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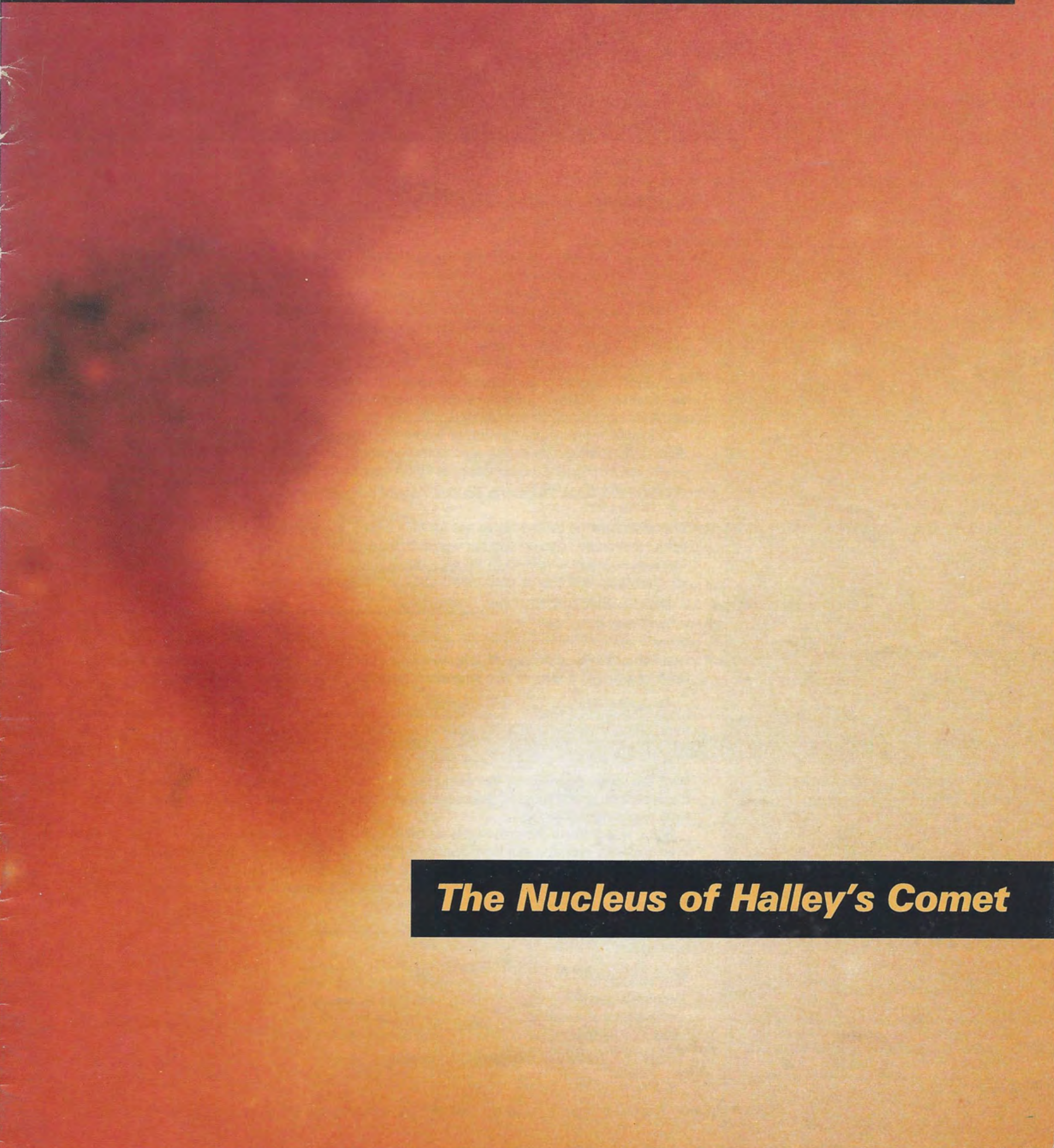

The Nucleus of Halley's Comet

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COVER: As Giotto closed in on Halley's Comet, it took this image of the peanut-shaped nucleus from 18,000 kilometers away. Scientists estimate the nucleus to be roughly 15 x 6 kilometers in size, somewhat larger than they expected. The Sun illuminates the comet from the lower right side, warming the icy nucleus and causing bright dust jets to burst outward. The dark region on the upper left section of the nucleus has not yet been identified.
IMAGE: Max Planck Institut fur Aeronomie

Letters to the Editor

The name "Planetary Society" implies a program. The name expresses the international, global character of the organization. Although the majority of the Board of Advisors and most members are US citizens, there should not be too much room for nationalism.

The expanding membership of The Planetary Society indicates that there is a wish for a better community on our Earth. Since we have seen the Blue Planet from space, we recognize it as our home, which we must preserve.

People have always dreamed of Mars. There has been much fantasy and science fiction about this planet. International cooperation could be based on two facts: the tremendous success of the American *Viking* Landers and the Soviet Lunakhod vehicle on the Moon. The continuation could be unmanned rovers on Mars, carrying the American and Soviet flags simultaneously.

But unification means division of leadership, prestige and power, and so there will be heavy opposition to planetary exploration by humanity as a whole. Planetary exploration could bring a new era of peaceful competition. Is NASA prepared? The Soviets apparently are.

