The PLANETARY REPORT

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Mysterious Mars

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COVER: The still-mysterious planet Mars appears in this digital mosaic composed of 104 images taken by Viking Orbiter 1 on February 11, 1980. It was early northern summer on Mars and white clouds thinly veiled parts of the northern hemisphere. The southern winter is manifested in the carbon-dioxide-frosted polar cap, which appears blue in this color-enhanced image. A geologic boundary cuts across Mars, dividing it into ancient cratered highlands in the south and a younger, heavily reworked surface in the north. We still have much to learn about this most Earth-like of our neighboring planets: How do the clouds form? How are the polar caps made? Why are the northern and southern hemispheres so different? We are still far from answering the most intriguing question of all: Was there ever life on Mars?

Image: Jody Swann, US Geological Survey

FROM THE EDITOR

Welcome to *The Planetary Report*'s New Format

If you're like me, the first thing you do after picking up a magazine is to thumb through it, look at the pictures and see what topics are covered. If so, you've probably noticed that something has changed in *The Planetary Report*. With this issue we are instituting a new format designed to make the magazine easier to read, to further involve our members in The Planetary Society's primary publication, and to bring you even more exciting features on planetary exploration and the search for extraterrestrial life.

The first and most obvious change is the new and larger type. The most frequent complaint we'd had about *The Planetary Report* was that the type was too small to read easily. We're pleased that our members' principal dissatisfaction with the magazine is so easy to fix. But we are paying a price for the new-sized type. We've always had to struggle with the problem of having more fascinating material to bring you than we've had the space to print. With the larger type, we will be able to fit in about one-sixth less copy. We're trying to make up for it by editing the copy to be shorter and snappier. Your comments will tell us if we're successful.

You may also have noticed that this regular issue of *The Planetary Report* is a bit heftier than such issues used to be. The Planetary Society's organizational success and our growing membership have enabled us to expand the magazine. We're beginning by increasing our regular issues to 24 pages and our special issues to 32 pages. We hope eventually to reach 32 pages with every issue to give you more with your membership!

We've also instituted three new regular columns and added new features to old columns. The first new addition, obviously, is this editor's introduction. In future issues I will be using this space to guide you through *The Planetary Report*, commenting on articles, telling you what to look for and where in the issue the information is to be found. I'll begin that service with the next issue, after you've been properly introduced to the new format.

On the opposite page you'll find our Members' Dialogue. A few issues ago we asked you to let our Directors and staff know your positions on policy issues that concern The Planetary Society. Your articulate and thoughtful responses inspired us to make this dialogue a regular feature, so now each page 3 will be devoted to our members' opinions, with a sidebar featuring material concerning the Society and its policies culled from other media sources.

Our occasional Questions & Answers column has always been extremely popular, so with our expansion it becomes a permanent feature. Do you have a question about planetary science or the possibility of extraterrestrial life? If so, let us know. Our answers can only be as good as the questions we are asked. As a sidebar to this feature, we'll offer "Factinos" about planetary science to keep you up-to-date on new developments that we may treat later in more depth.

What articles will you find in this issue? First, we have a report on a very successful Planetary Society project, an educators' workshop in Mexico City, reported on by its organizers, Carl Pilcher and Adriana Ocampo.

The search for extrasolar planets has become one of the hottest fields in science. We continue our coverage of this fast-changing area with a report by astronomer Bruce Campbell, who with his colleagues recently announced some of the best data yet indicating that several nearby stars may harbor planets.

The Planetary Society seeks out research projects that may, for a small investment, pay large dividends. One such project is Jeremy Tatum's astrometric work at the University of Victoria. He reports to our members on his progress.

After 25 years of exploring the solar system with spacecraft, what don't we know about our planetary neighborhood? Society President Carl Sagan guides you through the many questions raised by planetary exploration and suggests where answers may be found.

So, we hope you enjoy *The Planetary Report*'s new format. Read on, and let us know how you like it.—*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.

TO: ALL PRESIDENTIAL CANDIDATES

The United States needs a strong, brave space program, a program with a purpose, a meaning, a destination. Only the President can set this goal for our people.

The Soviets already have a permanently crewed space station on which they are performing experiments that we only hope to do in ten years. They have a rocket booster the size of a *Saturn 5*, an ambitious program to explore Mars starting this year and a reusable shuttle nearly ready. Europe, Japan, China and India are all scrambling fast to get into space.

Why are you not talking about this in your campaign? What is your position on space policy? Isn't space a topic for you to seize on?

Presidential leadership set this country's infant space program sailing smartly "on that new ocean" to the Moon. Kennedy gave this country a vision, purpose and destination: the Moon.

We hear of "new ideas," "new directions," "new industrial policy," a "new relationship with the Soviet Union," "excellence" in schools, at work, in government. I ask you, for what larger vision could these increasingly hollow sayings be applied than a bold space program?

Presidential candidates could set this goal for our people. Say that you support the thinking of the President's Commission on Space, *"Pioneering the Space Frontier,"* and the Ride Commission's Initiatives. Say that the United States is going to Mars with or without the Soviet Union, and that we plan to industrialize, not militarize, space. Say that the solar system is the extended home of all, and that for the further benefit, education, enrichment and glory of humankind we are going and all may join us as they like.

But say something! Enlarge the debate, change the atmosphere, summon our common energies, intrigue our youth, lead us peacefully into space.

GERALD A. WARD, *Auburndale, Massachusetts*

I feel that The Planetary Society should support NASA's space station. We should continue to lobby for planetary missions while supporting the station.

If the funding for the space station is lost, the government, being what it is, would spend it elsewhere and most likely not on a planetary mission. If they wanted to fund other space missions, they would. Getting the funding for space missions is like fighting a war—if nobody wants it, you are not going to win. I can't see how fighting against the space station is going to help the cause of the Mars mission.

The space station would at least be a good reason for building up the space industry again. The Soviets seem to be using their station as a testing ground for a Mars flight and we could too. While I would fully support a Mars flight, a space station followed by a lunar station would be more reasonable.

The general rule should be that if the government is willing to spend money on a non-military space program, we should support it. Once the jobs are created and the money is flowing it will be easier to open the tap a little more.

WILLIAM G. RUDD, *St. Clair Shores, Michigan*

I was greatly saddened when, in the State of the Union address, Ronald Reagan announced the addition of a paltry $4 billion to NASA's budget while at the same time failing to fund the CRAF program. We could have learned a great deal from this wonderful project but now it's nearly been killed because of the government's continued misguided commitment to a very sick manned space program. The manned program has become a black hole sucking away funding from excellent scientific projects.

I hope that The Planetary Society will, in the name of good science and common sense, rethink its policies and drop its support for manned space exploration. Instead, I hope it throws its full support behind unmanned projects such as CRAF, the *Mars Observer* and Mars rover sample return missions.

PAUL A. HOLT, *Pt. Williams, Nova Scotia*

NEWS BRIEFS

In February, Soviet Cosmonaut Alexei Yeliseyev spoke to a group of about 80 students from the Massachusetts Institute of Technology.

When asked if the Soviet leadership is ready for a joint venture to Mars, the cosmonaut replied: ". . . I'm convinced of one thing: If we did establish a joint US-Soviet space project, this could only be beneficial. People all over the world are interested in programs like this, not just Americans and Soviets, and I think a joint program like this between our two countries would make things interesting for peoples of all countries. I know that the Soviet scientists are interested in the possibility of participating in Mars joint venture projects, and probably US scientists are interested too. So what we need is some kind of impetus to begin a project like this *and* start moving forward."

—from Eugene Mallove in *Tech Talk*

On February 14 the status of Soviet science was on display at the AAAS annual meeting in Boston. Soviet scientists presented a broad sample of their work in twelve talks ranging from ecology and microbiology to space science and engineering research. The impression the Soviets gave is that their science lags a little behind that of the US due to lack of good instruments and computer capabilities. However, in space science the Soviets currently excel.

—from Philip H. Abelson in *Science*

In March, the European Space Agency agreed, after two years of negotiations, to participate in the United States' space station project. The agreement calls for cooperation in the design, development, operation and use of the station.

ESA plans to contribute a permanently attached laboratory module to the station at a cost expected to exceed $2 billion.

—from *The New York Times*

PURSUING THE CHALLENGE

The Planetary Society Promotes Planetary Science in the Developing World

by Carl Pilcher and Adriana Ocampo

In July 1986, in the southern French city of Toulouse, space scientists from around the world came together at the 26th plenary meeting of the Committee on Space Research (COSPAR) to discuss how to pursue the challenge of space.

One of the many topics covered was "Remote Sensing of Interest to Developing Countries." Dr. Ade Abiodun of the United Nations Outer Space Affairs Division discussed the UN's efforts to promote the infrastructure developing countries need to participate fully in space activities. Among the programs he described were training courses aimed at teachers in developing countries who could share their knowledge with others.

Planetary Society member Carl Pilcher attended that workshop and wondered why the same approach could not be applied to planetary science. Thus began a program which saw its first fruits in Mexico City last September, when about 40 Mexican scientists and science communicators gathered at the Museum of Technology for the first of a series of Planetary Society-sponsored workshops aimed at disseminating the findings of the planetary program in the developing world. The Society chose Mexico for the first workshop because of its active and enthusiastic community of space scientists and because proximity made it a good first test of the necessary international logistics. Also important were the cooperation and support of the Mexican Society for the Popularization of Science and Technology (SOMEDICYT), which cosponsored the workshop.

The program was ambitious. We met for three weeks. The first week focused on primitive materials: the asteroids, meteorites and comets which provide insights into the nature of the materials from which the solar system formed. The second week was devoted to geology and included a field trip to a local volcanic field. The third week we addressed planetary atmospheres and magnetospheres.

The participants—among them many faculty members from the Autonomous National University (UNAM) and staff members from several planetaria—heard lectures in Spanish and English by leading planetary scientists from both Mexico and the United States. They asked lots of questions and worked together in hands-on sessions to get a taste of actual planetary research. Videotapes of all the sessions are being dubbed in Spanish or English as necessary to bring the entire workshop to an even larger audience in both the United States and Latin America.

The workshop opened with a public presentation in Spanish by Walter Alvarez of the University of California at Berkeley that attracted a crowd of 500. Alvarez's topic, the impact hypothesis of dinosaur extinction, was developed in collaboration with his father, Nobel laureate Luis Alvarez, and their colleagues. Alvarez teased the audience's imagination by asking what the world might be like today if the impact that he believes ended the dinosaurs' reign had not occurred. Would Earth still be ruled by giant reptiles?

The regular workshop program began the next day with an introductory lecture by Carl Pilcher. He provided an overview of the solar system and set the stage for the three intensive weeks to come.

Clark Chapman of the Planetary Science Institute (PSI) in Tucson continued with a discussion of asteroids and meteorites and their interrelations. He found himself challenged at one point by participant Arcadio Poveda, a former Director of the Astronomy Institute at UNAM, to defend his argument that the asteroids are not the remnants of a disrupted planet. A lively evening debate ensued at UNAM. Chapman also gave the participants overnight assignments, such as analyzing how the martian moons Phobos and Deimos might be similar to or different from asteroids.

Comets were next on the agenda, presented by Humberto Campins, also of PSI, and Héctor Pérez de Tejada, a professor of geophysics at the Ensenada campus of UNAM. They discussed cometary phenomena and the latest results from the Halley encounters. Participants were particularly intrigued by the movie

With a slingshot, a small projectile and colored sand, instructor Ron Greeley demonstrates the cratering process to his fascinated students.

Photographs: Carl Pilcher

made from the closest approach images of the Halley nucleus taken by the *Giotto* spacecraft.

The following week began with Ronald Greeley, Chairman of the Department of Geology at Arizona State University (ASU) in Tempe, leading the discussion of the geology of the terrestrial planets. A veteran of several spacecraft imaging teams, Greeley asked participants to construct a geologic map of a portion of the Memnonia region of Mars and compare their results to those of researchers at ASU.

With terrestrial planet geology fresh in their minds, participants, instructors, and organizers next spent a long day in the field guided by astronomer Lucrecia Maupome and geophysicist Roman Alvarez, both of UNAM. A three-hour bus ride brought the group from Mexico City to the impressive Cuenca de Oriental volcanic region in the state of Puebla.

