The PLANETARY REPORT

Volume XVII Number 3 May/June 1997

Carl Sagan—A Tribute

On the Cover:

Carl Sagan's scientific life centered on the search for life in the universe. The two images on our cover symbolize the range of his work: the amino acid glycine, seen here in crystallized form, is one of the crucial building blocks of life on Earth. Its spectra have been detected in gas and dust clouds among the stars, suggesting that it—and the life that can spring from it—may be common in the universe. The nearby planet Mars has carved into its surface evidence that it once possessed a climate that may have supported life. Here Ma'adim Vallis, a 600-kilometer-long channel (400 miles), drains into the crater Gusev. Channels like this, with a morphology typical of earthly rivers, show that water once flowed on Mars. Discoveries like these, of the elements of life, propelled Carl's work.

Glycine photograph: Alfred Pasieka, Peter Arnold, Inc.
Mars image: US Geological Survey, Flagstaff

Table of Contents

Volume XVII
Number 3
May/June 1997

Features

4 Carl Sagan, Teacher
"Carl Sagan taught science to the whole world," writes one of his students, Chris Chyba. Yet a fortunate few had a traditional and intimate teacher-student relationship with Carl in his primary career as a professor of astronomy. Chris recounts the effects Carl had on their lives.

8 Carl Sagan, Spokesman for Science
It was in this role as a spokesman and popularizer of science that Carl was best known—and sometimes controversial. Hans Mark often found himself opposing Carl on some issues, but he treasured Carl's ability to put science within the reach of anyone who wanted to learn.

11 Carl Sagan, Partner in Exploration
It's hard to imagine two more divergent personalities than Carl Sagan and Bruce Murray. For over 30 years their careers entwined, and they found a way to work together—and formed the Planetary Society.

16 Carl Sagan, Scientist
Carl's very real scientific accomplishments were sometimes overshadowed by his persona as a popularizer. Renowned astrophysicist Frank Drake reminds us how much Carl contributed to the advance of planetary science.

20 Ode to the Alien
Poet and author Diane Ackerman wrote this provocative and evocative piece at Carl's request.

22 Carl Sagan, Visionary
Apollo 11 astronaut Buzz Aldrin knew and admired Carl for decades. When the Planetary Society asked him to speak at our commemoration, Buzz commissioned this speech from writer Wyn Wachhorst.

23 The Future of the Planetary Society
The Planetary Society has lost its most illustrious spokesman, but the organization remains strong, and with the help of our friends and our members, we can become a stronger and more effective force for planetary exploration.

Departments

3 Members' Dialogue
26 News & Reviews
27 Society News
28 Basics of Spaceflight

From The Editor

Since Carl Sagan's death, the directors, advisors, and staff of the Planetary Society have been moved by the depth of affection so many have expressed for both Carl and the organization he helped found. Their commitment to his vision of the future has manifested in a determination that the Society will come out of this transition even stronger and more capable than before.

It's clear now that, even though we have lost an irreplaceable leader, we have many highly capable, talented, and committed friends who will work with us to advance the Society and its goals. Already four energetic and experienced leaders have joined the Board of Directors (see page 24). We are reconstituting the Board of Advisors and setting up an Editorial Advisory Board, and we are soliciting time and advice from a wide array of friends. And, most important, Planetary Society members demonstrate over and over their support for and commitment to our organization.

So, as you read this issue looking back on Carl's life and work, keep in mind that the Society is poised to take on the future with renewed strength and vitality. We will miss him greatly, but together we will go on, dedicated to exploring the planets and searching for life in the universe.
—*Charlene M. Anderson*

Contact Us

Mailing Address: The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106-2301
General Calls: 818-793-5100 Sales Calls Only: 818-793-1675
E-mail: tps@mars.planetary.org World Wide Web Home Page: http://planetary.org/tps/

The Planetary Report (ISSN 0736-3680) is published bimonthly at the editorial offices of the Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106-2301, 818-793-5100. It is available to members of the Planetary Society. Annual dues in the US are $25 (US dollars); in Canada, $35 (Canadian dollars). Dues in other countries are $45 (US dollars). Printed in USA. Third-class postage at Pasadena, California, and at an additional mailing office. Canada Post Agreement Number 87424.

A Publication of
THE PLANETARY SOCIETY

Members' **Dialogue**

Good Work

I just wanted to let you know what a great report you put out. Being a mechanic who is interested in space and having a son in aerospace engineering, it is wonderful to sit down and be able to read a technical piece of information that the lay or working person can understand. Keep up the good work.
—PETE DOUGHERTY,
Hazleton, Pennsylvania

Worldwide Cooperation

"The Launch and Loss of *Mars '96*" (see the January/February 1997 *Planetary Report*) brought to mind how little all the spacefaring agencies are willing to learn from each other and how the lack of Earth-wide cooperation continues to impede progress. You refer to 22 science instruments and the hopes of hundreds of scientists from more than 20 nations. Did all the nations contribute to the tracking and data system supporting the launch phases? I doubt it. You say that no one knew that the second firing of the fourth-stage burn never occurred. Was this burn stage out of the view of any station on Earth, civilian or military? You state that the lack of a Russian tracking ship may have caused the blank region.

Maybe offers of cooperation in the future, along with offers of scientific instruments and investigators, would permit more adequate planning, on a global basis, of large and potentially international missions, whether launched by Delta, Proton, Ariane, Long March, H, or whatever. Our current technical capabilities should permit realistic back-up and automated command capability to override the onboard timer, if necessary, and enhance the reliability of the launchers.

Maybe nothing could have helped this fiasco, and maybe we'll never really know what happened, but let's cooperate, all of us, to support the next launch with all means possible and available.
—KURT HEFTMAN,
Bay Harbor Islands, Florida

For Carl Sagan at the Winter Solstice, 1996

Other astronomers and mathematicians talked
their thick and sluggish calculus,
ponderous theories of things too vast to know,
math models too tangled to hang a handle on.

Where others saw chalk dust, blackboards, impenetrable formulas,
you saw the raw beauty of the cosmos.
You were our universal translator.
You handed us the perfect symmetry of stars,
the intrigue of black holes and the flavors of quarks,
the lives of cells and the death of comets,
the warp and weave of infinite space.

Tomorrow the earth lifts again,
tilting back to face the light from our private star.
You're busy elsewhere, working your way out
to become stardust again.
Who can play the music of the spheres as well as you?

SARAH BLANCHARD,
Pomfret Center, Connecticut

The Mars Rock Issue

The January/February 1997 issue of the *Planetary Report* is perhaps the most interesting and scientifically significant contribution of the Society to humankind.

In 1968 or so I worked on a study with the late Harold C. Urey in which we examined the freshly exposed surfaces of the 1864 Orgueil carbonaceous chondrite with a scanning electron microscope. While our instrument could only show topography, we did find one view that suggested three more or less spherical objects about 30 microns across, apparently embedded then exposed, with an interesting beaded surface. To our chagrin, these later proved to be bubbles, perhaps stabilized by the platinum coating from some material within the sample that resulted from the vacuum coating treatment.

Although these efforts were not highly significant, I am rather proud to have been involved at the time and to have a background that makes the "life on Mars" question particularly important to me.

I congratulate the Society on the beautiful presentation of this issue.
—CHARLES M. DREW,
Wellington, Nevada

Please send your letters to
Members' Dialogue,
The Planetary Society,
65 North Catalina Ave.,
Pasadena, CA 91106-2301
or e-mail: tps.des@mars.planetary.org.

CARL SAGAN, TEACHER

One of his greatest gifts was his commitment to the truth. Not what's going to make you feel good, less afraid, less small, more central to the workings of the universe. But to what's true.

—Ann Druyan, at the Planetary Society's commemoration of Carl Sagan, February 17, 1997

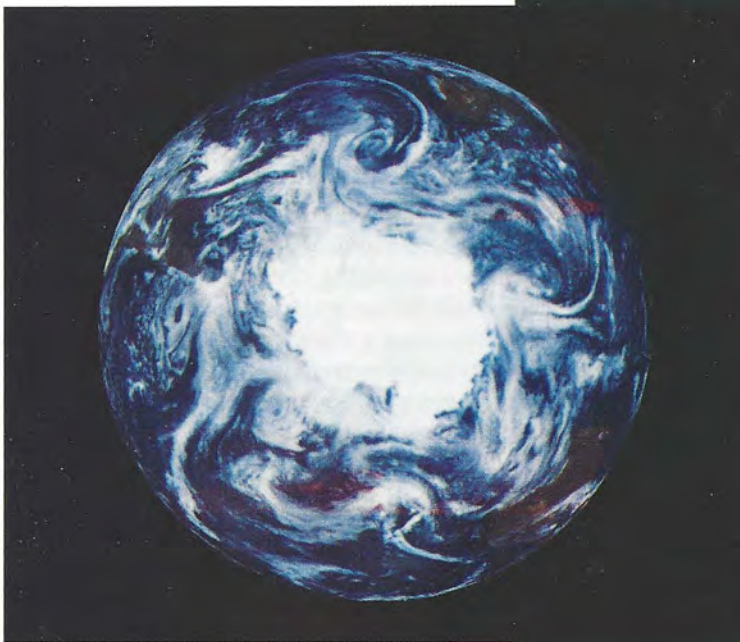
by Christopher Chyba

Carl Sagan taught science to the whole world. But well before he became famous for his popular books and television programs, he had established himself as an exceptional teacher in the smaller setting of college lecture halls and seminar rooms. Students in his general education courses as well as advanced seminars enjoyed inspired teaching by a man who was in love with science.

Many scientists have remarked to me how important Carl was in their decision to choose science as a career. Many have stories of how he personally responded to letters they had written him while still students.

In my own case, I was overseas in the midst of graduate work in physics when, after reading about Carl's scientific research, I decided to switch fields. I applied to the Department of Astronomy at Cornell University in the hope of working with him. Out of the blue one day I received a telegram: "phone collect Dr. Carl Sagan." Before we even spoke, he wrote me a letter, presenting a long list of exciting spacecraft and laboratory projects, and offered me the opportunity to participate directly in "actual mission operations and early data analysis" from several planetary spacecraft. His letter was overwhelming. Carl's enthusiasm lifted you up and carried you along.

Carl brought this enthusiasm to every course he taught. In a sense, his public-television series *Cosmos* was a record on videotape of what he had been doing in the lecture hall for many years. Steve Soter, who later joined Carl and his wife Ann Druyan as a co-writer of *Cosmos*, was a graduate student at Cornell when Carl first arrived there from Harvard University in 1968. Soter watched him describe to a lecture



Above: This view of Earth was created by Carl's student, the late Reid Thompson, from images returned by the* Galileo *spacecraft as it swung by our planet on its way to Jupiter. At center is the Antarctic continent; swirling around it are the water vapor clouds characteristic of this world.

Image: Reid Thompson, Cornell University

Right: Land, water, and blue sky—these things make our world unique in our solar system and testify to the benign climate that nurtures life.

Photo: Greg Vaughn, Tom Stack & Associates

Far right: A "pale blue dot," seemingly suspended in a beam of sunlight—this is how Earth appeared to the camera of* Voyager 1 *as it looked back one last time at the planet of its birth. Carl had suggested this task for the spacecraft as a way of emphasizing the preciousness of our small, watery world.

Image: JPL/NASA

hall filled with non-science majors the escape of molecules into space from Earth's upper atmosphere. To convey the key ideas, Carl impersonated the individual molecules as they collided with one another, adding "whoosh!" noises at the appropriate moments. Somehow, he got the science exactly right even while he kept the audience rapt with attention—or simply in stitches.

This enthusiasm carried over into his much more technical graduate seminars. Carl's seminars were a fusion of his deep scientific grasp with his skills as a communicator. Bill Newman, now a professor at UCLA, took one of Carl's planetary science courses in the fall of 1973. Newman witnessed a teaching style he had never before seen in advanced science seminars. Carl performed a kind of hula to demonstrate the dance of photons in a "random walk," a staggered motion that requires statistics to describe.

Two of Carl's seminars bracketed my years as his

> Somehow, he got the science exactly right even while he kept the audience rapt with attention—or simply in stitches.

student. It was characteristic of Carl that he agreed to give the second of these, "Planetary Exploration and the Origin of Life," because his student had asked that he do so. Week by week, Carl's seminars were an event, filled with ideas for research projects that he would simply toss out to any student willing to take them up. His seminars spawned many published papers.

My own first paper in planetary science grew out of one of these suggestions; yet when it came to taking credit, Carl maintained that since I had pursued the topic alone, I should be sole author of the final publication. He was unfailingly scrupulous about authorship: if he had not made major contributions to the research, he would not be a co-author, and if he had not been responsible for the majority of ideas in the paper, he would not be first author. Not all graduate advisors are this generous regarding the work of their students.

Dave Stevenson, now a professor of planetary science at the California Institute of Technology, has similar recollections. The first course in planetary science he ever took was from Carl, and Carl encouraged him to turn his term paper for the course into a journal article. Stevenson, staying up to watch Carl's first appearance on the Johnny Carson show, knew already through personal experience that "Carl could inspire."