GEORG PANZRAM, *Hamburg, Federal Republic of Germany*

The best hope the United States has for the continued exploration of the solar system is to establish a permanent base on another world. In the late 1960's and early 1970's we learned that the Moon is not only an object in the sky, but is a real *place*. Studies should begin to see if a specially outfitted shuttle could land and take off from the Moon.

JAMES C. SEMCZUK, *Danbury, Connecticut*

After the Challenger tragedy we received many letters from our members expressing their grief at the loss of the seven astronauts. Here are two moving responses:

I was greatly disheartened at the space shuttle tragedy, but at the same time I realize that each new frontier has its accompanying dangers. As the oceans of the world took the lives of pioneering seamen, so too will the heavens take their allotment of lives.

Many commentators have worried that the young people of America will be frightened away from the space sciences by this accident. On the contrary, I believe this temporary setback of the American space program will serve to strengthen our resolve to "boldly go where no man has gone before."

Some will dismiss these thoughts as the dream-like meanderings of a 17-year-old. However, everyone with even the slightest twinge of human spirit must feel them. *Voyager* has unlocked incredible enigmas within our solar system. Who can estimate the myriad possibilities beyond our little niche in the universe? As long as man has lived he has had a thirst for knowledge. The space program will not die.

WILLIAM PASCOE, *Denver, Colorado*

SEVEN HEROES

they vanish;
become a part of the sky:
a rain of metal tears
cries into the ocean.

billowing, that cloud
become a cenotaph:
a wreath we laid
on our voyage to planets.

KEITH GOTTSCHALK, *Claremont, South Africa*

An Asteroid for Chesley Bonestell

Last year The Planetary Society held a contest among its members to name an asteroid discovered by Eleanor Helin of the Jet Propulsion Laboratory (see the May/June 1985 Planetary Report*). She "donated" the asteroid, (3129)1979MK2, to the Society in appreciation of its support for her Asteroid Search Project, funded by NASA and the Society and administered by the World Space Foundation. We received hundreds of entries, from which we chose the name "Bonestell," in honor of Chesley Bonestell, the 98-year-old dean of space artists. The name was submitted by Ronald Paludan of Tucson, Arizona, who has won a painting of an asteroid by Maralyn Vicary, one of the many young artists inspired by Chesley Bonestell.*

Throughout his distinguished career, Mr. Bonestell's magnificent renderings of other worlds have inspired generations of people fascinated by space. One of those people has contributed the essay below.

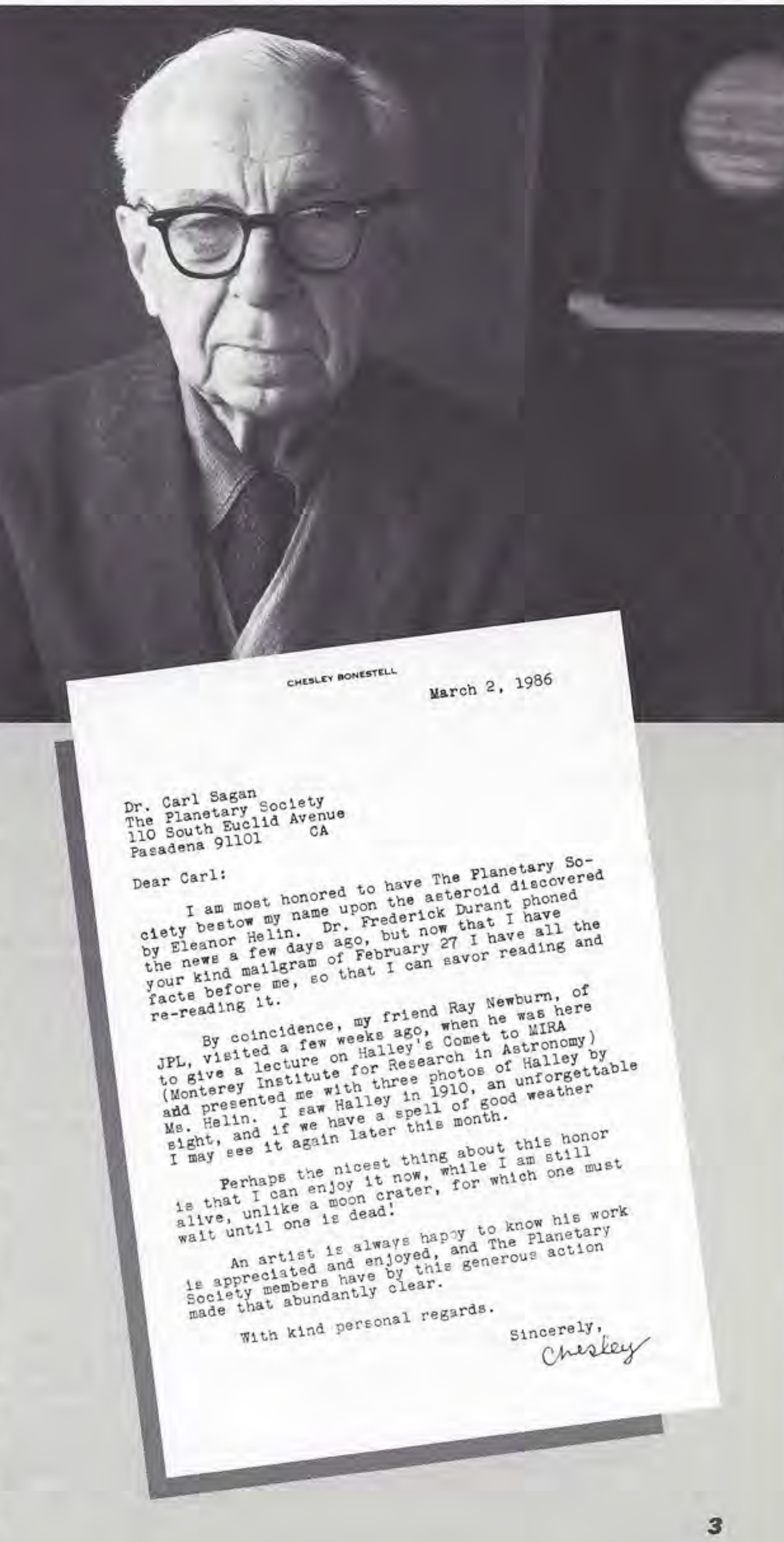
In my boyhood I found myself fascinated with the idea of other worlds. Earth was one of nine planets and there were billions of stars in the Milky Way galaxy. I read books on astronomy and a few science fiction novels. But somehow my sense of those other worlds remained blurred, muted. They never seemed to have a reality of their own. In my mind's eye they were just slightly more exotic versions of Earth. There was some imaginative leap I was unable to make.

