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Return to the Rings



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Cover: The striking contrast between the blue of the C-ring and the yellow of the B-ring is a product of the processing of three images taken through different color filters. False color processing provides scientists with information unavailable in "real" color. Differences in the surface compositions of ring particles in the major divisions in Saturn's rings show up as color variations.

PHOTO: JPL/NASA

PLANETFEST '81, the Pasadena Planetary Festival, was initiated by a nationwide high school essay contest on the theme, "Why Explore the Planets?" We have chosen this essay, by Vicki Colvin, of Las Vegas, Nevada, as representative of the support so many young people show for planetary exploration.

Why Explore The Planets? by Vicki Colvin

"All I am asking for is three ships and economic backing...Is that too much, considering the potential?"
"It's too much money...we must feed people and buy weapons. We shouldn't take the chance..."

"But think what might be gained...a whole new world!"

The preceding sounds like a dialogue between a NASA administrator and the head of the House Appropriations Committee, but it could just as easily have been Columbus and Queen Isabella. Where would humanity be if no one had taken that chance 500 years ago? Planetary exploration has many benefits. The unique kind of knowledge that can be gained is invaluable. Exploration is also a stepping stone to more extensive space activity. Most important is the attitude space exploration invokes; it offers benefits to the economy, society, and technology, and, perhaps more importantly, to the human spirit.

Five billion years ago an expanding shell from a supernova triggered a nebula's collapse. This spinning cloud of chaos eventually became the Sun and its planets. Over the ages some planets, like Earth, went through violent change, and most information concerning their births and subsequent evolutions was obliterated. Other planets were destined to float silently and unchanging with gold-mines of historical information preserved in their surfaces. Now humanity is striving to understand Earth's beginnings. Earth has limited information concerning its evolution, but other planets preserved much vital evidence of their creation. Exploration would bring this information to us so that we might finally understand our true origin.

The natural sciences have long warned of the perils of anthropomorphizing. Perhaps we have overlooked our tendency to "terramorphize." The entire body of human knowledge, with a few rare and recent exceptions, has been gleaned from Earth (Terra), and perhaps, like the "Flatlanders," there are phenomena and dimensions of which we have not yet conceived. With each new planet we explore, and with each new star, we will see more clearly what is common about us and what is unique.

Earth is a finite object with many limitations. How can it feed, clothe, and give opportunity to over 3 billion people? We must relieve some of the pressure we are putting on the Earth to fulfill our needs, and space-oriented projects will help. Solar-power satellites and moon mining, both of which would improve our economic and energy situations, are two ideas for future space applications. But before we can begin to use space extensively, we must first have the basic technology and experience which would be needed for any new endeavor. This is where planetary exploration can help. Interplanetary probes can develop the existing space technology and familiarize us with the solar system. In addition, the more we work with space the better able we will be to predict what may or may not happen out there. Basic exploration of the planets is the first step to a more comprehensive space program.

Many of the world's major problems today are attitudinal. Most of our wars, for example, have been caused by national self-interest, religious conflicts, or racial hatred—all of which stem from our tendency to divide ourselves. The belief that one is a "Russian," "Jew," or "Hispanic" is destructive to our species. Humanity must rid itself of the parochialism caused by the conglomeration of religious, ethnic, and national categories we have created. The exploration of space encourages this. In exploring the solar system, we see how small and fragile this planet is in the face of the universe. This perspective induces a feeling of global unity, because humanity sees itself as part of a larger entity, the solar system.

Why explore the planets? Books have been written discussing the question. Countless arguments have arisen on both sides. "We can't afford it! People are starving!" "Why waste money on space? We must protect ourselves," are examples of the arguments against funding for the space program. Countries are already spending billions feeding their people, yet the increasing world population outstrips any attempt to satisfy its hunger. Another common argument, concerning defense, is very short-ranged, because in twenty years the best we can expect to get from our spending is an excess of unused warheads. Humanity can stay on Earth, protecting itself from itself, and attempting to satisfy its increasing numbers, but it would then be destined to wonder about the points of light in the night sky, instead of understanding them. We would be tied to Earth, draining it, trapped in our own little world. If humanity ever reaches that point it would be fair to wonder, as did the gods...

"Give them time. Only yesterday they were apes..."

"Once an ape, always an ape!"

"No, it will be different this time. Come back in an age or so, and you shall see..."

Will they...?

—H. G. Wells (*The Man Who Could Work Miracles*)

Encounter Diary

by Anita M. Sohus

For ten days in late August, 1981, scientists and journalists, programmers and analysts, managers and engineers at the Jet Propulsion Laboratory went through their fourth planetary encounter in 29 months, as Voyager 2 flew through the Saturn system. The term "encounter" as used at JPL has not yet made its way into the dictionary. A JPL encounter is an event, not a chance, momentary meeting. This kind of encounter will never be forgotten by those of us lucky enough to be participants.

June 5, 1981: Voyager 2 officially begins its Saturn encounter, 82 days and over 76 million kilometers before its closest approach on August 25. All instruments are observing the Saturn system—the planet, its rings, satellites and magnetosphere.

July 31: The planet is too close to be photographed entirely in one frame. Mosaics begin.

August 18: TCMB9, Voyager 2's ninth trajectory correction maneuver. The navigation is so accurate that Voyager 2 is only about 40 miles off its aim point, after a billion mile journey, and only 2.7 seconds early for an appointment set 9 years ago when the Voyager project was approved by Congress.

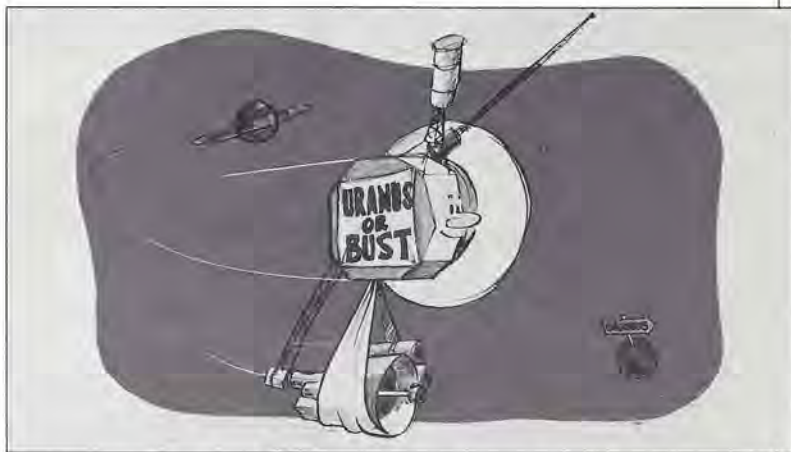
Friday, August 21: The press room is now officially open, although media people have been arriving all week. Frank Bristow, manager of JPL's Public Information Office, steps to the podium precisely at 10 am. "Good morning, ladies and gentlemen." Our first speaker is Ek Davis, Voyager Project Manager, who gives a report on the spacecraft's health. Then, Imaging Team Leader Brad Smith begins showing false-color images of the planet. In false-color, some features become more apparent. Voyager 2's cameras seem to have better vidicon tubes than Voyager 1's; the pictures show much more detail from greater distances. The third speaker is Ed Stone, Project Scientist. He gives one of his masterful tutorials on Voyager 1's results from its Saturn flyby, and looks ahead to how Voyager 2 will supplement that story. The press conference breaks near noon, and people make a mad dash for the photo office to get the day's released photos. The print journalists scurry for their typewriters. Reporters, with tape recorders and microphones in hand, waylay scientists and project people as they straggle out of the auditorium. It is a routine to be repeated over the next ten days.

Encounter has begun.

Saturday, August 22: Brad Smith shows more shots of Saturn's atmosphere. Anticyclonic features are clearly visible near the jet streams—some of which are flowing as fast as 150 meters per second. He discusses the tiny satellites of Saturn, and what may be learned about them. The reporters have many questions. Among them, what is a moon? Brad smiles. Objects whose orbital period can be pinned down and whose orbits can be tracked will be labelled as moons.

Flyers have appeared announcing "Saturnalia—the Voyager 2 way," Saturday night at Caltech, featuring the Titan Equatorial Band. JPLers and journalists have joined their musical talents to jam a little.

