of kilometer-sized objects should have accumulated throughout the nebula—silicate-rich ones on the inside, ice-rich ones on the outside. These objects should have been generated, not primarily through grain-by-grain collisions, but instead by a fundamental gravitational instability in the solar nebula, in which objects a few kilometers in size formed quickly and preferentially.

Both dust and gas gravitationally collapsed to form the disk. But it takes a great deal of gravity to hold on to so lightweight and thus fast-moving a molecule as hydrogen. In the middle part of the nebula, the kilometer-sized lumps collided and grew into still larger objects until a few aggregations of matter were able to retain the cold gas around them. This was the evolutionary line to the jovian planets. The original accretion core was smothered in a vast sphere of gas. In the warmer inner solar system the grains, divested of their ice, grew more slowly, and the temperatures were higher—both effects making it more difficult for the gas to be captured by the growing rocky spheres. This was the evolutionary line to the terrestrial planets.

Big objects would sweep up smaller ones on adjacent orbits. Because the relative velocities were low, the two bodies would tend to collide softly and merge. Eventually, a few large objects were produced in orbits that never intersect. These became the planets. A kind of collisional natural selection was at work here. Starting out with a large number of growing objects in chaotic orbits, through a process of collision and growth and only occasionally the shattering of worlds, the solar system became regularized, simplified. The number of worlds steadily declined, from trillions to thousands to dozens.

If you look at the planets today, you

A spherical shell of cometary nuclei surrounds our Sun, as calculated to exist by astronomer Jan Oort, for whom the Oort Cloud is named. Planetary scientists believe that these bodies are remnants from the solar system's formation and that when one of these ice balls falls into the planetary part of our solar system it becomes a long-period comet.

Painting by Jon Lomberg from *Comet* by Carl Sagan and Ann Druyan (Random House, NY, 1985).

find them decorously spaced, their orbits by and large almost perfectly circular; except for the case of Pluto, planets give each other wide berth. Those early bodies on highly eccentric orbits were in danger; very soon they would collide with a world or be ejected from the solar system. Eventually, the only planets left were those that had by chance developed on orbits that quarantined them from their neighbors. It is just as well for us that they did; frequent world-shattering collisions are probably not good for the development of life.

The planets so formed would be orbiting the Sun in the sorts of orbits we recognize for the planets today. While no one has been able to prove that exactly nine planets should form—and not, say, six or forty-three (the entire question of the ultimate number of planets being a matter of collision statistics)—the general picture is very successful and explains not only the orbits but also the overall chemical differences between the terrestrial and the jovian planets that we observe today.

On Hold in the Oort Cloud

When we calculate the fate of that original population of small worlds, we discover that gravitational interactions with the newly finished jovian planets would have ejected multitudes of kilometer-sized worlds into the outermost gravitational frontier of the solar system, like an automatic pitching machine throwing baseballs into the bleachers once a minute for a hundred million years. This is how the Oort Cloud (named for the Dutch astronomer Jan Oort, who first postulated its existence) is thought to have been generated. There is a population of primitive bodies that four and a half billion years ago were sequestered so far from the Sun that no vaporization, no collisions, nothing at all could transform them. They are the stuff from which the solar system was formed, and they are waiting for us in the Oort Cloud. Even a single comet newly arrived from the solar system frontiers is the answer to an astronomer's dream.

In the 1960s, V.S. Safronov, a Soviet specialist in the early history of the solar system, and in 1981, J.A. Fernandez, a young Uruguayan astronomer, and W.H. Ip, in Germany, showed that if primitive cometary bodies (those kilometer-sized objects) were formed in the vicinity of Jupiter and Saturn, gravitational perturbations by these massive planets would eject them out of the solar system altogether. But if these protocomets were born in the vicinity of the less massive planets, Uranus and Neptune, their gravitational influence would tend to eject the cometary bodies into the Oort Cloud, but not out of the solar system. So if these primitive icy and rocky worlds had condensed throughout the solar system, most would have been used up in making planets and in being ejected into interstellar space. But trillions at least would have been relocated to the Oort Cloud.

If the protocomets had been formed in the vicinity of Jupiter, exotic ices would not have survived; and, if formed still closer to the Sun, even ordinary water ice would not be retained. Thus, two independent considerations—making the primitive comets out of the right stuff, and ejecting them into the right orbits—point to an origin in the rough vicinity of Uranus and Neptune.

Comets, it seems, were formed ultimately out of interstellar grains within the solar nebula, just a little before the moons and planets formed, some 4.6 billion years ago. Many comets collided with each other, forming larger bodies and sacrificing themselves so the plan-

Comets usually grow two types of tails: one a long, straight, faint tail, and the other a short, curved, broad tail. The first type is the ion tail, formed when gases released as sunlight vaporizes the surface are ionized and carried off by the solar wind. The second type is the dust tail, created as tiny solid particles blow off the nucleus and enter orbits of their own about the Sun. This illustration of Donati's Comet over Paris on October 5, 1858 clearly shows both types of tails.
Illustration from Amedee Guillemin's *Les Cometes*.

ets would be made. Our planet also seems to have been formed from such objects, poor in ice, rich in rock.

Many other comets were gravitationally ejected from the solar system altogether as, sooner or later, they made close passes by the jovian planets, especially Jupiter. But the calculations show very clearly that a substantial population of the original comets must have been ejected to the far reaches of the solar system, where the random gravitational shuffling of passing stars would have forced them into more circular, randomly inclined orbits. Not all would have been ejected out to the very periphery of the solar system, and the calculations predict a substantial population of comets on near-circular orbits from hundreds to tens of thousands of Astronomical Units out—a population of comets fairly impervious to gravitational disturbances by passing stars.

Comets may also have formed at these distances in the accretion disk of the solar nebula. It is therefore possible that astronomers on Earth have never seen a typical denizen of the inner Oort Cloud. It is entirely plausible that much bigger comets than those several kilometers across were ejected into the Oort Cloud. But there are far fewer of these, and much more rarely will we see one redirected into our small but well-lit volume of space.

If this currently popular picture is correct, a typical short-period comet (one that circuits the Sun every few years) is an aggregate of interstellar matter condensed during the origin of the solar system almost five billion years ago and ejected by the newly formed planets to the solar system frontiers, its orbit there circularized by gravitational encounters with passing stars. A few billion years later, the cumulative gravitational influence of further stars and interstellar clouds drives the comet back into the planetary part of the solar system, where close planetary encounters—this time especially with Jupiter—reduce the large elliptical orbit into the more modest dimensions of a short-period comet. The homecoming has been long delayed, and the solar system has changed considerably in the interim.

The comets are way stations in the evolution of planets. They have seen much. As remnants of the forming solar system they can tell us much. Both the comets and the planets are formed of interstellar materials. The difference is that the planets have been enormously reworked, physically and chemically, since the beginning of the solar system, while the comets of the Oort Cloud remain comparatively unscathed by the ravages of time. This is the principal motivation for the dawning age of spacecraft exploration of comets. When we study the comets, we study our own beginnings.

Carl Sagan, President of The Planetary Society, is the David Duncan Professor of Astronomy and Space Sciences and directs the Laboratory for Planetary Studies at Cornell University. Ann Druyan was recently elected Secretary of the Washington-based Federation of American Scientists. She was Creative Director of NASA's Voyager *Interstellar Record project and, together with Sagan and Steven Soter, wrote the* Cosmos *television series.*

CHANGING VIE

Before the *Mariner*, *Mars* and *Viking* spacecraft visited Mars, astronomers engaged in a continuing quest to observe and record the finest martian detail possible. In those pre-spacecraft days, their observations provided the only clues about the nature of Mars' surface and the seasonal changes that affect it. To anyone who has looked through the eyepiece of a moderately large telescope in good seeing (when Earth's atmosphere is clear and still) and when Mars is favorably placed in the sky, the subtle changes and myriad splotches hint of a fascinating world of sandstorms and spectacular landforms.

It's not surprising that since the 1960s and 1970s, when the *Mariner* and *Viking* spacecraft provided closeup views from orbit, scientific emphasis on groundbased observations has diminished significantly. Yet we still have much to learn from such observations about atmospheric circulation, dust storm propagation, and both long-term and seasonal changes in Mars' bright and dark surface markings.

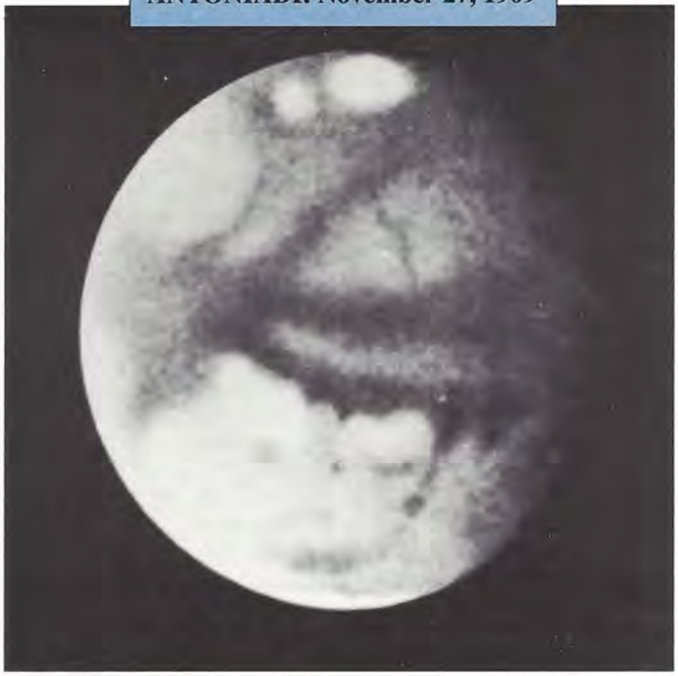
Recently, because of the superior sensitivity of solid-state charge-coupled device (CCD) detectors compared to traditional photographic emulsions, astronomers have been able to obtain higher resolution images of Mars from the ground. The images here, obtained with the 1.54-meter reflector at the Catalina Station of the University of Arizona Observatories, were taken during the recent favorable opposition.

One important advantage of CCD imaging is the ability to enhance the small features digitally. We can reduce the contrast between light and dark regions while increasing the contrast (and hence the visibility) of small features. Carried too far, this processing can produce misleading artifacts, but with the exception of the exaggerated bright limb (the planet's edge), we were able to see all of the small detail in contrast-stretched but unprocessed versions.

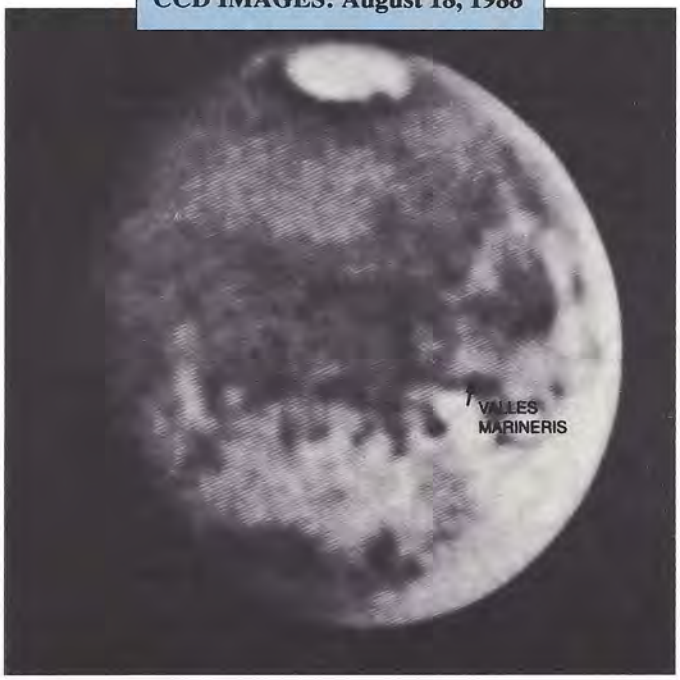
It is interesting to compare these images with drawings made by talented visual observers using large telescopes around the beginning of this century. Good examples are drawings by E.M. Antoniadi with the 0.8-meter refractor at Meudon Observatory in 1909 when the observing circumstances were very similar to those in 1988. Antoniadi

(continued on page 12)