Even as a young assistant professor at Harvard, Carl attracted remarkable students, among them Dave Morrison and Jim Pollack. Both went on to exceptional careers as planetary scientists. Jim Pollack, now deceased, once fondly recalled how Carl offered him idea after idea to pursue in his graduate research. Carl established a pattern of continuing to work with his students even after they had gone off to their own careers. For example, the original paper presenting the theory of nuclear winter included five authors—the last of whom was Carl. Two others, Jim Pollack and Brian Toon, had been his students.

As a student with Carl, I was often asked whether I "ever saw him." I was always able to reply honestly that I had no complaints at all in this regard. Carl went out of his way to present opportunities for his students. He made it possible for many students, including some undergraduates, to work at the Jet Propulsion Laboratory (JPL) during the *Voyager* encounters with Jupiter, Saturn, Uranus, and Neptune. Dave Pieri, who completed his PhD with Carl during the exceptionally busy years when *Cosmos* was in production, recalls heading out to JPL as a grad student to help map landing sites on Mars. Having come into the mission as a student with Carl, Pieri later became Project Scientist for *Viking*.

Carl helped post-doctoral students as well. Gene McDonald traces his career in exobiology to the day when, as he was completing a doctorate in biochemistry, an advertisement for a position in Carl's Laboratory for Planetary Studies caught his eye. For many years, there were not many paths into exobiology and origins-of-life research. Carl's laboratory, where he collaborated for virtually his entire professional career with Dr. Bishun Khare, provided one of the important routes into the field.

In the last years of his life, Carl was saddened by the deaths of two former students, Jim Pollack and Reid Thompson. Reid, another example of Carl's attracting outstanding students from disparate fields, had come to work for Carl from a graduate program in biophysical chemistry. In his obituary for Reid, Carl described Reid as "gentle, kind, and brilliant," and in conversation after Reid's memorial service, Carl quietly said to me that he had now lost Jim and Reid, and would I please take care of myself: he didn't want to lose anyone else.

Carl insisted that his students feel free to ask him any question. He publicly preached the ideal of skepticism and open debate, and he privately expected the same in his relationships with students. No topics were off limits; my informal conversations with Carl would often explore our disagreements in areas well outside our research. Peter Wilson, completing his dissertation with Carl at the time of Carl's death, had many discussions with him about animal rights issues.

> He publicly preached the ideal of skepticism and open debate, and he privately expected the same in his relationships with students.

Christopher Chyba's studies with Carl Sagan involved the role comets played in making Earth a world suitable for life. The water and organics they carried to our planet may have been crucial to the eventual rise of self-replicating—living—systems. Here Comet Bennett rises above a line of trees on a morning in 1970.

Photo: Dennis Milon

In Reid Thompson's obituary, Carl recalled their disagreements over UFO reports. Carl brought to these conversations the same inquisitive openness to the universe—and, often, strong opinions—that so characterized his writing.

No account of being a student of Carl's would be complete without mentioning the socializing Carl and his students enjoyed together. Dave Pieri once collided with Carl at the net in volleyball. Sprawled on the ground, Carl jokingly reminded Pieri that he would see him in class the next day. During the *Voyager* Wrap Party at JPL, Dave Grinspoon and Carl and Annie Druyan and others of us danced while Chuck Berry did his trademark "duck walk" with his guitar.

Some of the other memories are more somber.

Often during Carl's illness, and especially on one occasion when I saw the difficulty of his chemotherapy—for him and his family—my thoughts turned to a remark he had made to me on the sad occasion of the death of his long-time assistant Eleanor York. Carl had commented that if there was any lesson for those of us left behind, it was that we all had to try harder "to be kind to one another."

So soon after Carl's death, it is melancholy to think back to my arrival in Ithaca and to the excitement and anticipation of my first conversations as a student with Carl. I recall vividly a dinner party Annie and Carl hosted during my first winter at Cornell, when we watched the night-time snow fall through the floodlights looking out over one of Ithaca's deep gorges, and their guest, the magician Randi, spoke eloquently about psychic frauds and performed quiet sleight-of-hand under low light in a cluster of dinner tables, and all seemed mysterious, and terribly promising, and full of joy.

Christopher Chyba is an Assistant Professor of Planetary Sciences at the University of Arizona. From 1993 to 1995, he served on the national security staff at the White House.

Carl Sagan poses with former students at the celebration of his sixtieth birthday in October 1994 at Cornell University. From left to right: Peter Wilson, Dave Morrison, Chris Chyba, Carl Sagan, Steve Soter, and Brian Toon.

Photo: Courtesy of Chris Chyba

CARL SAGAN, SPOKESMAN FOR SCIENCE

by Hans Mark

> Carl was a hero in an era that preferred to diminish rather than magnify public figures. It's much easier these days to be an anti-hero. Instead of conquest, as with the classic hero, his venue was of the mind and spirit.
>
> —Bruce Murray, at the Planetary Society's commemoration of Carl Sagan, February 17, 1997

He was unique. Carl Sagan made major contributions both to science and to the public understanding of science. I can think of only one other person who was both a world-class scientist, as Carl was, and a superb interpreter of science to the general public: Thomas Huxley. It was Huxley who a century and a half ago developed the strategies, wrote the books, and delivered the lectures that ultimately led to public understanding of the theory of evolution as formulated by Charles Darwin and Alfred Russel Wallace. There is no doubt that widespread public knowledge of Darwin's work created a cultural framework that shaped much of the history of the twentieth century. A good case can be made that Carl Sagan has already had a similar impact and that his influence will grow in the coming century.

It is interesting that Sagan and Huxley concerned themselves with the same fundamental questions. What is the origin of life? What does it mean to be a human being? What is the nature of intelligence? In the end, these questions have no answers in a logical sense. Every generation asks them again, and the people who shape the debates—Huxley in the nineteenth century and Sagan in ours—exercise most extraordinary powers over human destiny. Although Carl himself is gone from our midst, I am firmly convinced that the influence of his work will grow in the coming years, just as Huxley's work gained an increasing audience after his death in December 1895.

I met Carl for the first time in 1961 or 1962 when he was a Miller Research Fellow at the University of California at Berkeley and I was a member of the faculty in the university's college of engineering. At the time, I had close connections with the physics department as well as the university's nuclear weapons laboratory at Livermore. I taught the senior level course on quantum mechanics during those years, and Carl sat in on a few lectures. He had been doing other things and he wanted to refresh his knowledge of the subject. The fact that someone who held a Miller Research Fellowship, which is the most prestigious award bestowed by the university, would sit in on some of my lectures caught my attention. I did not get to know Carl very well at the time, but there is no doubt that he made a lasting impression on me.

A little more than ten years later, I met Carl again, and this time I had the opportunity to work with him. I had moved to NASA Ames Research Center to become the center's director. Carl, in addition to establishing himself as a major scientific contributor, had also in the meantime started his public career by appearing as television spokesman for the Jet Propulsion Laboratory (JPL) during the *Mariner* flybys of Mars. NASA Headquarters asked Carl to do the same thing for Ames during the *Pioneer 10* flyby of Jupiter.

The work Carl did for us attracted considerable attention, and the San

Francisco PBS television station, KQED, provided full coverage. Carl did a superb job managing the productions and acting as master of ceremonies and television "anchor." Some years later he initiated the now famous *Cosmos* series on PBS. In a certain sense his work on *Pioneer 10* was a "dry run" for what was to come.

Carl and I shared a strong interest in the possibility of life elsewhere in the solar system and in the universe. Ames Research Center had taken on responsibility for developing and managing the life-detection package that would be put on the *Viking* Mars landers. In addition, Ames sponsored the first studies by the late Barney Oliver on the Search for Extraterrestrial Intelligence (SETI). Carl developed further his very real interest in that enterprise during his stay with us in 1973.

Above: The heavier elements—such as those that make up most of our world and ourselves—were forged in the death throes of giant stars, such as the explosions that formed these wispy clouds of the Vela supernova remnant some 11,000 years ago.

Photo: David Malin, Royal Observatory Edinburgh

Right: Some of the elements forged in the hearts of stars have found ways to combine and replicate themselves in a process we call life. DNA, seen here in synthetic form, is one such combination.

Photo: Phil A. Harrington, Peter Arnold, Inc.

From that time onward, Carl and I would see each other periodically to discuss a wide range of topics in which we were both interested. We agreed on many things, but it was obvious that there were two points on which Carl and I were fundamentally at odds. One was the matter of putting people in space. During the 1970s Carl was generally of the opinion that it was a waste of money to put people in space. He believed that missions using robotic spacecraft would yield better scientific results and would thus be more cost-effective. My feeling was that our enterprise in space required people both for political and, ultimately, technical and scientific reasons.

The second point of disagreement between us was about how to deal wirh the Soviet Union. While I had no problem working with Russian scientists, I did have real reservations about making broad, long-term collaborative agreements on large projects with the Soviet government. Carl felt differently, and in the early 1980s he began to advocate a joint mission with the Soviets to send people to Mars. On the one hand, I was pleased that Carl was pushing a mission that involved people. On the other hand, I could not agree that we should make an agreement to do this with a regime that was opposed to everything the United States has stood for in a history spanning more than two centuries. Carl and I occasionally discussed these matters, but there was obviously no way that we could resolve these disagreements.

We agreed on many things, but it was obvious that there were two points on which Carl and I were fundamentally at odds.

Throughout all of these discussions and debates, we never lost respect and even affection for each other. We corresponded occasionally, and Carl was especially influential in helping us to formulate our space science programs at the Ames Research Center. He recommended his students to us, and one of the most important moves I made at Ames was to hire Jim Pollack, who provided strong leadership for our scientific programs for more than two decades. Carl once told me that Jim was the very best student he ever had. Thus Carl had influence on what we did at Ames both through his own work and through Jim. Later, when I was serving in the Pentagon, I had the privilege of making some remarks about Carl's work and his growing influence when he was awarded NASA's Distinguished Public Service Medal in 1978 at a fine ceremony at JPL.

Looking back, I see that the passage of time has resolved our disagreements. Both communism and the Soviet empire are now history, and the US is working with the Russians to learn what we need to do to, as Carl would say, "go to Mars together." The space station *Mir* and the space shuttles have become part of the international infrastructure that must be in place before we can fulfill Carl's dream of seeing human beings on Mars.

The things that Carl and I disagreed on have, in the fullness of time, turned out to be fleeting. What we thoroughly agreed upon will have both permanent value and also long-term consequences. The search for evidence of life elsewhere in the universe goes on, and Carl was an articulate advocate on expanding this enterprise. I also fought to continue NASA's funding for this program, and in 1983 we managed to get enough votes in the Senate Appropriations Committee to retain the SETI program despite opposition from committee chairman William Proxmire. While the situation in NASA today is not favorable toward SETI, the program is being kept alive through other means, in large measure due to Carl's efforts and leadership.

I believe that reasonable funding for the SETI program will eventually be restored in NASA. More important, Carl's effort to develop programs to make the general public more familiar with the results and the consequences of space exploration will have lasting value. In the early years of the coming millennium, humankind will take the first real steps to expand into the solar system. Carl's work will then guide the thinking of the people who will lead this enterprise. That will be Carl's lasting legacy. I feel very privileged to have known Carl Sagan and to have been his friend. I mourn him and I miss him.

Hans Mark, former director of NASA Ames Research Center, is Professor and John J. McKetta Centennial Energy Chair in Engineering at the University of Texas at Austin. He is a member of the Board of Advisors of the Planetary Society.

Carl Sagan Timeline

1934 Born November 9 in Brooklyn, NY to Samuel Sagan and Rachel Gruber Sagan

1954 AB at University of Chicago

1955 BS at University of Chicago

1956 MS in Physics at University of Chicago

1957 Married Lynn Alexander and had two sons, Dorion and Jeremy, before divorcing in 1963

1960 PhD in Astronomy and Astrophysics at University of Chicago

1960 to **1962** Miller Residential Fellow in Astronomy, University of California, Berkeley

1962 to **1968** Assistant Professor at Harvard University

1962 to **1974** Editor-in-Chief of *Icarus*

1964 A. Calvert Smith Prize, Harvard University

1968 Married Linda Salzman, with whom he had one son, Nicholas, before divorcing

1968 to **1970** Associate Professor of Astronomy at the Center for Radiophysics and Space Research at Cornell University

1969 NASA *Apollo* Achievement Award

1970 to **1977** Professor and Associate Director at the Center for Radiophysics and Space Research at Cornell University

1971 US Delegate, Joint US-USSR SETI Conference

1972 NASA Exceptional Scientific Achievement Medal

1972 First appearance on the *Tonight Show* with Johnny Carson

1973 *The Cosmic Connection*

1973 *Mars and the Mind of Man*

1975 *Other Worlds*

1977 David Duncan Professor of Astronomy and Space Science

1977 *The Dragons of Eden: Speculations on the Evolution of Human Intelligence,* winner in 1978 of the Pulitzer Prize for Literature

1977 *Murmurs of Earth: The* Voyager *Interstellar Record*

1977, 1981 NASA Medal for Distinguished Public Service

1979 *Broca's Brain: Reflections on the Romance of Science*

1979 to **1996** Co-founder and President of the Planetary Society

1980 *Cosmos* television series airs on PBS

1981 Married Ann Druyan, with whom he had a daughter, Alexandra, and a son, Sam

1981 George Foster Peabody Award for *Cosmos*

1981 Hugo Award

1981 Humanist of the Year Award of the American Humanist Association

1983 John F. Kennedy Astronautics Award of the American Astronautical Society

1985 *Comet,* co-written with Ann Druyan

1985 *Contact: A Novel*

1985 *Nuclear Winter: The World After Nuclear War*

1986 to **1996** Visiting Distinguished Scientist at the Jet Propulsion Laboratory of the California Institute of Technology

1987 Tsiolkovsky Medal of the Soviet Cosmonautics Federation

1990 Oersted Medal of the American Association of Physics Teachers

1990 *A Path Where No Man Thought: Nuclear Winter and the End of the Arms Race,* co-written with Richard Turco

1991 Masursky Award of the Division for Planetary Sciences of the American Astronomical Association

1992 *Shadows and Forgotten Ancestors,* co-written with Ann Druyan

1994 Public Welfare Medal of the National Academy of Sciences

1994 *Pale Blue Dot: A Vision of the Human Future in Space*

1996 *The Demon-Haunted World: Science as a Candle in the Dark*

1997 Film version of *Contact* to be released in July

CARL SAGAN, PARTNER IN EXPLORATION

by Bruce Murray

H. G. Wells wrote:
"A day will come, one day in the unending succession of days, when beings, beings who are now latent in our thoughts and hidden in our loins, shall stand upon this Earth as one stands upon a footstool, and shall laugh and reach out their hands amidst the stars."
Carl Sagan was what H. G. Wells had in mind.
—Frank Drake,
at the Planetary Society's commemoration of Carl Sagan, February 17, 1997

The space programs of Earth have been transformed by the end of the Cold War. It's over, really over. We've moved from decades of superpower competition to a new era of rapidly evolving international cooperation and competition. To motivate ourselves once again to real achievements in space, we have to create a new, international paradigm to guide planetary exploration. How do we go beyond the bittersweet highs and lows of the Cold War into a new era also distinguished by great scientific accomplishments? How can our children and grandchildren leave their marks on history? These are the sorts of questions that Carl and I, through the Planetary Society, tried to address.