Sunday, August 23: Brad Smith has Iapetus pictures. The Image Processing Laboratory has been up most of the night working on the pictures to get a color product. A great debate is boiling around Iapetus, the weird "yin-yang" satellite whose leading edge is one-tenth as bright as its light, trailing side. Is the dark material on the leading side endogenic or exogenic—does it come from within or without? The debate rages, in a gentlemanly fashion, among the sci-



Its wounded scan platform in a sling, Voyager 2 heads out to its rendezvous with Uranus, five years away.

entists. Iapetus' dark surfaces show only 3 percent reflectivity—about twice as dark as the darkest part of the Moon, or about the same as asphalt, Brad notes. Another cartoon is added to the growing gallery outside the photo office. "Iapetus ski area," it reads, "Parking ahead, 50%." The cartoons have become a press room tradition. Some are quite scandalous, others display a gentle humor. They all reflect the camaraderie and sense of common cause among the journalists turned scientists and the scientists turned poets.

Monday, August 24: Ed Stone is full of surprises. This morning he walks up to the podium with one hand in his coat pocket. "I sent my kids down to the store for candy," he announces casually, pulling out a sack of dime store candy. One theory for ring stability has to do with the collisions between ring particles. If they are hard, like steel balls, they will ricochet off each other. He demonstrates this, dropping a ball bearing near an amplifier so all can hear the bounce. On the other hand, if they're mushy ice balls they won't ricochet, they'll just shatter. He drops the candy. It lands with a dull thud, rolls off the table, and shatters on the auditorium floor. Once again, Ed Stone's traveling road show brings down the house.

Today Brad Smith presents Hyperion. With characteristic flair, he describes it as a hockey puck. Or a beer can. (Brad, by the way, is the man who said he'd seen better looking pizzas than Jupiter's moon, Io.)

The days follow a familiar, hectic routine. The scientists meet every day at 2 pm to discuss their findings. At 3 pm, a group of experts breaks away to give tutorials to reporters in the auditorium. Today the subject is rings. A sequence of pictures of the B-ring spoke areas has been spliced together to form a movie, showing the same sequence over and over again. It's dubbed the "Saturn 500" because of the repetition and careening effect as the spokes whirl past, racing around the planet—all the way around.

Ed Stone's secretary has a message for him. It's on her chest. ED STONE FAN CLUB, her T-shirt proclaims. She could have sold hundreds of them, for the Ed Stone fan club grows and grows. Journalists and scientists, civic leaders and school children all appreciate Ed and his knack for explaining difficult subjects so they can understand and share

(continued on page 14)

Return to the Rings

by Richard J. Terrile

Some 1.6 billion kilometers from the Sun lies a giant, cloud-shrouded world ten times the diameter of Earth, surrounded by billions of moons tightly packed into a flat disk almost 300,000 kilometers across. This undulating disk, regularly tugged out of shape by orbiting worlds, acts as an enormous capacitor, occasionally sparking with a million times the power of lightning. This scene, hardly imaginable in the wildest science fiction, is, in reality, the alien world we call Saturn.

To an observer with a small telescope, the planet Saturn, with its spectacular ring system, is the most easily recognizable astronomical object. The enigmatic charm of this ringed planet has attracted astronomers through the centuries. In July, 1610, Galileo Galilei, using a crude 32 power telescope, became the first human being to see Saturn's rings. Describing Saturn in 1612, he wrote: "I do not know what to say in a case so surprising, so unlooked for and so novel. The shortness of time, the unexpected nature of the event, the weakness of my understanding and the fear of being mistaken have greatly confounded me."

During *Voyager 1*'s encounter with Saturn 369 years later, another scientist remarked on Saturn's rings. Dr.

Brad Smith, leader of the *Voyager* Imaging Team, said: "We've never been so confused for so long about anything so obvious." Our understanding of Saturn's rings seems to have progressed very little in nearly four centuries. But through his telescope, Galileo could determine only that Saturn was different from other planets because it possessed "companions" on either side. He never realized that those unmoving, dim shapes were rings encircling the planet. We have since learned that the rings are composed of billions of icy particles, ranging from dust-sized grains to house-sized blocks, each in independent orbits around Saturn's equatorial plane.

Voyager 1, which encountered Saturn in November 1980, raised nearly as many questions about the rings as it answered. *Voyager* project officials reprogrammed *Voyager 2* to help solve some of the surprising puzzles revealed by its sister craft, as well as to explore areas of the rings not seen by *Voyager 1*. Questions included: What are the spoke-like features revolving in the broad B-ring? Why does the thin F-ring appear clumpy and twisted? What mechanism can explain the clear areas in the rings? And finally, what clues can we find to the origin of the ring system?



Saturn's mystifying rings continue to confound scientists. The "braids" within the F-ring, photographed by Voyager 1 (top), seemed to have disappeared in one small section. The forces that caused the braiding, still not completely understood, appear to be transitory.

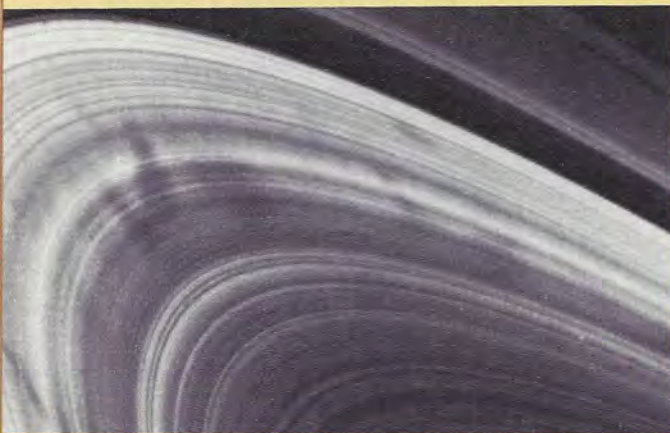
New assignments for *Voyager 2* included imaging the sunlit face of the rings, seeing them under different lighting conditions, obtaining high resolution color measurements of the rings, and observing the entire structure of the system with the photopolarimeter. Most of these ring science goals were accomplished, despite the jamming of the scan platform after the ring plane crossing.

Voyager 1 had discovered dark, shadow-like "spokes" revolving around in the thickest part of the rings. These generally radial features sometimes appear as tilted wedges up to 20,000 kilometers long. Since the rings are made up of myriad particles in independent orbits, particles close to Saturn will revolve around faster than particles farther away. Any radial feature, like a spoke, should tilt over and shear apart in a few hours. These mysterious markings, some as large as the Earth, were a main focus for *Voyager 2*. Time-lapse sequences of the rings, taken by the spacecraft and edited into a movie, enabled us to watch these spokes as they formed and evolved.

A coherent hypothesis of spoke formation is now emerging. Spokes are believed to be composed of clouds of dust levitated above the ring plane by electrostatic forces, similar to static electricity which makes dust stand up on a record album. The key observation leading to this conclusion was that



Top: The higher resolution of Voyager 2's cameras and its trajectory over the sunlit side of Saturn's rings gave this spacecraft a better look at the ring system than Voyager 1. The "ringlets" discovered by Voyager 1 last November appear here as the light and dark bands; Voyager 2 revealed that these ringlets are filled with more ringlets, down to the limits of resolution of the spacecraft's camera.



Bottom: One of the greatest puzzles of the ring system, the dark, radial "spokes" of the B-ring appeared clearly in Voyager 2's cameras. Their sharp, narrow appearance suggests short formation times, and scientists think the spokes are created by electromagnetic forces, although the exact process is not yet understood.

spokes seen with the Sun behind them appear bright, not dark—an effect explained as scattering of sunlight by small particles.