ANTONIADI: November 27, 1909



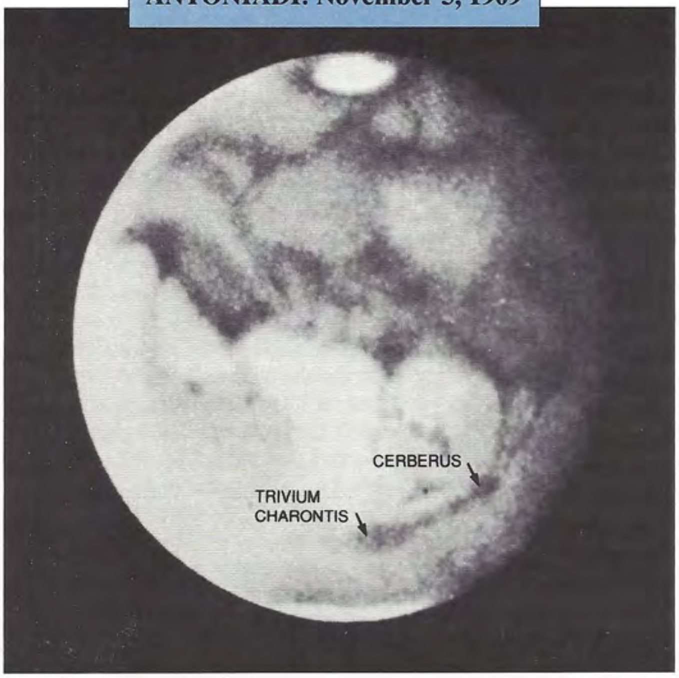
CCD IMAGES: August 18, 1988



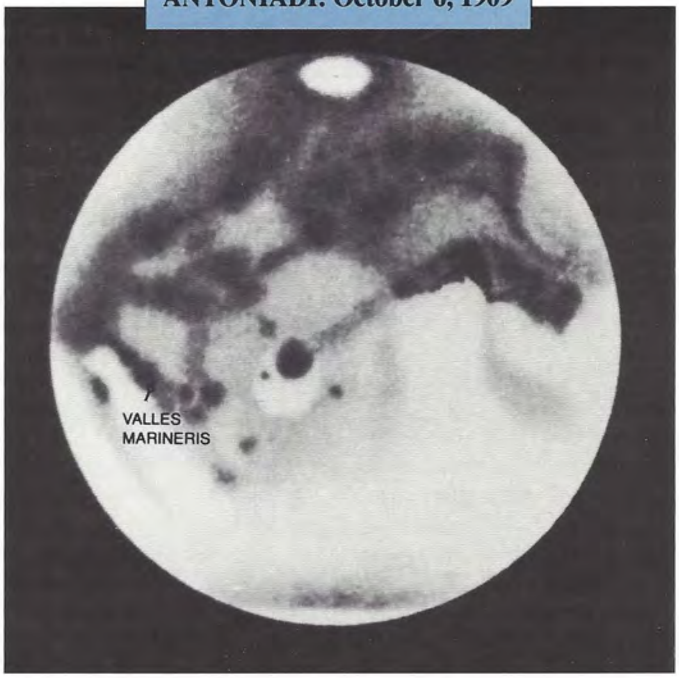
WS of MARS

BY STEPHEN LARSON

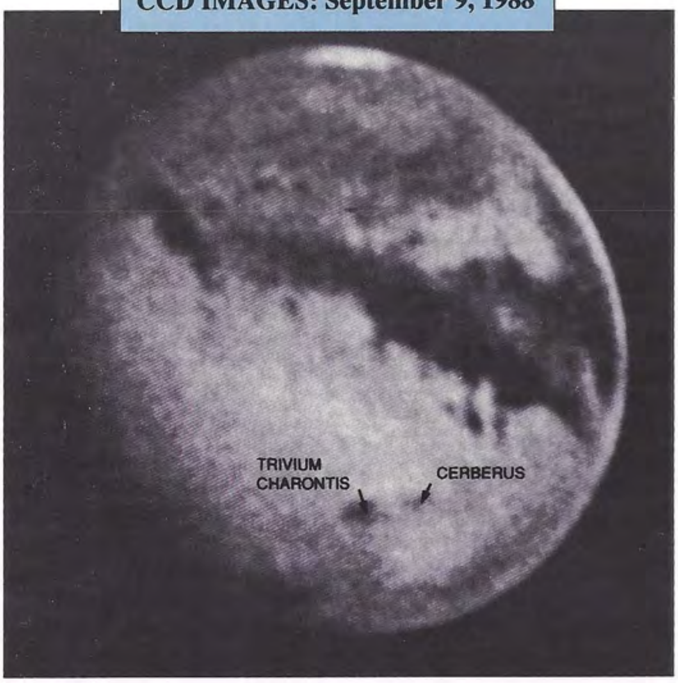
ANTONIADI: November 5, 1909



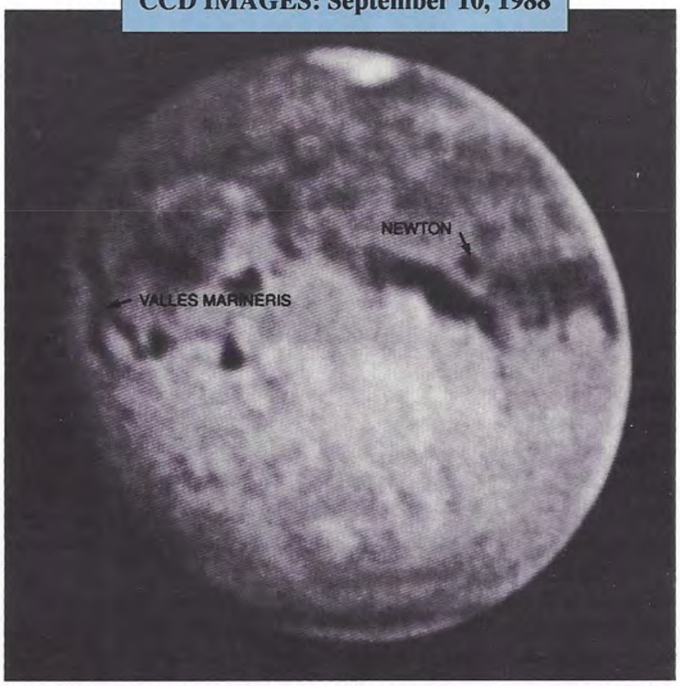
ANTONIADI: October 6, 1909



CCD IMAGES: September 9, 1988



CCD IMAGES: September 10, 1988

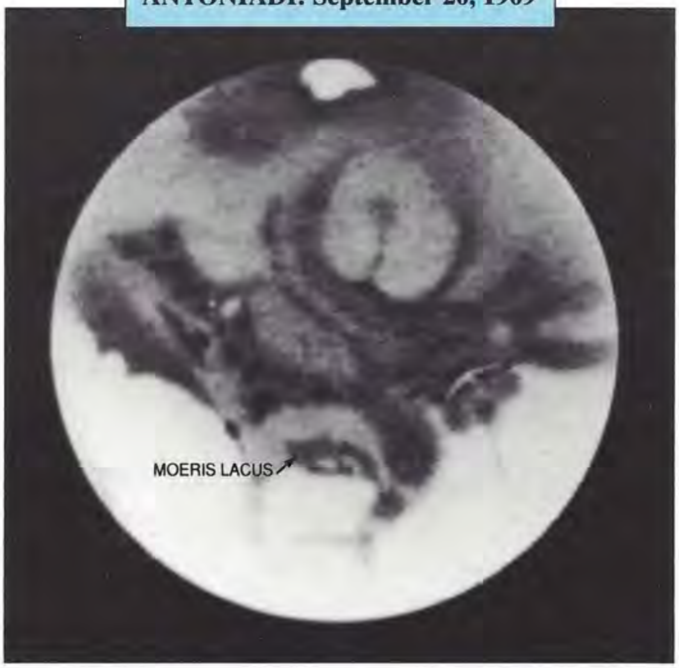


(continued from page 10)

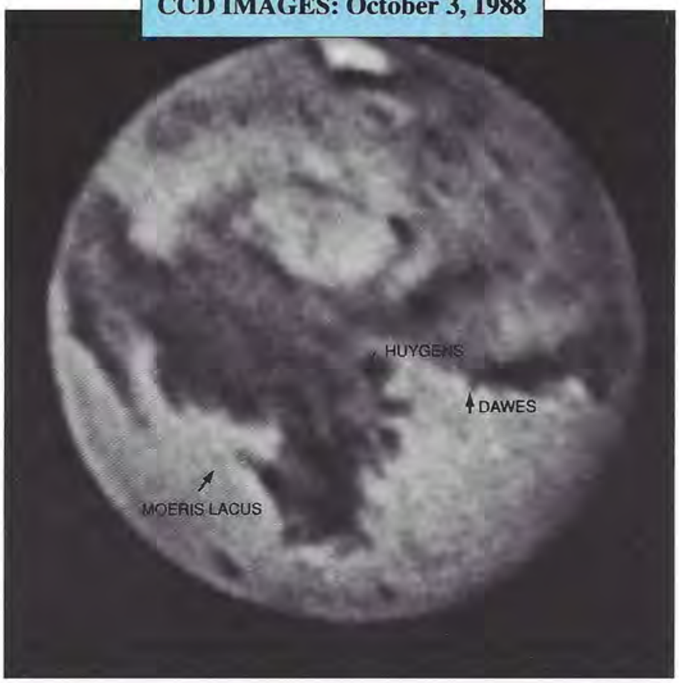
was a very careful and perceptive observer who pointed out that many of the canal-like features reported by Percival Lowell and others resolved into small spots when the seeing was very good.

In resolving features only 100 to 150 kilometers across, we are still seeing albedo markings (light and dark features) but not topographic structure. Only one feature hints of topography, and that is Valles Marineris. (Early telescopic astronomers saw this 4,000-kilometer-long canyon as a surface feature, but it was not understood to be a canyon until imaged by *Mariner 9* in 1972.) In the August 18 image, with the Sun overhead, we can see it as a connected series of dark spots north of Solis Lacus, while on the September 10 image it appears much more rectilinear and canyon-like. Since the Sun was only a few degrees above the horizon on the later image, some of the canyon slopes were in shadow and may have provided higher contrast to the surrounding area.

ANTONIADI: September 20, 1909



CCD IMAGES: October 3, 1988



It is tempting to equate the dark circular spots with craters, but the fact is that albedo features do not usually correspond to topographic structures. A good example is the crater Huygens located near the center of the October 3 image. According to United States Geological Survey maps, using spacecraft data, the dark circular spot is located on the eastern half of the crater. The small dark streak protruding north from Sinus Sabaeus and due west from Huygens covers only half of the crater Dawes. On the other hand, the dark spot near Mare Sirenum on September 10 seems to correspond to the crater Newton.

The dramatic evaporation of the south polar cap is obvious between August 18 and September 9. On August 18, there is a rift bisecting it across the center to the bay nearest Solis Lacus. On September 10, that bay appears much larger at the edge of the smaller cap.

Comparing the south polar cap Antoniadi drew on September 20, 1909 with our CCD images of October 3, 1988 shows the same detailed outline. Although the characteristic sizes of the smallest details are comparable, there are some differences attributable to long-term changes in the boundaries of some albedo features. For example, the usually dark Thoth-Nepenthes and Moeris Lacus were nearly absent in 1988. Trivium Charontis and Cerberus were also less prominent than usual last year.

Of course, future spacecraft, such as *Mars Observer*, will provide much more detail about long-term changes that have occurred since the *Mariner* and *Viking* missions, but groundbased images such as these may help show something of their evolution.

Stephen Larson is an astronomer in the University of Arizona's Lunar and Planetary Laboratory and carries out imaging and spectroscopic studies of planets and comets.

The Concept of Extraterrestrial Intelligence—

An Emerging Cosmology?

by Steven J. Dick

What place does the idea of extraterrestrial life hold in the history of science? Evolutionist George Gaylord Simpson once called it a science without a subject, a phrase often repeated. Physicist Frank Tipler believes that religion and philosophy have dominated its history and regards it even today as a pseudoscience. Others have seen its history as a fragmented and unrelated series of ideas with little relation to the mainstream of intellectual history. Even proponents would admit to its checkered career, with the exhausting furor over martian canals, the association of the idea with Unidentified Flying Objects, and a public all too willing to believe in little green men despite the evidence (or lack of it).

But the broad tapestry of the history of science offers another view of the debate, one that takes into account the idea's extraordinarily long history and the changing nature of science itself. From this vantage point three conclusions seem clear: cosmological world views inspired and have sustained the extraterrestrial life debate; the concept of life beyond Earth may itself be seen as a cosmological world view, with characteristics like those in other cosmologies; and the current search for extraterrestrial intelligence (SETI) may serve as a test for this new "biophysical cosmology."

The "Cosmological Connection"

We see the universe through the lens of our cosmology. This all-encompassing world view determines how we conceptualize our planet, our solar system and the entire universe around us. Cosmologies change with time, fashions and scientific developments, and what was once accepted as the true nature of the universe may gradually become a measure of our ignorance.

The idea of other worlds and extraterrestrial life is indisputably associated with the great cosmologies of the past. The idea of an infinite number of worlds was a central tenet of the Greek atomist system, generally regarded as the first scientific cosmology. Aristotle's highly ordered geocentric cosmology opposed this view. Aristotle argued for a single world, an idea widely debated but generally accepted throughout the Middle Ages. The heliocentric Copernican cosmology began a new era in the debate, for by positing an Earth in motion Copernicus implied that the planets were worlds like Earth. Descartes' vortex cosmology in the seventeenth century first gave a physical basis to the idea of other solar systems. And the Newtonians, pushed along by considerations of natural theology (theology deriving its knowledge of God from the study of nature rather than revelation), made a universe full of planetary systems an integral part of their cosmology.

Twentieth-century changes in cosmological world views have also affected belief in life beyond Earth. At the beginning of the century most astronomers believed that our Sun was located near the center of the galactic system, and some argued that this was a unique, privileged place that allowed life to exist. Three tumultuous decades later, the universe, seen through the eyes of the local intelligent species, had changed: Our galaxy had greatly enlarged, innumerable galaxies existed outside our own, the universe was expanding and much older than previously thought, our solar system was located on the galaxy's periphery, and Einstein had demolished Newtonian ideas of space and time.

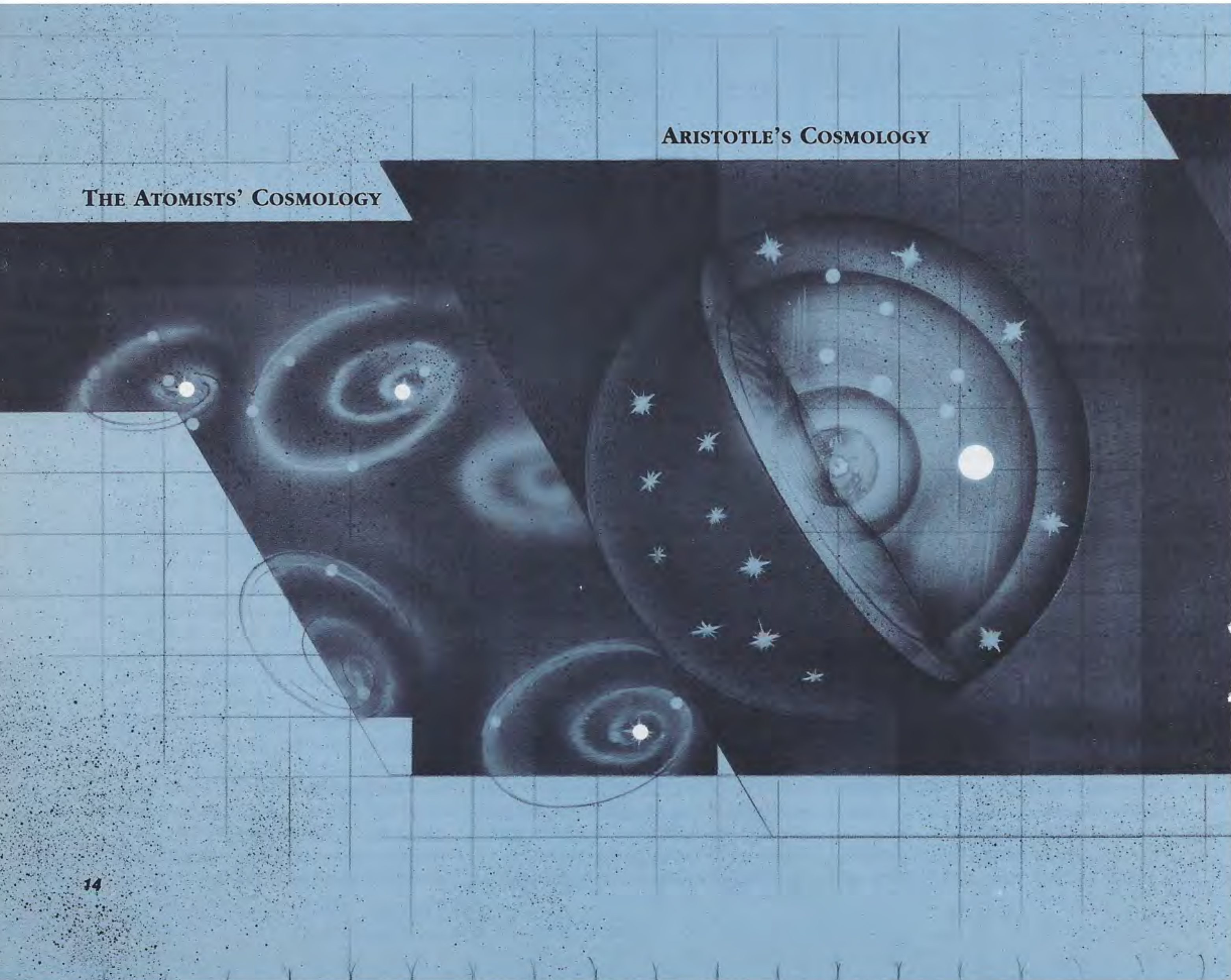
We should therefore not be surprised that the British astronomer Sir James Jeans, who had once championed the rarity of life in the universe (due largely to his belief in the rarity of planetary systems), asserted in 1942 that life might not be so rare in the new universe after all. Nor should we wonder that Henry Norris Russell, the dean of US astronomers and a skeptic in the early 1920s about life beyond Earth, by the early 1940s described "a radical change—indeed practically a reversal" of his earlier view. And Harvard Observatory Director Harlow Shapley, who had so ingeniously demonstrated our eccentric position on the outskirts of the galaxy, went from ridicule of the subject in the 1920s to the complete turnabout expressed in his well-known volume *Of Stars and Men*, significantly subtitled *Human Response to an Expanding Universe* (1958). In short, opinions on extraterrestrial life have not been monolithic but have changed with our views of the universe—our cosmologies.