And then, by chance, as a teenager — already dedicated to a career in planetary astronomy — I came upon a stunning book called *The Conquest of Space* (Viking Press, New York, 1949). It had an introduction by the rocket pioneer, Wernher von Braun, and a text by a science writer I had already read and enjoyed, Willy Ley. But the glory of the book was the paintings by someone named Chesley Bonestell. Here, before the whole Earth had ever been photographed from space, were plausible and meticulous renditions of our planet from above. There were utterly unearthlike visions of airless, cratered Mercury, a Venus swept with yellow dust clouds, a Mars covered with vegetation, Saturn in the blue and cloudless sky of its distant satellite Titan. And there was a chilling representation of Manhattan Island after an impact by a small asteroid. The paintings were believable; Bonestell (could the name really be French for "good star"?) had evidently taken great care to get things right. At last, I thought, I knew what other worlds might really be like.

As time went on, Bonestell's visions stayed with me. They helped me to think about what the planets were really like. When, in 1960, at the request of the journal *Science*, I prepared a summary article on new findings about the planet Venus, I included an illustration of Bonestell's Cytherean desert as a representation of what we thought we knew.

But in the last two or three decades, the pace of planetary exploration (and astronomy in general) has been breathtaking. Most of the artistic as well as scientific visions of those times have not survived to ours. We have learned much and — at least as far as the solar system is concerned — revised almost everything. Bonestell's paintings now hang in a place of honor at the National Air and Space Museum of the Smithsonian Institution in Washington.

Bonestell has inspired a new generation of space artists who have brought the vision of other worlds to a much vaster audience. Many of the leading practitioners of planetary science have been inspired by Bonestell and his successors. And so it is only fitting that we give back a world to Bonestell, who has given us so many. — *CARL SAGAN*



CHESLEY BONESTELL

March 2, 1986

Dr. Carl Sagan
The Planetary Society
110 South Euclid Avenue
Pasadena 91101 CA

Dear Carl:

I am most honored to have The Planetary Society bestow my name upon the asteroid discovered by Eleanor Helin. Dr. Frederick Durant phoned the news a few days ago, but now that I have your kind mailgram of February 27 I have all the facts before me, so that I can savor reading and re-reading it.

By coincidence, my friend Ray Newburn, of JPL, visited a few weeks ago, when he was here to give a lecture on Halley's Comet to MIRA (Monterey Institute for Research in Astronomy) and presented me with three photos of Halley by Ms. Helin. I saw Halley in 1910, an unforgettable sight, and if we have a spell of good weather I may see it again later this month.

Perhaps the nicest thing about this honor is that I can enjoy it now, while I am still alive, unlike a moon crater, for which one must wait until one is dead!

An artist is always happy to know his work is appreciated and enjoyed, and The Planetary Society members have by this generous action made that abundantly clear.

With kind personal regards.

Sincerely,
Chesley

SIFTING THROUGH

Circumstantial evidence: Evidence that tends to prove a fact in issue by proving other events or circumstances which according to the common experience of mankind are usually or always attended by the fact in issue and that therefore affords a basis for a reasonable inference by the jury or court of the occurrence of the fact in issue. — ***Webster's Third New International Dictionary***

In the world of courts and law, facts have been deemed proven on the basis of circumstantial evidence, and it has been enough to send people to prison. But in the world of science, circumstantial evidence is rarely enough to prove a fact — direct observation and measurement are usually required to satisfy the scientific "court." In some fields, however, direct observation and measurement are not possible with current instruments. This is the case in the search for other planetary systems.