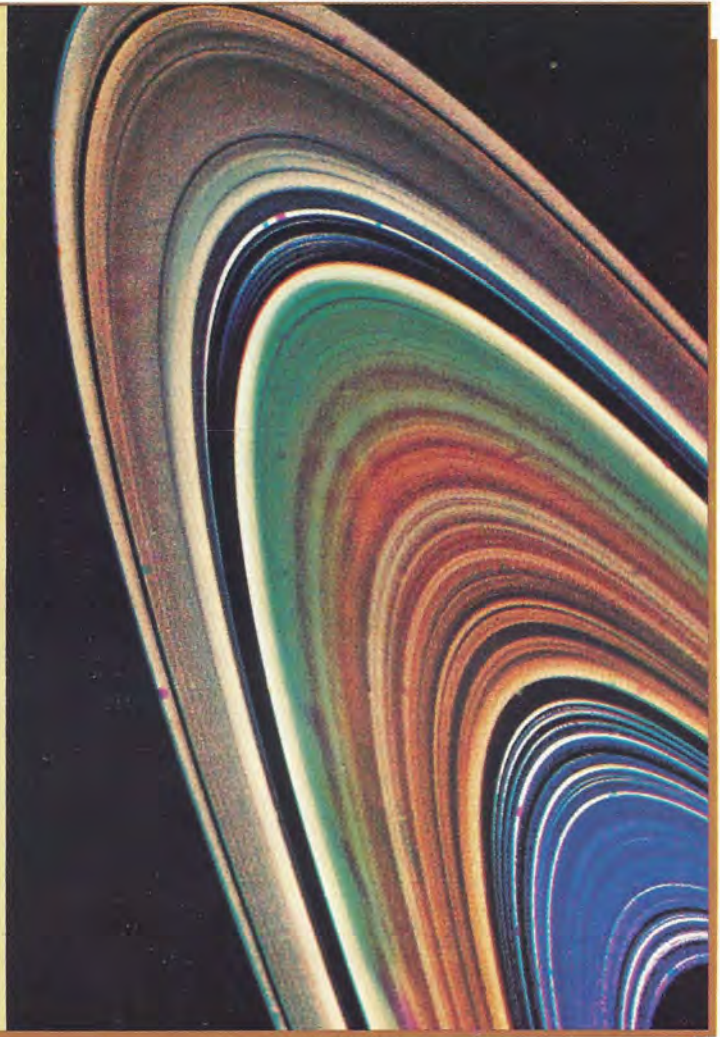
Electrical discharges, similar to lightning, probably play a role in sculpting the spokes into radial form. In fact, the *Voyagers'* Planetary Radio Astronomy experiment detected radio noise exactly analogous to static on an AM radio in an electrical storm. Jim Warwick and his radio team have traced the radio bursts to the rings and determined that they are one hundred thousand to a million times more powerful than Earthly lightning. This electricity is generated by ring particles charging up as they are bathed in unfiltered sunlight and as they revolve in Saturn's powerful magnetic field. A connection between the radio bursts and the spokes has not yet been made, but it is hoped that after further examination they can be tied together.

Perhaps the greatest surprise from *Voyager 1* was the braided and kinked appearance of the F-ring. This thin ring lies about 3000 kilometers outside the broad main rings. Pictures of five different areas of the ring were taken by *Voyager 2* and, surprisingly, braids were seen in only one small region. Whatever created the braid-like structure seems to be either temporary or confined to small regions. The F-ring's thin shape is thought to result from gravitational focusing or "shepherding" from two small satellites on either side of the ring. Disturbances of ring material from the close passage of these satellites may create the strangely shaped forms in the ring.

Voyager 2 found two apparently discontinuous rings in the Encke Division, one which was imaged at high resolution and appears to be kinky. The shape of this ringlet fits nicely with an hypothesis proposed by Peter Goldreich and Nicole Borderies at Caltech. The ringlet's shape is probably due to unseen small moonlets, maybe a kilometer in diameter, tugging on the kinky ring from nearby orbits. We may have found a miniature F-ring within a gap in the rings.

As we study the rings at progressively higher resolution, we continually find much finer structure. When we knew Saturn only as a blurry image in a telescope, we thought the Cassini Division was a 3000-kilometer-wide gap in the rings. *Voyager 1* showed that the division was filled with small rings separated by thin gaps. *Voyager 2* searched these gaps for moonlets which might be clearing the gaps of particles. Instead of moonlets, more rings were found, which change and wave back and forth as Saturn's large

When this false color image of Saturn's rings first appeared on their computer monitors, Voyager scientists thought the machine was playing tricks on them, for they did not expect such dramatic color variations within the B-ring. The blue color of the C-ring (lower right) and the Cassini Division (the dark band running through the rings) had been observed by Voyager 1. The rather homogeneous, mottled-brown color of the A-ring (outermost in this image) was expected, but the great variation from orange to green in the B-ring (between the C-ring and the Cassini Division) was a surprise. Different chemical compositions of ring particles may be the cause of these color variations, perhaps suggesting the sections of the rings formed from separate parent bodies.



satellites tug on them from far away. This major discovery is the first clear evidence that gravitational resonances with satellites control ring structure.

Enhanced color images are showing us that the rings contain subtle color variations. This indicates that either composition or surface properties of the ring particles vary with location. Surface property variations are probably due to processes which continually shape ring structure. But compositional variations could be signatures of the mechanism that created the ring system, surviving unchanged since its formation. Each major ring could be the remains of a different parent body or satellite, once orbiting Saturn, which has long since broken apart. This the-

ory of formation contrasts with other ideas that would have the rings composed of material left over after Saturn and its satellites formed from the solar nebula.

The next step in understanding the Saturn system is to confirm and test these ideas and apply them to all the data returned by *Voyager 2*. We have learned a great deal about the rings and the Saturn system, but we are far from a total understanding. Much remains unexplored. Always in the back of our minds remain the many unanswered questions. If only we could return to Saturn....

Dr. Richard Terrile is a member of the Voyager Imaging Team.

Through his rudimentary telescope, Galileo could only vaguely discern Saturn's rings, and, as these sketches show, he was not sure what to make of them as their appearance changed.



Radio Science at Saturn

by Von R. Eshleman and G. L. Tyler

An experiment without a dedicated instrument, the *Voyager* radio science investigation has proved to be an extremely valuable tool for understanding planetary systems. During the Saturn encounters it supplied unique results on the lower atmosphere of Titan, the characteristic sizes of particles in several areas of Saturn's ring system, details of the radial structure and information on the thickness of the rings, the masses of the larger encountered satellites, and the height and amount of ammonia near the clouds in Saturn's atmosphere. When asked for his assessment of the most interesting or exciting finding from *Voyager*, Carl Sagan cited the first two of these radio science accomplishments. While we might hesitate to make such a claim, we would not wish to quarrel with Sagan's judgment on this matter.

But what is "radio science?" Of the eleven *Voyager* experiment teams, ten have dedicated instruments on each of the two spacecraft. The radio science team, on the other hand, conducts its experiments with the spacecraft radio systems and the giant antennas of the NASA/JPL Deep Space Network tracking stations in Australia, Spain and Southern California. Our "science instrument" is a combination of onboard equipment that receives instructions from Earth and transmits back the pictures and other science and engineering data, plus the ground-based facilities that receive these radio signals and locate and command the spacecraft from Earth.

The radio links between planetary spacecraft and Earth can be thought of as slender threads that provide our only contact with the spacecraft. During the first United States planetary efforts, mission planners were understandably reluctant to break this seemingly tenuous contact even temporarily, and trajectories were designed to avoid the passage of the spacecraft behind planets as viewed from Earth. But this occultation geometry, where the spacecraft is hidden or *occulted* by the planet, was needed for the radio links or "threads" to pass through the planetary atmosphere so that its characteristics could be measured. In this conflict between mission plans and science goals, science lost out in the first mission (*Mariner 2* to Venus) but won in the second (*Mariner 4* to Mars) and subsequent U.S. planetary missions. For *Voyager* at Saturn, radio occultation investigations of the atmospheres and ionospheres of both Titan and Saturn, and Saturn's rings were all completed.

Using radio link measurements, we are able to make accurate determinations of very small changes in apparent distance. Our long radio thread is marked every few centimeters by a scale corresponding to the signal's wavelength, and we determine the changes in the number of wavelengths along the path by very precise measures of radio frequency. If, for example, the thread appears to lengthen

in one second by one centimeter as it passes through a planetary atmosphere, then this change can be ascribed to the relative amounts of gas present in that atmosphere along the path of the thread. (The gas shortens the local wavelength and makes the thread appear longer when measured in units of the vacuum wavelength.) Since the thread goes down through the atmosphere as the spacecraft moves in behind the planet, atmospheric characteristics can be determined over a wide range of heights. Changes of a few centimeters can easily be determined on the billion-mile path between the Earth and Saturn, and will later be possible on the even longer paths to Uranus and Neptune.

Knowing the relative amount of gas as a function of height in a planetary atmosphere makes it possible to compute the ratio of the gas temperature to the average molecular weight of its constituents. If the constituents are known, both temperature and pressure can be determined to an accuracy comparable to what could be measured with an atmospheric probe experiment. If other information on temperature is available from other experiments, such as infrared radiometry, the radio results can be used to help determine the atmospheric constituents. Other measurements of signal characteristics such as intensity and fading make it possible to study atmospheric turbulence and the location and density of absorbing clouds and their related vapors.