The Biophysical Cosmology

It is not enough to say that extraterrestrial life is an offshoot or implication of these cosmologies, any more than it suffices to say that Newtonian physics arises from the Copernican theory. Is this offshoot or implication a pseudoscience? A science looking for a subject? A subdiscipline of astronomy—or of biology? Another run-of-the-mill theory? Or should we perhaps see it as just another piece tacked onto our current physical cosmology?

We can make a good case that belief in extraterrestrial life constitutes a cosmology of its own that incorporates the physical cosmology. First, this belief makes a claim, testable in principle, about the large-scale nature of the universe—namely, that life is a basic property of the universe rather than a local aberration. As Newton proved the universality of Nature's laws, and nineteenth-century spectroscopy, by revealing the same signatures of atoms everywhere, showed the universality of the chemical elements on Earth, so the biophysical cosmology claims universal uniformity for Nature's biological principles. At what level a principle of biological uniformity might apply throughout the universe, whether to produce intelligence similar to us or very different, is a major question.

Secondly, this large-scale testable claim is distinct from physical cosmology. If the endpoint of evolution in the universe is life and intelligence, rather than stars and galaxies, we live in a universe very different from the one physi-

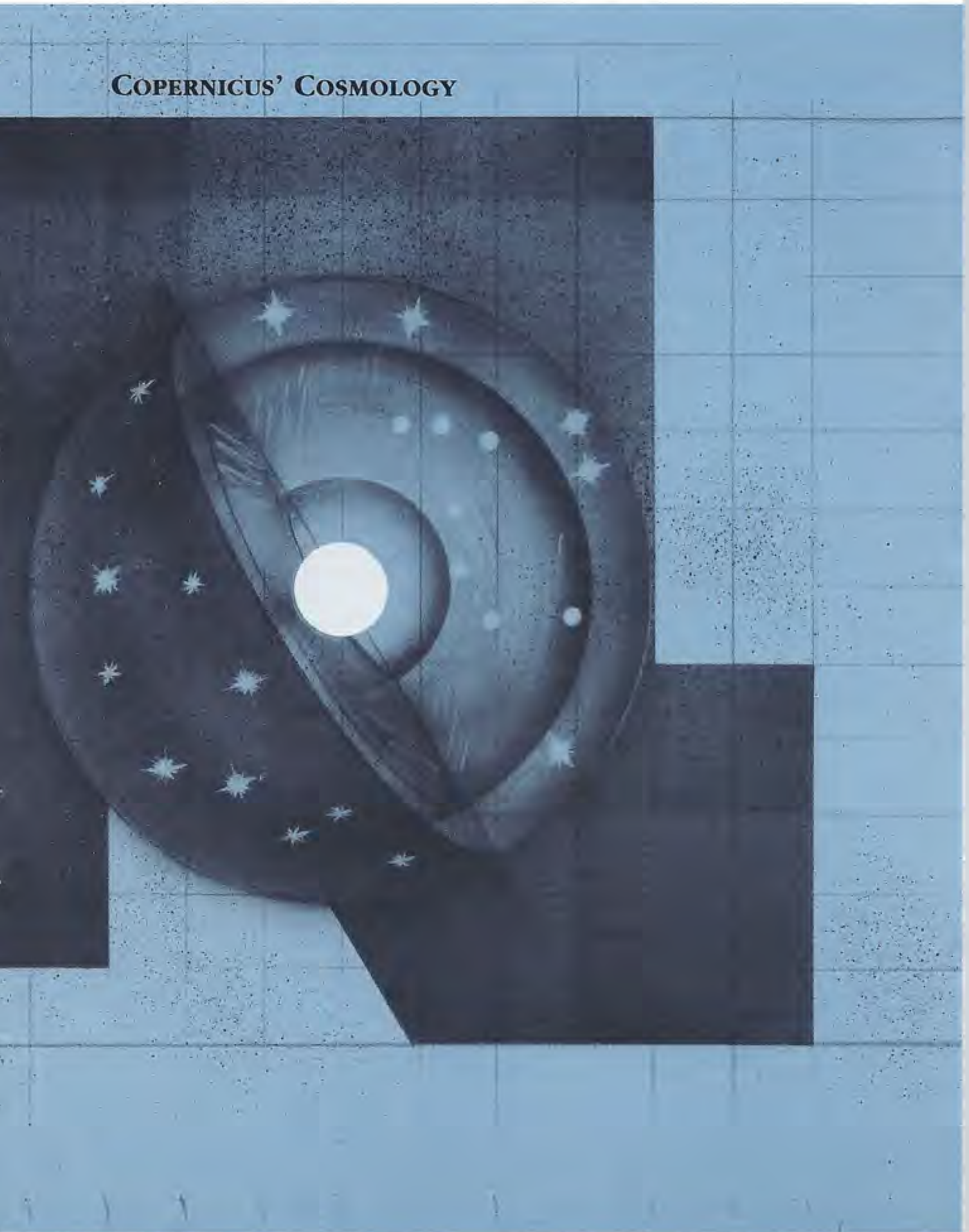


cal cosmology prescribes. We instead inhabit a universe where planetary systems are common, where life develops when conditions are right, and where the evolution of life may lead to technical civilizations. These are the components of the biophysical cosmology—as yet still not proven but given plausibility by the assumption that physical *and* biological principles are everywhere the same.

Finally, like other cosmologies, the biophysical cosmology redefines our place in the universe. In *Of Stars and Men* Shapley saw the extraterrestrial life concept as a "Fourth Adjustment" to humanity's place in the universe, following the geocentric, Copernican and what he termed "galactocentric" world views (the last of which he had himself proven). In *The Universe* (1962) the US astronomer Otto Struve also compared the extraterrestrial world view with the Copernican and Shapley revolutions. Surely this explains why the subject generates such passionate debate; it is not just another theory, but a world view that dramatically affects each of us and our beliefs.

Why can't we just regard life in the universe as an extension of our current physical cosmology? Because historically, new cosmologies have gone beyond mere extension. We would not say that Newtonian physics was a piece added onto the Copernican cosmology, or that Einstein's world view was tacked onto Newton's. These new world views added a new dimension to our knowledge of the universe, and the discovery of extraterrestrial life may do the same. The biophysical cosmology may well encompass parts of our present physical cosmology, but it may also alter our perception of the nature of the universe in some unsuspected way, just as Einstein's cosmology transformed Newton's.

(continued on next page)



The Atomists' Cosmology

Everything in the universe was made of tiny, discrete but imperceptible particles —atoms—according to this early and prescient cosmology taught by the Greek natural philosophers Leucippus, Democritus and Epicurus. Atoms floated through space, came together in whirls of undifferentiated matter, collided and separated out according to type, thus providing water, mountains, and living matter and other things that make up the world around us. The infinite universe was filled with innumerable worlds that might have planets like Earth, some without Suns, some with no moons, some being born, some thriving and some dying. No grand design or higher purpose ruled the atomists' universe, but in a universe governed by random chance, there was always the possibility that lifeforms, perhaps even humans, existed on other worlds.

Aristotle's Cosmology

There was only one world, and Earth was its center in this cosmology that dominated the Western world for over 1,800 years. This universe was composed of a series of solid spheres concentric around Earth and carrying the Moon, the Sun and the five known planets. The stars rotated on the outermost sphere, and beyond them, there was nothing—no other worlds, no stars, no empty space, just nothing. To the casual observer, Aristotle's cosmology seems to correspond to common sense: Heavenly objects do appear to circle round Earth. But astute astronomers soon noticed that the motions of the wandering planets were not easily explained by Aristotle's cosmology, and so amended versions appeared, created by Eudoxus, Callipus, Ptolemy and others. The Ptolemaic system was particularly successful at predicting planetary motion, and it held sway until the appearance of the Copernican system.

Copernicus' Cosmology

As in Aristotle's universe, this was a cosmology of solid spheres moving with uniform circular motion. But there was one distinct difference. The Sun sat at the center of this world, and Earth was but one planet among many orbiting about it. When Copernicus displaced Earth from the center of the universe, he engendered one of the greatest revolutions in the history of science. It was not a bloodless coup. The Inquisition imprisoned Galileo Galilei for holding that the Earth moved about the Sun. The revolution reached its climax when Johannes Kepler, working from Copernicus' ordering of the planets and Tycho Brahe's observations, discovered the laws of planetary motion.

Descartes' Cosmology

Rene Descartes followed in the traditions of both Copernicus and the Greek atomists. His corpuscular universe was made up of tiny particles that moved, collided and grew into planets and people, all while whirling in a series of vortices that gave shape to the world. A subtle matter filled space, and the planets were simply dense spots carried round by the vortices' motion. The Sun sat at the center of our local vortex, and the stars marked the centers of other vortices. In Descartes' universe planetary systems formed of necessity from the laws of motion and there was nothing to prevent life and possibly civilizations from arising on planets whirling about other stars.

Newton's Cosmology

As in Descartes' cosmology, this is a mechanical universe of empty space and matter, derived from Kepler's discoveries so that planets travel elliptical paths around their parent stars. Sir Isaac Newton postulated a universe where law-abiding objects behave according to rationally discovered precepts that could be expressed in mathematical terms. During his lifetime, Newton's universe was circumscribed only by the limits of telescopes and astronomers' understanding of bright objects in the sky. Nothing within his calculations limited the world to one solar system, and the theology of the time urged the belief in many solar systems. As telescopes became more powerful and astronomers realized that some fuzzy bright patches were other "island universes" or galaxies, Newton's universe expanded to encompass them as well. This universe is filled with galaxies, perhaps punctuated with innumerable solar systems and whatever might arise on their planets.

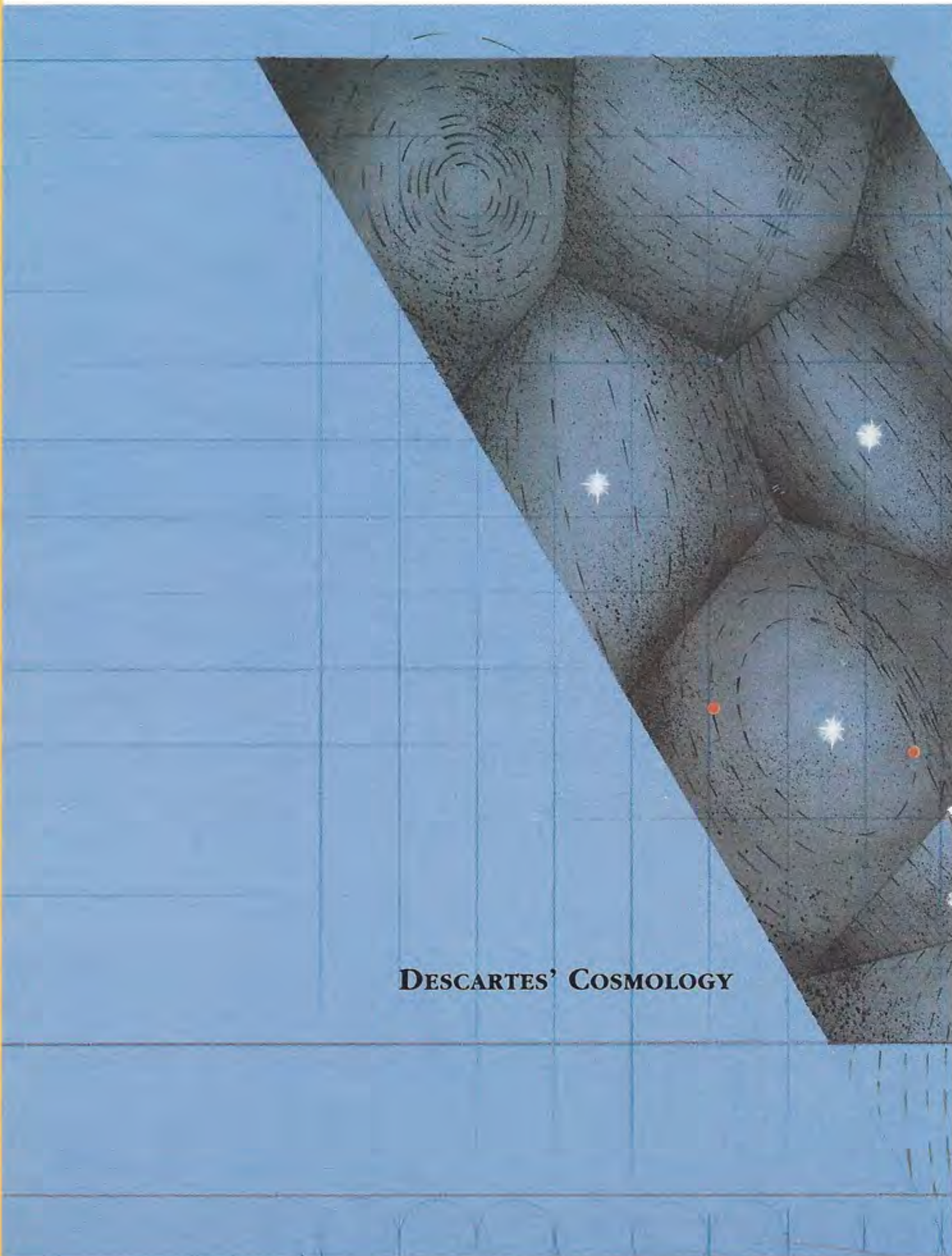
The Bioastronomers' Cosmology

Since Newton's time we've probed the universe with telescopes, spectroscopes and other instruments for discerning Nature's secrets. We've discovered that, as Newton claimed, the physical laws of Nature apply equally and everywhere. We've found the chemical building blocks of life scattered throughout the universe, even drifting in dark clouds among the stars. This universe could well be teeming with other solar systems, nurturing planets and amazing lifeforms. Some of those lifeforms might have followed paths similar to humanity's and developed radio as an efficient means of communication. If so, then listening for those radio waves is the easiest way to discover other technical civilizations. The Search for Extraterrestrial Intelligence (SETI) provides for the first time a test for this cosmology.