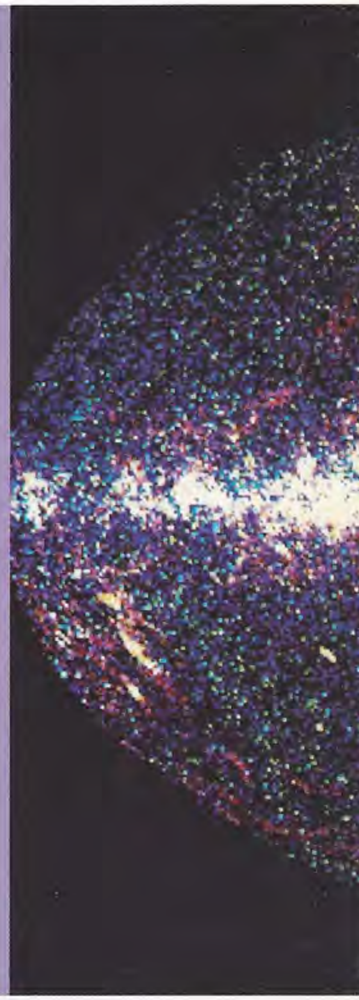
Around the world scientists are now searching for planets circling other stars in our galaxy, using both ground-based and orbiting instruments. Some claim to have discovered an extra-solar planet, while others have found evidence that something like planet formation may be happening around other stars (see the September/October, November/December 1984 and the November/December 1985 Planetary Reports). But no one has yet proven beyond the shadow of a doubt that our solar system has companions in this galaxy.

Much of the most recent evidence for other planetary systems has come from the Infrared Astronomical Satellite, launched in December, 1983. Around several nearby stars IRAS discovered disks of dust — possible evidence of planet formation. Following up this discovery, scientists have uncovered other types of information about these circumstellar disks.

In this article, Dr. Lewis Hobbs presents the evidence that planetary systems are orbiting stars other than our Sun. The steps in developing the case are not always easy to follow, and the conclusions are only tentatively drawn. Direct observation and measurement are not yet possible, so deductions from indirect evidence have to be painstakingly pieced together using rigorous scientific logic.

In the next few years, with the launch of the Hubble Space Telescope and the development of other powerful observing methods, we may uncover direct evidence of planetary neighbors in the galaxy. But until then, the evidence remains circumstantial.

— CHARLENE M. ANDERSON



In 1983, a group of scientists led by H. H. Aumann of the Jet Propulsion Laboratory pointed IRAS at several dozen very bright, nearby, well-studied stars. Observing Vega, Fomalhaut and Beta Pictoris, they found one of the most provocative surprises of the entire mission. All three stars are of a particularly simple kind, thought to be well-understood, and for many years astronomers had extensively observed them in visible and ultraviolet light. With this extensive prior knowledge, they could predict the color and brightness of the infrared light expected from these stars with unusually high confidence. In fact, Vega is *the* "spectrophotometric standard star" and observations of it were used in part to verify the proper operation of IRAS.

To the scientists' surprise, the three stars appeared up to 100 times brighter than expected in the low-energy band [see box on page 6], while the highest-energy-band measurements agreed with those predicted. The IRAS team studied Vega most thoroughly. By mapping the sky around the star, they showed that the source of the "excess" low-energy infrared radiation extends at least 85 Astronomical Units from the star. (One Astronomical Unit is the average distance from Earth to the Sun, about 150 million kilometers. By comparison, at its aphelion, or greatest distance from the Sun, Pluto reaches some 50 AU in distance.)

The simplest explanation fitting these unexpected results is that two distinct objects, a star and a surrounding shell of cold solid particles, together provide the radiant energy received by telescopes. The ultraviolet, visible and high-energy infrared light is mostly normal starlight. A very small fraction of this starlight is intercepted and absorbed by the surrounding solid particles. The particles then signal their (previously unsuspected) presence by reemitting the absorbed energy as light in the far infrared.