In the case of Titan, the radio measurements were fundamental in probing the temperature-pressure structure of the lower atmosphere to the surface, and in concluding that nitrogen gas is the principal atmospheric constituent. At Titan's surface, the pressure is about 60 percent greater than at the surface of Earth and the atmospheric density is 4.6 times as great. The temperature is about 93 degrees Kelvin, or -290 degrees Fahrenheit. We were surprised to find that this cold, dense atmosphere also causes our radio signal to twinkle, suggesting that the atmosphere is turbulent. The clouds consist of frozen methane particles; both methane rain and snow may be falling onto a surface covered with methane ice and pools of liquid methane.

Of all the planets and satellites of the solar system, only Titan shares with Earth the characteristic of an atmosphere consisting primarily of nitrogen. Prior to the first spacecraft missions to Mars and Venus, many scientists predicted that they would have nitrogen atmospheres with only minor amounts of carbon dioxide, similar to Earth's. But our two planetary neighbors have carbon dioxide atmospheres. Now that we have found a nitrogen atmosphere in an entirely different part of the solar system and not one nearby, it appears that Earth may be the oddball of the inner solar system. If life had not developed here, Earth might well have had a carbon dioxide atmosphere, as do Mars and Venus.

Precise radio measurements of the changing distance from spacecraft to Earth also made it possible to "weigh" several Saturnian satellites. Their gravitational pull changed the spacecraft's trajectory as it sped by them. Measurements of these changes provided the data needed to compute the masses of these satellites. While mass is a fundamental characteristic of such bodies, we are even more interested in their average densities. The average density of a moon or planet indicates of what it might be made, and this in turn helps to determine how, when and where it formed, how it evolved and what its characteristics are now. To derive densities we need not only masses, but also volumes (or radii for spherical bodies), and these are obtained from the imaging experiment. (For Titan, however, where the surface was hidden by the thick atmosphere, the radius was found by the radio occultation experiment.)

Voyager 1 found a value near 1.3 grams per cubic centimeter for Rhea, or 30 percent more than the density of liquid water. This is very near to the value that would be expected if it condensed from a primordial cloud of so-called solar elemental composition, at a temperature below the freezing point of water, but above the freezing point of methane. Rhea would then consist of about 40 percent silicate rocks and 60 percent water ice by mass. Before *Voyager 2* flew through the Saturnian system, it appeared that Mimas, Enceladus, Dione and Iapetus might have about this same density, although the uncertainties were large.

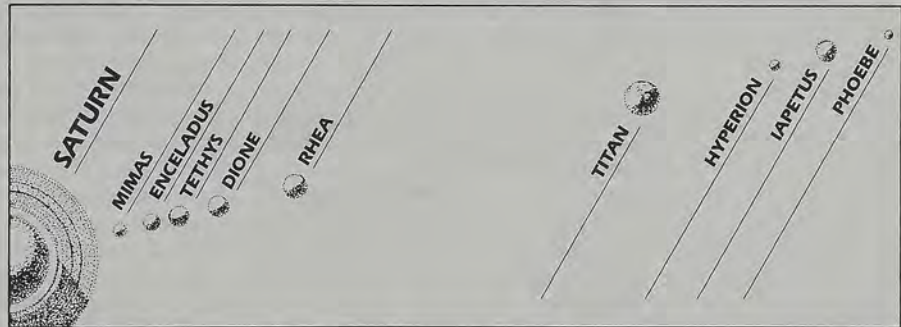
The *Voyager 2* measurements will provide more accurate values of mass and radius for several of these moons. Preliminary analyses now indicate that Iapetus may be less dense than the others, implying an important difference in its makeup. One possibility is that because it is more distant from Saturn than the other moons, Iapetus may have formed from material whose temperature was low enough for methane ice to be present.

Iapetus is also unique in that its surface shows extreme variations in brightness, including a very dark region at low latitudes, generally centered on the apex, or leading point, of the moon in its orbit. There is a possible connection between the dark surface material and the above methane hypothesis. If, for example, Iapetus formed from material that included 10 percent methane (CH₄) ice by mass, then it contains about 10²³ grams of carbon. If the methane were evenly distributed, there would be about 5 billion tons of carbon within the first centimeter of depth below the surface. The dark areas might then result if either free carbon or complex dark hydrocarbons were produced at the surface due to exposure of the methane to the environment, or if such material formed deep in the interior and later escaped to the surface of the moon in restricted places. That is, the surface material on parts of Iapetus may be dark as pitch...because it is pitch.

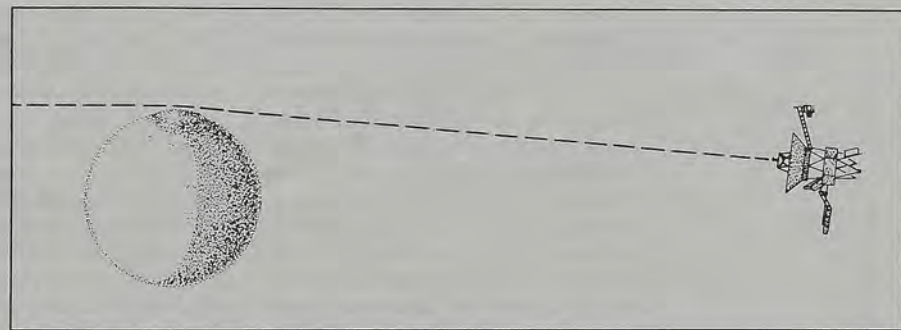
At this stage of data-gathering and analysis, no one can say whether or not this is the explanation for Iapetus' strange visage, but it is obvious that it and the other Saturnian satellites will have much to tell us about the processes through which such bodies form and evolve—processes perhaps generic to our solar system as a whole.

Professors Von R. Eshleman and G. L. Tyler of Stanford University are members of the Voyager radio science team, which also includes J. D. Anderson, G. S. Levy, G. F. Lindal and G. E. Wood of the Jet Propulsion Laboratory and T. A. Croft of SRI International.

RIGHT: Half of Iapetus is nearly invisible (bottom right) against the darkness of space in this image of Saturn's strangest satellite. The reflectivity of the dark region is close to that of asphalt and contrasts sharply with the light-colored, icy crust of the moon.



ABOVE: The moons of Saturn are shown in their relative positions to the planet, but not to scale.



ABOVE: The path of the radio signal between Earth and the spacecraft bends as the beam passes through Titan's heavy atmosphere.



ABOVE: Voyager's 3.7-meter-wide antenna dominates the appearance of the spacecraft.



For three days at the end of August, Pasadena, California was the scene of an unprecedented happening: As *Voyager 2* swung through the Saturn system, pictures of the planet, rings and moons appeared on a large screen in the Civic Auditorium, and a festival of planetary arts and sciences went on in the Pasadena Center. Sponsored by The Planetary Society and a number of contributing corporations and individuals, Planetfest '81 was a bold and successful attempt to bring to the public the wonders of 20 years of discovery in the solar system. It was at once a celebration of achievement and an expression of hope for the future.

Planetfest '81 was scheduled for August 23-25, to coincide with *Voyager 2*'s encounter with Saturn. But festivities began a day earlier for the 35 winners of The Planetary Society's national high school essay contest, who came to Pasadena from 30 states. An informal lawn party Saturday evening at the home of Dr. Marvin L. Goldberger, President of the California Institute of Technology, gave the festival staff, along with Carl Sagan and Bruce Murray, an opportunity to get acquainted with the winners.

The first official day of Planetfest '81, Sunday, August 23, dawned hot and dry, but over 5,000 people braved the 100 degree weather to tour the Jet Propulsion Laboratory near Pasadena. JPL scientists and technicians at 19 working sites explained their specializations, over and over again, to the thousands of curious visitors. A

highlight of the tour was the Spaceflight Operations Facility, the heart of the Deep Space Network. With tracking stations in California, Australia and Spain, the SFOF controls all deep spacecraft 24 hours a day.

While early festival-goers poured onto the grounds at JPL, others jammed registration lines at the Pasadena Holiday Inn. The patience and indulgence of all festival participants were immensely appreciated—especially at registration time—by a staff struggling with their first major production.