We spent most of the day examining several explosion craters and other volcanic features. We studied impact features in miniature in exposed crater walls where boulders, lofted in explosive eruptions, struck layered deposits of volcanic dust.

The following morning the group reconvened to hear about and discuss the latest *Voyager* and ground-based findings on the outer solar system presented by Torrence Johnson of the Jet Propulsion Laboratory. As an exercise, participants calculated the escape velocity of material from volcanoes on Io, Jupiter's innermost Galilean satellite, using only *Voyager* images of Io's volcanic plumes, a ruler and a calculator.

At the end of the week Antonio Lazcano, a faculty member of the National School of Biological Sciences at the National Polytechnic Institute in Mexico City, discussed the origin of life.

The final week of the workshop began with a series of lectures by Jim Pollack of the Ames Research Center on the climate and origin of the terrestrial planet atmospheres and the origin and evolution of the giant planets. Displaying his well-known versatility, Pollack also discussed Jupiter's ring and plans for the *Mars Observer*, as well as fielding questions on a wide range of planetary topics.

Conway Leovy, Director of the Institute for Environmental Studies at the University of Washington, followed with lectures on planetary atmospheres. As he explained the wide variety of atmospheric conditions found in the solar system, Leovy took the participants from the hellish temperatures of Venus through the dust storms of Mars and out to the frigid organic ocean hypothesized for Saturn's satellite Titan.

Next came presentations by Pérez de Tejada on interactions between planets and the solar wind and by Mario Acuña of NASA's Goddard Space Flight Center on planetary magnetospheres—the vast regions of space surrounding planets in which the motions of charged particles are controlled by the planets' magnetic fields. Pérez de Tejada focused on the ways in which the ionosphere of Venus is compressed, deformed, eroded and stirred by the force of the solar wind. Acuña's presentation ranged from the solar-wind-driven dynamics of Earth's magnetosphere through the unique plasma of the Io torus surrounding Jupiter to the startling gyrations of the magnetosphere of Uranus.

The presentations ended with a public lecture Saturday morning by Arcadio Poveda, who summarized the workshop's events for a large group of children and their parents. The presentation of certificates to the participants concluded the workshop.

The participants' enthusiasm and commitment and the instructors' sense of gratification indicate that the workshop was a great success. As organizers, we were deeply moved by the participants' appreciation and the welcome extended to us in their homes and community. Many participants attended for the full three weeks; others were called away by their professional responsibilities, highlighting a central problem of the workshop: the time commitment required by its scope. Nonetheless, the broad scope did draw together people of diverse backgrounds who might not otherwise have met.

Workshop participants examine layers of volcanic material deformed by the impact of a boulder still visible in the center of the formation. A violent volcanic eruption lofted the boulder and deposited the fine material in which it is now embedded. The overturned strata on either side of the boulder are characteristic of structures found under the rims of large impact craters.

The workshop's ultimate success must be judged by the degree to which the participants incorporate their new knowledge and the materials left in Mexico into their teaching and other educational programs. The initial results are encouraging. At least two new courses and two books in Spanish on planetary exploration are planned by workshop participants, and many more general commitments have been made to enhance the coverage of the solar system in educational and other public programs. The Planetary Society will keep its members informed as this program develops.

Carl Pilcher, Associate Astronomer at the Institute for Astronomy of the University of Hawaii and a Visiting Fellow at the Woodrow Wilson School of Public and International Affairs at Princeton University, is a member of the Project Galileo *Imaging Team and holds a MacArthur Foundation Postdoctoral Fellowship in International Security awarded by the Social Science Research Council of New York. Adriana Ocampo, a member of the technical staff at JPL, is a Science Coordinator for the Near-Infrared Mapping Spectrometer Experiment on the* Galileo *mission and a Representative for Interdisciplinary Scientists on the* Mars Observer *mission. Pilcher and Ocampo designed, organized and ran the Mexico City workshop.*

Planets Around Other

SOME EXCITING NEW

by Bruce Campbell

In this article we learn of a current attempt to show, by careful and patient measurements of stellar motions, the gravitational effect of invisible planetary objects orbiting some stars. Bruce Campbell's spectroscopic technique reveals stellar movements approaching and receding from us; for many decades other astronomers have used astrometry, the technique of measuring stellar motions in the plane of the sky. Though several astrometric detections have been reported and have even found their way into textbooks as established facts, the existence of extrasolar planets has yet to be accepted as proven by observation.

It is a vexing subject. Many lines of evidence show that the solar system cannot be unique, but the nearest stars are so far away that seeing planets around them is impossible with present techniques. However, more stars are members of binary or multiple systems than are single. And we see a continuous distribution of sizes and brightnesses among stellar companions, many of which, though massive enough to be stars, are invisible because of distance and only detected by their gravity. Why, then, should the distribution not continue down to planet sizes? Most people believe that it does, and many think planets will turn out to be abundant.

In recent years we have seen the peekaboo appearance of an object called Van Biesbroeck 8B, at first thought to be a sort of super-Jupiter (see the November/December 1985 Planetary Report*), later having its very existence denied, and now the subject of a continuing puzzle. But astronomers and engineers are persistent: what we can't see now, we shall try to see in the future.*

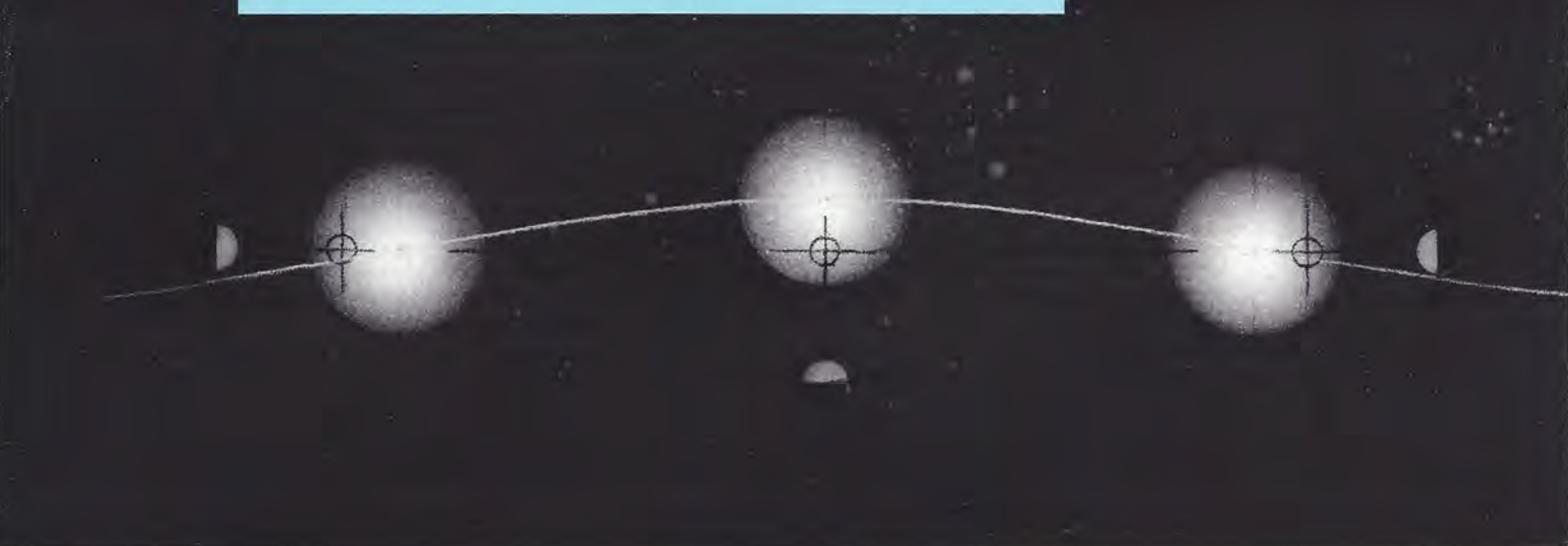
Active studies are already in progress to determine what sorts of large observing instruments might be placed in space to detect faint planetlight amid the glare of a parent star. Perhaps a spectrometric survey of neighboring planetary systems will be one exciting, long-term task of observatories in space. —James D. Burke

Ask most people, even professional astronomers, if they believe there are planetary systems associated with other stars, and the vast majority will respond, "Yes." But confirming this widespread belief remains a problem. Despite numerous claims in the past few decades, all have either been dismissed or remain unconfirmed. Planets are so small and insignificant in comparison to stars that finding them at the great distances of even the nearest stars is a formidable task.

Consider Jupiter, the largest planet in the solar system, and the Sun, a typical star. The Sun produces about 1 billion times more light than Jupiter reflects. Viewed from the vicinity of the nearest star, Proxima Centauri, which is 4.2 light years away, Jupiter would appear so close to the Sun that it would be completely lost in the tremendous glare of sunlight. Most astronomers now agree that it will be a long time before we can overcome this problem and directly "see" a planet near another star. Fortunately, such direct detection is not the only way to discover planets.

Other methods examine a planet's effects on its parent star. Although stars are very much more massive than planets—the Sun is 1,000 times the mass of Jupiter—the stars do not remain at rest

A planet in orbit about a star will cause the star to move in a tiny counter-orbit about their common center of mass (see cross). Even if not directly detectable, the planet's presence can be inferred from the parent star's motion. The total extent of the stellar motion and the period of the orbit reveal the planet's mass. Illustration: S. A. Smith



Stars?

EVIDENCE

Although it is the most massive planet in our solar system—more than 300 times the mass of the Earth—Jupiter is only 1/1000th the mass of the Sun. This photo of Jupiter was taken by the Voyager spacecraft. **Photo: JPL/NASA**

in the center of their solar systems. Instead, each star moves in a tiny counter-orbit in response to the orbital motion of its planets. For example, the Sun has a counter-orbit 1/1000th the size of Jupiter's orbit and moves around in this orbit in about 12 years, Jupiter's orbital period. If you could detect this reflex movement of a star and measure its size and period, you could infer the presence of a planetary companion. This inference underlies a number of projects now underway to detect planetary systems other than our own.

One way to detect a star's tiny reflex motion is by measuring its position relative to other stars much farther away from us. As the nearby star executes its counter-orbit, it will appear to move back and forth if the orbit is edge-on as seen by us, in a circle if the orbit is face-on, or in an ellipse if the orbit is somewhere in between. However, the total extent of this motion will be small under even the best of circumstances. If you viewed the Jupiter-Sun system from 4.2 light years away, the Sun's total motion would amount to an angle equivalent to the size of a dime 300 miles away!

Measuring such a small change in the position of a star is difficult, but not impossible. Over more than three decades, Dr. Peter Van de Kamp at the Sproul Observatory in Swarthmore, Pennsylvania observed the nearby Barnard's Star and concluded that it has two planets, but other scientists questioned the detection. Now, at the Allegheny Observatory in Pittsburgh, Dr. George Gatewood and his colleagues have developed an instrument with unprecedented precision for this type of measurement and have begun to look for small motions in a number of stars close to the Sun.

Another way to detect a planet's effect on a star's motions is to look for the component of this motion toward and away from us. Of course, stars are all moving relative to their solar systems, much like a very lazy swarm of bees. Astronomers have measured such motion for years using the doppler effect, the characteristic change in wavelength, or color, of a star's light—to red if a star is receding or to blue if it is approaching. They measure changes in wavelength using the gaps, known as spectral lines, in the component colors of starlight. By comparing the wavelengths of these lines with those predicted from laboratory measurements on Earth, they determine the velocity of the stars relative to Earth.