We found a focus for our efforts in the planet Mars.

From the telescopic observations of the nineteenth century to the robotic exploration of the past few decades, Mars has dominated planetary science. It has been dominant for one reason: the possibility of life. As we entered the Space Age during the Cold War, the single most important person in the search for life on Mars was Carl Sagan.

Furthermore, the issue of life on Mars tied Sagan and Murray together intellectually for 36 years like an odd pair of twins. We came from very different perspectives: I'm a geologist. I look upon life as originating in a geological context. Carl came from the life-oriented view. He looked at the possibility of life as the central fact of Mars—everything else was context.

It took us nearly 20 years to sort out those differing perspectives, sometimes through heated discussions. Carl was extremely poised, taking abuse incredibly well. But at one point in our journey toward consensus, I got to him. He snapped, "You at Caltech live on the side of pessimism." He meant that I focused on observations and the limits they impose. In return I thought, "You at Cornell live on the side of optimism." Push an idea as far as it might go. In a sense, we mirrored the opposition of two great traditions of western law. I adhered to the Napoleonic Code: facts are wrong until proven right. Carl was more aligned with English common law: theories are in the right until proven guilty of error.

Our dualism, illustrating something basic about scientific inquiry, has been a theme in the story of discovering the real Mars. In a good story, the characters evolve, and they converge to a shared reality. That's what happened to us.

> In a good story, the characters evolve, and they converge to a shared reality. That's what happened to us.

One of the products of our creative tension and evolution was the Planetary Society; another was a very rich personal friendship. The story I will tell here points out the scientific milestones in a quest we pursued together.

Nineteenth-century astronomers rendered their eyepiece observations in shaded drawings. They recorded light and dark markings on Mars and occasional linear features, but one observer, Percival Lowell, became convinced of the existence of an extraordinary network of narrow dark lines, the sharpness and clarity of which, for him, increased with each new map. He became obsessed. He hypothesized that this "network" was the relict of a great system of canals built by an intelligent civilization destroyed by a gradual planetary drying. That was very, very powerful stuff for the popular mind. It led to H. G. Wells' *War of the Worlds* and later to Ray Bradbury's *Martian Chronicles*.

Few scientists accepted Lowell's notion of an inhabited Mars. There were many common-sense arguments against it. However, the idea of plant life there remained a plausible expectation.

There were incontrovertible seasonal changes on Mars, as "a wave of darkening" seemed to spread across a hemisphere as it headed into summer, while similar features faded on the opposite hemisphere. To observers on the verdant Earth, this phenomenon could be simply explained: the changes reflected seasonal cycles of vegetative growth. In the Martian spring, plants sprouted. In summer, they flourished. In fall, they died back. This Earth-analogous explanation was reinforced by the seasonal advance and retreat of the planet's polar caps.

Additional support for seasonal plant activity on Mars came in 1956 and 1960 from the leading astronomical infrared spectroscopist of the time using the 200-inch telescope on Mt. Palomar. Measurements of the dark areas corresponded, as well as he could tell then, to the spectra of chlorophyll in plants. It seemed we had positive evidence of plant life on Mars. This is where matters stood in 1960, when Carl and I first became associates. Space exploration was just getting started. The search for life on Mars became the central theme of US planetary exploration.

How wrong we were about Mars in 1960! First, the changing polar caps were not water ice but dry ice, solid carbon dioxide. It's so cold and so dry on Mars that no liquid water exists on the surface, and it hasn't for billions of years. The thin atmosphere is more than 90 percent carbon dioxide, with no oxygen gas and only a small amount of nitrogen. The total pressure is equivalent to less than 0.1 percent of Earth's. To find equivalent pressure on Earth you would have to soar to an altitude of 130,000 feet.

The seasonal changes in dark markings on Mars are due mainly to blowing dust and other atmospheric effects—they are not vegetative activity. Carl—that long seeker after life—was one of the first people to propose this non-biological explanation.

In July 1965, when *Mariner 4* became the first spacecraft to fly by Mars, the expectation of an Earth-like Mars was still high. As a junior member of the imaging team, I had been studying how to recognize geologic features in images from our primitive television camera. We were looking for features such as folded sedimentary layers laid down by ancient oceans on Mars.

Instead we saw giant craters like those on the Moon. In the best of the 21 framelets sent back by *Mariner 4*, we saw the edge of a huge impact crater about 300 kilometers (200 miles) across. The significance of so large a crater was profound. We knew that the giant impacts necessary to produce a crater that size had happened billions of years ago. We knew also that topography of that kind gets scraped off Earth in a hundred million years or less by our aqueous atmosphere. So we had found a fossil surface on Mars. There had been no Earth-like erosion or weathering for billions of years and, therefore, no oceans, rainfall, and rivers. We knew immediately that Mars was not like Earth. It seemed more like the Moon.

Expectations for life on Mars plummeted. And there was more disappointing news to come. Robert Leighton, my colleague at the California Institute of Technology (Caltech), was puzzled about Mars' very thin carbon dioxide atmosphere. He made some basic energy calculations and demonstrated that the physical consequence of that atmosphere was that the frost cap should be carbon dioxide, not water ice.

Mariners 6 and *7* flew by Mars in 1969 and reaffirmed the cratered surface. However, their better camera systems showed that the craters had been blanketed and smoothed. Now we could see the handiwork of an *ancient* thick atmosphere, not the thin atmosphere there today. Most important, *Mariner 7* had been targeted to fly near the edge of the retreating south polar cap. The spacecraft carried an infrared radiometer developed by Gerry

> In 1971-1972, *Mariner 9* . . . changed our view of Mars and resurrected the possibility of life.

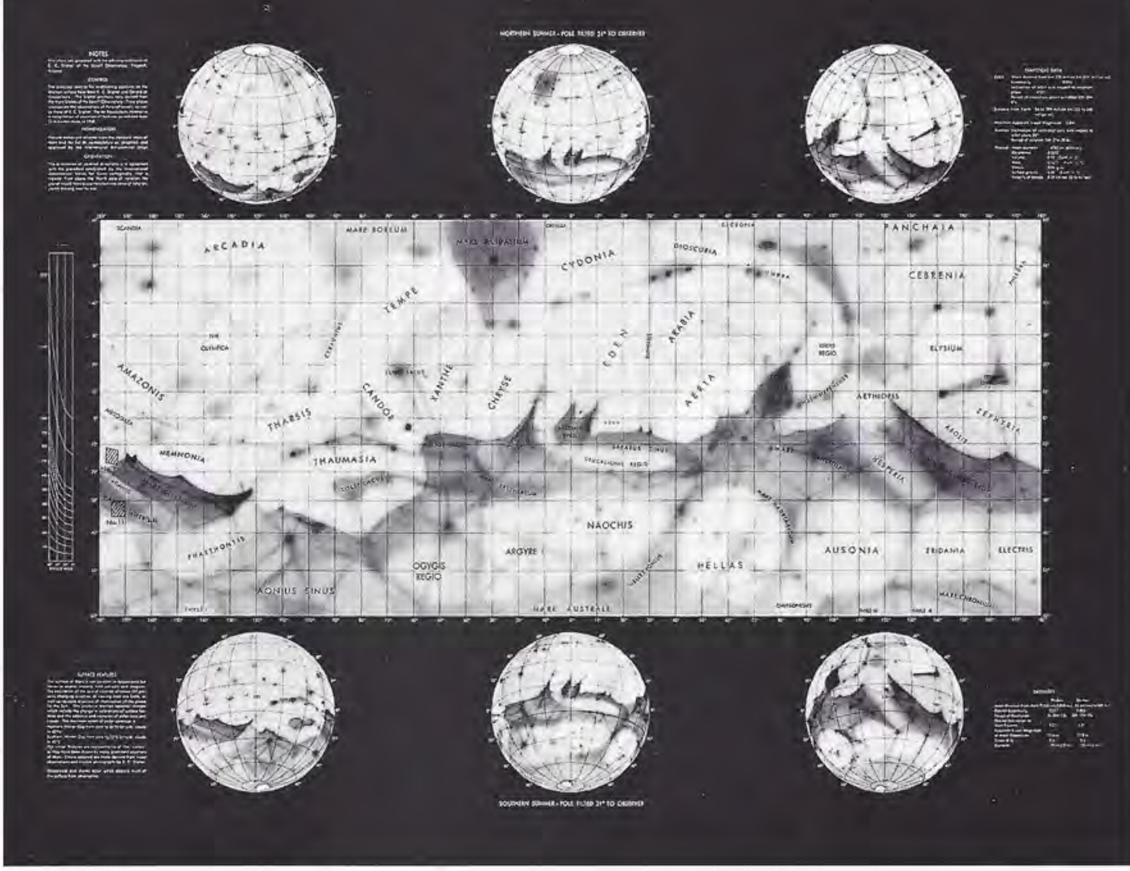
Neugebauer, also from Caltech, as well as an infrared spectrometer developed at the University of California at Berkeley. These instruments confirmed that very, very dry carbon-dioxide ice made up the seasonal cap. The last nail seemed to have been put in the coffin of life on Mars.

The next chapter of Mars exploration brought more surprises. In 1971-1972, *Mariner 9* made systematic observations from orbit. Carl and I were both members of the imaging team. This mission changed our view of Mars and resurrected the possibility of life.

Up in the polar regions, we discovered thin, uniform layers of airborne sediment and ice. They lay nearly flat, so they showed up as curvilinear surface patterns of low relief. These enormous layers clearly chronicled global climate changes—thus Mars was quite unlike the Moon. Something had been going on, perhaps analogous to glacial epochs on Earth. It seemed possible that during those climatic fluctuations conditions were much more amiable and life might have survived on Mars.

But the biggest surprise was the channels—not the imaginary ones Lowell saw but great gouges in the planet created in ancient times by catastrophic floods. Furthermore, the enormous craters we first recognized with *Mariner 4* and saw again with *Mariner 6* were now revealed to have many small gullies. Apparently ground water eroded them shortly after the craters formed billions of years ago. The great channels were likewise carved in ancient times—after the huge craters but before the emplacement of vast plains of lava that smoothed regions of Mars.

The channels completely changed the game. We saw that Mars' surface recorded a very old but very powerful aqueous history. Ancient life became plausible. Maybe some microbial forms even survived to the hostile present. Carl was a leader in that line of reasoning.



Above: Before spacecraft reached Mars, telescopic observations from deep within our bubbling atmosphere were the best information available about the Red Planet. Maps of its mysterious surface seemed to evoke the fantasy world of Percival Lowell. This map was created not in the heyday of Lowell's canals but in 1965.

Map: US Geological Survey

Right: In a 1965 article for the* National Geographic, *Carl speculated about what Martian life might look like. Since Mars lacks a protective ozone layer like the one blanketing our planet, life-forms there would have to develop ways to shield themselves from the deadly rays of the Sun. Carl's creatures possessed glassy shells or developed tolerance to the solar radiation.

Illustration: Douglas Chaffee, in consultation with Carl Sagan. © National Geographic Society

Timed to coincide with the US Bicentennial in 1976, *Viking* was the most elaborate unmanned mission ever deployed, involving two orbiters and two landers. The landers carried laboratories equipped with some of the most powerful life-detecting experiments ever built.