On Sunday evening, Planetfest '81 was resoundingly launched by a splendid concert, "Sounds of the Cosmos," with composer John Williams conducting the Pasadena Symphony Orchestra. The program began with J. S. Bach's "Brandenburg Concerto No. 2 in F Major," which is included on the record attached to the *Voyager* spacecraft. After introductory remarks by Carl Sagan, the orchestra continued with five selections from Gustav Holst's "The Planets," followed by selections from John Williams' scores for the films "Star Wars," "The Empire Strikes Back," and "Close Encounters of the Third Kind." After the concert, 450 people dined under the stars at a festival fund-raising dinner—a perfect counterpoint to a perfect festival opening.

Monday promised to be hotter yet, and exhibitors raced the clock to finish their displays in the Pasadena Center's Conference Building. At the same time, busloads of students went to Griffith Observatory in the Hollywood Hills above Los Angeles, and to the Mount Wilson Observatory in the San Gabriel Mountains above Pasadena. At noon, festival participants surged into the Conference Building, where the corridors were brightly decorated with some 80 paintings, drawings and sculptures in the astronomical art show—the largest of its



kind. Here, too, the "Tour of the Planets" began, with Mercury, Venus, Mars, Earth, Moon, Jupiter, Saturn, Uranus, Neptune, Pluto, the Sun, comets and asteroids illustrated, explained and discussed in rooms filled with photographs, maps, models, globes, charts and posters, amid a great array of other exhibit material—all designed to provide the most current data available. Scientists from JPL hosted each exhibit, describing it and answering questions.

Another series of exhibits, "Building Blocks of the Future," provided festival-goers with a glimpse into the future. Astronauts David Hilmers and Robert Parker discussed living and working in space. An Apple II microcomputer planned flight paths from Earth to Saturn orbit. Computer-generated drawings of a particular planet or of the solar system were given away. Science fiction writers, including Larry Niven, Poul Anderson, Jerry Pournelle, Hal Clement, Theodore Sturgeon and Ray Bradbury, happily lamented the demise of their planetary visions and welcomed the triumph of fact over fiction. Future missions—Aerocapture, the *Galileo* Jupiter orbiter and probe, the Halley Intercept Mission, missions to the far outer planets, the International Solar Polar Mission, missions to the asteroids, and the Venus Orbiting Imaging Radar—were featured with pictures, models, and hosts to explain and describe them.

Any participant who felt just a little tired after touring the Conference Building had a wonderful opportunity to relax while enjoying the continuous showings of space exploration and documentary films in the Little Theatre Film Festival.

PHOTO: KEN TANG



TOP: Crowds entering the Pasadena Civic Auditorium before the "Sounds of the Cosmos" concert.

ABOVE: Carl Sagan, composer John Williams and Governor Edmund G. Brown, Jr. at the fund-raising dinner.

PHOTO: GLORIA LARKIN



ABOVE: The radio-controlled "Martian rover" delighted festival-goers.

RIGHT: Two performers from "The Martian Chronicles."

PHOTOS: KEN TANG



Planetfest '81: CELEBRATION AND HOPE

by Linda Bridge Beek

The focus of Planetfest '81, the "Voyager Watch," also opened at noon in the Civic Auditorium, next to the Conference Building. Members of the JPL Amateur Radio Club provided the link between JPL and the Civic so that live transmissions of pictures from *Voyager 2* could be projected onto a 25-foot screen. (Color would be introduced later by computer processing on Earth.) During periods when signals were not being received from the spacecraft, JPL scientists presented *Voyager* updates and described future missions. The only controversial issue at the festival concerned the necessity of insisting that participants leave the cool of the auditorium at 7 pm for the hot evening outside while the staff prepared for the evening programs which began at 7:30 pm.

The Monday evening program featured a science panel review of the accomplishments of the last twenty years of space exploration. George Alexander, science writer for the *Los Angeles Times*, moderated a panel that included four distinguished scientists with four different opinions. Dr. Eugene Shoemaker, a geologist with the U.S. Geological Survey in Flagstaff, Arizona, suggested that knowledge about comet and asteroid collisions with planets was the most significant result; Dr. Peter Goldreich, a theoretical astrophysicist from Caltech, felt that exploration of the solar system has given

scientists practical information to measure against their predictions, adding that the facts have very often been humbling experiences. Dr. Von Eshleman, an electrical engineer from Stanford University, suggested that the most important findings have come from the investigation of the atmospheres of other planets. Dr. James Pollack, a scientist from Ames Research Center, proposed that the failure to find life elsewhere in the solar system, although it has existed on Earth for nearly all of its 4.5-billion-year life, is the most significant event of the 20 years of exploration.

Even though Tuesday was hotter than Monday, festival-goers increased in number to continue exploring the Conference Building exhibits and to sit in on "Voyager Watch." In addition, a special presentation on Mars opened in the Center's Exhibition Hall. "Mars Past" featured a Disney film produced in the 1950's covering the range of speculation about what we would find on Mars. Photographs, drawings, old posters, an Orson Welles tape and dramatic vignettes from Ray Bradbury's play "The Martian Chronicles" contributed to a sense of what we used to think about the red planet. "Mars Present" featured a *Viking* Lander spacecraft from Martin Marietta Aerospace, sitting on simulated Martian ground that was created, painstakingly, by people from JPL. A model of Valles Marineris, the "Grand Canyon of Mars," on loan from the "Cosmos" television show, and photographs returned to Earth from spacecraft, illustrated Mars as we know it today. "Mars Future" emphasized our potential for inhabiting Mars. Models of various Martian rovers for exploring the red planet's surface and the "mini-sniffer" airplane were exhibited. Imaginative paintings and murals depicted human activities on Mars.

Soon after the Exhibition Hall opened, a prototype solar sail built by the World Space Foundation was unfurled for the first time. It was a spectacular sight as the shiny Mylar was slowly spread out, covering one corner of the enormous hall.

During the day Tuesday, speakers shared their views on planetary exploration from a podium in the Exhibition Hall. They included James Beggs, NASA administrator; Shirley Hufstедler, Secretary of Education in the Carter Administration; Carlos Moorhead, Congressman; Ray Bradbury, author and poet; Gerard O'Neill, Princeton professor and proponent of space settlement; Gene Roddenberry, "Star Trek" creator; Eric Burgess, author and co-founder of the British Interplanetary Society; Diane Ackerman, poet; Nichelle Nichols, "Star Trek" actress and founder of Space Cadets; and Louis Friedman, Executive Director of The Planetary Society.

The Planetfest '81 finale, "What Lies Ahead?," was held Tuesday evening in the Civic Auditorium, integrating an all-star panel with a live feed of "Nightline," the ABC news program hosted by Ted Koppel. The program included Bruce Murray, Carl Sagan, Ray Bradbury and Gene Roddenberry. At 9:50 pm, as the exchange among panelists and members of the audience continued, the *Voyager 2* spacecraft reached its closest encounter with Saturn—101,000 kilometers from the dark side of the planet, and some 1.5 billion kilometers from Earth. Minutes later, Planetfest '81 ended with thousands of people going out happily into the night. It was a unique and ephemeral event, and its spirit will surely remain.

Linda Bridge Beek coordinated Planetfest '81 and has now joined the staff of The Planetary Society.



ABOVE: JPL Director Bruce Murray and author Ray Bradbury in front of the mock-up of the Viking lander.



TOP RIGHT: The World Space Foundation prototype solar-sail in the Exhibition Hall.



RIGHT: Essay contest winners chat with Carl Sagan.

News & Reviews

by Clark R. Chapman

An essential part of scientific research is communication of the results to other scientists and to the public. Researchers may communicate with other specialists in their fields via technical specialty journals, such as *The Astrophysical Journal*. More useful for a broader range of planetary scientists are "review articles" written for such journals as *Reviews of Geophysics and Space Physics*. Less technical reviews, accessible to scientists and the educated lay public alike, appear in magazines like *Scientific American*. Still less technical articles, often emphasizing the human side of scientific research, may be found in an increasingly large variety of popular science magazines.

Given the diverse backgrounds and interests of Planetary Society members, I try in this column to provide access to *all* of these types of articles and books. All should be available in local city or university libraries, unless you live in a rural area. Some of the more popular magazines cover space science regularly and you may want to enter a subscription.