To use this approach to detect planets, you would look for periodic change in a star's velocity as it swings around in its counter-orbit. Such a change would be a small effect added to the star's general motion in space toward or away from Earth. The velocity variation and the period taken for a complete cycle could reveal the mass of the unseen planet. However, the velocity variation caused by a planetary companion is much smaller than traditional measurement techniques can detect. Jupiter causes the Sun to move at about 44.8 kilometers per hour, but most velocity techniques cannot sense

STARS SUSPECTED OF HAVING LOW-MASS COMPANIONS

Name	Distance (Light Years)	Stellar Mass (Solar Masses)	Companion Mass Range (Jupiter Masses)
Epsilon Eridani	11	0.8	1-5
61 Virginis	18	0.9	1-7
Xi Bootis A	21	0.9	2-8
Beta Virginis	31	1.3	1-10
36 Ursae Majoris	42	1.1	1-15
Beta Aquilae	42	1.3	1-14
Gamma Cephei	8	1.6	1-7

In this highly imaginative painting, a jovian-type planet orbits a cooling star. Glaciers advancing from the poles herald this world's final ice age. Advancing techniques of planetary detection may soon enable us to find planets such as this around nearby stars. Painting: Ron Miller

a speed change smaller than about 3,200 kilometers per hour! Fortunately, several research groups have developed new techniques in the last few years that can measure the relative speed of stars to about 32 kilometers per hour or better. The late Krzysztof Serkowski began this pioneering project at the University of Arizona, and the work has continued under the leadership of Robert McMillan. William Cochran of the University of Texas at Austin and Geoff Marcy of San Francisco State University have each begun developing potentially powerful new techniques for measuring stars' radial velocities.

Gordon Walker, Stephenson Yang, and I have also been working to develop a new way to measure stellar velocities. We began this development in 1978, and in 1980 we started to observe a sample of nearby stars with the hope that we might be able to measure velocity changes as small as about 32 kilometers per hour. We had no proof that our technique would work since the only way to test it was to observe some stars. We also faced the problem that at least some of our target stars were likely to show velocity variations due to unseen companions much larger than normal planets. Such objects, intermediate in size between planets and stars, are known as brown dwarfs. Astronomers have sought evidence of their existence for many years. Our fear was that there might be so many brown dwarfs that nearly every star we examined would show large velocity changes, but not due to planets.

The first big surprise came in 1986, when we were able to look at our results for most of the stars we had been studying. We realized that none of these stars (with the exception of two obvious binary stars) was varying very much in velocity. This meant that our technique was working as well as we had hoped. But more important, it meant that none of our target stars had a brown dwarf companion nearby. This result accords completely with the findings of many other recent searches for brown dwarfs, none of which has turned up a single confirmed candidate. Brown dwarfs seem to be very rare, if they exist at all.

We have also excitedly observed that over the past seven years, 7 of our 16 stars have shown very slight velocity variations that could be due to tiny companions. In only one case—Gamma Cephei—do we have evidence for a complete orbital cycle, so we cannot yet specify precise masses for most of these objects. But the existing evidence suggests that the companions are in the range of 1 to 10 times the mass of Jupiter. These objects are much less massive than conventional brown dwarfs, and it is possible that they represent the most massive planets.

We hope that other groups will study the same stars in the next few years to see if they can uncover similar evidence for tiny companions. We will continue our own observations to see if we can identify more orbital periods. The current evidence is tantalizing, but we need still more to confirm the existence of extrasolar planetary systems. At least we can say that we're hot on their trail!

Bruce Campbell is an astronomer at the University of Victoria in Victoria, British Columbia.

Bruce Campbell describes one more piece of evidence for the existence of extrasolar planets. How fortunate we are to be living when this subject is slowly coming out of imagination and into reality for the first time in all human history on Earth! Philosophers and religious thinkers have grappled with the problem for centuries. In a large volume published in 1986 by the Cambridge University Press, Michael J. Crowe of Notre Dame has collected and analyzed many fascinating ideas and speculations. His title is *The Extraterrestrial Life Debate, 1750-1900: The Idea of a Plurality of Worlds, from Kant to Lowell.*

With many quotations, Crowe explores the attempts people made to understand the cosmos during an age when telescopes were opening its wonders to their eyes, and simultaneously their minds were occupied with a lively branching of Christian religious thought. (Crowe wisely limits his study to Western ideas; even at that, it is a huge tome.) A parade of scholars, doctors, preachers, poets, geologists and astronomers passes as we learn of the solitary struggles and satirical exchanges that went on among those who, on the one hand, believed humans to be God's unique and highest creation, and on the other, saw Earth and its inhabitants as a mere speck unworthy of any special status.

A great difficulty is posed by Scripture: humanity fell into sin; Christ the redeemer came to Earth. Does the incarnation then offer salvation to sinners everywhere? Or does Jesus have to die a million deaths, upon a million worlds? Or is sin unknown except here? The testaments are silent, but Christian scholars, especially in Victorian England and Scotland, threw enormous mental effort into the debate, whose terms are of course dominated by what one believes as to the existence or non-existence of other inhabited worlds.

In today's secular climate of scientific thought it is easy to forget the long intellectual history of human attempts to comprehend the starry heavens. As we reach outward with modern instruments it is good to be reminded of the labors of others who, lacking any means of proof, still dared to think seriously about the implications of this question: Are we, or are we not, alone? *—J.D.B.*

Tracking Asteroids—

The Planetary Society Supports Astrometry Project

by Jeremy Tatum

Astrometry, the practice of measuring stars' positions, may sound like some tedious activity of nineteenth-century astronomy, far removed from today's exciting frontiers of black holes, quasars, pulsars and planetary exploration. But there is something deeply satisfying and exciting about striving to measure precisely the positions of asteroids and comets, to calculate their orbits, and to predict where they will go next. Keeping precise track of interplanetary bodies is vital to today's and tomorrow's explorers of the solar system.

The tremendous successes of the spacecraft trips to Comets Giacobini-Zinner and Halley depended greatly on ground-based astrometry. Future exploration of comets and asteroids, such as NASA's proposed Comet Rendezvous Asteroid Flyby (CRAF) mission, will also need accurate measurements of their targets. The Planetary Society has provided us with a generous grant to assist with this work, so I'd like to share with members some of the excitement we feel about our project.

Let's begin with a brief review of the types of objects we're observing. There are 130 or more short-period comets, those whose orbits are known and whose return can be predicted years in advance. In addition, every year some dozen or more long-period comets are discovered. They move across the sky for a few weeks and then disappear, not to return again for tens of thousands of years. Most of the approximately 3,700 minor planets or asteroids have fairly well known orbits in the asteroid belt between Mars and Jupiter. A few, called the Trojans, are in almost the same orbit as Jupiter, 60 degrees ahead of or behind the giant planet.

An important and exciting few have eccentric orbits that sometimes take them close to Earth. Because these Earth approachers seem to move so rapidly across the sky, we often call them "FMOs," short for fast-moving objects. These asteroids with well-known orbits have a permanent number attached to them, and most of them have names; 46 Hestia and 433 Eros are just two examples. They are often called "numbered asteroids."

Every month astronomers observe additional very faint asteroids that they cannot identify. Many thousands of these "unnumbered asteroids" exist, quite a few of them FMOs. They receive a temporary designation—usually a year plus two letters, such as 1987 HR—and most of them are lost shortly after discovery. But a few are observed over a sufficiently long time span—maybe a few weeks—to enable astronomers to compute at least rough orbits.

Sometimes two apparently distinct objects seen in different years prove to be the same object, and then we can find precise orbits. If an unnumbered asteroid is well observed at three or more apparitions, it may become the proud possessor of a permanent number or even a name. We are particularly interested in recovering unnumbered objects and following them long enough so that they can receive a permanent number. Some 20,000 asteroids have at least rough orbits.

With so many objects to keep track of—most exceedingly faint and hidden in the background of millions of stars—how can we find any given asteroid? Or if we spot an asteroid in a photograph, how can we identify it or tell whether it might be a new one never spotted before? First we must understand a little bit about orbits.

Each asteroid's orbit is approximately an ellipse, with the Sun at one focus.

This computer-enhanced image reveals the project's first asteroid—1987 HR, discovered by Dave Balam. On the original photograph, the streak was scarcely visible with a microscope.
Photograph: Leopoldo Infante

Each orbit is characterized by six orbital elements: the first two numbers describing the size and shape of the orbit, the next three angles describing the orientation of the orbit in space, the last telling the instant in its orbit when the minor planet is closest to the Sun.

We can calculate the orbital elements from a set of astrometric measurements of the object—that is, from a number of observations of the precise positions of the object at different times. This is not an easy calculation. Nevertheless, astronomers have calculated the six orbital elements for almost 10,000 asteroids, and these 60,000 numbers require little space on the disk of a modern computer.

From the orbital elements we can then compute an ephemeris, an hour-by-hour, day-by-day, or week-by-week prediction of exactly where the object will appear against the starry background of the night sky. The most difficult part of this calculation is the need to allow for Earth's position in its journey around the Sun, a calculation made particularly difficult by the perturbing effects of the Moon. Nevertheless, a modern computer can make fairly short work of it and can include certain refinements such as allowance for the position of the observer on Earth's surface or for the time required for light to travel from the asteroid to Earth.

We have stored in the University of Victoria's computer the orbital elements as well as a program for computing the ephemerides of all the asteroids. At the beginning of each month we decide which asteroids we might be interested in observing. We simply type numbers on the computer keyboard, type the single word ELLIPSE, and presto! Within seconds the computer calculates for us an ephemeris, at half-day intervals, for the entire month for all the asteroids requested.

Our telescope, a 10-inch-diameter Schmidt that is quite tiny by modern standards, is a wide-field astronomical camera. Still, the stellar images are so sharp and we can use so many of them for comparison stars that the system has proved very effective for astrometric work.

We have a few extra tricks. We sometimes use a colored filter to increase the contrast between a faint asteroid and the sky's light pollution. We also have a device that is especially useful for fast-moving objects. The image of an FMO appears as a thin line on the photograph, while the stars appear as sharp dots. With our electronically controlled system, we can automatically move the crosshair (spun for us by a real, specially trained spider!) of our guiding telescope at the right speed and direction predicted for the asteroid's or comet's motion. The stars then appear as short streaks, while the asteroid or comet is a steady bright dot. This enables us to photograph objects so faint that they would not be detectable at all if the image were allowed to drift across the photograph during the exposure.

Most of our exposures are made near the ecliptic (the plane cut by Earth's orbit about the Sun; most known solar system objects lie in or near the ecliptic), so a photograph may show several or even a few dozen asteroids. Of course, it also includes the images of hundreds of thousands of stars. The asteroids are exceedingly small and faint and can be seen only with the aid of a high-power microscope. How can we possibly find and correctly identify these tiny images?

Our solution is to take two photographs a couple of hours apart. During this interval, the image of each asteroid will have moved—perhaps a distance comparable to the diameter of the image, maybe just a few thousandths of a millimeter. Nevertheless, it has moved. We put the two photographs into a great contraption called a blink comparator, which enables us to look rapidly to and fro from one photograph to the other, two or three times a second. The image of each asteroid then appears to oscillate rapidly to and fro, and this movement can be quickly spotted against the background of numerous but stationary stellar images. The search can be quite tedious, but we experience a special thrill each time we spot one of these tiny planets.

Another trick used by some observers is to look at the two photographs through a stereoscopic viewer. The images on the two plates then overlap completely except for any asteroid that has moved between exposures. The asteroid then stands out fairly obviously.

It is all very well to find an asteroid, but how do we know which of many thousand it is? We consult the computer again. This time we type in the astronomical coordinates of the center of the photograph, the time it was taken, and the single word PLATE. The computer reads through the entire list of orbits of all the asteroids and works out the position of each object for the time when the photograph was taken. It then calculates to see whether the asteroid would have been in the telescope's field of view at the time, and, if so, it prints out the asteroid's coordinates. As a bonus, it prints an asterisk if the object is within a degree and a half of the center of the field of view.