Two of the experiments used different broths, which were offered as something that any Martian bugs scooped up with soil samples might like to eat. These experiments looked for chemical changes resulting from metabolic activity—if any. A third, nearly dry experiment measured uptake of radioactively tagged carbon dioxide. We reasoned further that if there was life, there had to be organic material in the soil—perhaps the bugs themselves, but certainly their carcasses and residual chemistry, in trace amounts at least. *Viking*'s gas chromatograph/mass spectrometer (GCMS) provided an extremely sensitive way to look for organic material in the soil.

The day of the first *Viking* test, soil was put into the broth. There was an extraordinary reaction. The data ran off scale! There was a tremendous evolution of gases. This was not a biological effect but an inorganic chemical reaction. Some natural compound in the Martian soil was breaking down *Viking*'s liquid reagents.

This "unearthly" superoxidizing process was confirmed by the GCMS. Analyzing for organic materials—from simple hydrocarbons to more complex compounds—it found none at all. We realized then that the surface of Mars, as it is now, is self-sterilizing. Organic material, even that brought by meteorites and comets, doesn't last long in Mars' superoxidizing soil. Otherwise we would have seen it.

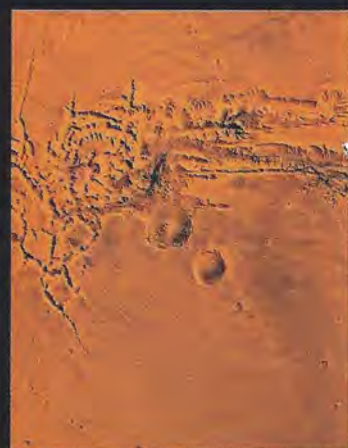
This is where the convergence of Sagan's and Murray's ideas came about. Carl's optimism about finding a living biota on Mars' surface had faded, but there was, despite my original pessimism, overwhelming evidence that Mars once had a lot of water on the surface in different forms. Life might have formed on early Mars as it had on early Earth. Later on, Mars experienced a change of atmospheric state, from benign to extremely hostile, probably about 3 billion years ago.

The post-*Viking* scientific focus became the search for clues to past life. On Earth, the most abundant clues to the presence of life are indirect—geological strata containing high amounts of biogenically deposited calcium carbonate or, better yet, strata containing organic matter. If we could discover similar layers of ancient calcium carbonate on Mars, it would suggest an earlier life-bearing epoch. The definitive indirect proof would be discovery of deposits of ancient organic matter.

Because the present surface environment of Mars destroys organic matter, we would have to dig below this oxidizing layer. But how deep? A meter? Ten meters? A hundred meters? Surely there must be uncontaminated strata from that early aqueous period somewhere on Mars. Such locations are what we want to find, especially near enough to the surface that robots equipped with drills or other systems can search directly for organic material. Should they find anything, those sites could become the objectives of future human missions.

The search for life on Mars brought us together as close friends and collaborators in exploration. The Planetary Society was the outcome.

Following *Viking* and the *Voyagers'* extraordinary exploration of the outer solar system, the US planetary program collapsed. NASA became completely committed to a technological objective, the space shuttle. It was a bad choice, making every launch dependent on a piloted vehicle. We abandoned that approach after *Challenger*, but it cost the US space program nearly 15 years of progress. The most critical damage was to robotic deep-space missions, which required the greatest propulsion to get to the planets.



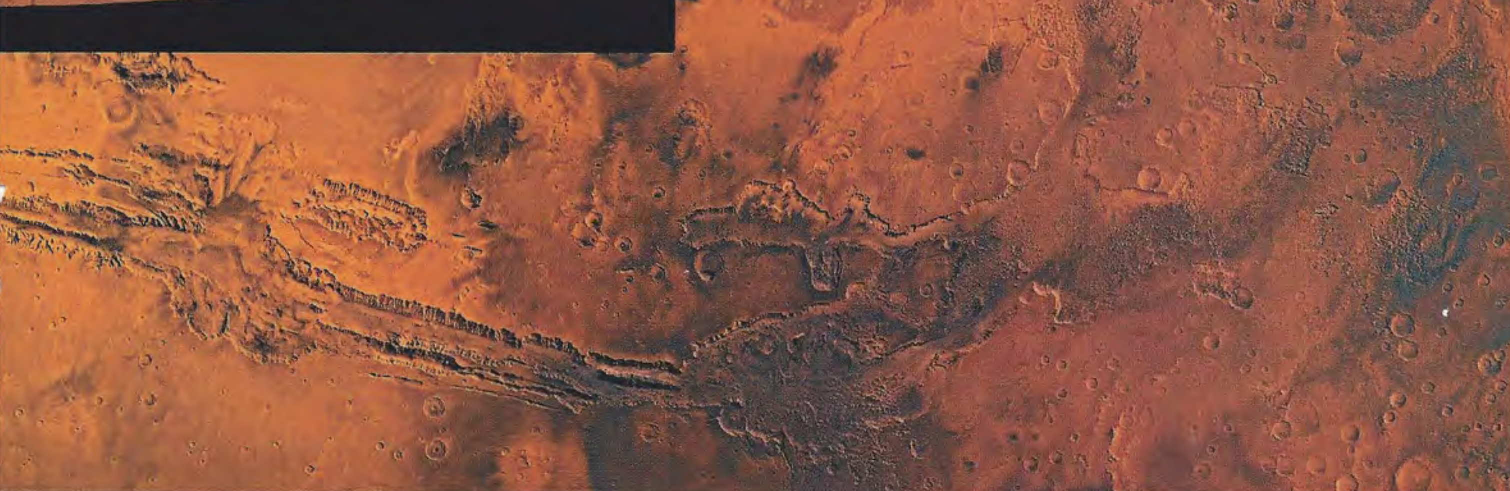
Right: To honor Carl and his love for Mars, the US Geological Survey branch in Flagstaff created this spectacular panorama of the great canyon Valles Marineris. Over 3,000 kilometers (2,000 miles) long, and averaging 8 kilometers deep (5 miles), it dwarfs even the Grand Canyon of Earth. Valles Marineris begins in the west in the fractured terrain of Noctis Labyrinthus and extends to the huge, ancient river channels in the east that drain toward Chryse Planitia. Scientists can't yet tell the full story of how this great canyon formed. Someday spacecraft—and maybe human explorers—will traverse this canyon and bring us back a full story of Valles Marineris.

This image was respectfully presented by the US Geological Survey, Flagstaff, Arizona, in honor of the memory of Carl Sagan

In 1979 to 1980, Carl was in Pasadena to participate in the *Voyager* mission. I was then Director of the Jet Propulsion Laboratory. We spent considerable time together. Both of us had become convinced from our independent and somewhat overlapping experiences that the enthusiasm, commitment, and hope of people for planetary exploration and the search for extraterrestrial intelligence remained high. Yet that hope wasn't manifested in the space programs of the world. So Carl and I organized the Planetary Society, joined quickly by Lou Friedman as Executive Director.

The search for life on Mars brought us together as close friends and collaborators in exploration. The Planetary Society was the outcome. We invented a nongovernmental entity that could precede governments in developing cooperation among the spacefaring nations. Carl and I and Lou spent a lot of time, especially during the Soviet era and in the transition to the Russian era, out in front of the US government's

***Left:* Mars is strangely divided, nearly along its equator, into the relatively young, smooth lowland plains of the north and the older, heavily cratered highlands of the south. This image of the Ismenius Lacus region clearly shows the division. Along the border is a belt of flat-floored valleys, mesas, and buttes that must be spectacular when seen from the surface. Some features within the valleys are similar to features on terrestrial glaciers, and on nearby hills are terraces that may be either layered rock or terraces cut by the action of ancient waves.** Image: US Geological Survey, Flagstaff



eventual progress in this direction. At the same time, Roald Sagdeev (now on the Society's Board of Directors) pushed international cooperation from a personally more dangerous position—within the restrictive Soviet Union.

The Planetary Society has organized and sustained a series of collaborative Mars exploration projects. These efforts include development of a novel Mars balloon and instrumented guide-rope by French, Soviet, and US partners. We devoted major efforts to international field testing and development of a Russian Mars rover prototype. In 1985, the Society began to advocate the goal of international human flight to Mars during the first quarter of the next century. That goal remains the unifying long-range goal of current Mars exploration efforts around the world.

This nongovernmental organization, with 100,000 dedicated members spending their own money, has made a difference in many ways, but especially in the case of Mars. The fact that there is a tangible future on Mars now —after all the setbacks and disappointments—is partly due to the Planetary Society.

Where does all this lead? The robotic exploration of Mars is at center-stage in the international space community. The United States launched two missions to Mars in 1996. The Japanese and the US are developing missions that will be launched in late 1998 or early 1999. Russians are working on American missions. The long-term goal of international human exploration of Mars is becoming more widely shared.

The search for life on Mars began at the telescope, full of misconceptions, which were exposed by early space flights. New misconceptions cropped up, which were, in turn, clarified by further exploration and experiment. Through it all, Carl Sagan kept alive the quest for life on Mars. The unifying theme of his life was the search for life on other worlds, and the enhancement of life on this one. That was the essence of Carl Sagan.

Bruce Murray, Professor of Planetary Science at the California Institute of Technology, is now President of the Planetary Society.

CARL SAGAN, SCIENTIST

by Frank Drake

Carl said, "Perspective is the fundamental scientific return of planetary exploration." As a scientist he was always pressing himself and his colleagues not to become comfortable with a perspective limited by what we thought we already understood.

—Edward Stone, at the Planetary Society's commemoration of Carl Sagan, February 17, 1997

Carl Sagan produced a truly remarkable and steady stream of scientific papers. Their impact on scientific understanding, and on the course of research, was of the highest order. Not only did Carl contribute far more than the usual scientist to the body of scientific knowledge, but his work provided guidance to others in their choice of projects.

Carl published a single paper on genetics in 1957, based on work he did as an undergraduate. Then in 1960 he began to publish seminal, rich papers at the rate of about 14 per year. In some years he published more than 20. Only in 1980, when he was preoccupied with the *Cosmos* television series, did his production decline; yet even in that year he published 4 papers. His bibliography shows 16 papers for 1996, a period when he was dealing with the ravages of a serious disease. Some of his last papers, not yet published, are on tantalizing subjects. We look forward to reading them.

Although he was very widely known as an astronomer, it is less well known that Carl, from the beginning of his career, was fascinated with the chemistry of life and its origins. As an undergraduate he worked with Nobel laureate H. J. Muller to gain knowledge of genetics. He made the rare step of taking time, through post-doctoral and other appointments, to educate himself in this discipline to a level where he could conduct competent work and data analysis. Crossing the lines of specialization in science was something Carl did throughout his career.

A review of his career reveals he pursued three main themes. Foremost were studies of the nature and history of planetary atmospheres. Here his timing was certainly right, for these endeavors coincided with exploration of the solar system by spacecraft, which commenced at the same time as Carl's career. Indeed, he was a scientific team member on every major planetary mission. The second enduring theme of Carl's work was manifested in ongoing experiments in prebiotic chemistry, with particular emphasis on how the major planets came to be as we see them today. The third theme was the theory of and search for extraterrestrial life, especially intelligent life. Knowing full well that detection of such life was difficult, and perhaps beyond our reach, he was drawn nevertheless by the paramount significance of such a discovery if it could be made, and he dedicated himself to bringing it about if possible.

The most important ideas guiding his work were his own, and most appear in papers written by him alone. However,

The great spiral galaxy M83 reminds us that our own Milky Way is but one among many such islands in space. This prolificacy of nature feeds the hope that somewhere among the stars there may be other life forms.

Photo: Anglo-Australian Telescope Board

a large majority of his papers were written in collaboration with others. He was a good partner in these collaborations; he did not add his name to a list of authors unless he had made a substantial contribution to the paper. In most of these collaborations he served as mentor, guiding both the work to be done, to the great benefit of the eventual research results, and the professional development of the collaborators. He always carefully reviewed and altered to his satisfaction the report on a project. He chose his collaborators well; virtually every one either was or became a highly regarded scientist. As examples of highly successful collaborators, one can name the late James Pollack, who worked often and well with Carl on topics relating to Venus; Joseph Veverka, who collaborated on studies of various planetary phenomena; or Bishun Khare, who continues their research in prebiotic chemistry. In his later years Carl often worked with Reid Thompson and Chris Chyba. He shared his work with many brilliant PhD students, such as David Morrison, Steven Squyres, and Chris Chyba.

His earliest major focus was on the nature of Venus' atmosphere. This research began at a time when radio astronomers were observing surprisingly high emissions from Venus. The data suggested a surface temperature near 750 kelvins (480° Celsius, 900° Fahrenheit), amazingly hot. Carl constructed a variety of atmospheric models to see if the radio observations could be explained through some alternative to the hot surface, such as a hot, thick ionosphere. The alternative explanations did not work. Given, then, that the surface of Venus really was that hot, how was this high temperature produced? Carl developed, in a series of some of his finest papers, a theory of a massive carbon dioxide atmosphere that produced the high surface temperature and concomitant radio emission through a very strong greenhouse effect. Subsequent observations by spacecraft and Venus landers confirmed Carl's theory, a great triumph for him.

In a little-known but brilliant and elegant paper, he used the early radar observations of Venus to determine the surface temperature of 750 K. He noted that the surface was about 50 kilometers below the clouds. Knowing that the atmosphere was almost certainly in convective equilibrium, and that the adiabatic lapse rate was that of almost pure carbon dioxide, he was able to trace the rise in temperature with descending altitude, starting from the cloud-top temperatures observed by radar and using the lapse rate to compute temperatures down to the surface. One did not even need the details of the greenhouse.