The Atmosphere of Venus

In the July, 1981, issue of *Scientific American*, Gerald Schubert and Curt Covey summarize what's known about the atmosphere of our neighboring planet, Venus. The focus of research about Venus is changing from finding out what the hot, thick, poisonous ocean of air is like on Venus to determining *why* it behaves as it does. The great remaining mystery—which is not treated in this article—is *how* the atmosphere of Venus ever got to be so radically different from our own planet's life-sustaining envelope.

According to Schubert and Covey, the biggest difference between the meteorology, or atmospheric dynamics, on Venus and on Earth is that the atmosphere of Venus is hot at the bottom and cold at the top, whereas the opposite is true on Earth. This is due to the "greenhouse effect" of Venus's exceptionally thick blanket of carbon dioxide and other gases that trap the solar heat.

A second difference is that Venus spins on its axis so slowly that there is a negligible Coriolis force, which is the deflection of poleward-moving parcels of air in our own atmosphere by the rapid spin of our planet. The atmospheric motions on Venus are best understood near the cloud-tops, where most of the solar heat is absorbed, driving the circulation. That is also the level of the mysterious ultraviolet spots, which let our *Pioneer* Venus spacecraft photograph actual cloud motions. Evidently there is a large gyre, called a Hadley cell, of circulating air. The air warmed at the equator rises and moves to the poles, where it sinks and returns to the equator. Two similar deeper cells are thought to exist, but the evidence is more ambiguous. In general, there are both similarities and differences between the atmospheres of the two sister planets, Venus and Earth, and we hope that continued comparative studies will shed more light on our own weather and climate.

Outer Solar System Atmospheres

Only a few months ago, the prolific planetary astronomer Larry Trafton published a comprehensive, technical review

of the atmospheres of Io, Saturn, Titan, Uranus, Neptune, Triton, and Pluto (February, 1981, issue of *Reviews of Geophysics and Space Physics*).

It is a measure of the rapidity of planetary research that much of the article is already obsolete. Two *Voyager* encounters with Saturn—especially the pictures taken by *Voyager 2*—have revolutionized our knowledge of Saturn's atmosphere. And many of the mysteries of Titan discussed by Trafton were resolved by *Voyager 1*.

The article is a fine historical backdrop for continued telescopic studies of Uranus, Neptune, and Pluto, which are refining our knowledge of their rotation periods, atmospheres, and surface compositions. In a particularly interesting discussion of Pluto, Trafton reminds us of the unexpected answer to the question, "Which planet does Pluto approach most closely?" Why Neptune, of course, most of us might say, since Pluto's orbit actually crosses that of Neptune. We would be wrong, for Pluto is in a resonance that keeps it far from Neptune. It can come nearly twice as close to Uranus, and Trafton thinks Pluto might even be an escaped satellite of Uranus!

Meteorites from Mars?

In the mid-1970's, many scientists thought that the most important scientific mission NASA could undertake would be to retrieve a few samples from the surface of Mars so that they could be studied, as were the moonrocks, in our laboratories. It now seems that we may have such samples already in hand, fallen freely from space.

Several years ago, Ed Stolper and several other scientists began to look closely at three unusual types of meteorites—the shergottites, nakhlites, and chassignites—and began to wonder how they could ever have formed on an asteroid-like parent-body. Their crystallization ages imply that there was active magmatic activity only 1.3 billion years ago and their other traits seemed to imply origin on a planet-sized body. The Earth is ruled out by irreconcilable differences in oxygen isotopes.

Mars, with the impressive evidence of relatively recent volcanism near Tharsis and Olympus Mons, now seems to be the preferred candidate, according to Charles Wood and Lewis Ashwal. In an article being published in the *Proceedings of the 12th Lunar and Planetary Science Conference*, these Houston scientists find many reasons to believe that these meteorites come from Mars. The authors go even further and attempt to use the meteorites as samples of Mars to better understand the red planet.

There remain grave difficulties with obtaining meteorites from Mars, however. How is it that scientists have generally recognized no meteorites on Earth from the Moon, if we get meteorites from Mars? The Moon, after all, is much closer to us and it is easier to launch fragments from it at escape velocity due to its lesser gravity.

But these three meteorite types are telling us *something* important, even if they don't come from Mars, for the problems of creating them on asteroids are very great. Wood and Ashwal quote Arthur Conan Doyle: "...when you have excluded the impossible, whatever remains, however improbable, must be the truth."

If you don't want to purchase the voluminous *Proceedings* and decipher the technical arguments of Wood and Ashwal, I recommend a popular account of the meteorites-from-Mars debate that appeared in the October, 1981, issue of the new magazine *Discover*.

Clark R. Chapman is a research scientist with the Planetary Science Institute (in Tucson, Arizona), a division of Science Applications, Inc.

Society Notes

by Louis Friedman

Because of the special August/September, 1981, issue of *The Planetary Report* on the future in space, we missed doing this column. Consequently, we have a great deal of Society news to report, most of it quite exciting.

Interest in The Planetary Society continues to grow and it is now fair to say that everywhere we look around the country, we find ourselves. Membership ranks have swelled to over 90,000, which is amazing when you consider that one year ago we had less than 1,000 members.

Planetfest '81

But size is not everything; our activities are also expanding. In August we sponsored Planetfest '81, the Pasadena Planetary Festival. Its success is yet another demonstration of the popularity of planetary exploration. More than 6,000 people attended three days of events, and the Society was featured on national television, in magazines and newspapers. Deep space exploration was shown to be an achievement worthy of aspiration for the nation's young people.

We realize that many members could not come to Planetfest '81. After all, it could only be held in one place at one time. But the beautifully illustrated program for Planetfest '81 is available for \$2.00 by writing to The Planetary Society, Dept. P, P.O. Box 3599, Pasadena, CA 91103. We intend Planetfest '81 to be the first of our major public programs, giving our members an opportunity to enjoy the results of deep space exploration and to participate in the adventure of discovering new worlds.

Upcoming Events

While we may be limited to producing festivals at yearly intervals, we will be involved in many public events throughout the year. On October 31 and November 1, 1981, the Lunar and Planetary Laboratory, Tucson's Planetary Science Institute (Science Applications, Inc.) and The Planetary Society are co-sponsoring the Tucson Planetary Festival. The program will celebrate U.S. planetary exploration and will feature movies, slide shows, exhibits and speakers. The sessions are free and open to the public on a first come, first served basis. For further information, contact Gail S. Georgenson, 602/626-4861.

I will be speaking on the wondrous results of the *Voyager* mission at the University of Alabama in Huntsville on November 10, at 7:00 pm. The Planetary Society will sponsor a reception for members at 5 pm, in the Faculty Lounge, Madison Hall (second floor), at the university. For additional information only, call 205/895-6010. I'm looking forward to meeting our local members.

Halley and SETI

To get attention focused on a U.S. mission to Halley's Comet and a real program for the search for extraterrestrial intelligence, the Society has started a fundraising effort to make these things happen. Drs. Sagan, Murray and I, as optimistic as we are, were amazed by the response to this appeal. More than \$75,000 was collected. (At the time it represented more than \$1.00 per member of the Society.) And it was done so rapidly that we were able to turn around and begin a national letter writing campaign in support of the Halley's Comet mission. The results are still uncertain, but we know that our presence was felt. Hundreds of letters came into the White House each day, and had to be boxed up because of their overwhelming volume. Several other space interest groups joined us in this effort to get the word on the Halley mission out and urge presidential action.

On the other aspect of our appeal, the SETI project, Dr.

Tom McDonough has volunteered to be the Society's SETI coordinator. He will interact with NASA, JPL, university and independent researchers involved in the search for extraterrestrial intelligence. Dr. McDonough will also be responsible for the Society's program for public participation and support of SETI activity. As a first step, we have contributed \$2500.00 to the search for planets around other stars. A research group at the University of Pittsburgh is building an optical telescope and detector system that will considerably enhance the ability to find other planets. Finding such planets is, of course, crucial to the theories about extraterrestrial intelligence and to the selection of areas for radio telescope searches.

Book Offerings

The response to the Society's offerings of pictures, posters and books has been extremely good. While expanding this program in the succeeding months and years, we hope to continue to offer books and other publications dealing with the latest results and discoveries from our exploration of the solar system at substantial discounts or even at cost. In some cases, we will enter into arrangements with publishers that will provide these books at substantial discounts and also benefit the Society, as we did with *The New Solar System* from Sky Publishing, which we offered in the June/July, 1981, *Planetary Report*.