SETI as a Cosmological Test

We may suspect that the biophysical cosmology will follow a line of development similar to that of other cosmologies. Foremost among these stages of development are observational tests, so important in modern science. Just as physical cosmologists search for observational evidence for the origin and age of the universe, expansion rates, and missing mass, so biophysical cosmologists search for life on Mars, planetary systems, intelligent radio signals, or Freeman Dyson's proposed infrared spheres (shells built around stars by technologically advanced civilizations to harness stellar energy), not merely as ends in themselves but as tests of their cosmological world view. One local test, *Viking*'s search for life on Mars, failed. For the first time, SETI holds the promise of testing the biophysical cosmology over large distances, beyond the confines of our solar system. Whether we should look, how long we should look, and how much money we should spend are valid questions of science policy and interesting expressions of public preference in a democratic society with many competing programs.

We should not expect final confirmation of extraterrestrial life to come soon. Centuries elapsed between claims made for the Copernican theory based on observation and the actual proof of Earth's motion by James Bradley's observation of the aberration of starlight (the tiny but apparent displacement of a star due to Earth's speed through the galaxy) in 1729 and Friedrich Bessel's measurement of stellar parallax (the apparent shift in a star's position due to Earth's motion) in 1838. The biophysical cosmology has had several disputed claims but at present has no undisputed evidence. In proposing extraterrestrial intelligence we are still at the stage of Aristarchus, wondering if the Earth



DESCARTES' COSMOLOGY

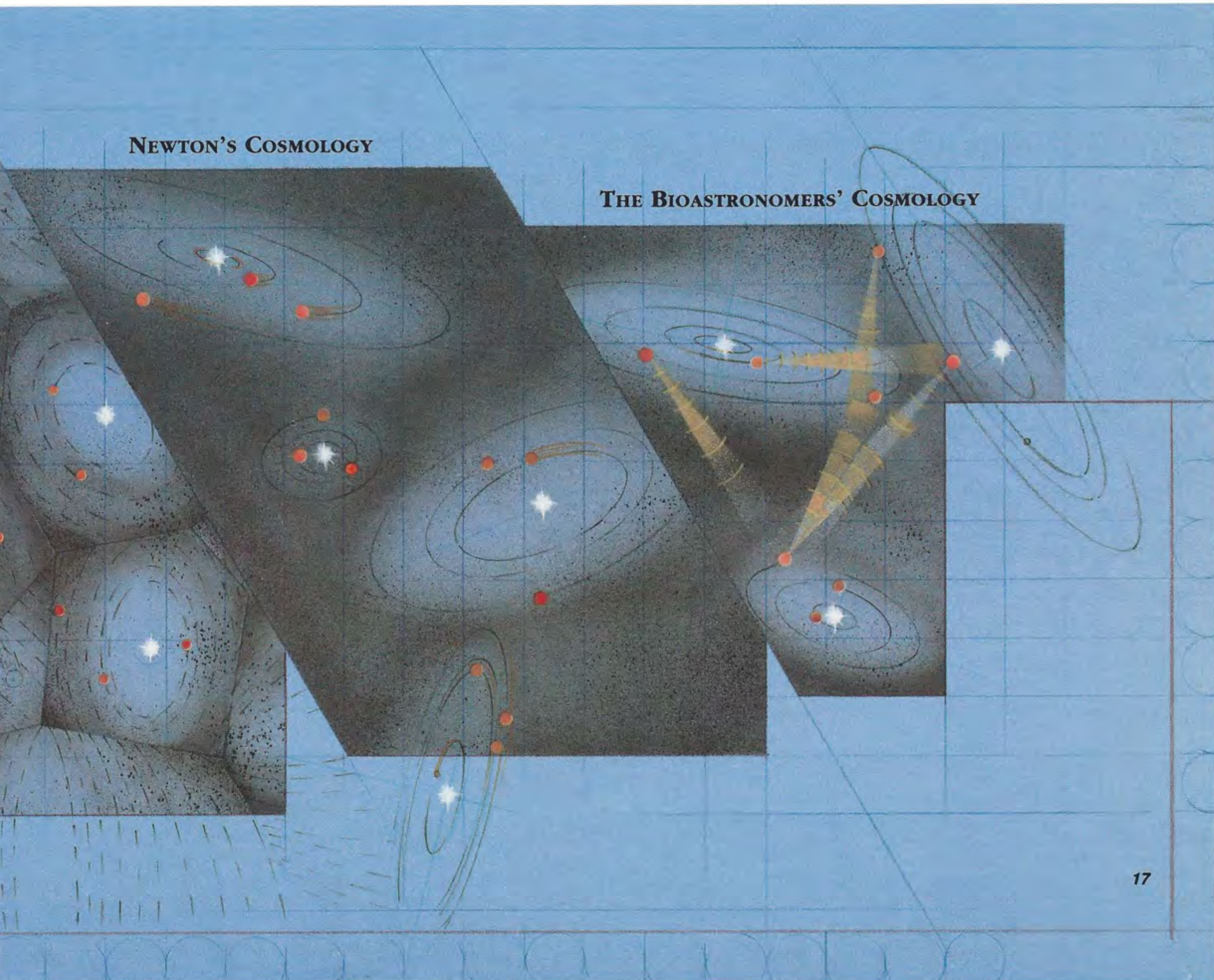
might move.

Yet it is interesting that despite the lack of physical evidence, and exceptions such as the 1920s notwithstanding, the biophysical cosmology has been widely accepted since about 1750. There is perhaps no greater demonstration of the change in human attitude from the Renaissance to the Enlightenment than this: While the Copernican cosmology was resisted for centuries, the biophysical cosmology triumphed in the eighteenth century on far less evidence—indeed, some might say, on no evidence at all. But we should not confuse acceptance with proof. Although some have accorded the idea the status of accepted myth, we should still regard it as a scientific hypothesis (as a scientific *cosmology*, I have argued here), realizing that proof is yet to come.

When we view the extraterrestrial life debate within the broad context of the history of science, we see its close association with major cosmologies. We recognize it as an emerging, embryonic cosmology of its own. And SETI assumes its importance as a far-reaching test for this biophysical cosmology. Frivolous dismissals of bioastronomy as a science in search of a subject surely mistake the nature of science. Any would-be science is by definition looking for a subject. Like protostars forming out of the nebular mass, the age-old concept of extraterrestrial life may today best be termed a protoscience, one that will either coalesce or dissipate into thin air.

To attribute belief in extraterrestrial life primarily to metaphysics is a gross oversimplification that ignores the subject's origins in cosmology, and, indeed, the existence of philosophy in all our cosmologies and all our science. Nor does it explain the way that individuals' views change with changes in astronomy and cosmology, or do justice to the complexity of frontier science and its practitioners. In short, such a claim does not withstand historical scrutiny. Without cosmology there would be no belief in extraterrestrial life, and without the concept of extraterrestrial life, the history of science would surely lack one of its most interesting, if controversial, cosmologies.

Steven J. Dick, an historian of science at the US Naval Observatory in Washington, DC, is the author of Plurality of Worlds: The Origins of the Extraterrestrial Life Debate from Democritus to Kant *(1982) and* The Twentieth Century Extraterrestrial Life Debate: A Study of Science at Its Limits *(forthcoming). He presented a longer version of this article, which will appear in the Conference Proceedings, in October 1988 at The Planetary Society's International SETI Conference in Toronto.*



World Watch

"LET'S GO TO MARS—TOGETHER." Since our President, Carl Sagan, first issued this call in 1984, The Planetary Society has enthusiastically embraced the goal of Mars exploration led by the United States and the Soviet Union. We have played a key role in focusing the attention of the public and policymakers alike on the need for a well-planned space program leading to human exploration of Mars early in the next century.

Some have misunderstood our advocacy, thinking it too narrow or too single-minded. (Dr. Sagan dealt with these and other criticisms in the November/December 1988 *Planetary Report*.) That the Mars goal is indeed in the mainstream of space policy has recently become evident by wide-ranging and varied support.

Rethinking Space Policy

The US presidential campaign provided many opportunities to consider space policies. Several candidates—including the new chairman of the NASA authorizing subcommittee in the Senate, Albert Gore—supported our Mars goal (see the September/October 1988 *Planetary Report*). Although President Bush has yet to declare himself, a little noted but apparently carefully considered statement in the Republican Party platform asserted: "a resurgent America, renewed economically and in spirit, must get on with its business of greatness. We must commit to a manned flight to Mars *around the year 2000* (italics ours) and to continue exploration of the moon." We have no way of knowing if this declaration resulted either directly or indirectly from The Planetary Society's testimony to the Party's platform committee, but it certainly did follow our Mars advocacy. The similar endorsements by both the Republican Party and the Reverend Jesse Jackson were particularly telling.

As each new administration prepares to take office, many groups submit studies to the transition team in hopes of influencing the President's policies. The Center for Strategic and International Studies (CSIS), a Washington "think tank," submitted the first of two major space policy studies. The chairmen were Brent Scowcroft, now President Bush's National Security Advisor, and John McElroy, Dean of Engineering at the University of Texas at Arlington. They determined that US space policy coordination is a broken system that needs fixing by White House leadership. They were influenced by the internal NASA "Leadership Report" (Ride study), which offers alternative goals for the US civil space program. The CSIS study concluded that human exploration of Mars should be the United States' long-term goal; that it should be a prime purpose of the space station (along with US technological competitiveness); and that it should be international, following a carefully planned and negotiated series of steps involving both US allies and the USSR. The CSIS also stated that the civil space program must be structured to serve major US national objectives: education, environment, competitiveness and exploration.

The other study, conducted by the National Academies of Science and of Engineering, was chaired by Dr. H. Guyford Stever, the former head of the National Science Foundation. It too called for presidential leadership in setting space goals and recognized that any major space initiative must be political in origin. It concluded that human exploration of the solar system should be the guiding principle behind any such initiative and that it was *the* right goal for the space station.

In December 1988, NASA's new Office of Exploration issued its first report to the Administrator. It studied several human exploration scenarios: establishing a lunar base, landing on Mars' moon Phobos, a Mars mission, and the settlement of Mars. All have as the major goal human exploration of Mars. And just recently that office noted that US-Soviet cooperation is the best and most likely way to carry out the program. This year the office will begin studying international partnership in mission design.

Notably the House of Representatives included the initiation of an American-Soviet Mars mission in its 1989 NASA authorization bill. Unfortunately, the Senate's bill did not include that provision. Despite the United States' equivocal position, President Gorbachev has on several occasions publicly called for American-Soviet exploration of Mars.

Success?

Admittedly, we don't all agree on *how* to reach the goal of landing humans on Mars. But our differences are secondary; if we can agree to an international expedition, scientists and engineers can and will get us there.

Have we won? Some say the Society should declare victory and assume that the Mars goal is in place. Others point out that the hard steps have not yet been taken—the space station has not been redirected, the US has no launch vehicle policy suitable for human missions to Mars, the US-USSR Space Cooperation Agreement (see the January/February and May/June 1987 *Planetary Reports*) is still too little and too slow, and many robotic precursor steps to Mars are unapproved and unfunded. But the widespread recognition of our position gives us reason to believe that we are making considerable progress.

Looking Backward: How We Put Mars Back on the Agenda

In June 1984, when US-Soviet cooperation in space was moribund and relations between the two countries nearly non-existent, The Planetary Society organized a meeting in Graz, Austria, of leading Soviet and US planetary scientists to discuss bilateral cooperation in planetary missions. This meeting led to new steps in data exchange among *Viking* and *Venera* scientists as well as informal contacts in the *Vega* and *Phobos* missions and, most important, paved the way for official government action, especially the renewal of the 1972 intergovernmental agreement on US/USSR cooperation in space.

In September 1984, Dr. Sagan's article "The Case for Mars" appeared in *Discover* magazine, outlining both the scientific reasons to return to the planet and the envisioned goal of international cooperation in peaceful ventures: "Suppose the people of Earth are one day fortunate enough to discover new leaders in Washington and Moscow dedicated to a new beginning and to seal that new beginning they embark on a dramatic joint enterprise—something like the *Apollo* program but with cooperation, not competition, the goal."

That same month Carl Sagan and Louis Friedman testified to the Senate Committee on Foreign Relations about international cooperation in space. Dr. Friedman stated, "A cooperative US/USSR program in planetary exploration that might lead to human flight to Mars would be of enormous significance to the cause of global security and international stability."

By October 1984, through the initiative of Senator Spark Matsunaga (D-HI), the US Congress had passed—and the President signed—a Joint Resolution urging renewal of the space cooperation agreement. By then The Planetary Society was advocating international cooperation in space as a goal for NASA.