Next comes the part that ought to be tedious—the careful measurement of the position of each asteroid or comet image. We have to compare the position of each object with that of several stars whose positions are known precisely from catalogs. Fortunately, the scale of the photographs closely matches that of a reliable star atlas, so we can quickly

ELEMENTS OF AN ORBIT

NAME	SYMBOL	DEFINITION
Semimajor axis	a	Half the long axis of the ellipse.
Eccentricity	e	A measure of the shape of the ellipse—the distance between the foci of the ellipse divided by the major axis.
Inclination	i	Angle of intersection between the orbital planes of the planet and of Earth.
Longitude of the ascending node	Ω	Represented by Greek capital omega. Angle from the vernal equinox (where the ecliptic and celestial equator intersect with the sun crossing the equator from south to north), measured to the east along the ecliptic plane, to the point where the planet crosses the ecliptic traveling from south to north (the ascending node).
Argument of perihelion	ω	Represented by Greek lower-case omega. Angle from the ascending node, measured in the plane of the planet's orbit and in the direction of its motion, to the perihelion point (its closest approach to the sun).
Time of perihelion passage	T	One of the precise times that the object passed the perihelion point.

identify several comparison stars. The positions of the quarter of a million or more stars of the Smithsonian Astrophysical Observatory Catalog visible from our latitude are stored in the computer's memory; all we have to do is tell the computer the catalog numbers of the stars involved, and it will read the positions and other data from its enormous memory bank.

Our Magic Measuring Machine is a microscope with a stage that can be moved to left or right or up or down, or rotated at will. We place the photograph on the stage and look at it through a microscope that has a fine crosshair in its eyepiece. We try to bisect the image of each asteroid or comet and the comparison stars with the crosshair by moving the stage bearing the photograph beneath the microscope. Meanwhile, at the other end of the table where we are working is a mysterious metal box with a large display of neon numbers that change rapidly as we proceed. The numbers indicate the precise position of the microscope stage to one thousandth of a millimeter.

Most people know that often in magic it's all done with mirrors, and the sharp-eyed may notice a tiny mirror on the side of the microscope stage. A beam of laser light is reflected from this mirror, and the incident and reflected beams form a system of standing waves. The mysterious metal box is actually connected to the laser, and as the microscope stage moves, the alternating light and dark bands of the standing wave system are electronically counted, each band corresponding to just half a wavelength of the laser light.

The measurement over, the computer makes short work of some more calculations. It checks to ensure that all the star measurements are consistent with their catalog positions and warns us if any of our stars are misidentified, if we have made poor measurements, or if the catalog position is inaccurate. It will make corrections for the proper motions of the stars. The stars are not fixed, but move by an appreciable fraction of an arcsecond, or even more, per century, and it is essential to allow for this. The computer corrects for the refraction caused as the starlight passes through the Earth's atmosphere. But finally, if completely satisfied, it produces a position for the object we're investigating.

The computer may be satisfied, but will the Minor Planet Center in Cambridge, Massachusetts be? We know that the demands made there are, properly, very exacting and we don't want to risk our reputation by submitting observations that are in any way suspect. We know that ours will be scrutinized very carefully in comparison with those submitted to the Center by other highly skilled and experienced observers. A final stage, especially with newly discovered objects such as comets and Earth-approaching asteroids, is to add our observations to those already available and to refine the computation of the object's orbit and then see how far our measured position is from that predicted by the refined orbit. At last, if all is satisfactory, we submit our observation.

Dave Balam searches for asteroids with the blink comparator. The machine "blinks" rapidly to and fro between two photographs taken hours apart. It's easy to detect an asteroid by its motion. *Photograph: Charles Card*

Despite many astrometric measurements, we have not so far discovered many new objects, so our first asteroid discovery is especially exciting. David Balam found the faintest of telltale streaks on a photograph made by our colleagues Leopoldo Infante and Chris Pritchet with the Canada-France-Hawaii Telescope in April 1987. The original image was barely visible with a microscope, but it has now been computer-enhanced with an image processor to produce the rather impressive image accompanying this article. The object has been named 1987 HR. However, the chances of finding it again are not great, and its overall astronomical significance should not be exaggerated. Some observers routinely pick up lots of faint, previously unknown asteroids, and Leopoldo "discovered" some quarter of a million galaxies on the same photographs on which Dave found the asteroid.

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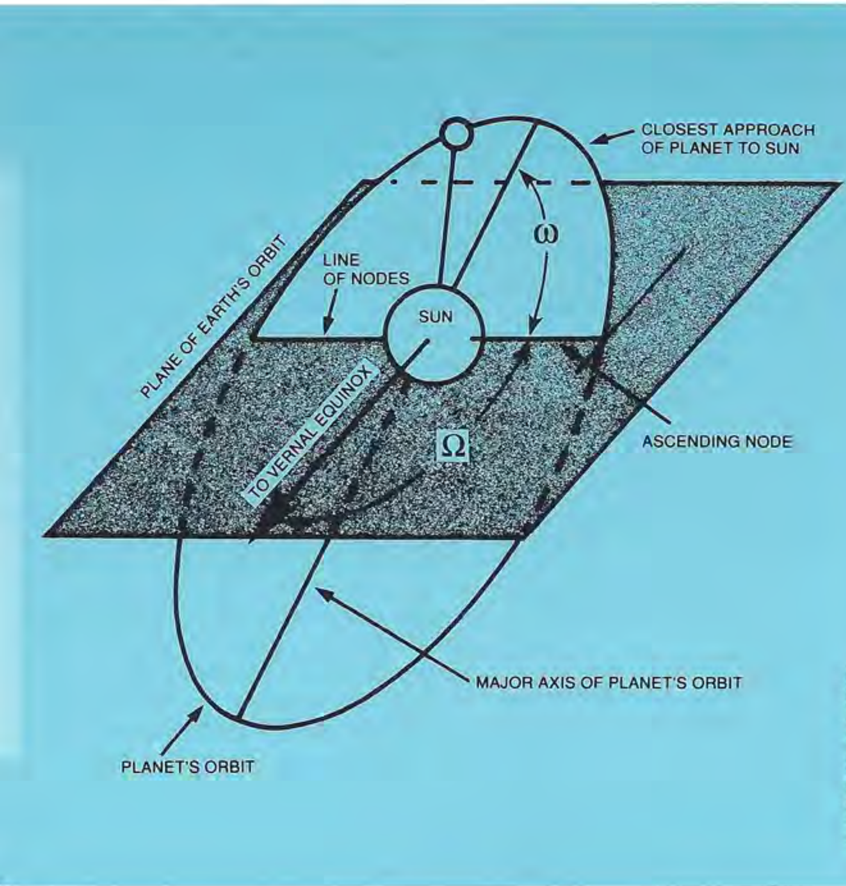


ILLUSTRATION: S. A. SMITH

*S*OME *M*YSTERIES OF *P*

December 14, 1987 marked the 25th anniversary of *Mariner 2*'s encounter with Venus, the first successful interplanetary mission. It accomplished many important things, including a demonstration that we humans—and especially we Americans—could send a spacecraft to another planet.

In the course of planetary exploration we have raised many more questions than we have answered—traditionally the sign of a healthy and successful scientific endeavor. Every planetary scientist must have his or her own list of favorite unanswered questions, and I cannot claim that my own list is more than idiosyncratic. But let me try to list what to me seem to be some of the major current mysteries.

Meteorite Origins

Let's start with something very mundane. If you go to the Smithsonian Museum of Natural History, you will find a nice collection of meteorites. Some are rocky; some are metallic; some are carbonaceous. They've all fallen from the skies; they've come from somewhere—most from the asteroid belt. If we knew exactly where each one of them had come from, we would then have samples of those parent bodies. We could then compare the laboratory sample with the astronomical or spacecraft observations and make much progress.

Recently a scientist with the auspicious name of Jack Wisdom (now at the Massachusetts Institute of Technology) has for the first time provided a specific mechanism for injecting asteroidal fragments on trajectories that will take them to Earth. But it may be a non-representative sample of asteroidal material that gets injected into these Earth-crossing trajectories. That, in turn, may mean that our museum meteorites are far from representative of the full range of asteroids.

There have also been good cases made in the last few years for the view that some meteorites come from the Moon and from Mars. But it would be nice to be surer of their origins than we are today. What about other planets? Have any meteorites in our museums come from Venus? We don't yet have enough wisdom to deduce that.

A very recent and interesting analysis by H.J. Melosh at the University of Arizona shows that in the course of generating a 100-kilometer impact crater, debris can be transferred from Mars to Earth or vice versa; the chunks being transported are big enough that anything inside them does not suffer significant radiation damage from the solar wind or solar ultraviolet light or cosmic rays during the roughly million-year time scale it takes to be ejected from the one world and swept up by the other. This has a serious biological implication. It suggests that on time scales of tens to hundreds of millions of years microorganisms from Earth arrive at Mars.

Is this true? If they survive the journey, would they survive the martian environment? And if we go to Mars looking for microbes and find one, is it indigenous, or is it some contaminant from Earth? How do we find out? And then there's even the remote possibility that a long time ago terrestrial microbes got transported to Mars, sat around and maybe proliferated a while, and then another big impact on Mars ejected their remote descendants back to Earth. How much did they change in the meantime?

As far as still bigger craters go, they're obviously due to the impact of very large objects—say tens of kilometers in diameter. We have excellent evidence for such an event happening 65 million years ago on Earth at the Cretaceous-Tertiary boundary. Are such impacts due to comet showers—a set of comets perturbed all at

Below: Viking 2 *sampled the soil at its landing site on Utopia Planitia but detected no signs of life. However, the* Viking *orbiters, as well as* Mariner 9, *returned images to Earth that strongly suggested that the element most crucial to life on Earth—water—once flowed across Mars.* Image: Mary-Ann Dale Bannister, Washington University

Inset: It is now widely held that this meteorite may have been blasted off the martian surface by a tremendous impact with a comet or asteroid, surviving to crash land in Antarctica. Photograph: Johnson Space Center

PLANETARY SCIENCE

by Carl Sagan

once by a passing star or interstellar cloud shaking up the Oort Cloud of trillions of comets beyond Pluto and hitting a multitude of targets in the inner solar system?