In a little-known but brilliant and elegant paper, he used the early radar observations of Venus to determine the surface temperature of 750 K.

He conducted similar theoretical studies of most of the other planets, finding them to have greenhouse effects, too, though none so significant as that on Venus.

Indeed, it is ironic that two of Carl's most important discoveries worked against the idea of the existence of life elsewhere in the solar system, something Carl hoped very much might exist.

Another prime area in his research was understanding the seasonal changes on Mars. Certain areas on Mars had long been observed to darken during spring and summer, and this phenomenon was touted as evidence for plant life. There had even been observations of spectra consistent with organic materials, though these turned out to be incorrect. Carl, more than anyone on Earth, emotionally wanted this interpretation of Martian seasonal changes to be true. Mars was his favorite object outside Earth. He relentlessly analyzed the data provided by spacecraft that went to Mars in the 1960s and 1970s. He found that the seasonal changes were the result of windblown dust. Thus one of the most tantalizing of our early observations of the solar system turned out to have a rather prosaic explanation. Carl must have been disappointed. Indeed, it is ironic that two of Carl's most important discoveries worked against the idea of the existence of life elsewhere in the solar system, something Carl hoped very much might exist.

The continuing Cornell University experiments on prebiotic chemistry, in which Bishun Khare was very active, were most often directed at duplicating processes that must have occurred on the Jovian planets and on Titan. There were many successes. They showed that introduction of electric arcs into simulations of the primitive atmospheres of those planets produced organic molecules of high molecular weight (kerogens and others) in significant abundance. Carl named these products "tholins." Most impressive was the fact that the tholins exhibited brown and orange colors very similar to the conspicuous and previously mysterious colorations of Jupiter, Titan, and, to a lesser extent, Saturn. This research led to a series of papers on the atmospheric structure of Titan. The soon to be launched *Cassini/Huygens* mission to Saturn and Titan may well confirm the validity of these experiments and analyses.

One of Carl's most significant contributions was his study, with four very able collaborators, of the consequences of a major nuclear war. The famous TTAPS study (TTAPS being an acronym of the authors' last names: Turco, Toon, Ackerman, Pollack, and Sagan) concluded that serious as the explosions and radioactive fallout would be, a possibly greater threat lay in the igniting of countless fires. The pall of smoke produced would cool the Earth to catastrophic low temperatures. The study showed that virtually the whole Earth would be enveloped in a cloud of smoke, persisting for months, which would terminate photosynthesis and reduce temperatures enough to destroy the food chain and with it most living things. A terrible "nuclear winter" would beset the Earth, ending life as we know it.

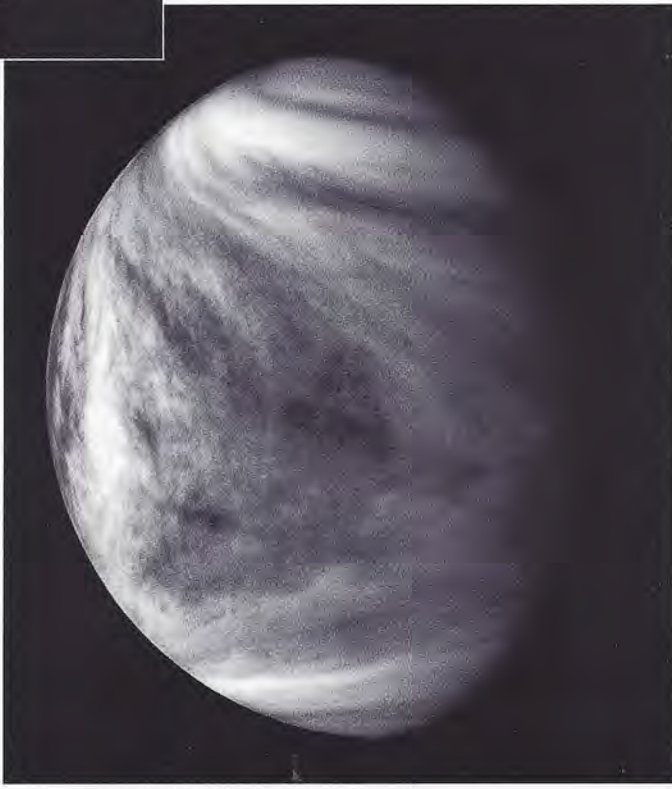
At the time of its release there were many criticisms that the report was too pessimistic in its assumptions about how much smoke would be produced by the burning of cities. A consensus eventually developed that the study had indeed overestimated the severity of nuclear winter. But the qualitative result—that there would be a devastating nuclear winter in the event of a nuclear holocaust—remained correct. Most important, these results spurred negotiations between the US and USSR for the reduction of nuclear arsenals, reducing a threat to all humanity.

The search for extraterrestrial life was a major priority in Carl's scientific work. He had a lifelong interest in the existence of and means of detecting, in particular, extraterrestrial intelligent life. He became one of the few world leaders in this field. Although he devoted only a small fraction of his time to this enterprise, his impact on the search for extraterrestrial intelligence (SETI) was enormous. His first major contribution, which was monumental, was to collaborate with the eminent Soviet theorist I. S. Shklovsky to produce a greatly enlarged and improved version of Shklovsky's book, originally in Russian, *Intelligent Life in the Universe*. Published in 1966, this book established in detail the scientific rationale for SETI and put the entire subject on sound scientific grounds. It informed both the scientific community and governmental funding agencies of the scientific realities of SETI, leading to increased financial support. It also inspired scientists to become involved in SETI themselves. Carl played a prime role in development of international cooperation in SETI; a high point of this activity was the Joint USA-USSR SETI conference of 1971, which was held in Byurakan, Armenia. There was a stellar

Most impressive was the fact that the tholins exhibited brown and orange colors very similar to the conspicuous and previously mysterious colorations of Jupiter, Titan, and, to a lesser extent, Saturn.

Left: Iapetus is another strange world of Saturn. Although it's an icy world, Iapetus' leading hemisphere is black as tar, the result of the deposition of carbon compounds.

Below: Venus was the subject of one of Carl's greatest scientific successes: the determination that, at its surface, this sister world of Earth is blazingly hot, some 750 K, or over 900 degrees Fahrenheit.



Above: The Saturnian system contains some of the most fascinating worlds in our solar system, including the moon Titan. Titan is unique among moons in possessing a thick nitrogen atmosphere; among planets, Earth claims that distinction. Titan's atmosphere is tinted a rusty red by an abundance of hydrocarbon compounds. The interactions among these compounds, which on Earth were precursors to life, were among Carl's research interests. _Images: JPL/NASA_

list of participants, and Carl did the hard work of gathering and editing manuscripts to produce a book of conference proceedings that is still of great relevance to SETI.

He was very active in promoting support for SETI, both with funding agencies and in the scientific community. He led in the development of the interstellar greetings carried by *Pioneer 10* and *11* and the two *Voyager* spacecraft. He recognized that it was very unlikely that these artifacts would ever be acquired by another civilization. They should perhaps be considered messages to humanity, instructing us that interstellar communication is possible and that we should pursue it.

Through the Planetary Society, with private funding, he established Project BETA, the major SETI program at Harvard University. He aided in the procurement of funds and other support that have allowed this project to improve continuously through a decade and a half of operation. The Harvard program spawned META II, now operating in Argentina, and the Society is now also supporting Project SERENDIP at the Arecibo (Puerto Rico) radiotelescope. He contributed many key ideas and papers influencing the course of SETI research. Carl was one of the few people to have made quantitative analyses of the significance of SETI programs.

What I have written here is but a necessarily abbreviated account of Carl Sagan's scientific career, deriving from his published works. He had a further impact that is not apparent merely from scanning his bibliography. He generated enthusiasm for science—among his colleagues, the general public, and officials of the funding agencies. This much is widely known. However, known only in the scientific community is the wisdom he brought to any scientific gathering graced with his presence. At large or small scientific meetings, whenever he entered the room, there was suddenly a striking hush; the participants knew that the level of discussion would now be higher, that Carl Sagan could be counted on to contribute some truly marvelous insights. For more than 36 years he enriched scientific culture in this special and important way, a way not reflected in the written record and yet, with Carl, quite as important and memorable as his recorded contributions.

Frank Drake, Professor of Astronomy and Astrophysics at the University of California, Santa Cruz, is the author of a series of calculations on the likelihood of extraterrestrial intelligence that helped establish SETI as a scientific pursuit. He serves on the Board of Advisors of the Planetary Society.

Ode to

by Diane Ackerman

In the star clouds of Sagittarius, near the center of our galaxy, space is thick with other suns. Around those suns other planets may revolve, and on those planets may be. . .

Photo: Royal Observatory Edinburgh/AATB

the Alien

Beast, I've known you
in all love's countries, in a baby's face
knotted like walnut meat,
in the crippled obbligato
of a polio-stricken friend,
in my father's eyes
pouchy as two marsupials
in the grizzly radiance
of a winter sunset, in my lover's arm
veined like the Blue Ridge Mountains.
To me, you are beautiful
until proven ugly.

Anyway, I'm no cosmic royalty
either: I'm a bastard of matter
descended from countless rapes
and invasions
of cell upon cell upon cell.
I crawled out of slime;
I swung through the jungles
of Madagascar;
I drew wildebeest on the caves at Lascaux;
I lived a grim life
hunting peccary and maize
in some godforsaken mudhole in the veldt.

I may squeal
from the pointy terror of a wasp,
or shun the breezy rhetoric
of a fire;
but, whatever your form, gait, or healing,
you are no beast to me,
I who am less than a heart-flutter
from the brute,
I who have been beastly so long.
Like me, you are that pool
of quicksilver in the mist,
fluid, shimmery, fleeing, called life.

And life, full of pratfall and poise,
life where a bit of frost
one morning can turn barbed wire
into a string of stars,
life aromatic with red-hot pizazz
drumming ha-cha-cha
through every blurt, nub, sag,
pang, twitch, war, bloom of it,
life as unlikely as a pelican, or a thunderclap,
life's our tour of duty
on our far-flung planets,
our cage, our dole, our reverie.

Have you arts?
Do waves dash over your brain
like tide along a rocky coast?
Does your moon slide
into the night's back pocket,
just full when it begins to wane,
and all joy seems interim?
Are you flummoxed by that millpond,
deep within the atom, rippling out to every star?
Even if your blood is quarried,
I pray you well,
and hope my prayer your tonic.

I sit at my desk now
like a tiny proprietor,
a cottage industry in every cell.
Diversity is my middle name.
My blood runs laps;
I doubt yours does,
but we share an abstract fever
called thought,
a common swelter of a sun.
So, Beast, pause a moment,
you are welcome here.
I am life, and life loves life.

CARL SAGAN, VISIONARY

by Wyn Wachhorst

Buzz Aldrin delivered this speech at the Planetary Society memorial for Carl Sagan, February 17, 1997.

I can't think of Carl without seeing that windblown figure strolling on the beach, telling us, over the roar of the breakers, in his em*phatic* rhythms and pro*phetic* style, that we stand on the shore of the cosmic ocean, riding our wisp of blue and white like mites on a floating leaf, in the whorls and eddies of a great galactic reef. It was in that first episode of *Cosmos*, seen by 400 million people in 60 countries, that he released to the sea breeze the dandelion seed that became his cathedral-like "ship of the imagination," drifting majestically among stellar fires and mysterious worlds.

That cathedral of the imagination was Carl Sagan's signature. More than anyone of his century, he reignited the sense of wonder in a world increasingly content to simply exist. Wonder was the core motif in the complex fugue of Carl's life: the six-year-old at the World Exposition, awe-struck by the utopian sights; the boy standing with outstretched arms in an open field, imploring the magic force that had carried John Carter to that blood-red beacon burning low in the night sky; and the proud ship *Voyager,* with its pictures of man and its heartfelt hellos from the children of Earth. Who but Carl would cast humanity's bottle into the cosmic ocean?

But it was also Carl's rare gift to walk that razor's edge between romance and reality. He was the dreamer and the doer, the theorist and the activist, combining his lofty speculations with cold, hard logic, balancing his soaring wonder with an unrelenting skepticism. It's been said of him that "few scientists have made such extraordinary claims" but that "fewer still have backed them up with such extraordinary evidence."

The dreamer brought to a shrinking world measureless oceans of space; the doer was arrested at a nuclear protest. A student, suggesting that Sagan had demystified all the beliefs that make us feel worthwhile, asked him what was left. Without pause, Carl said, "*Do* something worthwhile, and then you can feel worthwhile." But the common thread, running through his many-faceted career, was his confrontation with what he called our "failure of nerve." The self-indulgent state that has taken this nation from the world's largest producer and creditor to the world's largest consumer and debtor now cycles between pseudoscientific solipsism and existential despair, while the lone ego becomes a cosmos unto itself.

Into this new medievalism came Carl Sagan, a latter-day Bruno announcing an "infinity of worlds," a Copernicus holding that ego is not the center, a Galileo revealing that the heavens are more than a crystalline zodiac, that they are vast beyond imagination.