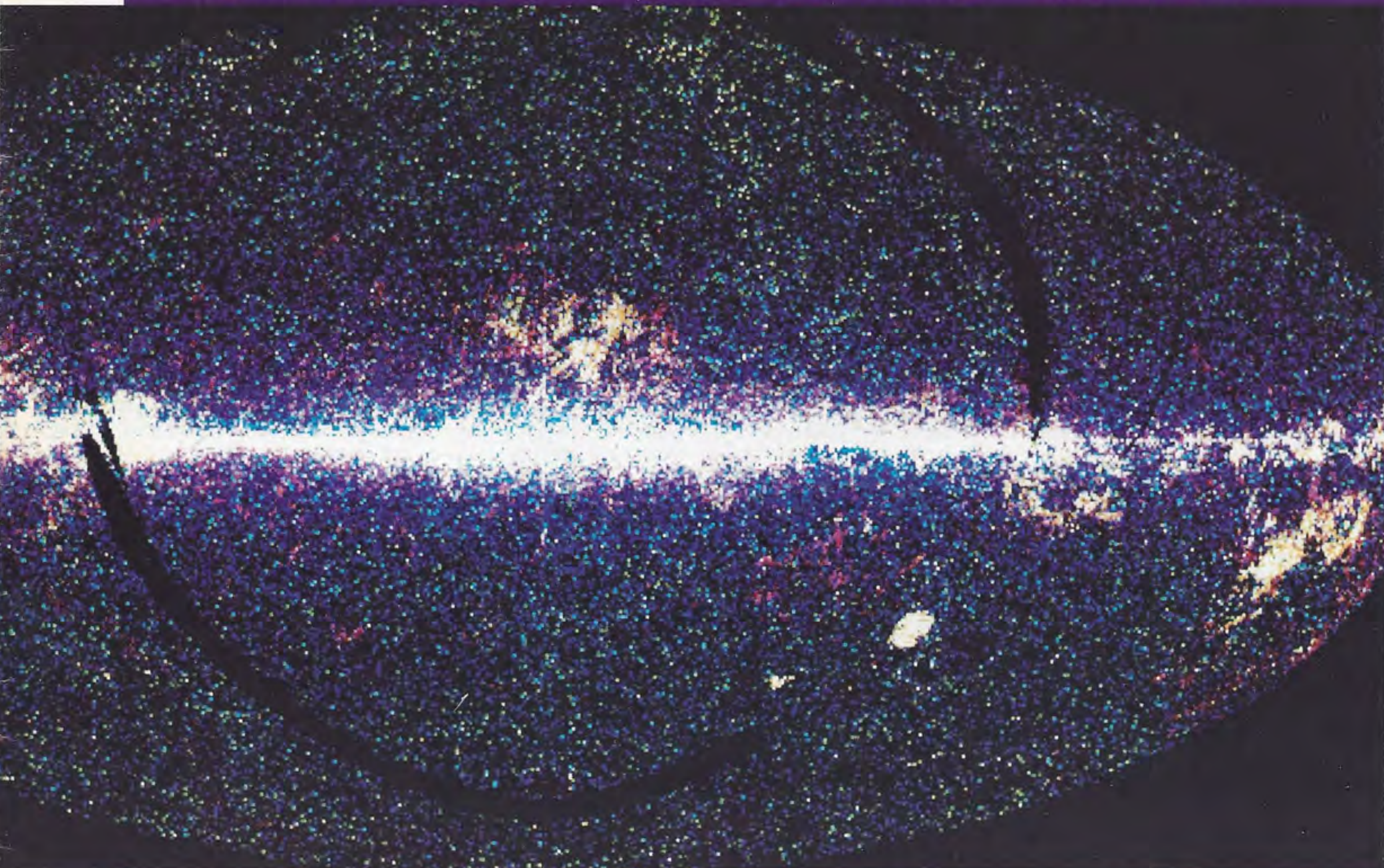
The measured color of this excess infrared light — the concentration in the lowest-energy bands of IRAS — makes these circumstellar disks exceptionally interesting. According to physical laws, particles emitting such "cold" light must themselves be very cold. The temperature of a typical particle must be about −185 degrees Celsius, only 88 degrees above absolute zero (−273 degrees Celsius).

This result is not immediately surprising to astronomers; for over 50 years they have studied tiny, still cooler particles, called interstellar dust, that are thinly spread between the stars scattered throughout galaxies. However, clouds of interstellar dust particles are cold because they usually drift at least 100,000 AU from any star

STARLIGHT

Evidence for Circumstellar Dust Disks

by Lewis Hobbs



OUR MILKY WAY GALAXY in infrared light, as revealed here by IRAS, is even more spectacular than it is to the human eye. The Infrared Astronomical Satellite scanned the entire heavens, except for small regions shown as dark arcs in this picture. Thousands upon thousands of sources — stars, clouds of gas and dust, and other galaxies — were recorded at four infrared wavelengths. Here the sources are plotted in galactic latitude and longitude, with colors indicating intensities in the infrared. IMAGE: JPL/NASA

whose light would heat them. In sharp contrast, the solid particles tightly orbiting Vega, Fomalhaut and Beta Pictoris are only about 100 AU from the stars and therefore are much more strongly heated.

An energy-balance calculation shows convincingly that this circumstellar dust can remain as cold as the IRAS observations require only by reemitting the absorbed starlight as infrared light about 100 times as efficiently as do the familiar interstellar dust particles. The circumstellar particles therefore must have representative diameters at least 200 times larger than those of interstellar dust, and they could be much larger. Although this minimum diameter (0.02 millimeter) is very small by everyday terrestrial standards, such large solid particles are known in only one other place in the universe — the interplanetary space of our solar system.

Interpreting the Results

It's not surprising that particles smaller than 0.02 millimeter are scarce in this circumstellar material; the pressure of intense starlight is enough to blow them away in a few years, just as sunlight draws out the dust tails of comets in our solar system. But three questions about the unaffected larger particles immediately stand out: Where did they come from? What is their total mass? How big are the typical particles, and the largest ones?

Our solar system is about 4.6 billion years old; Vega's age cannot exceed 0.3 billion years, and it may be even younger. The IRAS astronomers assumed that the individual dust particles have been bound in generally stable orbits since the birth of the star itself. Perhaps the disks of dust were left behind when the stars contracted from clouds of interstellar gas to their present sizes, about twice that of our Sun. Such an assumption leads to two primary consequences. First, the minimum diameter of these long-unprotected dust particles must now be about a millimeter. The Poynting-Robertson effect, a weak secondary action of the pressure of starlight, causes all smaller particles to spiral slowly inward to destruction near the parent star. Second, if there is no supply of the surviving larger particles, then they have grown rapidly in the disks — since there is no evidence that solid particles larger than common interstellar dust were present in the circumstellar disks at their births.