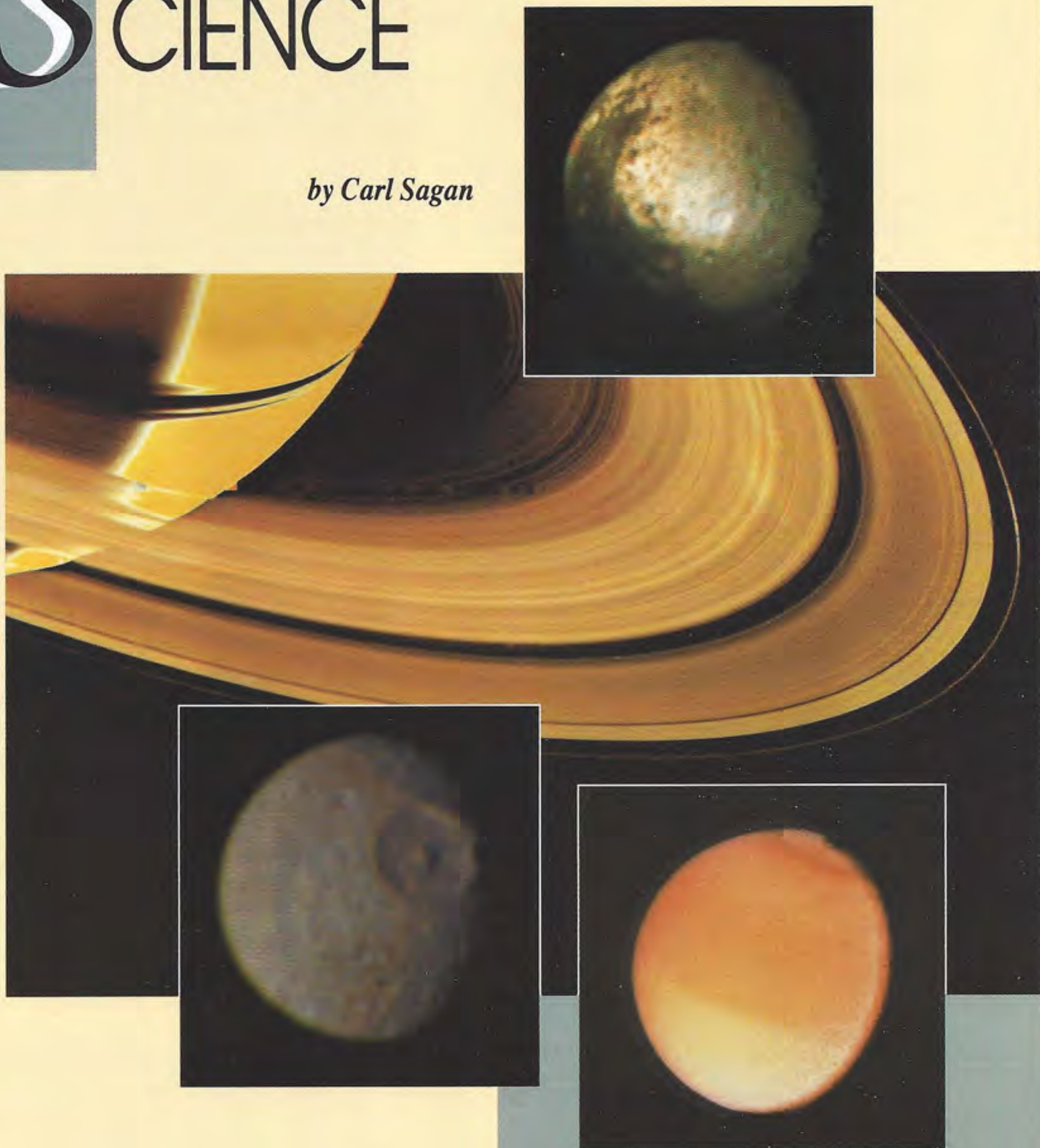
Solar Wind and Saturn's Rings

Let's tackle another impact question from a different direction. Consider a picture of Saturn. You can see its rings. Beyond the outermost dense ring you can see the E ring—more diffuse than the A and B rings, but certainly there. It's about the same distance from Saturn as a moon called Enceladus. Now the particles in the E ring found by *Voyager* at Saturn are about one micron in diameter. Charged particles trapped by Saturn's magnetic field will drive such small particles away in roughly 100,000 years. So if everything stays the same, there will "soon" be no E ring. That then strongly suggests that the E ring was made recently, a week ago Tuesday on the astronomical time scale.

Now how can that be? Either there's been recent volcanism or something similar on Enceladus—the only object nearby that seems able to supply material—or a recent impact on Enceladus has sprayed out this material. If this line of argument is valid, it suggests that at least some of the rings of Saturn are ephemeral and that there is a kind of balance between how fast the ring particles are created and how fast they are dissipated by magnetospheric charged particles and other mechanisms.

This raises other questions. The lifetimes of ring particles are partly determined by nearby shepherding satellites and plasma drag. If we come back and take a picture a million years from now, will the principal rings of Saturn still be there? If we had taken a picture a hundred million years ago, would we see those same ring systems? Are the main rings of Saturn and Jupiter and Uranus ephemeral?

Why are there no rings around the terrestrial planets? The terrestrial planets have moons. Those moons receive big impacts which must spew out particles. Why don't the terrestrial planets have significant ring systems? Why does Neptune apparently have not complete rings, but ring arcs? That is a question we will probably be able to answer after the *Voyager 2* encounter with Neptune in August of 1989.



Saturn, its rings and its moons still hold many mysteries not yet unveiled by spacecraft explorers. Are the elegant rings ephemeral features that will someday disappear? Strange little Iapetus (top) is snow white on one side and pitch black—from organics—on the other. What is the nature of that organic material? Mimas (above left) carries a gigantic crater from an impact that nearly knocked the moon to pieces. Have many small solar system bodies been blasted to pieces, reforming slowly to the states we see them in today? Titan (above), Saturn's largest moon, holds a substantial atmosphere with clouds of organic molecules. Where did they come from?

Images: JPL/NASA

About a dozen years ago I was asked to give a talk on what we didn't know in planetary science, and one of my questions was why Saturn was the only planet to have a ring system. That really puzzled me. We now know that the question was wrong from the start. Jupiter and Uranus do have ring systems, and, to the extent that arcs are incomplete rings, so does Neptune. We can today restate the question: Why do the jovian planets have rings and the terrestrial planets have none? Even the questions are very time-dependent in a field as exciting and rapidly changing as planetary science.

Now if you calculate, as Eugene Shoemaker of the US Geological Survey has, the flux of impacting objects back into time, you find that most of the moons in the outer solar system should have long ago been hit by very large objects and destroyed—broken up into an enormous number of small fragments.

So why are the moons still there? Shoemaker proposes that many of those fragments were thrown out into rings, and the particles in the rings gradually reaccreted into the moons we now see. That's a very dramatic and very catastrophic story. Is it true? Has any moon, much less many moons, been completely destroyed and then risen like a phoenix from the ashes?

Collision Courses

Thinking about such collisions takes us back to the earliest history of the solar system, when enormous numbers of objects must have been on trajectories that crossed planetary orbits.

What were the planets like when these big impacts were happening very frequently? Large late impacts, such as the Cretaceous-Tertiary impact, can be thought of as the tailing off of the giant impacts common in the earliest history of the solar system. Material of various compositions was falling on the planets in the late stages of accretion; indeed, this is how the planets were made. Material was carried to the forming planet, but, on the other hand, many impacts were of high velocity and sprayed material back into space. Where an impact giveth, it also taketh away, and the relative extent of the give and take is still in dispute.

For example, the entire water content of the terrestrial oceans could have been supplied by the impact flux. A recent study by Chris Chyba of Cornell University shows this very clearly. But there are other possible water sources, including indigenous water from inside Earth. Even today lavas contain a few percent water, although some of that may be carried down to the interior from the surface. Did the terrestrial oceans come from the inside or the outside? We don't know. Did Venus and Mars have large lakes or oceans in the first billion years of solar system history? The geological evidence for Mars is tantalizing, and it is at least generally agreed that the channel systems were once gushing with water. The issue is closely tied to the possibility of life in the ancient martian past.

In those early days was there ever a time when the impacts happened so quickly that an impact-generated dust cloud was formed, so that a continual pall of dust surrounded Earth and the other terrestrial planets? The answer, worked out by David Grinspoon of the University of Arizona and me, seems to be clearly yes. During that first few hundred million years of solar system history the planets were pitch dark at their surfaces and much colder than you would expect from the amount of sunlight striking the top of the dust cloud. What occurred at their surfaces suggests a quite different view of the early history of the solar system from the one we are used to.

Two apparent "paradoxes" arise. One has to do with the origin of life on Earth. Earth was formed some 4.6 billion years ago. Some recent work by two Japanese scientists, Yutaka Abe and Takasumi Matsui of the Geophysical Institute Faculty of Science at the University of Tokyo, suggests that the early stages of accretion carried so much kinetic energy to Earth's surface that it melted. So here was Earth, with no sunlight coming down from the top but molten at the surface and probably looking very much like the Doré vision of hell. That molten surface lasted for a hundred million years or so, and the continuous dust cloud (with a dark surface perhaps far below the freezing point of water) for maybe a few hundred million years after that. So not until about 4 billion years ago was Earth in any way ready for the chemical steps in liquid water leading to the origin of life.

On the other hand, fossils up to 3.5 billion years old have been found. These fossils are not remnants of little one-celled organisms. They are algal stromatolites, colonial beings a meter or so across. These stromatolites had to have evolved over a significant prior history. A significant history prior to 3.5 billion years ago takes you back to 3.7, 3.8, 3.9 billion years. So somewhere near 4 billion years ago, the origin of life had to have happened extremely quickly. It's an important conclusion if it's true because it suggests that similar processes could have happened on countless other worlds.

The other "paradox" is called the early faint sun paradox. One of the most secure conclusions from the modern theory of stellar evolution is that stars like the Sun slowly get brighter as time goes on. The Sun has brightened by more than 50 percent in four and a half billion years. Now suppose you take that result and run the movie backwards from today. You go back in time with an increasingly dimmer Sun but everything else the same. Earth stays the same distance from the Sun; Earth's albedo or reflectivity is the

For several reasons, both technical and programmatic, *Mariner 2* carried no cameras. Some felt that it didn't make sense to send cameras on interplanetary missions, that it was all too razzle-dazzle and public relations-oriented, that you couldn't do real science with cameras. Then, with the eventually successful *Ranger* lunar missions, opinion

As well as we know our home planet, Earth, we have yet to resolve many of its mysteries. Our theories of stellar evolution tell us that 2 billion years ago the Sun was too faint to heat the oceans to the melting point of water. Yet the fossil record tells us that life was then flourishing in the ancient seas. What key to the puzzle are we missing?
Photo: JPL/NASA

shifted. In the set of *Ranger 9* nested images you first see the Moon from a great distance. Then in a series of jumps you get closer and closer to a spot in the crater Alphonsus. You feel as if you are falling into the Moon. Every time I show that movie the viewers gasp as though they are about to hit the Moon. The dramatic quality of the *Ranger* photographs and the significant new scientific information they provided, such as insights about small craters, worked to change the prevailing opinion about the utility of imaging on planetary missions.

I think the fundamental scientific reason for imaging is that we are not wise enough to know in advance what questions to ask. Imaging shows you whatever there is in the optical frequency spectrum. It answers questions we have been too dumb to ask. —*C.S.*

same; the greenhouse effect—which is mainly due to carbon dioxide and water vapor in Earth's present atmosphere—is the same. What happens? You conclude that Earth's oceans were frozen before about 2 billion years ago. But there is excellent direct geological evidence that the oceans were not frozen almost 4 billion years ago. What's wrong with the conclusion? Surely Earth's distance from the Sun hasn't changed in that time. And the likely albedo changes only make things worse. So that leaves the greenhouse effect. The customary solution to the apparent problem of the Sun being dimmer, and therefore Earth being too cold early, is that a much more massive greenhouse effect than the present one held the heat in. There are debates about whether this effect was due to very small amounts of ammonia or (the prevailing view) very large amounts of carbon dioxide. But if this impact-generated dust cloud existed, all that greenhouse wouldn't have helped in the least because the cloud was high in the atmosphere and the greenhouse gases were below where the sunlight got stopped; the problem is not solved but, in fact, made much more difficult. (Perhaps the permanent impact dust cloud dissipated before four billion years ago.) What are we missing in the "paradox" of the faint early Sun?

Classifying Organic Matter

Let's go to another topic—organic matter in the solar system. We are fond of organic matter. We are made of it, and so is everyone we know and love. It is clearly the key to the origin of life. One of the most important findings of the last decade of solar system exploration, and infrared and radio examination of the interstellar grains and gas, is that organic matter exists almost everywhere. On the other hand, there is a lot we don't know. We don't know how much interstellar organic matter has survived the origin of the solar system, so that somewhere—on comets maybe—we can find samples of unprocessed primordial organic matter. We don't know if the various kinds of organic matter we see in the solar system have the same or different origins.

For example, there is a set of dark moons in the outer solar system. Saturn has a wonderful one called Iapetus that is pitch black, presumably with organics, on one side and snow white with water ice on the other. There are many other dark moons. Comets are loaded with organic matter. We now know this directly from the *Vega* and *Giotto* close encounters with Comet Halley. Is it different from the dark moons?

Titan, Saturn's big moon, is the only moon in the solar system (well, maybe Neptune's satellite Triton qualifies too) with a substantial atmosphere and opaque clouds. Those clouds are made of organic molecules richly distributed through the atmosphere. That's another kind of organic matter. And the dark carbonaceous asteroids are also rich in organic matter.

So what are the differences among these four repositories of solar system organic matter? Could they possibly all be of common origin? We have no sizeable pieces of organic matter from Titan or from Iapetus or even from comets to compare with the carbonaceous contents in meteorites.

Consider Jupiter. What causes that coloration? We don't know. One view holds that it is due to phosphorus and its compounds; another maintains that it is caused by sulfur and its compounds; a third asserts that it is due to a rich variety of complex organic matter. *Galileo* may resolve the issue. But there is now little doubt that at least high-altitude reddish or brownish hazes in the atmospheres of all the jovian planets are made of complex hydrocarbons.