While the degenerate media offer epiphanies in the form of aliens come to eviscerate cows and rape rural housewives, the epiphany for Carl lay not in a cosmos that comes across light-years to doodle in our wheat fields but one to which *we* must make the pilgrimage, across an infinite regression of Archimedean points, sailing outward into ourselves. The quest, for Carl, was not inward and backward but forward and outward.

Symbolic of both medievalism and solipsism—an Earth turning inward upon itself—is a budget that encourages the exploitation rather than the exploration of space. "Space *exploration*," Carl insisted, is not endless circles in low orbit, tending weightless tomatoes, it is "*going to other worlds*." The continued exploration of the solar system, he argued, is "a challenge that can bind together nations, inspire youth, advance science, and ultimately end our confinement to one vulnerable world."

Joseph Campbell has observed that in countless myths from all parts of the world the quest for fire occurred not because anyone knew what the practical uses of fire would be but because it was fascinating. It is fitting that those same myths credit the capture of fire with setting man apart from the beasts, for it is the earliest sign of that willingness to pursue fascination at great risk that has been the signature of our species. Man requires these fascinations, said the poet Robinson Jeffers, as "visions that fool him out of his limits." Carl's grand vision was of voyages on a stellar ocean teeming with life. He saw in spaceflight, as in all science, the spiritual quest—the sense of hope that is the heart of the human soul.

A teacher of the world, a risk-taker who often stood alone against the scientific establishment, who saw that there can be no meaningful success without the opportunity to fail, Carl Sagan passes into the lexicon with the likes of Verne, Wells, Heinlein, and Bonestell, Goddard, Oberth, and Von Braun—men who "fooled us out of our limits," leaving us finally aware that we live in the stars.

This was the promise of Carl Sagan's vision, that people from Earth would one day flow into the ancient river valleys of Mars, down the gorges three miles deep, out over desolate, wind-torn plains, out to the ice seas of Europa, the yellow skies of Titan, and the water volcanoes of Enceladus, out into the ocean of light, to those worlds within worlds where the star-children wait.

He was, as he said of science itself, "a candle in the dark."

Wyn Wachhorst, who writes speeches for Buzz Aldrin, has published numerous literary essays on the meaning of man in space.

The Future of THE PLANETARY SOCIETY

by Louis D. Friedman

"Dreams are maps." With that statement, Carl Sagan laid out the philosophy behind the Planetary Society. Our dream has been to inspire and encourage a vital, continuing effort to explore new worlds and search the universe for extraterrestrial life. For 17 years, we have determinedly pursued that dream. Through the growth of our membership, research projects, popular events, publications, and political influence, we have surpassed the goals we set at our founding in 1980. And we are fully committed to continuing the success of the Society. Still, since Carl's unexpected death last December 20, many people concerned about space exploration have asked us, "What is the future of the Planetary Society without Carl Sagan?"

Carl's death has triggered a transition for the Society and leads us to consider our goals and objectives. At our founding we set this mission statement: "To encourage the exploration of the solar system and the search for extraterrestrial life." In the mid-1980s, after much discussion, we broadened it to include promoting cooperation among the spacefaring nations of Earth. The success and vitality of the Society are, in large part, due to our focus on our mission statement. I think we are likely to keep it. Following its focus, the Society has grown into a remarkably vital organization, and the recent conduct of space exploration, at least in the American program, affirms our statement of purpose.

The present state of planetary exploration reflects a tremendous change from the situation at the time of our formation. The United States government was then considering canceling the planetary program. The idea of searching for extraterrestrial life was sneered at both by the scientific establishment and headline-seeking politicians. The world has changed.

NASA is now extolled once again as an agency focused on science and exploration. It has a vibrant planetary program underway. Carl and the Planetary Society played a part in setting this new priority on the pursuit of discoveries among the planets. In NASA's program, in President Bill Clinton's State of the Union message, and in the US National Space Policy, we find affirmations of the Society's purpose and mission.

Still, Carl's loss creates an enormous gap in how we conduct our mission. Despite his multitudinous commitments, he was extremely involved with the Society, not only in policy but in practice. He cannot be replaced by any one person. It's going to take a combined sense of purpose and the efforts of many individuals. The Society Board of Directors has made a commitment to expansion of the board and to growth for the Society. We are inviting individuals onto our board who we feel can make substantial contributions to our mission.

Four new members have already joined us: Astronaut Kathy Sullivan, Academician Roald Sagdeev, General Don Kutyna, and Ann Druyan, Carl's wife and collaborator. More will be invited. Bruce Murray, co-founder with Carl of the Society, has assumed the presidency, and Laurel Wilkening has agreed to serve as vice president. We are also changing our Board of Advisors, recruiting new people to help us make the transition from our founders to their successors. This group will now be called the Advisory Council, chaired by John M. Logsdon of the Space Policy Institute at George Washington University. Notable among the new members of the Advisory Council is Stephen Jay Gould of Harvard University, the famous evolution essayist and paleontologist.

We have begun an expanded dialogue among our directors, advisors, colleagues, and friends, bringing into the discussion scientists, leaders of the world's space programs, and, most important of all, our members. We are considering our objectives and programs, as we feel we must during this time of transition. I would like to share with you a few of the main themes emerging from this dialogue.

Finding the Way to Mars

Even among the strongest supporters of space exploration, there is still some debate over whether humans should be sent to explore the solar system or whether robots are sufficient for the task. Most moons and planets are too distant, difficult, or dangerous for humans to visit. But one world—Mars—is destined, I believe, to receive human explorers. The Mars exploration goal is symbiotic with our scientific interest in this most Earth-like of planets and with the growing interest in using telerobotics for exploration. Indeed, NASA's "smaller, cheaper, faster" theme has brought about a Mars program with launches planned every 26 months.

Not much appears to be happening to take human exploration beyond Earth orbit. Yet if we consider why the space station is being built and where the robotic missions are going, we are led to a human mission to Mars. The space agencies of the world, NASA included, have a lot of reorganizing to do if this international objective is to be met. But the bigger challenge is to garner the political support for such an ambitious undertaking. That will mean harnessing intellectual power to define the societal rationale for sending humans to Mars; this has to be done in terms that will be compelling in today's changing political context. The Planetary Society could undertake that challenge. I think we want the Planetary Society to be out in front of the space agencies, leading advocacy for international human exploration of Mars.

Building a Truly International Organization

I've found great support for the Society's efforts to become a truly international organization. But more is demanded from us to reach and serve members outside the United States. We need more popularization efforts in other countries. This will be a major challenge, both economically and in our marketing and public relations. The difficulty will be compounded by the decreasing government support for space science and planetary exploration in Russia and Europe. Perhaps by demonstrating popular support for these endeavors in those nations, we can help turn this situation around.

Becoming a Little Space Agency?

We often hear from members who suggest that the Planetary Society become a little space agency itself. Many hope that private donations can someday replace the need for government support. They express their appreciation for being able to say honestly, "We make it happen," and list our many accomplishments: the Mars Balloon and Mars Rover test programs, our asteroid discovery project, our support for searches for extrasolar planets, the soon-to-be-launched Mars Microphone, and many other experiments that have advanced planetary exploration.

Still, I think we are many years, if not decades, away from significant private funding for planetary exploration. Without government support, this endeavor will stop. Not everyone agrees with me, and innovative and creative catalytic roles are possible for organizations like ours to enable advanced research and development and to seed new ideas for planetary exploration. We will continue to encourage these ideas, and we will explore new roles.

Four Achievers Join

Four distinguished leaders in space exploration and science have joined our Board of Directors, broadening and strengthening the Planetary Society as we prepare for the twenty-first century. Society President Bruce Murray, announcing these appointments, drew attention to the high professional standing and diverse experience of the new board members. "The Planetary Society is accelerating to a robust new phase, galvanized by energetic new leaders."

—Charlene M. Anderson, Director of Publications

Roald Sagdeev has been a leader in the international space and physics communities for over three decades. He holds a unique joint appointment as Distinguished Professor of Physics at the University of Maryland and as Director Emeritus of the Space Research Institute of the Russian Academy of Sciences.

As leader of the Soviet planetary program, Academician Sagdeev devoted himself to promoting international cooperation in science. During the critical years that preceded democratization in Russia, he became an outspoken political activist, being elected to the Supreme Soviet in 1987, serving as an advisor to Mikhail S. Gorbachev at three summits, and serving as a deputy in the USSR parliament from 1987 to 1991.

Academician Sagdeev has been awarded the Lenin Prize and the title of Hero of Socialist Labor from the Soviet Union, the Tate Medal from the American Institute of Physics, the "Science for Peace" Prize from Italy, and the Leo Szilard Award from the American Physical Society.

Searching for Life Elsewhere

Our Search for Extraterrestrial Intelligence (SETI) program remains an outstanding example of how private donations can make real science happen. Our commitment to SETI will continue and evolve. The Planetary Society is now a major backer of three dedicated radio searches for signals from extraterrestrial civilizations: Project BETA in Harvard, Massachusetts; Project SERENDIP in Arecibo, Puerto Rico; and META II near Buenos Aires, Argentina. With these programs we are now searching the entire sky almost continuously. We should keep at it and be open to new techniques, and we should increase efforts to encourage the search for habitable worlds in other solar systems. The Society will continue to be a leader in this area of profound possibilities.

As we go through the process of expanding the Board of Directors, building an Advisory Council, involving more colleagues, establishing liaisons with other groups, and internationalizing the Society more effectively, we will be reminded surely that we cannot replace Carl Sagan. But there are many talented and creative people upon whom the Society can draw and with whom we should prosper. Our organization will grow in size and scope because of them.

The support of our many friends and members gives us the wherewithal to view the future optimistically. We deeply appreciate that support. As Carl wished, the Planetary Society can be a beacon illuminating the path of Earth's spacefaring nations into the next century. The twenty-first century can be one of exploration, seeing humans travel to Mars and explore the worlds beyond. It will mark a new millennium in which, with luck and perseverance, Earth recognizes its role in a galactic community, where we learn about our place in the universe and our true possibilities for evolution. Then, perhaps, as Carl hoped, "we can rejoice in our participation in the cosmos."

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

Board of Directors

Kathryn D. Sullivan brings experience as a scientist and astronaut to the board. Among the first class of space shuttle astronauts, she was the first woman to perform a spacewalk (1984). She helped deploy the Hubble Space Telescope in 1990, and in 1992 she served as payload commander on the Atlas-1 Spacelab mission.

After NASA, Dr. Sullivan went to the National Oceanic and Atmospheric Administration as Chief Scientist, responsible for research and development programs in such areas as climate and global change, satellite remote sensing, and marine biodiversity.

Dr. Sullivan now serves as President and Chief Executive Officer of Ohio's Center of Science and Industry, one of the United States' leading hands-on science centers.

Donald J. Kutyna is Vice President of Advanced Space Systems for the Lockheed Martin Corporation. During a distinguished career in the US Air Force, he rose to the rank of four-star general.

General Kutyna served as Commander of the US Space Command, managed the Department of Defense Space Shuttle Program, and oversaw the development and acquisition of the Titan 4 heavy-lift launch vehicle.

After the loss of the space shuttle *Challenger* in 1986, General Kutyna joined the presidential commission that investigated the accident. He chaired the panel that identified the cause and recommended changes for the shuttle program.

Ann Druyan, as an author, lecturer, and television producer, addresses the effects of science and technology on our civilization. With her husband Carl Sagan, she wrote the Emmy- and Peabody-Award-winning television series *Cosmos.* She also served as creative director for the *Voyager* Interstellar Record, a compendium of greetings from the peoples of Earth. A copy of the record is fixed to the two *Voyager* spacecraft as they travel to interstellar space.

In 1988, Ms. Druyan was elected Secretary of the Federation of American Scientists (FAS), the organization founded in 1945 by the scientists who developed the atomic bomb. The FAS seeks to deal with the dangers posed by misuse of science and technology.

She recently worked as co-producer of *Contact*, an upcoming Warner Brothers motion picture based on Dr. Sagan's novel. She is a Director of the Children's Health Fund of New York.

News and Reviews

by Clark R. Chapman

Science is more than a technical enterprise, more than specialists communicating with each other about their investigations. Science is part of human culture, an endeavor whereby a society—with government or private funds—hires scientists to study nature and thereby enrich the lives of everyone. In the past, when education was limited to a privileged few, and it was still possible to learn much of what there was to know, scientists could discourse with educated nonscientists one-on-one. With the increasing technical complexity of the modern world, those times are now long past.

The modern scientist spends years learning arcane mathematics, sophisticated instrumentation, and the techniques of a subspecialty before being able to contribute at the cutting edge of research. Typically, when such a scientist speaks about his or her work, it's as Greek to scientists in other fields as it is to interested citizens in the general public. So our society has evolved interpreters who learn the science and try to teach the rest of us what they have learned. Such science writers and reporters, high school teachers, documentary film makers, and others try to bridge the ever-widening gulf. Unfortunately, much often gets lost in the translation.

Bad Show, NBC

During February, I watched numerous TV shows dealing with a topic I study myself—the potential danger from impacting asteroids and comets. There were replays of PBS's *Nova* program (in which I assisted), a *National Geographic* special, a Discovery Channel special, a Fox special on various doomsday scenarios, and segments on local newscasts and on various programs like *Dateline* and *Unsolved Mysteries*, leading up to the heavily promoted, but dreadful, fictional miniseries *Asteroid*. Some programs (like the *National Geographic* special and the forthcoming *Toutatis* by the National Film Board of Canada) were pretty good, but most were not. Even the best could have been better, more like the fine article by Timothy Ferris in the January 27 *New Yorker*.