Building Mars Momentum

The Planetary Society's program gained momentum with a series of symposia, some directly addressing Mars exploration, others, like the symposium "The Potential Effects of Space Weapons on the Civilian Uses of Space" (cosponsored by the American Academy of Arts and Sciences) in January 1985, discussing the future use of space. There Academician Roald Sagdeev, then Director of the Institute for Space Research of the Soviet Academy of Sciences, suggested a joint Mars Sample Return-Rover project. Panel Chairman Dr. Bruce Murray, Society Vice President and former Director of the Jet Propulsion Laboratory, summed up the discussion with an alternative to space weaponry: "We should be looking toward a future in which humans will go to Mars."

To mark the 10th anniversary of the *Apollo-Soyuz* linkup, The Planetary Society cosponsored the conference "Steps to Mars" with the American Institute of Aeronautics and Astronautics in July 1985. Participants included the *Apollo-Soyuz* astronauts and cosmonauts; Roger Bonnet, Senator Matsunaga, Astronaut Sally Ride, Thomas Paine (now a Director of the Society), and James Beggs, then Administrator of NASA.

The Planetary Society addressed Mars exploration from every angle. Technical considerations were analyzed in a 1985 Society-commissioned report by the Science Applications International Corporation that studied human missions to the Moon, a near-Earth asteroid, and Mars. It provided the first post-*Apollo* cost estimate of a piloted Mars mission. The Society also cosponsored "Case for Mars" conferences in Boulder, Colorado, that brought together professionals and enthusiasts developing ideas for Mars exploration.

Louis Friedman presented a technical description of a program built around a Mars goal, "Towards Becoming a Multi-Planet Species," to the 1985 International Astronautical Federation Congress. Bruce Murray touched upon the political need for human flights to Mars in his article "Civilian Space: In Search of Presidential Goals" for *Issues in Science and Technology* in 1986. Dr. Sagan described the potential impact on society of such flights in "USA and USSR: Let's Go to Mars—Together," read by the 65 million readers of *Parade* magazine. The article appeared in the Congressional Record, was excerpted in *Pravda* and was reprinted worldwide.

Additionally, *The Planetary Report* covered Mars exploration with issues such as "Humans on Other Worlds," March/April 1985; "*Viking*: the Tenth Anniversary," July/August 1986; and "Exploring Mars," May/June 1987.

In the summer of 1987, US and Soviet space scientists and policy-makers met via satellite link-up in the Society-sponsored Spacebridge "Together to Mars?" For four hours experts from the two countries discussed Mars exploration. Although they reached no consensus as to whether life exists on Mars or where the best landing sites are located, everyone agreed that pooling resources and efforts would enhance not only future missions but also global cooperation. The panelists also defined the value of joint robotic missions to characterize the martian environment. That fall PBS televised nationally a one-hour special entitled "Together to Mars?" based on the Spacebridge; similar programs were shown on Soviet and Japanese television.

Triumphs Despite Trials

In April 1987, when NASA delayed the *Mars Observer* two years from a planned 1990 launch, Planetary Society members wrote over 10,000 letters of protest to Congress and NASA. Although the 1990 launch date was not reinstated, NASA delayed the mission over strong congressional objections.

The Society broadened its campaign by circulating a Mars Declaration listing twelve cogent reasons for visiting our neighboring world. The Mars goal captured the imagination of a strikingly diverse group of US leaders. Initial signatories included leaders of peace groups and retired Army, Navy, Air Force and Marine general and flag officers; astronauts and religious leaders; labor and industry executives; politicians and poets; Nobel laureates and sports figures; ambassadors, university professors and former presidential advisors; former cabinet and sub-cabinet members; and every former NASA Administrator since the agency's founding except the then incumbent. Subsequently, tens of thousands have signed the Mars Declaration, with hundreds of new signatures arriving daily.

US scientists are now working on the Soviet *Phobos* mission, and Soviet scientists will work on the US *Mars Observer* mission; three bills were put before Congress in 1988 setting the goal of human exploration of Mars and encouraging US/USSR cooperation toward that goal; and more than 30 editorials urging these objectives have appeared in such publications as *The New York Times*, *The Los Angeles Times*, the *Atlanta Constitution*, *US News and World Report* and the *Christian Science Monitor*.

In 1988 The Planetary Society presented testimony supporting the US planetary exploration program, in particular the proposed Comet Rendezvous Asteroid Flyby, to the Senate Committee on Commerce, Science and Transportation; urged members to support NASA's Project Pathfinder, a technology development program for future space missions, including a piloted Mars mission; and supported development of Mars ballooning for implementation on the Soviet *Mars 94* mission. This year Dr. Sagan testified for two hours to the House Space Science and Applications subcommittee about planetary exploration and the long-range goal of Mars.

The Planetary Society continues to advocate cooperation in space, long-term mission goals, and a peaceful focus for the combined energies of the world's superpowers. The time may be right to commit to the future, to commit to the human exploration of Mars.

Louis Friedman is The Planetary Society's Executive Director. Susan Lendroth is the Society's Manager of Events and Communications.

Lunar Pol

Water ice may be hidden in protected nooks near the Moon's poles; the south pole is located in the dark region near the bottom of this image. The crater Amundsen (center), named for the first human to reach Earth's south pole, is about 100 kilometers across.

Image from Lunar Orbiter 4, *frame 005 H3, NASA*

In 1692 Giovanni Domenico Cassini, the first Director of the Paris Observatory, set forth in detail the Moon's observed laws of motion. Due to causes still unknown, the Moon spins about a polar axis almost perpendicular to the plane of the ecliptic (the plane cut by Earth's orbit about the Sun). Therefore it has no seasons. At the lunar poles, the Sun is always near the horizon. In craters there, some regions must always be in shadow; there may also be mountains of perpetual light.

These facts have led scientists to speculate about what may lie in those unknown polar regions. In 1961 Bruce Murray (now Vice President of The Planetary Society) and his colleagues published a paper suggesting that it must be so cold in the perennially dark polar craters that ice could accumulate over geologic time. In the mid-1960s, *Lunar Orbiters 4* and *5* photographed most of the lunar surface, including both poles, but of course they could not see into the shadows. In later years various people have attempted to improve on the theoretical arguments, but highly capable scientists still reach opposite conclusions as to the presence or absence of the ice. The only way to settle the question is to send a spacecraft to look for it.

Importance of the Poles

The lunar polar regions are important because only there can one enjoy relief from the rest of the Moon's succession of scorching two-week days and frigid two-week nights. [Midday equatorial temperatures reach about 130°C (about 260°F). At midnight the temperature plunges to about -150°C (about -240° F). At the poles, we find temperatures permanently below about -230 to -195°C (about -390 to -315°F).] The dark craters are thus ideal sites for those kinds of astrophysical telescopes that require cryogenic (very low) temperatures to reduce background noise.

With or without ice, international protection of these special, small regions will be essential for a coming age of lunar settlement. But water ice and other frozen volatiles, if present in usable amounts at or near the surface, could transform the whole course of lunar settlement and development. If we cannot find hydrogen in ices, we might be forced (with much greater difficulty) to mine it: a small amount is implanted in lunar soil by the solar wind. Hydrogen from water, combined with the Moon's abundant oxygen, could fuel the long-dreamt-of argosies of rocket ships that will someday make the solar system our home. (If the hydrogen is successfully mined, an important byproduct will be helium-3, a fusion power fuel.) Engineers are barely beginning to examine these unearthly kinds of mining and processing. Assessing their comparative costs is a task that will be made feasible by work now in progress at the University of Arizona's Center for the Utilization of Local Planetary Resources and at the Space Studies Institute in Princeton.

The Little Spacecraft That Could: Will It Ever Fly?

"I think I can" detect the ices—so says Dr. James R. Arnold of the University of San Diego. Arnold's remote sensing instruments mapped the parts of the Moon visited by *Apollo* but have never flown to the poles. For more than twenty years he and his US, Soviet, and Japanese colleagues have been urging their governments to launch a lunar polar orbiter. The tattered history of this mission concept is almost as dreary as the long, sad story of *Galileo*, the decade-old, yet-to-be-launched mission to Jupiter.

In December 1972, Harrison Schmitt and Eugene Cernan stepped off the lunar surface and rejoined Ronald Evans in orbit. As they left, Schmitt spoke these hopeful words: "As I take man's last steps from the surface back home for some time to come but we believe not too long into the future.... As we leave the Moon at Taurus-Littrow, we leave as we came and, God willing, as we shall return, with peace and hope for all mankind. Godspeed the crew of *Apollo 17*." But any followup to that magnificent beginning was already doomed. The US, mired in Vietnam and having achieved its primary political objective with *Apollo*, quit the Moon, and the Soviets cut their losses when their *Apollo* competitor failed. NASA funded some small studies of an automated polar-orbiting mission that would carry Arnold's gamma-ray spectrometer and other instruments and might find the ices, but nothing came of that work. In subsequent years Soviet, Japanese

ar Explorers

by James D. Burke

and US groups proffered other fruitless proposals.

In 1987, The Planetary Society got involved. Murray and California Institute of Technology graduate student Tom Svitek revisited the theories, concluding that the anti-ice arguments had great merit but were inconclusive: Perhaps the elusive bonanza could still exist. The Society, led by Svitek and another Caltech student, Eric Gaidos, assembled a small team to study proposals for a series of "cheap, quick" missions, one of which was a lunar gamma-ray probe.

Others shared their interest, including the Space Studies Institute (SSI) in Princeton, the (then) L5 Society, and a Jet Propulsion Laboratory (JPL) team studying low-cost missions. Dr. Lew Allen, JPL Director, was supporting in-house funding for small, low-cost missions, one of which was a lunar ice-finder based on NASA's "Getaway Special" program. That program encourages students to fly small, self-contained experiments on the shuttle. The JPL design used solar-electric propulsion with argon propellant to avoid the hazards of carrying chemical propellants in a Getaway-Special container. Despite analyses and cooperative meetings of the interested groups, in the end The Planetary Society's studies were reluctantly abandoned. (SSI's effort continues.)

While The Planetary Society's study showed the possibility of low-cost missions and provided a library of spacecraft and launch-vehicle data useful in later work, it did not point toward an inexpensive mission that could definitely confirm or negate the presence of lunar polar ices. An extensive scientific survey found that to do remote sensing of the quality required, the mission's cost, though small in NASA terms, would be too great for a project funded entirely by the Society. But as Friedman reasoned: "Sometimes the Society must start a research effort and fail—otherwise we are not trying hard enough."

This same demand for unambiguous measurements is partly responsible for the lack of a Soviet mission. Up to now, Soviet proposals have been based on gamma-ray detection in sodium iodide, which is less sensitive than the germanium now used in US spectrometers. (This situation may change if the Soviets start making germanium-based spectrometers or decide to use foreign ones.) Although innovative and well conceived, so far Japanese proposals have not competed successfully with other scientific missions in their program. Thus we are left with the choice of waiting until some government launches the project or of returning to some private or partly private approach. The Space Studies Institute continues to explore this possibility with collaborating individuals and groups, and in 1989 the International Space University will make it the subject of a student design project.

Where To, Now?

In the present NASA plan, a lunar polar orbiter may fly in the mid-1990s. Named *Lunar Observer*, it will probably be built out of spare parts obtained from the approved *Mars Observer* project. Because *Mars Observer* must retain those parts until its 1992 launch in case of need, the *Lunar Observer* has no realistic prospect of flight before about 1996. And of course the parts may be used for some other mission or for their original purpose as spares.

Very recently some Soviet scientists have again been promoting a lunar polar orbiter for 1992 or 1994. Whether this possibility is real or merely promotional is not clear at this time.

With such dreary possibilities facing governmental lunar programs, it is no surprise that groups of lunar enthusiasts have been seeking other avenues. If lunar polar ices are present and international agreements for their controlled exploitation can be reached, the whole course of lunar inhabitation could change. But even if the ices are absent, we will still need international agreements simply because of the other unique environments mysteriously provided by Nature in the polar regions of the Moon.

James D. Burke is a member of the Technical Staff at the Jet Propulsion Laboratory and serves as Technical Editor of The Planetary Report.

Remote Sensing of Planetary Ices

It may seem incredible that a spacecraft a hundred kilometers up can detect frozen volatiles beneath a planet's surface. This remarkable possibility has been demonstrated in laboratories but not yet in flight. It depends on the physics of nuclear particles' interaction with matter. When a cosmic ray particle strikes the nucleus of a deuterium (heavy hydrogen) atom, the nucleus emits a burst of light, a gamma ray with an energy of 2.2 million electron volts, which can be registered in a detector using sodium iodide or germanium as the sensor.

With complications caused by the need to cool the detectors and to shield against spurious radiations and particles, this is the principle of gamma-ray spectrometers to be used on both the *Mars Observer* and the *Lunar Observer*. Besides detecting deuterium, these spectrometers are also very precise and sensitive detectors of gamma rays at other energies emitted by radioactive elements in a planet's crust.

Another way to look for ices is to examine the spectrum of neutrons coming up from the planet. An excess of slow-moving neutrons may mean that they have been "moderated" (slowed) by light elements, including hydrogen, in the surface materials. Finally, a radar altimeter might possibly show surface shapes or patterns caused by subsurface ices. Patterns of this kind are well known on Earth, and some similar ones have been seen in *Viking* imagery of Mars. However, if the lunar ices have never warmed up toward their melting or sublimation temperatures, no patterns may be evident.—*JDB*

SOCIETY *Notes*

ASTRONOMY DAY

The Planetary Society is helping to sponsor Astronomy Day, which will be observed on May 13, 1989 with events throughout the United States. For more information, send a self-addressed, stamped envelope to Gary E. Tomlinson, Astronomy Day Coordinator, Astronomical League, c/o Chaffee Planetarium, 54 Jefferson Avenue SE, Grand Rapids, MI 49503 or call (616) 456-3985. Contact me c/o The Planetary Society if you can help staff a Society exhibit table at an event in your area.
—Marshalle Wells, Volunteer Network Coordinator

VIDEO HIGHLIGHTS MARS DECLARATION

The Society's Mars Declaration videotape, which explains the Mars goal and includes dramatic footage of Mars and other space projects, is available for loan or purchase ($35, 24 minutes long). Contact me for more information.*—Tim Lynch, Director of Programs and Development*

SUPPORT FOR TEACHERS LAUDED

The Planetary Society has been honored with a certificate of thanks from the National Science Foundation and the National Science Teachers Association acknowledging our contribution to the 1988 Presidential Awards for Excellence in Science and Mathematics Teaching. The awards recognized one science and one mathematics teacher from every state, the District of Columbia and Puerto Rico. The Planetary Society gave a year's membership to each of those exceptional educators.
—Charlene M. Anderson, Director of Publications

MISSION TO PLANET EARTH

Planetary Society President Carl Sagan highlighted the Society's concern for our home planet in his keynote address on February 28, 1989 at the Global Climate Change Conference in New York. Dr. Sagan discussed global warming caused by the greenhouse effect and what can be done about it, the reliability of climatic predictions, and the relation between Earth and the other planets. To initiate a new program supporting a "mission to planet Earth," The Planetary Society helped organize a public meeting of interest groups in conjunction with the conference.
—Louis D. Friedman, Executive Director

FINANCIAL REPORTS AVAILABLE

Our annual Price Waterhouse audit resulted in an unqualified opinion finding the Society's 1988 financial statements in conformity with generally accepted accounting principles. Copies of the financial statement, which includes a report on restricted funds resulting from members' donations, are available upon request.*—Lu Coffing, Financial Manager*

STAMP HONORING RADIO TELESCOPE?