Triton, the big moon of Neptune, appears to have a nitrogen/hydrocarbon ocean, but that is not yet by any means certain; we will be able to understand a lot more when *Voyager 2* flies by Triton. There also seem to be hydrocarbon oceans on Titan. At least that seems to follow from the chemistry of the atmosphere and the pressure and temperature of the surface. On the other hand, attempts with radar to detect the specular reflection signature of that ocean have so far been ambiguous.

The calculations suggest that as much as one kilometer of complex organic matter generated by charged particles and ultraviolet sunlight in Titan's atmosphere may have built up over the age of the solar system. What is that stuff like? What will it tell us about the early Earth, where similar processes must have led to the origin of life some 4 billion years ago?

Then there's the question of organic matter on Mars. There isn't any. Why haven't carbonaceous compounds been found on Mars? Even the present martian atmosphere should generate small amounts of organic matter and yet the *Viking* data show less organic matter on Mars than on the Moon. Why? The prevailing view is that it's efficiently destroyed by surface oxidants produced by ultraviolet light, but that's by no means established definitively. Is there a region below the oxidant diffusion zone—where we've never looked—which holds abundant organic matter?

Evolving Solar Systems

Let me conclude with the ultimate unanswered question about the solar system, which I can best describe if I imagine a computer program of the distant future. It contains only physics and chemistry—first principles and material properties. You input the mass, the angular momentum, the composition, and other data concerning the solar nebula—the big disk of gas and dust from which the planets formed. You press a button, there's a pause and out comes the resulting evolution of the solar system—the distribution of planetary orbits as a function of time, the masses of the planets as they accrete and are whittled away by impacts, planetary compositions over time, and the internal and atmospheric evolution of the individual bodies. The same kind of data pours out for satellites and asteroids and comets.

Now in principle this should be possible. But we are desperately far from having any such capability. In fact, modern models of the origin of the solar system can barely make Uranus and Neptune form in the age of the solar system—according to most of these models, they just finished being made yesterday, which is awkward. Believable models will require that we know what our solar system is about, that we understand where it came from, how it has evolved, and incidentally where it is going. We're going to have to have a lot more data before that's possible.

Besides exploring the solar system itself, the key way to answer these grand evolutionary questions is to discover other planetary systems. We currently are stuck with the difficult situation of drawing a general conclusion from a single example. Just one other planetary system would provide the last piece of evidence that our solar system is, in the words of Philip Morrison, a statistic and not a miracle. We still do not know for sure that there are any other planetary systems, although recent evidence has now converted almost everybody to the idea that planets are commonplace.

In the next 25 years, the same time that elapsed between *Mariner 2* and now, many practitioners in this field think there is an excellent chance that, if planetary systems are abundant, we will catch dozens of them around nearby stars. But these will be detected only by their Jupiters and Saturns and Uranuses. Terrestrial-type planets are too small to be detected early.

Even the distribution of the jovian planets, however, would be extremely interesting. For example, around the abundant low-mass, low-luminosity stars do the jovian planets huddle in close, or are they distributed at comparable distances to the jovian planets in our own system? For brighter, more massive stars than the Sun are the jovian planets much farther out? Even this most fundamental issue—the connection between the distance of the planets and the luminosity and mass of the central star—confounds us. Here, as for many other mysteries, we sorely need observations to advance our fundamental knowledge about the nature and origin of our solar system.

We also need to explore planets within multiple star systems, such as those on tight orbits around individual stars as the components of the binary go around each other. Or we might consider very distant orbits around both stars, or even figure-eight orbits. What, in fact, *is* the disposition of the planets, if any, in other star systems? We don't know.

Of course, if somebody lived on a terrestrial planet in a distant star system and sent us a message, then we'd have a chance to learn a lot about them. That's the focus of the radio search for extraterrestrial intelligence (SETI). In this case the existing technology has well exceeded our courage to mount a program that implements it. By far the most advanced radio search program for extraterrestrial intelligence is the Megachannel Extraterrestrial Assay (META) program at HarvardUniversity, which is financed by contributions from members of The Planetary Society. A still more advanced program is in works at NASA.

Framework for the Future

Most of the chief unsolved questions are of an evolutionary character, involving the history of the individual moons and planets and the solar system itself. An overarching framework of investigation will be needed to answer these questions. This framework must embrace at least a decade or two and be coherent and clearly understood—not just by the scientific community but by Congress and the President and the public. It must have an exciting exploratory focus but contain within its umbrella the various facets of NASA—the robotic program, the scientific program, the manned (and womanned) program, and major public outreach. If we're going to have anything like the kind of expenditures needed, it has to be something that captures the global imagination. The last time we did that was *Apollo*, when there was an overarching framework driven by perceived political necessity. Within that framework all those lovely missions up to 1972 and even the programmatic underpinnings of *Viking* and *Voyager*—the Golden Age of planetary exploration—were set. Can we do it again?

Carl Sagan is the David Duncan Professor of Astronomy and Space Sciences at Cornell University, and the President of The Planetary Society. [This article is based on a talk given on December 9, 1987 at the Solar System Exploration Symposium co-sponsored by The Planetary Society at George Washington University's Space Policy Institute. The author is grateful to Dr. Philip Nicholson for a stimulating discussion. Copyright 1988 by Carl Sagan.]

Many billions of stars make up our home galaxy, the Milky Way. Is the Sun the only star with planets? If planets are common, has life evolved on any other worlds? Will we someday contact other advanced lifeforms? These are some of the most profound questions facing planetary science today.

Photograph: Hale Observatories

World Watch

by Louis D. Friedman

WASHINGTON—In the Reagan administration's proposed budget for fiscal year 1989 (which begins in October 1988), NASA receives $11.5 billion, an increase of 27 percent over its 1988 funding level. Reflected in this raise are the expected recovery and resumed launches of the space shuttle, accelerating work on the space station, and increased support to space science, including a new start for the Advanced X-ray Astrophysics Facility (AXAF), the beginning of NASA's Search for Extraterrestrial Intelligence (SETI), and a new advanced technology program called Project Pathfinder, for human exploration of the solar system.

Although severely cut in the 1988 budget, NASA's space station is slated for an increase of $600 million in 1989, bringing its total in the President's budget to nearly $1 billion. NASA was forced to accept responsibility for leasing space on an automated orbiting platform to be built before its own station is completed. Whether or not this platform will be the proposed Industrial Space Facility (see the March/April 1988 *Planetary Report*) depends both on the ability of its designers to raise financing for construction and on government procurement rules.

Planetary scientists were disheartened that the Comet Rendezvous Asteroid Flyby (CRAF) mission did not receive a "new start." This delays until the next century any US spacecraft encounter with a comet. Congress will be asked to add a new start for CRAF, but given the budget's already astronomical size, this doesn't seem likely. The space science budget does include development money for pre-project work on CRAF, and NASA officials expect to present a plan next year that includes both CRAF and *Cassini*, the Saturn orbiter-Titan probe mission being studied as a collaborative project by NASA and the European Space Agency (ESA).

Planetary-program watchers are also concerned about the *Mars Observer*. Last April NASA delayed this mission and, as The Planetary Society predicted at the time, the costs have risen significantly. NASA has asked the project scientists to consider removing scientific instruments from the planned spacecraft. This would be a serious blow to US Mars exploration.

Congress is now considering the budget. Both the House of Representatives and the Senate will hold authorization and appropriations committee hearings before voting on the provisions and sending the budget to the floor. Planetary Society members who wish to submit their opinions to the committees may do so by contacting:

Senator Don Riegle
Subcommittee on Science, Technology and Space
US Senate
Washington, DC 20510

Senator William Proxmire
Committee on Appropriations
US Senate
Washington, DC 20510

Representative William Nelson
Subcommittee on Space Science
US House of Representatives
Washington, DC 20515

Representative Eddie Boland
Committee on Appropriations
US House of Representatives
Washington, DC 20515

WASHINGTON—In January President Reagan signed a Presidential Directive on National Space Policy. The full policy is classified, and only an abbreviated summary has been released. A full summary was scheduled to be released with the State of the Union message, but due to internal disputes within the administration, it was delayed. The release on February 11 contained only a shortened version of the summary.

The confusion surrounding the release was unfortunate because it diverted attention from the substance of the administration's position. The new policy reaffirms the importance of science, international cooperation and "human presence and activity beyond Earth orbit into the solar system." It encourages private-sector investment, but specifies no new policies for that investment. The policy also endorses national security space activities and supports both anti-satellite and strategic defense initiatives.

Both versions of the space policy summary are available from The Planetary Society. The longer, unofficial version is more complete, but its authenticity cannot be verified. The shorter version is official. If you would like copies, send $2 to cover postage and handling to: Space Policy, The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106.

MOSCOW—Soviet scientists at the Institute for Space Research of the USSR Academy of Sciences are considering use in 1994 of an Earth return vehicle to bring back high-resolution film images of the surface of Mars. The vehicle would weigh less than a communication system but do the same job, and would have the additional advantage of being able to provide a partial test for the crucial Mars surface sample return planned for the late 1990s.

The Soviets stated that the film return would be unnecessary if a cooperative program were instituted giving them access to *Mars Observer* data. Cooperation has improved lately, and NASA is studying the possibility of including a French receiver on the *Mars Observer* to provide extra telemetry capability from the Soviet Mars balloon. This would provide additional surface imaging data to aid in planning for future missions.

The Planetary Society funded a study of Mars balloon imaging last year and is currently working with American and Soviet scientists to establish an international Mars balloon advisory group to help define objectives for imaging and for obtaining surface information about Mars.

Louis Friedman is the Executive Director of The Planetary Society.

News & Reviews

by Clark R. Chapman

One of the most profound questions we face is whether habitable planets like Earth are rare accidents or fairly commonplace. The answer involves many separate puzzles. For example, are planets ubiquitous by-products of the processes that form stars? Is it likely that a solar system of planets will have at least one that is "habitable"? Although we cannot be sure what range of environments could sustain life, our own solar system seems to have only one habitable planet: Earth.

Several years ago, Michael Hart's studies of Earth's climatic evolution suggested that if Earth were located just a little closer to the Sun, there would have been a "runaway greenhouse" as on Venus, the oceans would have evaporated, and any fledgling life would have succumbed long ago. Furthermore, his calculations suggested that if Earth had been as little as one percent farther from the Sun, then there would have been runaway glaciation, the oceans would have frozen solid, and our planet would have become as inhospitable as Mars. If Hart's conclusions about the narrowness of the "zone of habitability" are correct, it is very fortunate for us that Earth just happened to form at the right distance from the Sun. Many other stars might have planets, but if they are made anything like the Sun's planets, then only a few stars would likely have a planet at just the right distance to balance between the predominant climate extremes and provide a potential abode for life.

Planetary Climates Compared

In the February 1988 *Scientific American*, James Kasting, Owen Toon, and James Pollack take issue with Hart's work and conclude that Earth's climate is a self-correcting system, less prone to catastrophic runaways than had been thought. Everyone who has studied the issue realizes that it is very complex. Earth is a system of many interacting influences. The oceans, the land and the atmosphere all contribute to an array of chemical and physical processes that affect the climate. Water vapor enters the atmosphere by evaporation from the ocean's surface. Other chemicals are disgorged by volcanos. Clouds form, reflecting sunlight back into space and cooling Earth. But clouds also dissipate, raining their moisture onto the land, chemically weathering rocks and further releasing chemicals into the air, including the greenhouse gas, carbon dioxide, which traps solar radiation and warms the atmosphere. Other chemicals dissolve in the rivers and run back into the sea. Carbonates precipitate onto the ocean floors, which—through plate tectonics—are eventually subducted beneath ocean trenches, heated, transformed by volcanism and brought to the surface again. Greatly complicating the chemical and physical processes on Earth are the myriad of complex lifeforms.

Authors Kasting, Toon and Pollack acknowledge the role of the biota—for example, that the carbonates are precipitated chiefly by plankton and other shell-forming sea organisms. But they don't go so far as adherents to the Gaia hypothesis, who believe that living organisms have been chiefly responsible for fashioning Earth's climate to their needs. The bottom line, Kasting et al. feel, is that if life were to die on our planet, physical and chemical cycles would still protect Earth from becoming like either Venus or Mars.