Much responsibility for public confusion and ignorance of science lies with the scientific community. Although Carl Sagan came to be widely appreciated by his colleagues eventually, it was not always the case. As perhaps the most effective communicator of science during the last half of this century, Sagan inspired countless citizens of the world to pay attention to science and thousands of students to pursue careers in science. But many scientists disparaged his efforts. Most of the rest of us appreciated what he was doing, but left it all up to him.

Carl Sagan is no longer with us. The media cannot generally be expected to reach out effectively to other scientists to take his place. (Evidently NBC didn't care to pay a single scientist a few hundred dollars out of their reported $20 million budget to critique the script for *Asteroid*.) Scientists must become proactive. Professional societies can do more. So can the Planetary Society. NASA already requires that a small percentage of funds go toward educational outreach. But we need an attitudinal sea change. I know PhDs who can't write a coherent sentence. A year ago, eminent planetary scientists refused to rehearse before a *Galileo* probe press conference; they were incoherent before the cameras, resulting in "the press conference from Hell."

How to Bring About Change

A science education should include learning how to write, how to talk, how to prepare visual materials, how to program for the World Wide Web . . . and how to explain research—no matter how specialized—in accurate but understandable lay language. Professors should be handsomely rewarded for excellent teaching and for writing "popular" articles and books, and they should no longer be judged primarily by a count of their technical publications. Scientists should work cooperatively with public communications professionals (press officers, script writers, fact checkers), and they should be hard on communicators whose efforts are shoddy or lack integrity.

While all scientists should value public communication, we are not all gifted in these directions. Some scientists actually should be barred from participating in a press conference. If there is a budding Carl Sagan who can explain a spacecraft experiment, even though someone else is the principal investigator, let the would-be Sagan do it!

As citizens, we can do more. We can encourage the development of college curricula toward careers in space art, science journalism, science museum curation, and science teaching at all levels. We can ask our local book dealers to expand their science offerings. We can complain to local TV outlets about pseudoscience shows and encourage programming in new directions. If we have influence with major film studios, foundations, or industries, we can encourage them to raise the level of scientific integrity in their films, their funding choices, and their advertising.

Our society will not survive if so many voters, jurors, school board members, elected officials, and corporate managers continue to be scientifically illiterate. Carl Sagan reached out to billions. It will take many of us to sustain what he accomplished alone. We must begin now to develop this legacy in the memory of a great scientist and a great teacher.

Clark R. Chapman has tried to promote science communication, in part by writing this column since Vol. 1, No. 1 of the Planetary Report. *His appreciation for Carl Sagan appeared in the March issue of* Sky & Telescope.

Society News

Red Rover, Red Rover Lets You Drive on Mars

Red Rover, Red Rover sites are now active throughout the United States, as well as in Canada, Denmark, Germany, and Japan. Sites are linking up through the Internet, as ever-increasing numbers of students get involved in the hands-on program. Participants build rovers from LEGO Dacta kits and explore, via computer linkup, simulated Martian landscapes that they create.

Students can explore landscapes at remote sites, just as scientists will use teleoperation technology to explore the Martian surface with *Mars Pathfinder*'s rover *Sojourner*. Each student rover carries a camera that sends still images to a classroom computer. Students analyze the images on their computer monitor to decide what commands to send to the rover.

To participate or learn more about the project, write to Red Rover, Red Rover at Society headquarters or e-mail: tps.cp@mars.planetary.org.
—Carlos Populus, Volunteer Coordinator

Society's Executive Director Honored

The Planetary Society's Executive Director Louis D. Friedman was honored by the American Association for the Advancement of Science (AAAS) with a fellowship. According to AAAS Executive Director Richard S. Nicholson, Friedman was honored for "astrodynamics research and development in advanced planetary mission analysis and for leadership in public information and education through the Planetary Society."

Each year the AAAS council elects fellowship members for their social and scientific accomplishments in advancing science and its application. Friedman was honored at the AAAS Fellows Forum, part of the association's annual meeting held in Seattle in February.
—Bill McGovern, Production Editor

We Need Your Help

Sign up now to take part in the Planetary Society's Planetfest '97, July 3 to 6, 1997 at the Pasadena Convention Center in Pasadena, California. We need volunteers to hand out information, take tickets, check badges, operate slide projectors, navigate the World Wide Web, build water rockets, tally sales orders, and assist in many other areas. For information, contact Volunteer Coordinator Carlos Populus at Society headquarters or by e-mail: tps.cp@mars.planetary.org.
—Susan Lendroth, Manager of Events and Communication

MarsLink Evolves into Red Planet Connection

In February 1996, the Planetary Society sent its latest edition of MarsLink to nearly 2,000 teachers around the country. Made possible by Society members and the Kenneth T. and Eileen L. Norris Foundation, the free educational program has been designed to teach students about craters and volcanoes on Mars and other planets. The program complements other Society-sponsored educational programs, such as the Red Rover, Red Rover project.

In September 1996, the popular MarsLink curriculum was turned over to the Arizona Mars K-12 Education Program. The project has now evolved into a new children's science newsletter, *Red Planet Connection: The Science Resource for Future Martians*, designed to create a direct link between students and Mars exploration efforts.

Program materials are designed to be teacher-friendly and require no classroom computer technology. Four versions of the program have been developed: for grades K-2, 3-5, and 6-8, as well as a teacher's edition. Science and interdisciplinary activities, puzzles, and the latest news about Mars exploration and career-path information are all included. Specific topics and themes will be chosen for each school year.

A one-year subscription to the newsletter is $30 per package of 30, including a teacher's edition. The price covers only the cost of printing the material. For more information or free samples, contact T. Dieck, Arizona Mars K-12 Education Program, Department of Geology, Arizona State University, Box 871404, Tempe, AZ 85287-1404 or e-mail: saelens@imap2.asu.edu.
—Ken Edgett, Arizona State University

Dates to Remember

Mark your calendars for upcoming Society events, tours, and expeditions:

• Planetfest, July 3 to 6, 1997, Pasadena, California. For information, contact Cindy Jalife at Society headquarters or e-mail: tps.cj@mars.planetary.org.

• Belize expedition (slated for January 1998). Part of our Cretaceous-Tertiary (K/T) series of searches for evidence of the impact 65 million years ago that led to the extinction of the dinosaurs. Contact Lu Coffing at Society headquarters or by e-mail: tps.lc@mars.planetary.org.

• Caribbean cruise to view the total solar eclipse on February 26, 1998. Contact Susan Lendroth at Society headquarters or by e-mail: tps.sl@mars.planetary.org.

More News

The Mars Underground News:
The Case for Mars, NASA budgets stabilize, Mars mission updates.

The Bioastronomy News:
Colleagues contribute to a commemoration of Carl Sagan's work in the search for life in the universe.

The NEO News:
New East Coast craters reveal their 35-million-year-old secrets; old renderings of a 1690 Jovian impact.

For more information on these newsletters, please contact Planetary Society headquarters; see page 2.

Basics of Spaceflight: The Deep Space Network

by Dave Doody

The Deep Space Network (DSN) is an essential part of interplanetary spaceflight. Operated for NASA by the Jet Propulsion Laboratory (JPL), the DSN is the largest and most sensitive scientific telecommunications system in the world. There are three principal DSN sites, called Deep Space Communications Complexes (DSCC). One DSCC inhabits California's Mojave Desert at Goldstone. There's a DSCC at Tidbinbilla, near Canberra, Australia. The third DSCC is near Madrid, Spain (see also the March/April 1991 *Planetary Report*). The DSCCs are spaced about equally around the Earth, so that as our planet turns at least one of the DSCCs can "see" any interplanetary spacecraft we have out there, such as *Galileo, Mars Global Surveyor,* or NEAR. For example, just when Jupiter and *Galileo* are setting in the west as seen from Goldstone, they are rising in the east as seen from the Canberra DSCC.

More than a thousand people worldwide work in the DSN. JPL engineering and technical personnel make up the US staff who manage the worldwide network, assisted by contract engineers and technicians. The Canberra and Madrid DSCCs are operated by agencies of the Australian and Spanish governments and their contractors.

Massive Ears

Let's look at the antenna, where the DSN meets the spacecraft. A DSN antenna, considered with all its components, is called a Deep Space Station (DSS). Components include the reflector dish with its steering mechanisms, the waveguides and switches, amplifiers, control subsystems, and transmitters.

A spacecraft's signal, typically weak and diffuse, bathes the Earth. A DSS, as shown in the diagram, collects the signal in the large parabolic surface of the main reflector. The signal bounces up to the smaller subreflector, then down into a feed horn. Focusing the signal from the wide area of the main reflector to the small area of the subreflector concentrates the signal, making it strong enough to process further. This reflecting arrangement, known as a Cassegrain system, was invented in 1672 and is commonly used in optical telescopes too.

A DSS's precision design and construction keep all the radio waves in phase as they reflect: that is, each wave's high-intensity "crest" and its low-intensity "trough" arrive in step at the feedhorn. This is no mean feat, since the distance between crests and troughs is a matter of centimeters, while the DSSs are very large mechanical systems. The three largest DSSs have main reflectors 70 meters in diameter; others have a diameter of 34 meters. It's important to keep the waves in phase, lest they cancel each other out and weaken or otherwise jumble the collected signal.

A 70-meter antenna and its mount, which can rotate in azimuth (horizontally) and in elevation (vertically), weigh nearly 2.7 million kilograms (6 million pounds). Motion in azimuth works by means of a hydrostatic bearing. The structure's entire weight "floats" on a pressurized film of oil.

Each DSCC has a special high-efficiency 34-meter DSS. The latest model, now being installed at each DSCC, has its low-noise amplifiers, transmitters, and other equipment located motionless in the basement rather than on the moving reflector. The new model optimizes wave collecting ability through a system of articulated waveguides—pipes that work like speaking tubes, ducting signals from the reflector to the equipment in the basement.

At each DSCC, the receivers, telemetry equipment, and all the other computers are located in a signal processing center that connects to all the DSSs at the complex.

Keys to Interplanetary Communication

The huge precision-reflector system, collecting and concentrating weak signals in phase, is but one of several keys to successful interplanetary communication. It takes some fairly astounding technologies—a whole set of keys—to work with the attenuated signals from spacecraft. The power arriving at a DSS from a *Voyager* can be 20 billion times weaker than the power in a digital wristwatch.

The next key to communication is making the concentrated radio-frequency signal more powerful, without introducing noise. That's the job of the low-noise amplifier (LNA). In the 70-meter DSSs, the best LNA is a cooled maser. *Maser* is an acronym for Microwave Amplification by Stimulated Emission of Radiation; its counterpart in the visible-light spectrum is the familiar *laser*. Without wading too deep into maser technology, we can say it's a highly sensitive amplification system that introduces very little noise while increasing signal strength up to 700,000 times. The maser's core is a synthetic ruby crystal in a strong magnetic field. The DSS uses liquid helium near absolute zero to minimize radio noise.

LNAs in various DSSs use other technologies that are less expensive and simpler to work with than masers, though somewhat less efficient. The non-maser LNAs use Field-Effect Transistors and High Electron-Mobility Transistors, not unlike the system in a satellite TV antenna.

Another key is the use of very sensitive, computer-controlled receivers. A receiver takes the signal from the LNA, with many different frequencies, and selects exactly the spacecraft's frequency—adjusted, of course, for Doppler shifts induced by the spacecraft's motion relative to the listening Earth. The receiver further amplifies only that one selected signal until it is strong enough for us to read the data it contains.

There's a key here, too. The spacecraft and the DSN cooperate in various digital error-correction schemes, using special coding and decoding. We won't go into detail here, but, for reference, these include Viterbi coding, Golay coding, and Reed-Solomon coding—named for their inventors. Your CD player probably uses the Reed-Solomon scheme to correct data errors before the bits become music.

Pointing is another important key. The massive Cassegrain reflector of a DSS is sensitive to only a small portion of the sky, about equivalent to looking at the sky through a soda straw. This tunnel vision is a big advantage for receiving the weak signal from a distant spacecraft: it limits the amount of external noise that can enter the antenna. Once the antenna has been pointed to a spacecraft's predicted location in the sky, operators make adjustments for best results. They run a program to move the antenna's pointing in little circles, observing whether the signal gets stronger or weaker. The circular movements then tighten toward the strongest signal. The movements in this technique are performed by the subreflector rather than the main reflector.

All these sophisticated keys used together result in a high ratio of spacecraft signal to noise—high enough that virtually every digital bit sent from *Voyager, Galileo,* or any other spacecraft is captured and delivered intact to project teams. Losses of data are rare overall, only a few percent at most (many losses are from such mundane causes as the weather).

Another result is our ability to determine the spacecraft's speed, distance, and location in the sky with high enough precision to navigate reliably. The latter is a task called tracking. Tracking relies on Doppler, ranging, and other techniques (see the July/August 1995 issue). The quality of timing information is critical—every amateur navigator can testify in principle to this. The DSN uses highly precise frequency standards, among the most precise in the world, derived from hydrogen masers located in temperature-controlled rooms at each DSCC.