Any book offered to members which involves Society officers (particularly Drs. Sagan and Murray) is being handled so that they receive no financial benefit from the sale of those books to Society members. Any honoraria or remuneration that Society officers receive for writing or speaking about the Society, or at Society events, are given to the Society as a whole and do not go to any individual.

We greatly appreciate the assistance of the University Space Research Association (USRA) in managing the book sales. Personal thanks go to David Cummings and Jean Loftus of the USRA and to Dave Hagie, a Pasadena office volunteer, for their help with the book sales program.

Louis Friedman is Executive Director of The Planetary Society.

SETI KILLED

Just as NASA was about to start looking for signs of intelligent life elsewhere in our galaxy, Congress decided the search was not worthwhile.

NASA had recently started a modest project to build sophisticated receivers. These would be used to search the sky for radio or television signals that might be broadcast by alien civilizations. Costing 2 million dollars per year, too small to even appear in most federal budgets, the program nevertheless came to the attention of Senator Proxmire.

On July 30, 1981, the Senator proposed an amendment to the federal budget stating that "...none of these funds shall be used to support the definition and development of techniques to analyze extraterrestrial radio signals for patterns that may be generated by intelligent sources."

The amendment was passed by Congress. The human race's main program to search for other civilizations was dead.

The Planetary Society is now investigating ways to support such research.

UNDERSTANDING THE EARTH'S WEATHER AND CLIMATE

by Moustafa T. Chahine

Weather is the momentary state of the atmosphere. It is characterized by the daily fluctuations of temperature, pressure, winds and moisture. Climate, on the other hand, is usually defined as average weather over a month, season or longer. Nearly all aspects of human life are to some extent sensitive to changes in weather and climate.

The processes that influence weather and climate can be described, with drastic simplification, in a few steps.

Earth is a solar-powered planet. About one-third of the solar radiation that falls on the Earth is immediately reflected and scattered out into space, and so is lost. Most of the remaining two-thirds is absorbed by the surface and then reradiated from oceans and land. Water vapor absorbs and carries this reradiated heat upwards, then condenses to clouds, and releases energy to churn the atmosphere.

Clearly, climate may change if perturbations occur in the solar energy

flux, particularly if they persist over a long time. Is our Sun a star of constant brightness, or does its energy occasionally increase or decrease? On April 8, 1980, a JPL experiment on the NASA Solar Maximum Mission spacecraft detected a drop of 0.2 percent in the total solar energy. This drop, which lasted for about two weeks, was observed again on September 3, 1980. It showed that the Sun is indeed a variable star. In the future, the solar output will be monitored from space over



long periods to determine trends in the energy input to Earth.

For the entire Earth, incoming solar energy and outgoing thermal energy balance over time, but regional and local imbalances set weather and climate in motion. The tropics get much more solar energy than the poles, setting up circulation cells. These air mass flows are greatly influenced by the Earth's rotation and by surface features such as oceans, land masses and mountains.

Oceans are extremely important to the terrestrial climate system. They cover almost three-fourths of the globe and absorb over half the solar radiation reaching the Earth's surface. A warm surface layer of water, heated by the Sun to a depth of about one hundred meters, lies over most of the world's oceans. Because the specific heat per unit mass of water is about four times that of air, the heat stored in this surface layer alone is twenty times that of the overlying atmosphere. This warm ocean layer is thus a huge reservoir of heat which regulates the atmospheric circulation through exchanges of heat, moisture and momentum. These exchanges are due to small-scale turbulence in the layer between the air and ocean. This process is still not adequately understood. While both the atmosphere and the ocean determine these interactions, they tend to be dominated by the ocean, particularly on seasonal time scales.

Quantitative analyses of ocean-derived climate changes cannot be based on air-sea interactions alone, without a large risk of error, because of the many degrees of freedom of the ocean-atmosphere system. A change in the ocean-surface temperature in one location may modify the transfer of heat to the overlying atmosphere and thus affect the atmospheric circulation and cloudiness. This then affects ocean-surface temperature and, subsequently, the deep ocean temperature distribution. For example, the warm and cool pools of surface ocean water in the North Pacific influence storm tracks, which affect the position of the jet stream, which in turn influences weather over the United States.

Increased snow cover reflects more solar radiation, reducing surface temperature, which to a first approximation results in more snow—an example of a positive feedback effect.

Climate may also change when perturbations in the Earth's vegetation cover occur, due to agriculture or the clearing of forests. Recent calculations with the NASA Goddard Space Flight

Center General Circulation Model have shown that the global rainfall, temperature and motion fields strongly depend on the land-surface evapotranspiration produced by vegetation.

Human activities, such as the burning of fossil fuels and high-sulfur coal, may also change the climate. This can directly influence atmospheric circulation by altering the concentration of gaseous absorbers of solar and thermal radiation. Likewise changes in the concentration of aerosols may, by virtue of their scattering properties, influence the local energy deposited in the atmosphere. The effects of aerosols and atmospheric trace gases, such as carbon dioxide (CO₂), sulfur dioxide (SO₂) and ozone (O₃), provide a large set of feedbacks which can alter the character of the climate in a complex way.

One of the most useful approaches to understanding the climate system is numerical modeling. A climate model is a system of mathematical equations which describe the various physical processes that govern the behavior of the atmosphere and its interactions with oceans, land masses, ice, vegetation, solar irradiance, etc. These equations are solved on large, fast digital computers.

Numerical models, however, are by definition only approximations to the real world, and their accuracy depends on the validity of the various hypotheses employed and the accuracy of the geophysical data used to set them up. It is common practice to test the validity of new theories and hypotheses against different sets of climate conditions, such as atmospheric compositions, surface features and rotation rates. The parameters of the Earth's climate system present only one data set for testing such theories. Additional tests can be made using information from other planets, such as Mars, Jupiter and Venus.

Data on the Venus greenhouse effect have already been used to test our understanding of the effects of increased CO₂ on the Earth's atmospheric heat budget. While the climate feedback mechanisms on Venus are different from those on Earth, our ability to predict the Venus atmospheric heat balance has increased our confidence in making similar predictions on Earth.

Mars presents quite a different set of climate processes. The Martian global dust storms have produced almost instantaneous climate change right before our eyes. Data on the effects of such storms on the energy balance in the atmosphere have been used successfully to test our ability to model the

effects of aerosols on climate. The Martian atmospheric circulation also offers a subtle example of the role played by topography in perturbing storms on Earth. Because the atmosphere of Mars is essentially dry, it offers a simpler dynamic system in which the role of mountains as obstacles to regional flow is much easier to understand and model.

With the recent *Voyager* data on Jupiter, Saturn and Titan, climatologists who once studied only the Earth are becoming acquainted with the entire solar system and now can examine climate processes from a wider perspective. For example, Jupiter's white oval spots and its Great Red Spot behave similarly to strong high pressure systems on Earth. Such quasi-stationary high pressure systems act to block incoming fronts on Earth and may lead to prolonged periods of drought. However, the behavior of this blocking mechanism is not yet well understood and remains a formidable scientific problem.

Our newly gained ability to observe the Earth from space with satellite remote sensing techniques has given us a unique perspective on the Earth's weather system. Besides a comprehensive view of cloud patterns and of atmospheric and ocean structures, polar-orbiting and geosynchronous satellites provide measurements of the movements of water vapor, the upward flow of thermal radiation, atmospheric and sea-surface temperatures and surface winds.

Future years will see continued improvement of numerical modeling and expanded computer capabilities, and a variety of approaches will expand the climate data base. We appear to be on the threshold of a deeper understanding of the Earth's weather and climate system. Recent studies at the NASA Goddard Space Flight Center have shown conclusively that global remote sensing of temperature can significantly improve short-term forecasts and make ten-day forecasts possible. More recent studies are just beginning to establish the physical basis for monthly and seasonal climate forecasts, given global measurements of the relevant variables. Even in their present state of development, general circulation models are already realistic enough for preliminary assessments of the consequences of certain human activities on our climate.

Dr. Moustafa T. Chahine is an atmospheric scientist and manager of the Earth and Space Sciences Division at JPL.

GOODBYE:
SATURN
HELLO

(Encounter Diary/continued from page 3)

the excitement. Congratulated on this knack for simplifying, he protested, "But that's how I understand things."