The IRAS observations yield no information about either the maximum size of a typical particle or, consequently, the total mass of the disk. The total mass of solid particles could, for all we know, exceed that of our planetary system. However, most of the observed infrared excess must be emitted by large numbers of solid bodies much smaller than asteroids or comets. Larger objects would contribute little to the excess, and so we cannot detect them by measuring it. At present, we have no way of knowing if planets have already evolved, or will never form, or are now growing.

The American-Dutch-British Infrared Astronomical Satellite, IRAS, surveyed the heavens in a spectral region that cannot be usefully observed from Earth. Infrared radiation is what warms your face around a campfire. In the cosmos it is emitted by relatively cool objects, including the clouds of gas and dust that may be the birthplaces of planets.

The liquid-helium-cooled telescope of IRAS, orbiting above the infrared absorption and emission of Earth's atmosphere, recorded more than a hundred thousand celestial sources radiating in wavelength bands 12, 25, 60 and 100 microns (a micron is a millionth of a meter; our eyes can see only light with wavelengths around a half a micron). By observing differences in intensity in the four IRAS wavebands, scientists can determine the temperature and many other properties of objects such as a dust-shrouded star or an interstellar gas cloud, and by comparing IRAS observations with ground-based optical and radio data they can create models of the star systems, clouds and galaxies observed by IRAS.

Infrared astronomy is just beginning a role that will grow greatly in the future as we search the cool places of the universe, where organic and biological molecules can survive, for evidence of our own origins and for clues to the existence of other life. — *JAMES D. BURKE*

Observing the Cold Dust

Following the publication of the IRAS results, in March and June, 1984, other scientists quickly turned their attention to the circumstellar disks. In October, 1984, a group of astronomers at the University of Chicago, headed by D. A. Harper, published a measurement of the excess infrared light from Vega in a still lower energy band. They used a telescope in NASA's Kuiper Airborne Observatory.

The IRAS team had inferred that the minimum diameter of the particles exceeds one millimeter. For particles this large, the infrared flux expected in lower energy bands could be predicted fairly reliably. But the Chicago group found Vega to be about three times less bright than predicted. They drew the important conclusion that the *maximum* diameter allowed by this deficiency could be only about 0.1 millimeter. If further work confirms the limited range of 0.02 to 0.1 millimeter for most of the particles in Vega's disk, then the total mass of the particles is less than one-thousandth of Earth's mass. This uncollected dust would be incapable of forming planets comparable to those in our solar system, but the presence of already formed planets is not excluded.

The Chicago group consequently was forced to put forward a different view of the particles' origin. Their picture is based on processes known to operate in the interplanetary space of our solar system. It is believed that the smaller particles here are continuously resupplied from debris ejected by passing comets. There is, apparently, a long-term balance between removal and resupply. In Vega's disk, a modest reservoir of comet-like bodies would similarly balance the steady removal of the submillimeter-sized particles. The recently released particles now exposed to starlight would have been previously protected within the interiors of the comet-like bodies.

In this picture, the circumstantial evidence for larger solid bodies takes a different form. Instead of small dust particles in Vega's disk evolving to larger sizes, this analogy with the solar system suggests that whatever events led to the formation of comet-sized bodies might similarly lead to the formation of larger objects, perhaps planets.

The first direct "photograph" of the near-infrared starlight reflected from a circumstellar dust disk was published in December, 1984. Obtained at the Las Campanas Observatory in Chile by astronomers Bradford Smith of the University of Arizona and Richard Terrile of the Jet Propulsion Laboratory, the picture spectacularly shows a highly flattened disk surrounding Beta Pictoris. It extends at least 400 AU from the star — 10 times farther than Pluto is from the Sun. This image demonstrated for the first time that the solid particles orbiting at least one of these "IRAS" stars are not arranged in a spherical shell, but, like the principal masses of our solar system, are concentrated in a single plane.

Gas Among the Dust

Observations reported in 1985 have directed attention to another component of the disks surrounding Vega, Fomalhaut and Beta Pictoris. Interstellar dust particles are invariably found mixed with highly rarified gas, with solid particles making up only about one percent of this mixture. The observations of dust around the three stars stimulated astronomers to search for gas mixed with the dust.

A clue provided by the example of our solar system was superficially discouraging: The amount of uncollected gas in our interplanetary space is quite small. However, the much greater age of our solar system and the likelihood that any free gas originally present would have either been ejected from the system or captured by its larger bodies suggested that very young circumstellar disks could be gas-rich.

A powerful method for detecting such gas is to measure spectroscopically the absorption of light passing through it. We use sets of absorption lines to detect the presence of gas and to identify the chemical elements in it. (The term "absorption line" refers to absorption confined to one extremely narrow range of wavelengths of light.) Some of the light we receive from any of the parent stars may pass through its circumstellar disk. A careful study of the star's spectrum can reveal both the presence of circumstellar gas and many of its physical properties.