The DSN has lots of detailed information and pictures available at http://deepspace1.jpl.nasa.gov/dsn on the World Wide Web. If you don't normally have access to the Web, come to Planetfest '97, July 3 to 6 in Pasadena, California, and hook into the Web with the high-speed Internet-browsing computers that will be available!

In the next issue, we'll continue the DSN story with a look at some history, specialized capabilities, and the DSN's many functions beyond "mere" interplanetary travel.

Dave Doody is a member of the Jet Propulsion Laboratory's Advanced Mission Operations Section and is currently working on the Cassini *mission to Saturn.*

If you have access to the World Wide Web (via a Web browser like Netscape or Mosaic), be sure to look in on JPL's *Basics of Space Flight* manual, on-line at http://www.jpl.nasa.gov/basics/.

Anatomy of a Deep Space Station

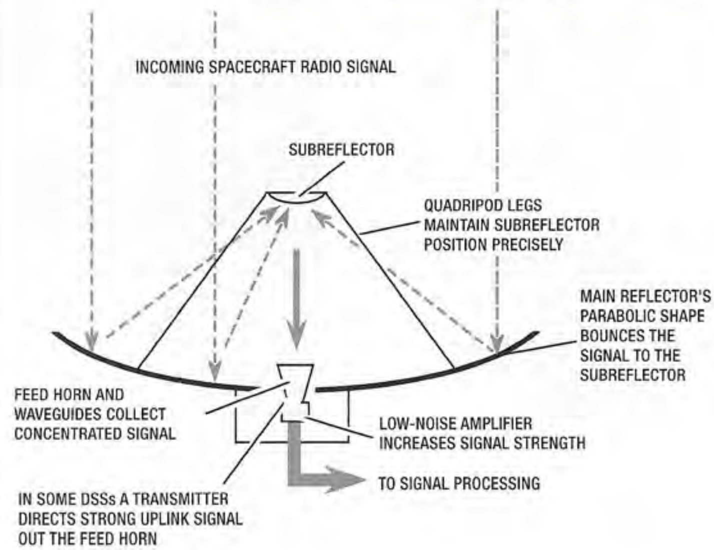
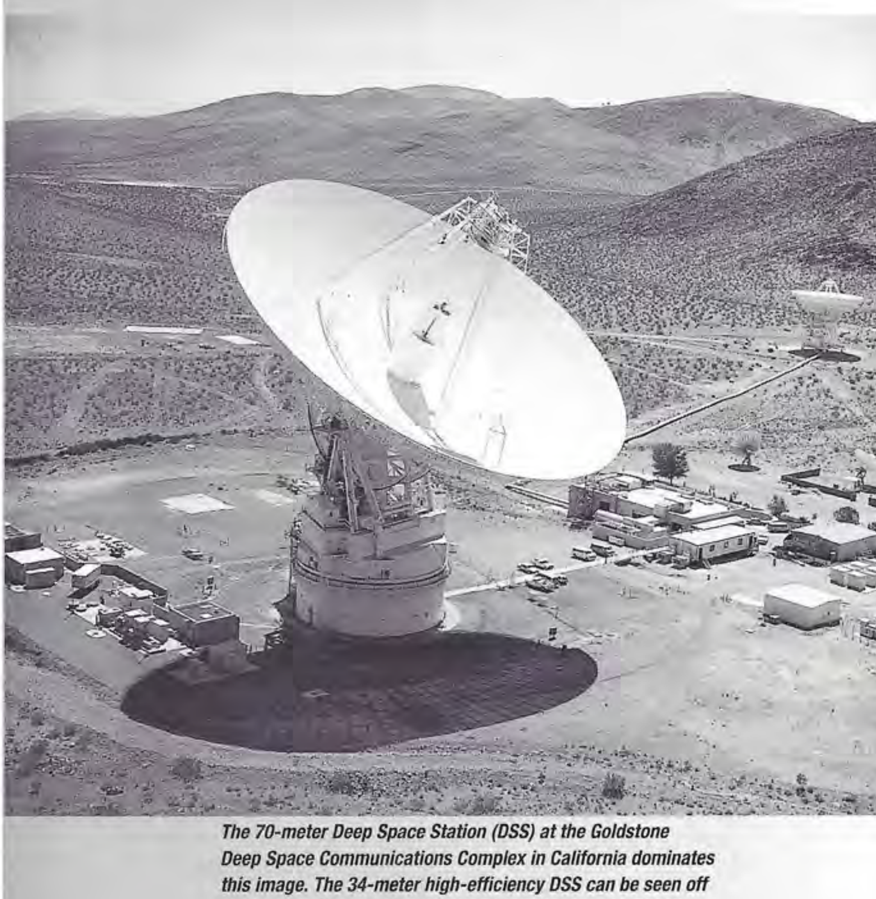


CHART BY DAVE DOODY; MODIFIED BY B. S. SMITH



The 70-meter Deep Space Station (DSS) at the Goldstone Deep Space Communications Complex in California dominates this image. The 34-meter high-efficiency DSS can be seen off to the right. The building between them houses the signal processing center for the complex. The 70-meter DSS has three feedhorns, each leading to a different configuration of equipment. Operators select a feedhorn by repositioning the subreflector, poised above the dish on four legs. Goldstone's desert location helps minimize radio noise.

Photo: JPL/NASA

Discover Distant Worlds!

Far-out Fashions

The Planetary Society T-Shirt
Adults' M, L, XL, XXL. 1 lb.
#583 $16.00
Children's S, M, L. 1 lb.
#584 $14.00

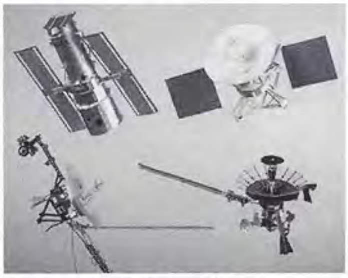
Go *Galileo* T-Shirt
S, M, L, XL.
1 lb.
#570 $16.00

We Make It Happen T-Shirt
S, M, L, XL.
1 lb.
#663 $16.00

Mars T-Shirt
S, M, L, XL.
1 lb.
#530 $18.00

Project BETA T-Shirt
L, XL.
1 lb.
#543 $16.00

Other Items



Spacecraft Science Kits
1 lb. **$14.00 each**
#525 Hubble Space Telescope
#538 *Magellan*
#560 *Voyager*
#524 *Galileo*
#529 Keck Telescope (not shown)

***Planetary Report* Binder**
2 lb. **#545 $12.00**
Special Value—
Order Two Binders for $22.00!

Planetary Society Note Cards
Set of 16 cards. Envelopes included.
1 lb. **#544 $10.00**

Slide Sets

Impact Craters
20 slides and 12-page booklet. 1 lb.
#212 $17.00

***Magellan* Reveals Venus**
40 slides, fact sheet, and 3-D glasses. 1 lb.
#217 $15.00

Need a catalog?
Call 818-793-1675, and we'll send you one.

Check out our merchandise on the Web:
http://planetary.org/tps/

Images of Mars
20 slides and 12-page booklet. 1 lb.
#213 $10.00

***Viking 1* and *2* at Mars**
40 slides with audiocassette. 1 lb.
#220 $12.50

***Voyager* Encounters Neptune**
20 slides. 1 lb. **#234 $6.25**

***Voyager's* Mission to Jupiter**
20 slides. 1 lb. **#232 $6.25**

Comet Shoemaker-Levy 9 and Jupiter Crash
20 slides. 1 lb. **#203 $6.25**

Posters

Pillars of Creation
24" x 30" poster.
1 lb.
#329
$10.00

Portrait of the Milky Way
40" x 27" poster. 1 lb. **#330 $15.00**

Earth and Its Moon
18" x 24" poster.
2 lb.
#318
$8.50

Sun Poster
22 1/2" x 29" poster.
1 lb.
#342
$7.50

An Explorer's Guide to Mars
40" x 26" poster. 1 lb. **#505 $6.00**

Jupiter Watch Poster
18" x 24" poster.
1 lb.
#682
$5.00

Nighttime Earth
1 lb. **$8.00 each**
#308 Earth at Night 35" x 23"
#309 Europe at Night 24" x 36"
#326 North America at Night 29" x 22 1/2"

Solar System in Pictures
Nine 8" x 10" mini-posters. 1 lb.
#336 $10.00

Images of the Planets

These large, attractive prints are 20" x 16".

1 lb. **$8.00 each**
#305 Earth
#315 Earthrise
#319 Jupiter
#323 Mars (Atmosphere)
#325 Mars (Full Disk)
#332 Saturn
#333 Eight-Planet Montage
#337 Uranus
#340 Venus

Spend This Independence Day On Mars!

This summer, Southern California, famous for great beaches, amusement parks, and landmark attractions, will be hosting some out-of-town visitors—as will the planet Mars!

On July 4th, *Mars Pathfinder* will land on the Red Planet and release its microrover *Sojourner* to explore that alien world. You can share in its journey at Planetfest '97, a four-day celebration of space exploration and science, July 3 to 6, 1997 at the Pasadena Convention Center, Pasadena, California. Join the Planetary Society as we welcome scientists, visionaries, and planetary enthusiasts from around the world to celebrate our exploration of other worlds.

Live Transmissions from Mars

The historic July 4th arrival of *Mars **Pathfinder*** will come to us live on Earth. Planetfest '97 visitors will follow the mission step-by-step on the giant video wall as the Jet Propulsion Laboratory receives the first images.

The Discovery Symposium

Leading scientists discuss space exploration—where we've been and where we're going.

The Hall of Technology

Hands-on exhibits allow Planetfest '97 participants to explore and experiment with technological innovations.

Exploring the Art of Space

View the imaginative renderings of other worlds in a juried exhibition of fine space art.

A Child's Universe

Interactive exhibits make learning and experimenting fun for children and families.

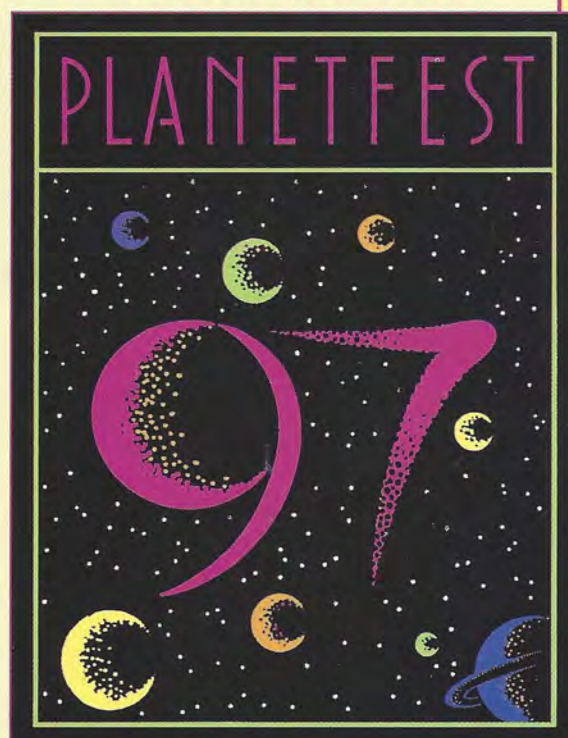
The Gene Roddenberry Theater

Drop in on continuous screenings of documentaries and science fiction films.

Exploring Distant Worlds Book Extravaganza

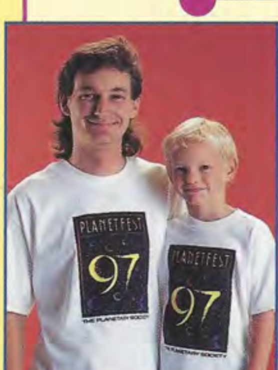
Listen as science and science fiction authors discuss their creations.

Register Today!
(800) 969-MARS
or 818-793-5100



Worldwide Link-Up, New World Boutique and Exhibit, and MORE!

Out-of-This-World Fashions



Wear our new T-shirts on your visit to Mars!
Available now (see the sales order form bound into the magazine) as well as at the Planetfest '97 New World Boutique.

- **Planetfest '97 Logo T-Shirt**
  Adults' sizes L, XL. **$14.00**
  White **#825** Red **#826** Purple **#827**
  Kids' sizes S, M, L. **$10.00**
  White **#815** Red **#816** Purple **#817**
- **Get Planetary T-Shirt** Sizes L, XL. Black **#820** **$14.00**

Don Davis used his computer instead of a paintbrush to create this portrait of Europa and Jupiter. He took a *Voyager* mosaic of Europa from the United States Geological Survey and, piece by piece, overlaid it with new data from *Galileo*. He finished the process by wrapping this "texture map" around a sphere. *Galileo*'s observations of this mysterious world suggest that an ocean of water—and the possibility of life—may lie hidden under its icy crust. Recent images from the Hubble Space Telescope provide a fresh look at Jupiter's ever-changing cloud bands. The giant planet's thin ring and a faint section of the Milky Way are also visible.

Don Davis now uses a computer as his primary creative tool, producing illustrations, animation, and visual effects for television and planetarium productions.

THE PLANETARY SOCIETY
65 North Catalina Avenue
Pasadena, CA 91106-2301

PRINTED ON RECYCLED PAPER
Printed in USA