Most scientists are pretty clear about what happened on Venus. It simply was so hot that water was evaporated, photodissociated by sunlight in its upper atmosphere, and lost from the planet. There are different scenarios for exactly how this happened. In any case, huge amounts of carbon dioxide remain trapped in Venus's atmosphere, with no ocean to mediate its burial in carbonate rocks. Less clear is what happened to Mars. Kasting and his co-authors believe that if Earth were at the distance of Mars, it should not have become frozen—the habitable zone for Earth-like planets is much broader than Hart had calculated. Evidently, the geophysical state of Mars has long prevented it from completing the carbonate-silicate cycle. In particular, Mars may never have had—or may have been unable to maintain—plate tectonic processes to move precipitated carbonates back to the surface and into the atmosphere as warmth-producing carbon dioxide. So it froze, and most of its complement of water and carbonates remains bound and buried in its interior.

Greenhouse Threat

The *Scientific American* authors note that civilization's burning of fossil fuels will lead to warming, but they pooh-pooh the seriousness of the threat. After a few hundred years, fossil fuels will be used up, carbon dioxide levels will fall, and our climate will return to normal, they say. Few others are so sanguine. Earth, after all, *is* on the inner boundary of the habitable zone. And our understanding of all the complexities of climate is too incomplete for us to be sure that tinkering with the carbon-dioxide budget of Earth's atmosphere (which has risen 25 percent during this century) will not create a runaway.

As Wallace Broecker points out in the October 1987 *Natural History*, our worldwide greenhouse experiment is "pushing the Earth into an unknown realm" of warmth. We simply don't know how the Earth's climate system will respond. Other factors are still being discovered. As reported in *Science News* (December 5, 1987), it has just been realized that dimethylsulfide produced by ocean plankton may find its way into the atmosphere, affecting cloudiness, and thus modifying global temperatures and climate. There is one thing that scientists are becoming more and more sure about, according to a Research News report in the February 5th issue of *Science*: not only has the world warmed by about one degree Fahrenheit in the past century, but it is more and more obvious that the cause of the warming is, indeed, the greenhouse we ourselves have produced.

Clark R. Chapman is the author of a recent brochure produced for NASA's Solar System Exploration Program.

SOCIETY *Notes*

WE NEED YOU!

Willing to devote a few hours to help spark public interest in planetary exploration? We need volunteers to help circulate the Mars Declaration; to place the Society's new brochure in libraries, schools and museums; and to speak out about Mars Watch, the Mars Declaration, or planetary science in general. Pledge your time and talents! Write to volunteer supervisor Marshalle Wells for details. (Information has been sent to volunteers who are already signed up.)—*Tim Lynch, Director of Programs and Development*

LUNAR BASE PERSPECTIVES

Soviet scientist Vladislav Shevchenko offered a "Soviet View of a Lunar Base" in a public lecture co-sponsored by The Planetary Society and the Department of Earth and Space Sciences at UCLA on March 29. An audience of 300 listened to a Soviet perspective on design possibilities, feasible uses, and cost effectiveness of such bases. James Burke of the Jet Propulsion Laboratory and *The Planetary Report*'s Technical Editor then provided an overview of US lunar exploration. A lively question and answer period moderated by Mr. Burke followed.—*Susan Lendroth, Manager of Events and Communications*

ACTIVITES DOWN UNDER

On January 10 the Society's Senior Consultant, Jon Lomberg, appeared on Sydney, Australia radio. Mr. Lomberg discussed the Society, the Search for Extraterrestrial Intelligence (SETI), and how Australians could participate. Society members gathered on January 13 in Sydney and the next evening in Melbourne to hear Mr. Lomberg discuss his work as chief artist on the *Cosmos* TV series and as a designer on the *Voyager* Interstellar Record. Hats off to the active Aussies!—*SL*

US-SOVIET MARS CONFERENCE

At a press conference at the Institute for Space Research in Moscow, I was privileged to discuss "Opportunities for International Cooperation in Mars Exploration." To more than 50 journalists, artists, and film producers I described planned US missions for planetary exploration once the space shuttle resumes flight, NASA studies on the Mars Rover Sample Return, and US-Soviet cooperation. Following the presentation, they asked me questions ranging from the US administration's attitudes toward international cooperation to rumors of UFO sightings in North America.

Representatives from both the Union of Artists and the Union of Writers hope to work with The Planetary Society to publish *The Planetary Report* in the USSR and make it available to Soviet citizens outside the scientific community.—*Louis D. Friedman, Executive Director*

ARTISTS' EXCHANGE

The Planetary Society has entered into an agreement with a group of US space artists, including International Astronomical Artists Association members, to serve as liaison in arranging exchange visits and cooperative projects with Soviet counterparts. On my recent Moscow visit, I finalized an agreement for a US-Soviet exchange program, to begin with a workshop in Iceland this year and exchange visits at the *Phobos* and *Voyager* encounters in 1989.

We are now working with the US Association of Science and Technology Centers to develop an exhibition of art about international cooperation in space. We've set a fundraising goal of approximately $25,000 to initiate the project. If you would like to help support these programs, write to me at the Society's offices.—*LDF*

LIFE ON MARS?

Is there life on the Red Planet? Has there ever been? What are the implications of these questions for Mars missions? Society President Carl Sagan moderated a US-Soviet discussion on these topics on March 24 in Sunnyvale, California. The crowd of 2,000 that flocked to the event evinces the burgeoning interest in cooperative US-Soviet Mars exploration. The Society apologizes to those who were turned away at the door. Listeners heard the views of Harold Klein, Chairman of the National Academy of Sciences Committee on Biology and Chemical Evolution; Stanley Awramik of the Department of Geology at the University of California at Santa Barbara, an expert on early life on Earth; Mikhail Ya. Marov of the Institute of Applied Mathematics at the USSR Academy of Sciences; and Lev Mukhin, Staff Scientist at the Soviet Institute for Space Research. Co-sponsored by The Planetary Society and NASA Ames Research Center, the panel closed a three-day conference on Exobiology and Future Mars Missions.—*SL*

NEW MILLENIUM COMMITTEE WELCOMES. . .

Sydney real estate developer Emanuel Cashell has joined the New Millenium Committee as its first Australian member. The Committee was created to fund Society projects whose benefits might not be realized until the 21st century (or the third millenium).—*LDF*

TO MARS TOGETHER?

That question was the focus of a symposium on US-Soviet space cooperation held at the University of Alabama in Huntsville on March 28. Co-sponsored by the Planetary Society and the university's Sociology Department, the evening featured a discussion with Soviet space expert Mikhail Ya. Marov from the Institute of Applied Mathematics at the USSR Academy of Sciences. Joseph K. Alexander, Assistant Associate Administrator in NASA Headquarters' Office of Space Science and Applications, presented a US viewpoint. Rick Chappell, Director of Science at NASA's Marshall Spaceflight Center, moderated.—*SL*

LET'S KEEP IN TOUCH!

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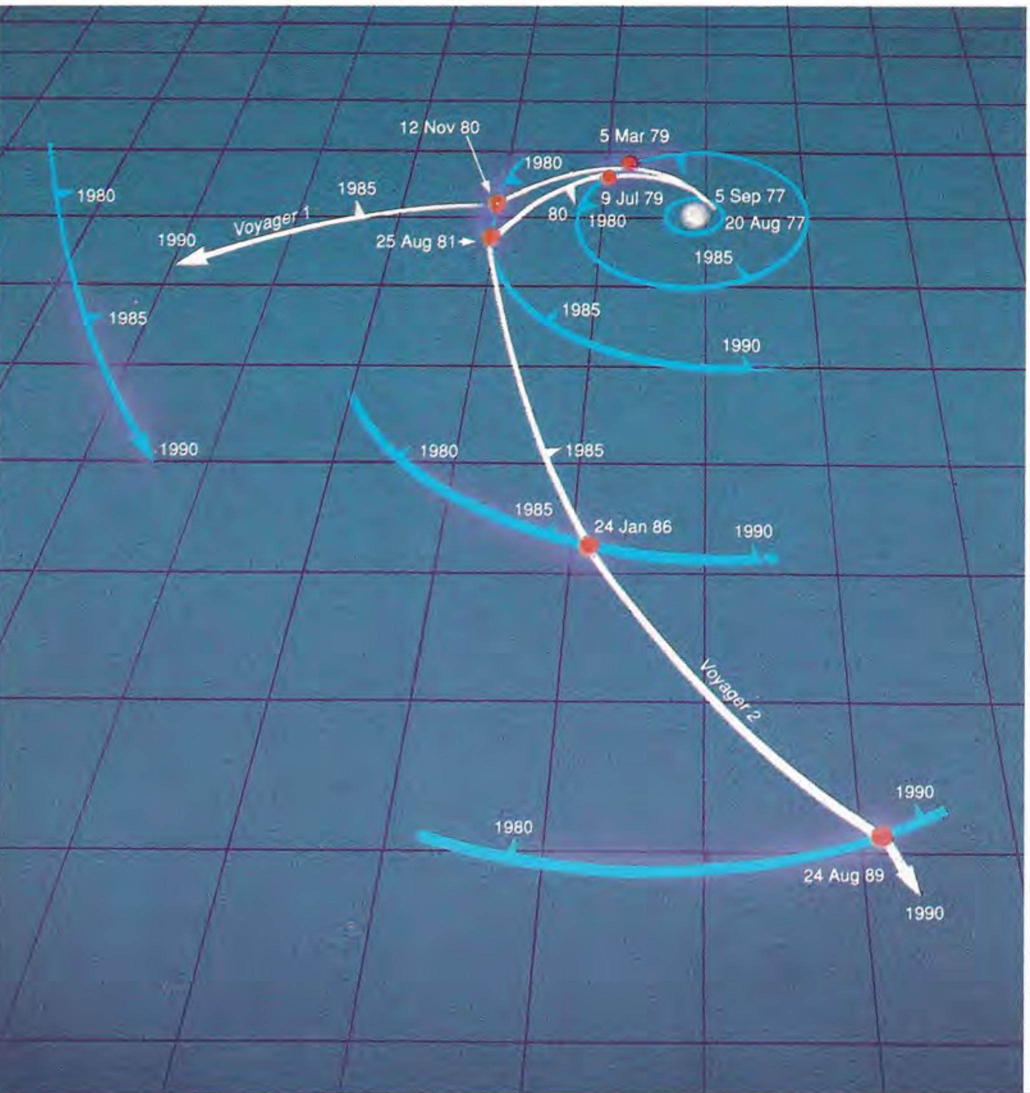
west of the Mississippi

Questions & Answers

Why can't the "gravity-assist" procedure that gave* Voyager 2 *the power boost to fly past Uranus and Neptune be used one last time to explore the Pluto/Charon system?
—Darlene Waddington, Pomona, CA

Our ability to use gravity assist to enable a single spacecraft to visit several planets is partly dependent on a fortuitous planetary alignment. The alignment of Jupiter, Saturn, Uranus and Neptune that made the multi-planet *Voyager* missions possible occurs only once every 177 years. Since *Voyager 2* carries enough fuel to change the spacecraft's direction only slightly, each encounter must be planned very carefully. *Voyager* must pass at just the right distance from each planet and at the right latitude to allow the planet's gravitational pull to deflect the spacecraft's path toward the next planet. *Voyager 1*'s planetary encounters ended with the Saturn encounter in November 1980 because the project's scientists felt that it was important to fly the spacecraft very close to Saturn's equator at encounter, and the gravity of the ringed planet pulled the spacecraft into a trajectory well north of the plane of the outer planets' orbits.

As *Voyager 2* approached Saturn, the scientists and project managers had a choice to make: should the spacecraft be targeted to go directly from Saturn to Pluto, or should it follow the original plan to go on to Uranus and Neptune? The choice was obvious: two major planets and their satellites, rings and radiation fields were surely more important than tiny Pluto. There have been no regrets that the choice was made to go to Uranus and Neptune.



For most of the final three decades of the 20th century, Pluto has been closer to the Sun than Neptune. To reach Pluto from Neptune it would therefore be necessary for *Voyager 2* to make a very sharp right turn, almost heading back toward the Sun.