Paul Vanden Bout, Director of the National Radio Astronomy Observatory, has urged Planetary Society members to encourage the US Postal Service to issue a stamp honoring the Very Large Array (VLA) radio telescope. The most used and most productive telescope on Earth, the VLA has operated in New Mexico since the 1980s and can be used for planetary observations. Letters of support may be sent to: Citizens Stamp Advisory Committee, Stamp Information Branch, 475 L'Enfant Plaza, Washington, DC 20260.*—CMA*

KEEP IN TOUCH

Our mailing address:
The Planetary Society
65 N. Catalina Avenue
Pasadena, CA 91106

Call for an updated events calendar:
(818) 793-4328 east of the Mississippi
(818) 793-4294 west of the Mississippi

General calls:
(818) 793-5100

Sales calls ONLY:
(818) 793-1675

UPCOMING EVENTS

CELEBRATE *MAGELLAN*

On Friday, April 28, 1989, The Planetary Society and NASA Kennedy Space Center's Spaceport USA, operated by TW Recreational Services, Inc., will sponsor a public event at the Kennedy Space Center in Florida to celebrate the launching of the *Magellan* mission to Venus. Speakers will discuss not only the *Magellan* mission itself but also how a serious return to planetary exploration could shape the future of the US space program. Admission is free; the Society must receive written requests for tickets (two per request) by April 18th.
—Susan Lendroth, Manager of Events and Communications

INTERNATIONAL *VOYAGER* WATCH

The Planetary Society will celebrate *Voyager 2*'s encounter with Neptune in August 1989 by sponsoring *Voyager* Watch, a program funded by the Norris Foundation and designed to educate and excite the general public about space exploration. The major activity will be Planetfest '89, a five-day, multi-media event in Pasadena, California. The Society will also create a master tape program of Jet Propulsion Laboratory *Voyager* videos and a slide program with 40 slides and an audiocassette featuring *Voyager*'s Grand Tour. Both will be duplicated and loaned out free of charge to educators and members wishing to sponsor regional events. Contact me for your free *Voyager* Watch information packets, special educators' packets or more information.*—Susan Lendroth*

Help Design a Mars Rover

by Louis D. Friedman

The martian terrain will not be easy to traverse, even with the best designed rover, and the most scientifically interesting regions may be the most treacherous. Valles Marineris (above), the rift stretching one-fifth of the way around Mars, could reveal much of the planet's geologic history, just as the Grand Canyon has taught us much about Earth. But its kilometers-deep canyons are probably too dangerous for an early rover mission. But even relatively safe regions, such as the Viking Lander 1 *site seen here (top left), can be rocky and difficult to move across.*

Images from JPL/NASA

Rarely do we have a chance to enable Planetary Society members to help plan and design an actual spacecraft mission. We have held contests to name both a spacecraft (*Magellan*, which will orbit Venus and image it with radar) and an asteroid (named for space artist Chesley Bonestell), but we have never had an opportunity for members to contribute to mission design.

This possibility has been suggested to us by Karoly Szego of the Central Research Institute in Budapest, Hungary. Dr. Szego has been a principal experimenter on several Soviet space missions, including *Vega* to Halley's Comet, and has also spoken at several Planetary Society events in the United States.

At the recent meetings in the Soviet Union about future Mars missions, Dr. Szego noted that there are many requirements for a Mars rover—a robotic vehicle that will travel across the planet to explore different terrains. The first rover may fly on the Soviets' *Mars '94* mission; it would land in 1995 to begin its experiments to analyze the martian environment and surface.

However, Dr. Szego noted, perhaps its most important job is to be prepared for the unexpected. Every time we have gone anywhere in the solar system, even when we looked back at Earth from near space, we have been surprised. We want any Mars rover to be able to seek out unusual things, to recognize them and investigate them, just as you or I would do if we were lucky enough to be the first humans to explore Mars.

Dr. Szego's questions to Planetary Society members are these: How do we teach a Mars rover to recognize the curious, strange or unexpected? What should it look for—size, color, brightness, flavor, smell, sound, motion? How do we use the rover to gather information and satisfy our curiosity?

Planetary Society members are invited to write us with ideas for teaching the Mars rover to explore. We will review your ideas and pass the most promising ones along to our colleagues in the Soviet, US and European space programs.

The first-prize winner will receive a library of books about Mars. Other entries that pique the judges' interest will be recognized as well.

All entries must be *received* by June 30, 1989. Send your ideas to Mars Rover Contest, The Planetary Society, 65 N. Catalina Ave., Pasadena, CA 91106.

We look forward to seeing your suggestions!

News & Reviews

by Clark R. Chapman

Halloween is that peculiarly American holiday that celebrates the contrast of appearance and reality. The 20th annual meeting of the Division for Planetary Sciences of the American Astronomical Society was held Halloween week in Austin, Texas, where the "DPS" began. It is the chief society of planetary scientists, especially those with an astronomical bent. Although the DPS is an American society, Catherine de Bergh of France was elected this year to the DPS Committee. Most things ran smoothly, on the surface, as researchers reported their latest discoveries, interpretations and calculations. There were talks about sodium emissions from the thin lunar atmosphere, the curious brightening of distant Chiron, hints of planets around other stars, a new phenomenon ("solid-state greenhouse") that revises our notions about icy satellites, and pictures of heat leaking through Venusian clouds. The research advances were real, but major discoveries seemed to be missing. Was this appearance or reality?

Thanks to the depressed Texas economy, the DPS could celebrate its 20th anniversary at bargain-basement prices in Hyatt Regency opulence, a far cry from the shabby Austin motel where the first one-day DPS meeting was held in 1968. Planetary science was then on its way up, with *Mariners* being launched every other year and the first lunar landing imminent. Despite the elegant venue for the 1988 meeting, the gloomy reality of NASA's planetary research program belied the meeting's superficial success.

Research Funding Cuts

I spoke with a scientist who is the only remaining expert using a crucial technique. Her research group's funding had been slashed, so she was put in charge of trying to recoup. Her efforts had been partly successful, but at a cost: The funds she won back would have to come from a colleague's hide, and the 20 percent effort she now spends managing is that much less time on her research. A few weeks earlier, another scientist—the world's expert in an important specialty—had all of his funding terminated by NASA. He came to Austin in a desperate, last-ditch attempt to save his failing career.

One ex-officer of the DPS, whose group's funding had shrunk so much that he is pursuing a more lucrative career part-time, was absent. I didn't see another regular DPS-er, from whom I had just gotten a bitter letter. NASA has stopped supporting his project, a lifelong dream. Instead of venting his anger at NASA officials who had always underfunded his project, robbing it of its potential, he railed against his colleagues. I learned in Austin that others had also received his retort to the anonymous referees. In fact, I had not advised NASA on this one. But his letter reminded me how NASA wastes scientists' precious time in mutual criticism, deflecting blame for cuts from NASA's mismanagement onto other scientists. The shrinking research community should be doing science, but NASA frustrates that by fostering a flood of proposals that have to be written (and evaluated) to chase ever-dwindling funds.

Just a month before Austin, NASA Administrator James Fletcher sliced another $10 million from planetary research and analysis (R&A) for 1989, despite Congress' clear intent and despite last spring's promises by other NASA officials that priority would go to *augmenting* planetary R&A because it was in the worst

THE CHANGING FACES

In Austin Bruce Hapke of the University of Pittsburgh became the Chairman of the Division for Planetary Sciences. In 1981, Hapke organized the Pittsburgh DPS meeting. That was an exciting time, just two months after *Voyager 2* encountered Saturn. It was also depressing, as Office of Management and Budget Director David Stockman advocated ending the US Planetary Program and tried to "zero out" *Galileo*'s budget.

I checked registrants at both the Pittsburgh and Austin meetings and asked why some came to one and not the other. There were mundane reasons like illness, but others reflect the evolution of planetary science.

Where Are They Now?

Jonathan Gradie works at the University of Hawaii studying asteroids, but also half time at a Honolulu company. In 1981, he was at the Pittsburgh DPS meeting. Last year he had traveled so much (partly for his non-planetary work) that he passed up Austin and "got some work done when everybody else was away." Because of "very, very tight" NASA funding, Gradie must gather funds from different sources to "put together a salary." He is not demoralized because there are "lots of other interesting things to do out there."

Ben Zellner works on Hubble Space Telescope operations for an HST Science Institute contractor—as he says, "earning a living doing industrial astronomy." By company policy, he has no money or time for the DPS. He hopes to return to science when HST is up.

John Dickel of the University of Illinois never was a full-time planetary radio astronomer, but a student, Imke de Pater, got him involved with planets. In the early 1980s, NASA cut out nearly all planetary radio funding, so Pittsburgh was Dickel's last DPS meeting. A new student "might well have kept me interested in planetary research," but he had no funds for a student. He remains a DPS member but has "gotten out of the planets game." His heart is in supernova remnants.

Dave Pieri, who first studied martian geology with Carl Sagan, talked about sulfur volcanism on Io at Pittsburgh. Then he moved into terrestrial research and now leads a volcanology group at JPL. He is finding many opportunities to advance his career in NASA's Earth Science and Applications programs. "It was like a steeplechase," Pieri says of hurdles facing planetary researchers, while Earth Applications is "like a paved freeway." Due to cutbacks, shape of all of NASA's generally hurting science programs. Following the usual approach in Washington—mortgage the future to battle current crises—NASA is using smoke and mirrors to put off some of the problem until next year: Most NASA-funded planetologists are being given just two-thirds of their approved funds this year; they must write renewal proposals just eight months after their last ones in the impractical hope that NASA can pay from new funds just as the next fiscal year begins. This ploy requires the new Bush administration to undo the willful cutback, Congress to pass the budget in time, and NASA's contracts and grants office to process paperwork with unprecedented efficiency. Even if successful, the trick will stave off only some of the damage. Research on data about Comet Halley and Uranus will be stopped regardless, not to mention the career-ending and project-ending decisions already implemented.

Halloween Horror Show

On Halloween evening, many DPS-ers joined throngs of Austin citizens parading as ghosts and goblins on Sixth Street. But the real horror show was witnessed by scientists who attended the traditional "NASA night session," where officials come from Washington and habitually promise how much better things will be next year (always *next* year). There was a ghoulish feeling of déjà vu as one official explained, for the fourth year, that *next* year was the year for a Comet Rendezvous mission new start. Worse, he exceeded his pollyannaish optimism of previous years by claiming that NASA's planetary program was already in good shape!

The scientists sat in stunned silence. Many left in disgust; some later reported feeling sick. The tension was as palpable as if Halloween skeletons had invaded the hotel. The gulf separating perceptions of the NASA official from those of the scientists had opened so wide that, during the question-and-answer period, not a word was spoken about what was on everyone's mind. I knew of a dozen planned retorts, but nobody dared to say that the emperor wore no clothes. A tenure-track professor at a major university told me later that he was itching to speak but couldn't risk his vulnerable career. The NASA official returned to Washington, probably oblivious to the frantic despair of "his" scientific community, which must be made healthy if it is to provide intellectual and instrumental substance to the spacecraft missions NASA hopes to fly.

The European Space Agency had just OK'd the joint *Cassini* mission to Saturn, it was reported at Austin, impelling the US to commit to its half of the mission. Indeed, a combined comet/Saturn project is now going through the federal approval process. But NASA plans to use fewer scientists on missions; it is even throwing instruments off *Mars Observer*. With NASA's planetary office absorbed with big, not-yet-flying missions and ignoring human infrastructure, the quality of the American planetary science community will be badly weakened before *Cassini* flies in the late 1990s. It may be unable to perform its wider mandate of researching the solar system, which is a vital facet of NASA's charter... unless, of course, there is a change of vision within NASA and a resolve never again to strangle research programs in our universities and national laboratories to solve short-term cost-overruns on big projects.

To try to explore the solar system without a robust community of the brightest, most talented scientists and engineers on board is like trying to fly blind. Unfortunately, NASA's recent history has been to build fancy vehicles, a space station and costly spacecraft—ostensibly for scientific purposes—and then to fail to foster the creative human intelligence needed to use the hardware productively. If talk I heard in the hallways in Austin was typical, it is late in the day for NASA to save planetary science. That is the reality behind the mask of continued planetary research productivity. It is tragic that NASA officials don't seem to know it.

Clark R. Chapman served on various NASA Advisory Committees from 1975 until last October.

AT DPS MEETINGS

just 20 percent of his funds are now for planetary work. "In a way it's a shame," he says, "but I enjoy the terrestrial research immensely."

Jim Cutts' last DPS meeting was Pittsburgh; then his group lost its planetary funding. He is now Deputy Director of a center for space microelectronics technology. It gets only a quarter of its $20 million per year budget from NASA. "I'm very excited about what I'm doing," he says. "Microelectronics is very much a growth area."

Tom Gehrels, whose Spacewatch Camera suffered NASA budget cuts, stayed in Tucson to work while everyone was away. He is often at the telescope because he can't hire an observer. Gehrels' autobiography, "On the Glassy Sea: An Astronomer's Journey," will be published soon by the American Institute of Physics. He wishes he could have met his old friends in Austin.

And Some New Faces

Marcia Nelson hopes to finish her PhD in Hawaii by May. She wasn't at Pittsburgh since she was just back in school after working on *Voyager*. She went to Austin to give her results on spectra of glasses, to talk with colleagues and to look for a job. "A lot of us who have been graduate students in the last five years are not going to get jobs," Nelson feels. But after seven years studying planets, "I'm not going to throw in the towel without a fight," she says, despite rumors of better prospects in Earth science. She expects to get a post-doctoral job but worries about the long term.