The first study of this kind published after the IRAS launch was carried out by Yoji Kondo of the Goddard Space Flight Center and Frederick Bruhweiler of the Catholic University of America, using the Earth-orbiting International Ultraviolet Explorer (IUE) launched in 1978. They found very strong absorption lines caused by gaseous atoms of iron and carbon surrounding Beta Pictoris. Comparing the strengths of the absorption in various lines, they found the density of the circumstellar gas about one AU from the star to be at least 10 thousand times larger than that of the interplanetary gas near Earth. These results strikingly revealed a rich supply of dense gas within the dust disk directly imaged by Smith and Terrile.

Independent, nearly simultaneous ground-based observations were published two months later by an international team, headed in the United States by myself and in France by Alfred Vidal-Madjar of the Institute of Astrophysics in Paris. We carried out our observations at the McDonald Observatory of the University of Texas and at the European Southern Observatory in Chile with spectrographs having 10 times the resolving power of the IUE. We searched the visible-light spectra of Vega, Fomalhaut and Beta Pictoris, and also analyzed older ultraviolet spectra of Beta Pictoris stored in the IUE archives.

In the light from Beta Pictoris, we detected strong absorption by calcium along with weak absorption by sodium and no detectable absorption by either zinc atoms or CH^+ molecules, both normally present in cosmic gases in minute quantities. From this combined information, we gained confidence that we understand the essential physical conditions in the absorbing gas near Beta Pictoris: It is cold and electrically neutral, despite its proximity to a hot star intensely irradiating the gas. Therefore, we could crudely but fairly safely estimate the mass of the circumstellar gas from its absorbing power.

The distribution of the dense gas with respect to the dust is nearly unknown at present. The simplest assumption is that the two are well mixed, as in most other cosmic examples. Using such a model, with the gas filling the dust disk imaged by Smith and Terrile, we found two principal results. First, the gas' density falls within the range allowed by the independent analysis of Kondo and Bruhweiler. Second, the mass of uncollected gas cannot exceed about one percent of Jupiter's mass, although it is vastly larger than the mass of interplanetary gas remaining in our much older solar system. In comparison with the upper limit on the mass of the dust disk, a mixture of 1 percent dust and 99 percent gas — common elsewhere in the galaxy — is permitted but not proved.

Planets or Not?

As with the infrared emission by the dust, these gaseous absorption lines are unlikely to reveal larger solid bodies such as asteroids or planets. Therefore, we reach a similar conclusion here. With what we know of the circumstellar gas near Beta Pictoris, either a massive planetary system has formed already or the uncollected gas now present is incapable of producing such a system, due to its small mass.

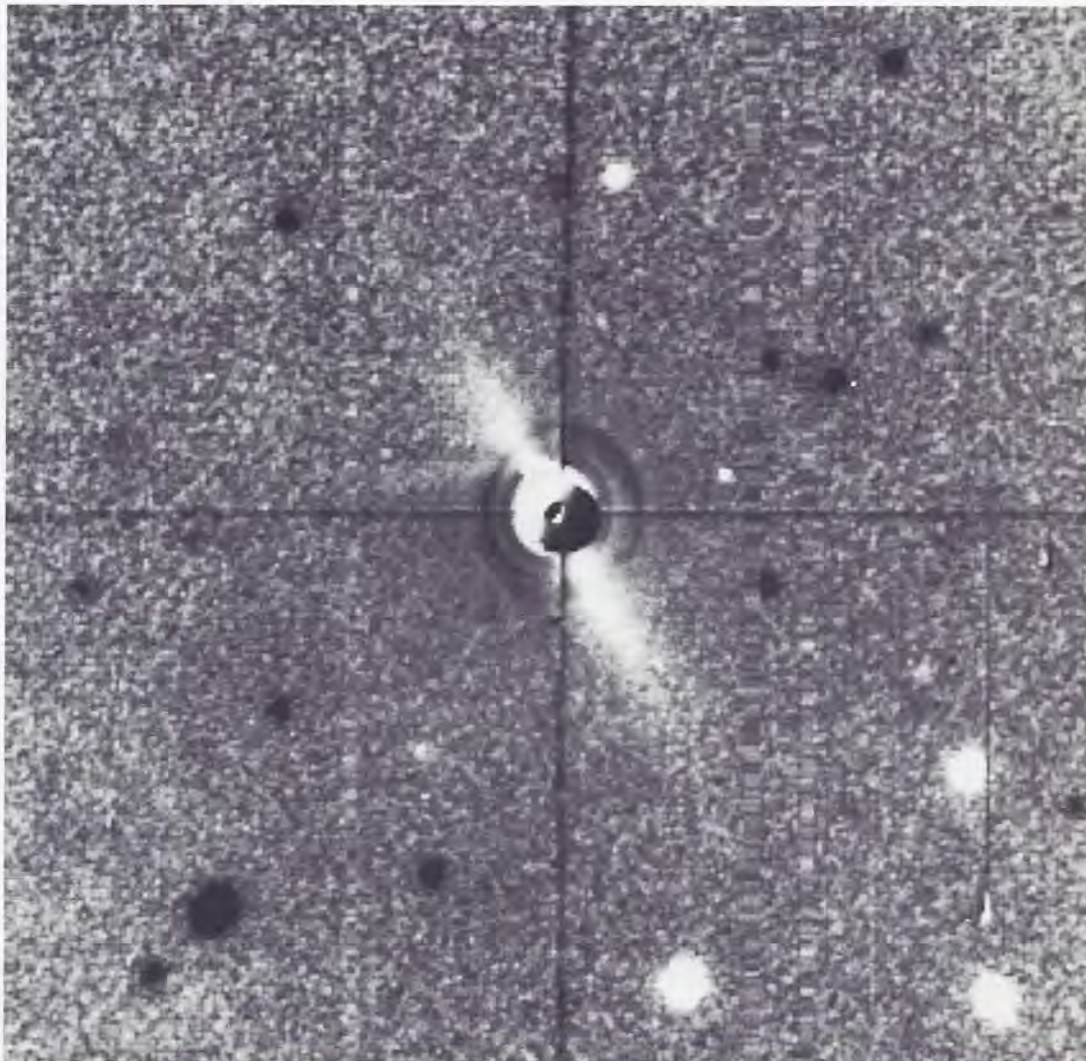
Our observations of Vega and Fomalhaut showed, in contrast, no detectable absorption of either calcium or sodium atoms. These negative results do not exclude circumstellar gas near these stars. In fact, they add an important confirming hint about the spatial distribution of gas and dust in these disks. Smith and Terrile's image of Beta Pictoris shows that we view the disk nearly edge-on from Earth. This is the best possible orientation for absorption studies, since the light from the star passes through the largest quantity of gas.