If Neptune were as small as Earth, yet still possessed the total mass it now has, it would theoretically be possible to fly *Voyager 2* close enough to bend its path toward Pluto. But Neptune has a diameter four times that of Earth and the needed flyby distance for *Voyager 2*'s deflection to Pluto would actually be inside the planet! Furthermore, we would have to abandon investigation of Neptune's larger satellite, Triton, which may prove to be a more interesting target than Pluto and Charon. Triton's encounter follows five hours after Neptune's, and Earth-based observers think that it may possess a substantial atmosphere and liquid nitrogen lakes on its frigid surface.

Voyagers 1 and *2* will continue their trek outward through the solar system, looking for the so-called "heliopause" (the outer edge of the Sun's magnetic field). Spacecraft investigation of Pluto will then await some future mission, probably well after the beginning of the 21st century.
—ELLIS D. MINER, *Jet Propulsion Laboratory*

What is the density of the asteroid belt? Is it a great mass of colliding planetesimals, or is it made up of random planetoids that never come close enough to touch?
—Andy Schmidt, Avon, CO

The density of the asteroid belt is sparse. Although it is populated with hundreds of thousands of objects ranging in size from Ceres, the largest at about 1,000 kilometers in diameter, to those a few tens of meters across, they are distributed over a vast area between the orbits of Mars and Jupiter. The main-belt asteroids are concentrated in a large doughnut-shaped region with a volume greater than the enormous spherical volume of the space inside Mars' orbit. It is estimated that the total mass of all the asteroids is only about 10 percent of the mass of the Moon and less than a percent of that of Earth.

The asteroids are distributed unevenly in families with similar orbits. This clustering may be the consequence of the breakup of a larger object whose remains still travel orbits similar to the parent body's. Jupiter's gravity plays a major role in affecting the orbital behavior of the material in this region. Since the birth of the solar system, Jupiter has influenced the original "leftover" material in the asteroid belt and may have caused the objects to cluster while producing gaps in the distribution.

So although there is a sizable asteroid population in the belt, because of the very low density in this large area of space, fewer collisions have occurred in recent solar system history. The typical science fiction movie depiction of the asteroid belt as a "mine field" of flying rocks is not accurate. It is true, though, that over very long periods of time collisions do occur.

The records now show that four probes (two *Pioneers* and two *Voyagers*) have journeyed through the asteroid belt without any significant impacts to the spacecraft. This gives us greater confidence in our assessment of the debris density in space which could threaten future ventures into the challenging depths of our solar system. To answer your question as to whether asteroids ever come close enough to collide with one another, one must respond that on the time scale of the solar system, they do.
—ELEANOR HELIN, *Jet Propulsion Laboratory*

What are the lightning levels of other planets?
—John P. Baun, Horsham, PA

We have evidence for lightning on Jupiter, Venus (here the existence is controversial; see the July/August 1987 *Planetary Report*) and Saturn. Lightning may be occurring on other solar system bodies such as Titan and may await discovery by spacecraft.

Spacecraft images have shown us the ammonia clouds of Jupiter illuminated by extremely bright lightning flashes. Analysis of these images indicates that the lightning is not occurring in the upper ammonia clouds, but in water clouds deeper in the atmosphere. Radio waves radiated by jovian lightning have also been reported. These spacecraft observations indicate that lightning is very common and intense on Jupiter—about 10,000 flashes occur per second. Still, because Jupiter has 100 times the surface area of Earth, the frequency of flashes at any location is similar to that of Earth.

When *Voyager 1* approached Saturn in 1980, radio pulses were observed that had lightning-like characteristics. Because the equipment was not designed to study lightning, we obtained so little information that it wasn't possible to be certain whether the lightning was occurring in the atmosphere of Saturn or its rings. We must wait for a new mission to Saturn to determine what sort of lightning activity is occurring on this planet.

In contrast to the reasonably clear picture we have for lightning on Jupiter, the data for lightning on Venus have produced only a murky picture. The radio data from both the Soviet *Venera* probes that landed on Venus and the *Pioneer* Venus Orbiter (PVO) indicate lightning, but they cannot tell us whether the lightning is occurring in the clouds or in volcanic eruptions. The low-frequency radio data that we have are ideal for detecting lightning but are very poor for determining the properties of the lightning flashes. A search for light flashes was made by *Veneras 9* and *10* during their two-month observation period. They recorded lightning-like events only once: for 70 seconds on October 26, 1975. A single thunderstorm was observed with a flashing frequency of 100 flashes per second. This implies a global flash rate of 45 flashes per square kilometer per year, which is 10 times higher than for Earth.

In contrast to the Soviet results, the PVO saw no light flashes. This implies that either the flash rate of lightning on Venus is lower than 30 flashes per square kilometer per year or the peak intensity is much lower than that of terrestrial lightning. This contrasts with the *Venera* result that lightning flashes are 15 times brighter and occur much more frequently than terrestrial flashes.

It is clear that this mysterious planet will not give us more than a glimpse of what's occurring in its cloud-shrouded atmosphere. Until new missions with better experiments penetrate its clouds, we can only guess at the characteristics of lightning on Venus.
—WILLIAM J. BORUCKI, *NASA Ames Research Center*

FACTINOS

Scientists who study the origin of the solar system have discovered a material that predates the birth of our Sun 4.6 billion years ago. This rare compound of carbon and silicon has recently been extracted from a sample of the 50-pound stony meteorite that fell near Murray, Kentucky in 1950 and is some of the oldest material yet known to science.
—from Robert C. Cowen in
The Christian Science Monitor

In January astronomers reported their surprising discovery that Pluto is much denser than the loosely compacted snowball they had thought it to be.

"It's very unusual for bodies in the outer solar system to have that high a density," said Richard P. Binzel of the Planetary Science Institute in Tucson. According to Binzel, Pluto has a lot of rock in addition to the methane and water ice that scientists had found previously.
—from Lee Dye in
The Los Angeles Times

Researchers now say the processes that led to life may have begun 4.2 billion years ago in the ocean's depths. There, complicated molecules could have developed protected from the trauma caused by meteorites and planetesimals striking the young Earth.

David Stevenson of the California Institute of Technology says, "We're talking about something that's even earlier than single-celled organisms. We're not really talking about biology at all; it's called pre-biotic."
—from *The Los Angeles Times*

"Chaos" is a new field of mathematical study with diverse applications from fluid mechanics to meteorology. Professor Jack Wisdom, a physicist from the Massachusetts Institute of Technology, is using novel algorithms and fast computers to search for possible chaos in the asteroid belt and among various moons in our solar system.

Chaos dynamics explains how tiny perturbations of a system can lead to wildly diverging trajectories and how even a simple deterministic system can behave unpredictably.
—from Eugene Mallove in
Tech Talk

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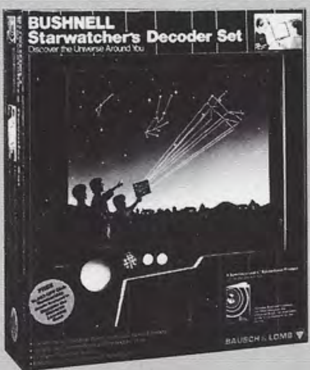

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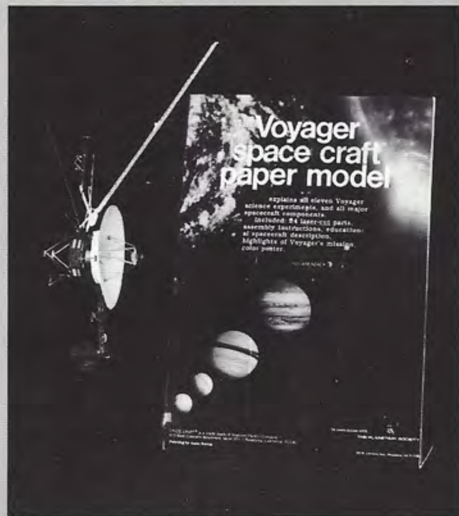

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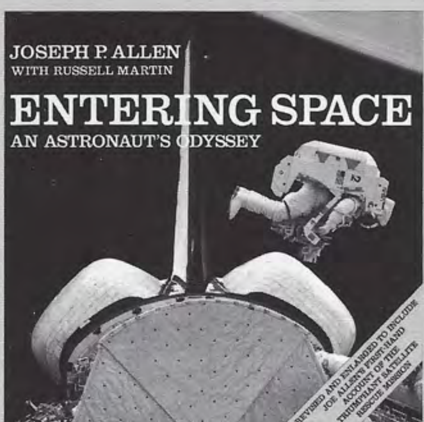

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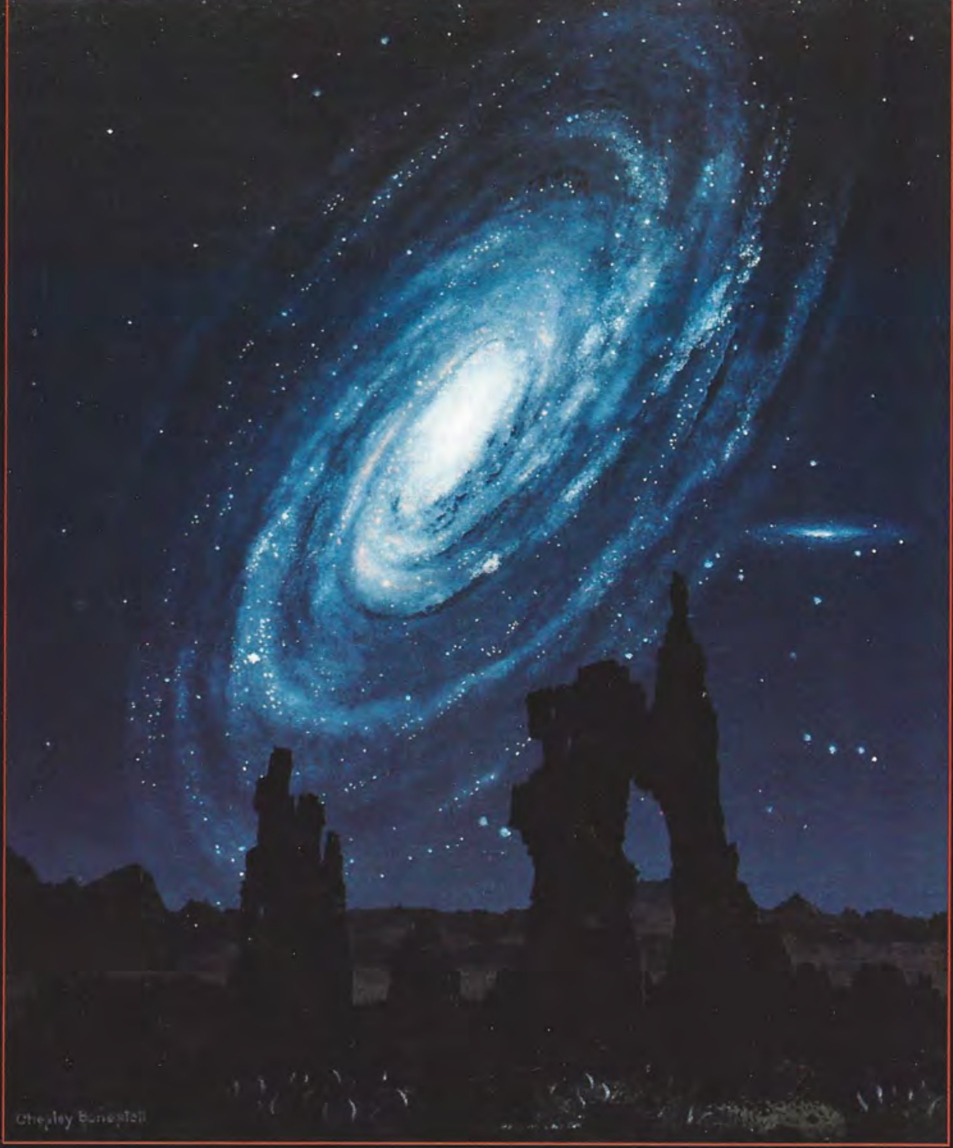

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