Alan Hildebrand hardly knew about planetary science in 1981, when he worked in Canada as a minerals exploration geologist. Now a planetary student at Arizona, Hildebrand went to Austin because he hadn't been to a DPS meeting before. Also, Austin is near an exposure of the Cretaceous-Tertiary boundary where he wanted to do fieldwork for his thesis on the impact hypothesis for mass extinctions.

Jacklyn Green would have gone to the 1988 meeting even if it hadn't been in Austin, where she was completing her PhD. In 1981 she was studying cataclysmic variable stars before she realized she really wanted to study planetary science. Green feels it's premature to think beyond her new post-doctoral job in Hawaii. "I want to make the most of this job so that I'll be ready for the next one. I'm an optimist," Green admits. —*CRC*

FUNDING PLANETARY SCIENCE—

A National Perspective

by Robert A. Brown

In his "News & Reviews" column, Clark Chapman expresses the feelings of some planetary scientists about their primary funding agency, NASA. Such feelings are not exclusive to the planetary field, but are part of a larger turmoil over the evolving relationship of science and government. Similar debates are now roiling between the biomedical community and the National Institutes of Health, and between physicists and the Department of Energy. The future of planetary exploration rests on the outcome, and so this debate is vital to the interests of The Planetary Society. To continue the discussion, we print here another view of the current situation in planetary science.

Clark Chapman's "News & Reviews" column gives one scientist's snapshot of an astonishingly productive national program. He captures the frustration of adjusting to evolving circumstances, but he identifies neither the nature nor the source of fundamental change. His perspective invites a broader view of the space program and of federally funded science in order to see where the planetary program is grounded in the national interest and to understand how the program attempts to serve it. Viewed broadly, our space exploration program is a brilliant servant of national policy, and it holds out ever-fresh opportunities to those who join it with realistic expectations.

The United States' planetary program has offered three generations of scientists—as well as engineers and managers—exciting challenges, new skills and knowledge, and the chance to contribute conspicuously to the nation's life, but it has *not* offered them tenure. Universities do. Nevertheless, like universities and unlike nature, program evolution and the selection of individuals for term support by NASA are based on peer review. It is healthy to examine one's activities and to have them assessed by others. The current approach tries to be fair and at the same time assure the planetary program a workable balance of competence, continuity and responsiveness to changing needs.

Planetary exploration, with the rest of the space program, has had to absorb the unexpected costs and delays from the *Challenger* accident. Nevertheless, two planetary missions—*Magellan* to Venus and *Galileo* to Jupiter—are scheduled to be launched in 1989, and Congress will vote this spring on the President's budget request for both the Comet Rendezvous Asteroid Flyby (CRAF) mission and the *Cassini* mission to study Saturn and its satellite Titan.

What is the national context of planetary exploration and the role of the planetary scientists it supports? Planetary exploration is a unique consequence of NASA's formation and of President Kennedy's declaration that Americans would travel to the Moon in the decade of the 1960s. Scientists contributed to the success of the Moon landing, and they assured the ensuing bonanza of new knowledge about the space environment of Earth and about the nature and history of the Moon itself. A community of researchers was formed, and it laid far-reaching plans for science in, from and about space.

A multiplicity of national needs gave birth to the *Apollo* program. It and the subsequent exploration programs into the solar system beyond the Moon—*Mariner, Pioneer, Viking* and *Voyager*—delivered a snowstorm of benefits both scientific and otherwise. Beyond science, these benefits have fallen across a broad spectrum of national aspirations, including international cooperation, national security, competitiveness in high technology, scientific and technical education, culture, and the pride and prestige of the United States. Planetary exploration has expanded and enriched our cosmic map—our understanding of humanity's place and scope of action, which is the quintessential effect of exploration. From society's standpoint, the primary return on investment in planetary exploration consists of the rich cluster of non-scientific benefits it delivers.

The future direction of the planetary program is now the subject of lively debate, as the readers of *The Planetary Report* know well. This is another sign of health. Planetary exploration is not an entitlement program, and its value and potential contributions must be continually reassessed. The program's content must respond to the thoughtfully defined needs of the United States. Among these needs, of course, are advances in pure knowledge: Progress in planetary science improves our understanding of the atmospheres, oceans and interiors of planets, including Earth.

To illustrate that the proper planning process is open and broad and not restricted to scientific interests, consider three themes that are discussed in the context of the future planetary program: continued scientific exploration, a big Mars initiative and a search for extrasolar planets. Of course, these options are not mutually exclusive, but they *are* different. Associated with each is a particular mix of programmatic elements and a variety of benefits that could accrue to society in return. This breadth demonstrates what it means for planetary exploration to be a *national* program. It teaches why planetary scientists guide and serve the program, not as a priesthood, but joined with other voices in the public arena so as to assure that a wide national interest is met. In this view, the unique contributions of scientists—to introduce the constraints of science, to draw distinctions of scientific merit and to extract scientific results—will be more effective because they are not mistaken for the whole.

Robert A. Brown served as Chairman of the Division for Planetary Sciences of the American Astronomical Society from 1987 to 1988.

tend to see only the research side of any endeavor. Well, it's about time the Society quit dreaming about the fun part of this program. Anybody can do that, and they are. That's the problem. The Society, with all its genius and clout, ought to tackle the ugly part of this program—building a plan that will convince the boss to pay for a trip to Mars and beyond, and then convincing the boss.

I urge the Society to propose a fundamental, far-reaching and cooperative world plan for the exploration of our solar system (including Mars) by a consortium of governments and companies with a view toward commercial exploitation of space—not just a sightseeing trip. I could support a plan like that. I cannot support the one currently proposed by the Society.
DANIEL J. POTTER, *Shorewood, Illinois*

Does a mountain climber scale a mountain because it's the prudent thing to do? No. Does that person climb a mountain "because it's there"? Maybe, but I doubt it. What motivates a mountain climber or any other person attempting something equally challenging? Pure emotion. Adventure, romance, fame, excitment, risk, triumph! And that's exactly what is needed in our space program today—emotion.

Will a child choose a scientific profession just to orbit Earth in a space station? Not all that exciting, I think. It's lamentable that our educational system doesn't encourage scientific study. Wouldn't dreaming of going to Mars be a more compelling reason for children to go into a scientific profession than a few days in orbit onboard the shuttle?

The Mars Declaration has in it the stuff of dreams to fire the imagination of even our youngest. Who cares if we don't have the technology yet? The most awesome trait of the American people is their ability to devise a way to make their dreams come true. Let's cast prudence to the winds and put some *emotion* into walking on Mars!
DONNA MOORE, *Gardena, California*

Your articles on whether or not Venus had oceans in the past are very interesting. (See the November/December 1988 *Planetary Report.*) However, does it really matter? Can we change the situation? Can we ever go and live on Venus after we have destroyed the face of Earth as a place to live? Yes, keep probing the questions about Venus, Mars and other parts of the universe as exercises to keep the mind alert, sharp and useful, but what about Earth? Look at what humans have done to the surface of our planet in just the past 200 years. At the present speed of destruction how long do we have before Earth looks like Mars or Venus?

Is it possible for great minds like James F. Kasting, David Grinspoon and others to turn their attention to what is happening to our Earth? Can they come up with a plan to save what we have—a paradise that is being destroyed right before our eyes?

I am all for going to the Moon and then on to Mars, but I would like to see planet Earth included in the plans and thinking of The Planetary Society.
SAMUEL J. McELREA, *Eugene, Oregon*

Planetary scientists have been at the forefront of those calling for the spacefaring nations to use the knowledge and technology gained from planetary exploration to better understand Earth. In fact, researchers studying the greenhouse effect on Earth use Venus as an example of a greenhouse gone wild. Scientists who had studied martian dust storms used that experience to develop the Nuclear Winter hypothesis. Recognizing that the planets have much to teach us about our own world, The Planetary Society is actively developing a new intiative to encourage the study of Earth as a planet. Look for a special issue of The Planetary Report *on this topic later this year.—Editor*

As a new member and first-time reader of *The Planetary Report,* I see that the members as well as world scientific communities are taking sides on whether or not to go to Mars, launch the space station or fix world hunger. Dear members, let's not get upset and question our membership if others express interest in one project over another. NASA needs, and has, a budget. They will not be able to fund every worthy mission.

I think we should support missions with the maximum learning potential for humankind. Once missions are chosen, we should all support them and see that they are doing all they can with their technology.

I believe the space station is a worthy mission. I like the idea of research from outside the atmosphere—to better see the wonders of the universe and to look back at our Earth to better see what might work to fix all that humankind has broken.
NICK EDGE, *Sussex County, Delaware*

NEWS BRIEFS

(continued from page 3)

"non-essential" passengers may fly. First priority will be given to the "teacher in space."
—from the Langley Research Center's *Researcher News*

Valentin P. Glushko, a prominent but secretive figure in the Soviet space program,died in January at the age of 80.

In the 1930s Glushko and his colleague Sergei P. Korolyov (who was later credited with founding the Soviet space program) pioneered the development of the liquid-fueled engines now used in all Soviet rockets. The key roles that Glushko and Korolyov played in the Soviet space effort were kept secret until 1963. [Mr Glushko co-authored "The Way to Mars" in the November/December *Planetary Report.*]
—from *The New York Times*

Researchers at the Jet Propulsion Laboratory are studying the possibility of putting a robotic spacecraft into orbit around Mercury. Chen-Wan Yen of JPL notes that while *Mariner 10* (the only other mission to Mercury) merely flew past the planet in 1974, an orbiter could study it for many months, photographing the whole planet (unlike *Mariner 10*) and studying its surface compostion.
—from *Final Frontier*

Phobos 2, one of the Soviet space probes launched last July to study Phobos, has begun sending back its first pictures of the quirky martian moonlet.

Western scientists were somewhat concerned about the condition of several instruments aboard the small spacecraft, and it was not known until the last minute whether the television camera would work. But "a high-quality image of Phobos from various angles was recorded on nine television sequences," the Soviet news agency Tass announced from Moscow.
—from Lee Dye in the *Los Angeles Times*

Questions & Answers

It seems to me that the rate and nature of evolution might be profoundly affected by tidal action. Has this aspect been given due consideration by those who search for intelligent life elsewhere?
—William V. Medlin, Houston, Texas

Scientists have wondered what would have happened if Earth hadn't had a moon. Without the Moon, you'd think, there wouldn't be any sloshing of the oceans from the pull of lunar gravity that we call tides. Then, if life arose in the ocean, critters wouldn't be sloshed around on the beach by tides; this would reduce pressures on lifeforms in this "intertidal zone" to learn to adapt to life in the air as well as in the water. Land-based, tool-using life might not arise at all.

In our own solar system, most planets have only feeble, distant moons, not powerful enough to raise respectable tides. Does that mean that life capable of transmitting radio signals is rare? Not to worry. Few people realize it, but the *Sun* also generates tides. They're about half the height of lunar tides.

The presence of the Moon has probably affected the evolution of life here, especially since it's now slowly moving away from us, so it must once have been closer and raised much bigger tides.

The tidal drag has also slowed down our spin, so Earth may once have had a day closer to the 10-hour period of planets like Jupiter and Saturn. This too could have affected evolution.

In any event, we are just barely able at present to detect planets around nearby stars. It will be some time before we'll be able to see how common moons are around other planets. The bottom line is that without the Moon, the series of evolutionary accidents that led to us would probably have been different. Life would still have arisen here, and probably land life too, perhaps even intelligent life—but *we* might not have.
—TOM McDONOUGH, *Planetary Society SETI Coordinator*

The pull of the Moon on Earth's oceans regularly exposes and then covers intertidal regions along the sea's edge. Many plants and animals have adapted to life alternately in the air and the water, and indeed, some of these regions are the most biologically productive on Earth. It's possible that from these special ecological niches lifeforms eventually moved permanently to land, and their descendants became the technology-using organisms that are now scanning the skies in search of other technological beings.

Photographs by Hal Clason, Tom Stack and Associates

What is the difference between a planetesimal, a planetoid and a protoplanet?
—Barney M. Colver, Hell, Michigan

This is a good question because these terms have been used widely but without any precise definitions. They are informal terms used mostly by scientists who discuss the origins of planets. *Planetesimals* refers to any small bodies that are aggregating to make planets. They can be any size from dust grains to the size of the Moon. Mostly the term refers to bodies ranging from millimeter scale to the size of small asteroids a few kilometers across orbiting around the early Sun or around newly forming stars.

Protoplanet generally refers to a much larger mass, the size of a planet or even larger. Protoplanet is a word that originated in earlier theories of planet formation. These early theories assumed that planets formed when large regions of the early solar nebula became gravitationally unstable and contracted under their own gravity to form planets. Such large portions of the nebula were called protoplanets. Many modern theorists think the giant planets formed this way. So "protoplanet" is used to refer to an extended region of the nebula that is contracting to make a Jupiter or a Saturn, for example. It might include a nearly Jupiter-sized central core with a massive, extended atmosphere around it, still contracting to make the finished planet.

Planetoid is now a nearly obsolete word for asteroid, but "asteroid" or "minor planet" has taken its place. Occasionally it is still used to refer to any small, present-day interplanetary body, such as a comet nucleus, asteroid or meteoritic body, without implying a distinction about what kind of body it is.
—WILLIAM K. HARTMANN, *Planetary Science Institute*

How can Mars' extremely thin atmosphere stir up such ferocious, planet-wide dust storms with winds that sometimes reach hurricane force?
—Charley Levinson, Smyrna, Georgia

High winds in the martian atmosphere are mainly caused by its very low density (only one percent that of Earth) and the sunlight warming the planet (only 44 percent of that reaching Earth). These combine to produce the pressure differences that drive the winds. Their speeds are directly proportional to pressure differences between adjacent points and inversely proportional to Mars' total atmospheric pressure. Although the absolute pressure of Mars limits the winds' driving force, the 100-times-less density means that moderate pressure differences on Mars will produce velocities 100 times greater than those on Earth.

Several major features produce large pressure differences on Mars: Its topography is extreme, with mountains that would dwarf Everest and chasms that could swallow the Grand Canyon. Great, dense dust storms absorb sunlight, creating temperature differences among different parts of the atmosphere. The boundaries between the reflective ices of the polar caps and the darker surrounding soil generate surface temperature contrasts. Global and Earth-like frontal circulations also contribute to the winds that may generate dust storms. In places like Olympus Mons or Valles Marineris, the nighttime buildup of a cold layer near the surface causes strong "mountain" or "valley" winds as the cold and denser atmosphere in the surface inversion drains down the slope at night and early evening. At the *Viking 1* Lander site, a slope of only one percent causes winds of five to ten miles per hour, and on larger slopes the winds could be far stronger.