Ed Stone's secretary isn't the only one with a special T-shirt. They proliferate. The science sequence designers are marketing an extremely popular bright blue T-shirt with *Voyager 1*'s departing picture on the front and a message on the back which reads, "Goodbye Saturn"—unless you stand on your head, in which case it reads, "Hello Uranus." The press room abounds with T-shirts from schools and planetariums and previous space-related events—planetary encounters, the shuttle landing, etc. And there's the oldie-but-goodie, "Ski Ganymede."

Tuesday, August 25: Encounter Day. Ed Stone is all smiles, full of anticipation. "This is a day of challenge," he proclaims, with obvious relish, "Everything we learn today will be new."

Shortly before *Voyager 2* enters Saturn's shadow, the photopolarimeter (PPS) records starlight from the distant star Delta Scorpii as it drifts across the ring system from the inner D-ring out to the F-ring, a distance of about 70,000 kilometers. The instrument's resolution is about 150 meters—about one city block. The PPS scientists are ecstatic. Lonnie Lane, the principal investigator, is grinning from ear to ear and handing out buttons. They read: "PPS, Perfectly Phantastic Science."

Voyager 2 has entered occultation and communications have ceased as the planet's bulk blocks radio signals. This is a tense period on every mission. *Voyager 2* has some especially important observations to make while it is in the shadow, including the dark side searches for lightning and auroras on the planet, observations of the spokes, and ring plane crossing. The spacecraft has approached the ring plane from above and will dip below it just 1200 kilometers outside the tenuous G-ring.

Wednesday, August 26: Shortly after midnight, the tracking stations pick up the spacecraft signal as *Voyager 2* exits occultation. Cheers resound. All's well. The radio science team is pleased with the occultation data. Tired crews head home for some much-needed sleep.

12:30 am. Something's wrong. The screen is blank. A phone call, "I think something is wrong with the spacecraft." Soon, confirmation from the operations people. The scan platform is stuck.

By morning, an inventory of lost observations has been compiled, diagnostic tests are being designed and replanning for the rest of the mission is underway. Saturn is behind. Uranus is ahead. A special session of the "Science Steering Group"—eleven principal investigators and managers—is called. The consensus: Protecting and preserving the Uranus encounter, nearly five years away, is more important than making departure observations of Saturn.

At the press conference, Dick Laeser, Mission Director and Deputy Project Manager, gives a status report. He's obviously exhausted. Still no report on the possible cause for the problem.

Thursday, August 27: After giving it some serious thought, Ed Stone says he's come up with a number indicating the success of the mission, 200 percent.

The photopolarimeter results are spectacular. Within the 340-kilometer Encke Division, the data show not only the "kinky Encke" or "Encke doodle" ringlet seen by the imag-

ing team, but at least one more ringlet feature about 3–3½ kilometers wide near the edge of the A-ring. Plotting 25 data points to the inch, the PPS team will need one-half-mile of paper to plot the 70,000 kilometer span of the starlight occultation experiment at a resolution of 150 meters.

Garry Hunt, of University College, London, gives some insights into Saturn's atmosphere. Unlike Jupiter, Saturn's wind velocities don't correlate with the color banding. It appears that unstable circulating storms transfer energy into the jet streams. Garry closes with a couplet: "Big whorls have little whorls that feed on their velocity, while small whorls have lesser whorls, and so on to viscosity."

On Thursday night, good news. The scan platform has been successfully commanded to move a short distance. Several more tests are sent up to the spacecraft. The response is hesitant and slow, but the platform does move.

Friday, August 28: Project officials have decided to try to move the platform back to face Saturn. The signal is due. Scientists, managers, engineers and journalists watch the monitors, hardly daring to breathe. No picture. Faces turn ashen, shoulders slump, someone sobs. But wait. Someone fidgets with the contrast control on the monitor. A cheer! A lovely sight. Rings! The southern hemisphere. "We're back on Saturn!"

Saturday, August 29: It's officially magnetosphere day at the press conference. But first, Carl Sagan of the Imaging Team reports the "organic goo" on Iapetus, and Larry Esposito of the photopolarimeter experiment displays more of their stunning data. With their incredibly high-resolution images of the rings, the PPS team has been the star of this show. Larry reports they may be seeing evidence of pressure density waves, similar to those that form the arms of spiral galaxies, within the rings.

Norm Ness, a magnetic fields investigator, Dave Chennette of the Cosmic Ray team, Herb Bridge, plasma expert from MIT, Tom Krimigis of the Low-Energy Charged Particles Investigation, and Don Gurnett of the Plasma Wave Subsystem Team summarize their findings up to this point.

During Q & A, a reporter asks Ek Davis why the scan platform stuck during the ring plane crossing. Without missing a beat, Ek replies, "According to Murphy's Law..."

Sunday, August 30: The last press conference. It's a day for looking ahead. Project manager Ek Davis speaks about the prospects for Uranus and Neptune, many years hence. He calls for his last slide—a cartoon of *Voyager*, headed for Uranus, with a sling around the scan platform and a big smile on its face. "We're healing and we're on our way," he proclaims.

Ed Stone swings into action one last time. He offers thanks to the skilled people who have made the *Voyager* missions possible. "Not only the scientists, but the world owes the [*Voyager*] team a great debt of gratitude for what they have accomplished!"

Sunday afternoon: The champagne is flowing. Encounter is over. Nothing like it will be seen again for at least 4½ years, when *Voyager 2* will encounter Uranus. The future of the planetary program is shadowy. Will we ever return to Saturn? In time, the party moves to the auditorium where, it is said, there is more champagne.

Anita Sohns is a technical writer at JPL assigned to the Voyager project.

HELLO:
URANUS
GOODBYE

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All Three Sets (15 <u>Voyager 1</u> prints)	\$23.00		
Voyager 2 Saturn Encounter (set of 10 prints)	\$14.00		
Photo-Montage of The Saturn System	\$ 2.00		

● 35MM SLIDE SETS

Voyager 1 Saturn Encounter (20 slides with analysis report)	\$15.00		
Voyager 2 Saturn Encounter (20 slides with analysis report)	\$15.00		
Voyager 2 Saturn Encounter (40 slides with sound cassette)	\$18.50		
Viking 1 & 2 at Mars (40 slides with sound cassette)	\$18.50		
Voyager 1 & 2 at Jupiter (40 slides with sound cassette)	\$18.50		

● VOYAGER COLOR POSTERS

Voyager at Jupiter (Six 23" x 35" posters)	\$16.00		
Voyager 1 at Saturn (Two 11" x 17" mini-posters)	\$ 6.50		
Voyager 1 at Saturn (Five 23" x 25" posters)	\$16.00		
Planetfest '81 (Two 23" x 25") (Saturn and the F-ring)	\$ 8.00		

● BOOKS

	PRICE	QUAN.	TOTAL
Voyage to Jupiter , by David Morrison and Jane Samz – Description of the Voyager encounters with Jupiter, illustrated with color photographs.	\$ 8.00		
Pioneer: First to Jupiter/Saturn and Beyond , by Richard O. Fimmel, James Van Allen and Eric Burgess – Complete description of two Pioneer missions, illustrated.	\$13.00		
Beyond the Atmosphere , by Homer E. Newell – History of the United States space program.	\$11.00		
Voyager 1 Encounters Jupiter – A colorfully illustrated booklet describing the Voyager mission to Jupiter.	\$ 4.00		
Voyager 1 Encounters Saturn – An illustrated booklet with many of the best pictures from the Saturn encounter.	\$ 4.00		
Mars and the Mind of Man – Illustrated results of the Mariner 9 mission, with commentary by Ray Bradbury, Arthur C. Clarke, Bruce Murray, Carl Sagan and Walter Sullivan.	\$10.00		
The Planets: A Cosmic Pastoral , by Diane Ackerman, A collection of poems about the planets.	\$ 4.00		

● PLANETFEST '81 SOUVENIRS

T-shirts (Adult sizes – S, M, L, XL)	\$ 7.00		
Buttons	\$ 1.00		

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***YOU ARE HERE**—Inspired by an encounter with the layout map of a large museum and her study of astronomy, artist Anne Norcia plays with the idea of locating oneself in the universe. The Milky Way galaxy fills the upper left of the painting and the planets and Sun of our solar system are shown in relative size to each other but not at their correct orbital distances.*

FROM THE COLLECTION OF THE ARDEN FAMILY

Anne Norcia is a freelance illustrator and designer in Waynesville, Ohio. She worked as an artist on the Cosmos television series and has been published in numerous magazines and books.

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