At the edge of the south polar cap, shortly after winter, the Sun shines on the contrasting red soil and white polar cap, producing large temperature differences. This generates strong winds and large local dust storms every year. This effect is stronger in the south because Mars' highly elliptical orbit brings it significantly closer to the Sun during late southern spring.

Although the *Viking* Landers provided us with years of data, we still have major questions about the great martian dust storms. What combinations of meteorological conditions are responsible for the large local dust storms, and are they the same in the northern and southern hemispheres? How do they differ with the season, and, especially, why are there intense global storms some years and not others? Also, are there any unusual triggering mechanisms? Some answers may be forthcoming from model studies, some might be discovered if it were possible to compute winds measured by *Viking 1*'s lander during the last three years of operation, and the final answers may have to come from the *Mars Observer* and other future missions.
—JAMES E. TILLMAN, *University of Washington*

FACTINOS

Recent infrared observations of asteroids and laboratory analyses of meteorites suggest that outer belt asteroids are made of some of the most primitive material in the solar system—only comets deeper in space are more pristine. They also suggest that asteroids, as well as comets, could have added water to planetary atmospheres during the early bombardment of the solar system.

Larry A. Lebofsky and Thomas D. Jones of the University of Arizona's Lunar and Planetary Laboratory have searched almost 40 of the largest carbonaceous asteroids for water. In their sample from the main asteroid belt, two out of three were rich in mineralogical water. But contrary to popular belief that the outer asteroids should contain more water and carbon than those in the main belt (because colder temperatures would cause less evaporation), the researchers find the outer bodies' surfaces to be water-free.

"That we're seeing no spectral evidence for water is a surprise," Jones said, "because these objects should look much like an inactive comet."
—from Lori Stiles in the University of Arizona *"A" News*

◇

According to David G. Jankowski and Steven W. Squyres of Cornell University, Uranus' moons Ariel and Miranda once had volcanoes that spewed frozen ice rather than molten lava. This is the first example of solid-state volcanism in the solar system.

Careful study of *Voyager 2*'s 1986 photos shows that some of the icy moons' mysterious surface features are best explained by resurfacing due to solid, icy materials. But because water ice at such a great distance from the Sun would be frozen so hard it couldn't possibly flow, the scientists conclude that other elements like ammonia and methane were probably mixed in to increase the water ice's mobility.
—from D. Jankowski and S. Squyres in *Science*

◇

The devastating Northern California forest fires in 1987 caused a self-perpetuating inversion layer to trap a pall of smoke over the Klamath River canyon. As a result, daily high temperatures for one week in September averaged 27 degrees less than normal. University of Maryland meteorologist Alan Robock says this lends credence to but doesn't prove the Nuclear Winter theory, which holds that there would be catastrophic global cooling in the aftermath of a nuclear war. [The concept of Nuclear Winter grew out of studies of martian dust storms.]
—from Larry B. Stammer in the *Los Angeles Times*

WE HAVE A SPACE PROBLEM!

Not outer space, but shelf space. The merchandise listed on this page will no longer be sold through *The Planetary Report*. A limited number of items are still available and must be sold to make room for new inventory. So we are having a sale! Prices are good through 4/30/89 (subject to availability).

#156 Saturn
by Seymour Simon
Simple, effective text and beautiful glossy photographs make this the perfect book to capture your child's imagination. Age 8-11. 28 pages. **$5.00**

#154 Rings – Discoveries from Galileo to *Voyager*
by James Elliot and Richard Kerr
Share the excitement of scientific exploration as uranian and jovian rings are discovered and Saturn unveils a complex, multi-ring system. 209 pages. **$5.00**

#124 Entering Space
by Joseph P. Allen
Astronaut Joe Allen writes of his journeys beyond this planet, allowing us an intimate sharing of day-by-day life in space. 239 pages. **$7.00**

REMINISCE ABOUT HALLEY

#110 Comet
by Carl Sagan and Ann Druyan
This lavishly illustrated *New York Times* bestseller is an enthralling encounter in words and pictures with the myth and science of comets, with special emphasis on Comet Halley. 398 pages. **$12.00**

#320 Halley Encounter
2 pictures from the *Vega* and *Giotto* missions. **$1.00**

#015 The Return of the Comet
by Dennis Schatz
This well-designed book contains an exciting variety of information and activities, both entertaining and scientific. Adult guide included. Age 9-14. 42 pages. **$4.00**

#004 The Comet and You
by E.C. Krupp, illustrated by Robin Rector Krupp
This humorous and informative book deals with all aspects of Halley's Comet in a format designed to capture the imaginations of your children. Age 5-9. 48 pages. **$5.00**

#003 Comet! The Story Behind Halley's Comet
by Greg Walz-Chojnacki
An exciting, fast-paced book written for older children, *Comet* supplies information and activities with a refreshing enthusiasm. Age 12+. 64 pages. **$5.00**

#002 Comet Halley – Once in a Lifetime
by Donald K. Yeomans
Historical anecdotes highlight this fact-filled book about comets. A very enjoyable reading experience. 175 pages. **$5.00**

REMEMBER MARS WATCH

#572 Mars Watch Buttons $.25 each
#571 Mars Watch Decal $.25 each

#175 The Mars Project
by Senator Spark M. Matsunaga
This timely and important book for future space exploration includes Senator Matsunaga's proposals to Congress and the President. 215 pages. **$5.00**

#530 I Love Mars. That's Why I Joined the Planetary Society T-Shirt
This attractive, burnt-orange shirt is knit from 50/50 polyester/cotton yarn. Medium and Small sizes only. **$5.00**

To verify availability of merchandise, call 818-793-1675 and use your credit card to order.

• Sale Items

ORDER NUMBER		PRICE (IN US DOLLARS)
002	**Comet Halley – Once in a Lifetime** by Donald K. Yeomans.	$ 5.00
003	**Comet! The Story Behind Halley's Comet** by Greg Walz-Chojnacki.	$ 5.00
004	**The Comet and You** by E.C. Krupp, illustrated by Robin Rector Krupp.	$ 5.00
110	**Comet** by Carl Sagan and Ann Druyan.	$12.00
015	**The Return of the Comet** by Dennis Schatz.	$ 5.00
124	**Entering Space** by Joseph P. Allen.	$ 7.00
154	**Rings – Discoveries from Galileo to Voyager** by James Elliot and Richard Kerr.	$ 5.00
156	**Saturn** by Seymour Simon.	$ 5.00
175	**The Mars Project** by Spark M. Matsunaga.	$ 5.00
320	**Halley Encounter** (pictures)	$ 1.00
530	**I Love Mars T-Shirts S M only**	$ 5.00
571	**Mars Watch Decal**	$ .25
572	**Mars Watch Button**	$ .25

• Books

ORDER NUMBER		PRICE (IN US DOLLARS)
108	**Beyond Spaceship Earth: Environmental Ethics and the Solar System** edited by Eugene C. Hargrove. 336 pages.	$20.00
126	**First Light: The Search for the Edge of the Universe** by Richard Preston. 263 pages.	$17.00
129	**Living in Space–A Manual for Space Travellers** by Peter Smolders. 160 pages.	$13.50
133	**Mirror Matter: Pioneering Antimatter Physics** by Robert L. Forward and Joel Davis. 262 pages.	$17.00
135	**Nemesis: The Death-Star and Other Theories of Mass Extinction** by Donald Goldsmith. 166 pages.	$14.00
140	**Out of the Cradle: Exploring the Frontiers Beyond Earth** by William K. Hartmann, Ron Miller and Pamela Lee. 190 pages.	$11.00
152	**The Quickening Universe: Cosmic Evolution and Human Destiny** by Eugene T. Mallove. 268 pages.	$17.00
157	**Starsailing: Solar Sails and Interstellar Travel** by Louis D. Friedman. 146 pages.	$ 9.00

• Books

ORDER NUMBER		PRICE (IN US DOLLARS)
158	**Space–The Next 25 Years** by Thomas R. McDonough. 237 pages.	$16.00
165	**The Grand Tour: A Traveler's Guide to the Solar System** by Ron Miller and William K. Hartmann. 192 pages.	$10.00
170	**The Home Planet** edited by Kevin W. Kelley. 256 pages.	$36.00
183	**The Search for Extraterrestrial Intelligence: Listening for Life in the Cosmos** by Thomas R. McDonough. 256 pages. **Soft Cover**	$13.50
185	**The Surface of Mars** by Michael Carr. 232 pages.	$16.00

• Videotapes

ORDER NUMBER			PRICE (IN US DOLLARS)
415 416 417	VHS BETA PAL	**Jupiter, Saturn & Uranus: The Voyager Missions** (60 min. videotape)	$30.00
425 426 427	VHS BETA PAL	**Mars and Mercury** (60 min. videotape)	$30.00
440 441 442	VHS BETA PAL	**Universe** (30 min. videotape)	$30.00
460 461 462	VHS BETA PAL	**Together to Mars?** (60 min. videotape)	$15.00

• Color Reproductions

ORDER NUMBER		PRICE (IN US DOLLARS)
305	**Apollo** – photograph of Earth, full disk (16″x20″ laser print)	$ 8.00
308	**Earth at Night** (23″x35″ poster)	$ 6.00
310	**Earthprint** – photograph of North America (8″x10″ laser print)	$ 4.00
315	**Earthrise** – photograph of Earth from the Moon (16″x20″ laser print)	$ 8.00
321	**Uranus Encounter** – 4 pictures from Uranus and its moons	$ 4.50
322	**Jupiter** – photograph of southern hemisphere (16″x20″ laser print)	$ 8.00
323	**Mars** – landscape from Viking Orbiter (16″x20″ laser print)	$ 8.00
324	**The New Explorers** (22″x34″ poster)	$ 7.00
325	**Other Worlds** (23″x35″ poster)	$ 7.00
330	**Planetfest '81** – Saturn and the F-ring (two 22″x35″ posters)	$ 5.00
333	**Saturn** – photograph of full view (16″x20″ laser print)	$ 8.00
334	**Solar System Exploration** (35″x35″ map with booklet)	$ 9.00

• Color Reproductions

ORDER NUMBER		PRICE (IN US DOLLARS)
335	**Voyager 1 at Saturn** (set of five posters)	$16.00
336	**Solar System in Pictures** – 9 pictures	$10.00
337	**Uranus** – sunlit crescent (16″x20″ laser print)	$ 8.00
340	**"You Are Here"** (23″x29″ poster)	$ 5.00

• 35mm Slide Sets

ORDER NUMBER		PRICE (IN US DOLLARS)
205	**Chesley Bonestell's Vision of Space** (40 slides with sound cassette)	$15.00
210	**Remember Halley's Comet** (20 slides with description)	$10.00
213	**Mars** (20 slides with description)	$10.00
220	**Viking 1 & 2 at Mars** (40 slides with sound cassette)	$15.00
225	**Voyager 1 & 2 at Jupiter** (40 slides with sound cassette)	$15.00
230	**Voyager 1 Saturn Encounter** (40 slides with sound cassette)	$15.00
231	**Voyager 2 Saturn Encounter** (40 slides with sound cassette)	$15.00
235	**Voyager Mission to Uranus** (20 slides with description)	$ 7.00

• Other Items

ORDER NUMBER		PRICE (IN US DOLLARS)
505	**An Explorer's Guide to Mars** (color map of Mars)	$ 5.00
510	**Back Issues** of *The Planetary Report* – each volume contains six issues (Vol. I-5,6; Vol. II-1,6; Vol. III-2,6; Vol. IV-2; Vol. VI-1,4; Vol. VII-4,5 have been sold out.) Specify the issues you are ordering by volume and number. **Each**	$ 2.00
515	**The Planetary Society Logo** – bookmark (6″x2″) (2 for $1.50)	$ 1.00
516	**We're Saving Space for You** – bookmark (6″x2″) (2 for $1.50)	$ 1.00
520	**Exploring the Universe** – 1989 calendar	$ 4.50
526	**Hugg-A-Planet Earth** – 14″-diameter pillow	$14.00
540	**Men's T-Shirt** – white with blue logo. S M L XL	$ 9.00
543	**Mission Stamps** – 10 sets (4 stamps per set)	$ 1.00
545	***Planetary Report* Binder** – blue with gold lettering (2 for $16.00)	$ 9.00
550	**TPS Buttons** – blue with logo	$ .50
555	**Starwatcher's Decoder Set**	$35.00
560	**The Voyager Space Craft paper model**	$14.00

IF YOU NEED MORE ROOM, JUST ATTACH ANOTHER SHEET OF PAPER

NAME ______________________

ADDRESS ______________________

CITY, STATE, ZIP ______________________

COUNTRY ______________________

DAYTIME TELEPHONE NUMBER (   ) ______________________

☐ CHECK OR MONEY ORDER FOR $ ______________ (Sorry, no C.O.D.s)

☐ VISA ☐ MC ☐ AM/EXP   EXPIRATION DATE __/__/__

COMPLETE ACCOUNT NUMBER ______________________

SIGNATURE ______________________

ITEM NUMBER	QUAN	DESCRIPTION	PRICE EACH	PRICE TOTAL

For faster service on credit card orders: Phone: 8 A.M.–5 P.M. (Pacific Time)

(818) 793-1675
SALES ONLY

Sales Tax: California residents add 6%. Los Angeles County residents add an additional ½% transit tax.

Shipping and Handling: All orders add 10% (maximum $10.00) Non-US add an additional $4.00

Total Order:

Officers of The Planetary Society do not receive any proceeds from sales of books of which they are authors and contributors.

MAIL ORDER AND PAYMENT TO: **THE PLANETARY SOCIETY, 65 N. CATALINA AVE., PASADENA, CA 91106**

In this painting by Michael Carroll, Galileo is quickly gathering data as it flies past Jupiter's turbulently volcanic moon, Io. The Galileo spacecraft is scheduled to be launched in October of this year to investigate the jovian moons and drop a probe into Jupiter's massive and stormy atmosphere.

Michael Carroll is a freelance artist who works as an astronomical illustrator and lecturer at San Diego's Rueben H. Fleet Space Theater. Mr. Carroll is also helping to organize a series of art shows by The Soviet Union of Artists and the International Association for the Astronomical Arts and made possible by The Planetary Society.

THE PLANETARY SOCIETY
65 North Catalina Avenue
Pasadena CA 91106

NONPROFIT ORG.
U.S. POSTAGE
PAID
THE PLANETARY
SOCIETY