If, instead, the plane of the disk were tipped so that we happened to see it nearly face-on, only a much smaller quantity of gas could contribute to the absorption. This probably could account for our negative results at Vega and Fomalhaut — provided that the gas, like the dust, is confined to thin disks. Indeed, we have long known that the apparent rotation rates of Vega, Fomalhaut and Beta Pictoris suggest entirely independently that any equatorially located disks would be seen nearly face-on for Vega and nearly edge-on for Beta Pictoris. Fomalhaut is intermediate between these two, though it resembles Beta Pictoris more than Vega. We conclude that both the gas and the dust are confined to thin circumstellar disks, not to spherical shells.

To summarize, several young, nearby stars in our galaxy harbor orbiting material rich in large solid particles and, at least at Beta Pictoris, uncollected gas. This material surrounding Beta Pictoris is confined primarily to a thin disk roughly comparable in size to our solar system. The total mass of uncollected dust near Vega and of uncollected gas near Beta Pictoris appears to be much less than the mass of Jupiter. Such small amounts of matter cannot be the raw material from which massive planetary systems might form. No direct detection of already formed solid bodies as large as comets, asteroids or planets would be expected from these measurements.

However, the large solid particles discovered in these circumstellar disks are known at present in only one other place in the universe — in our solar system. Their presence here is intimately related to, and strikingly betrays, the formation of a planetary system. Thus, while the case for other planetary systems remains open, there is now circumstantial evidence, firmly based on direct observations, for their current or future presence around nearby stars. Those stars are now being intensively studied.

After centuries of speculation, by directly comparing such young stars and their surrounding material with our own solar system, we may eventually clarify the nature and timetable of events leading to the origin of planets.



THIS COMPUTER-PROCESSED IMAGE reveals a disk of material orbiting the star Beta Pictoris. The visible disk, probably composed of ices, carbonaceous matter and silicates, extends about 60 billion kilometers from the star. Its inner regions may have been partly swept out by unseen planets. This system, about 50 light-years from Earth, may be only a few hundred million years old.
IMAGE: Bradford A. Smith, University of Arizona, and Richard J. Terrile, JPL/NASA

Lewis Hobbs is a Professor of Astronomy and Astrophysics at the University of Chicago.

HALLEY AT

For the first time, spacecraft from Earth ha
of the nucleus. As Halley's Comet swung
system, five spacecraft were waiting to me
the nucleus: Vega 1 on March 6, Vega 2 on Mar
Sakigake monitored the solar wind and the hyd
thousands of kilometers away.

These missions were triumphs of internationa
Soviet-led Intercosmos, a consortium of East E
USSR, Hungary, Bulgaria, Czechoslovakia, the G
Federal Republic of Germany and the United St
closest approach to the comet, targeted with the
in an effort called "Pathfinder." By working toge
harvest of data from humanity's first encounter

And what a harvest it was! The "dirty snowbal
the spacecraft revealed a peanut-shaped core a
warmer than expected. The images on these pa
continue to process the images and combine tha
the spacecraft to complete the picture of Halley

ABOVE: Last January, before it reached perihelion (closest approach to the Sun), Carolyn and Eugene Shoemaker photographed Halley's Comet with the 18-inch Schmidt telescope on Mount Palomar. The comet was then about 197 million kilometers from Earth, with its visible tail here about 10 million kilometers long. As the Vega and Giotto spacecraft revealed, all the brilliance and beauty of Halley's Comet comes from a small black nucleus, some 15 x 6 kilometers in size.
IMAGE: Carolyn and Eugene Shoemaker, United States Geological Survey, from film by Bobby Bus, Lowell Observatory

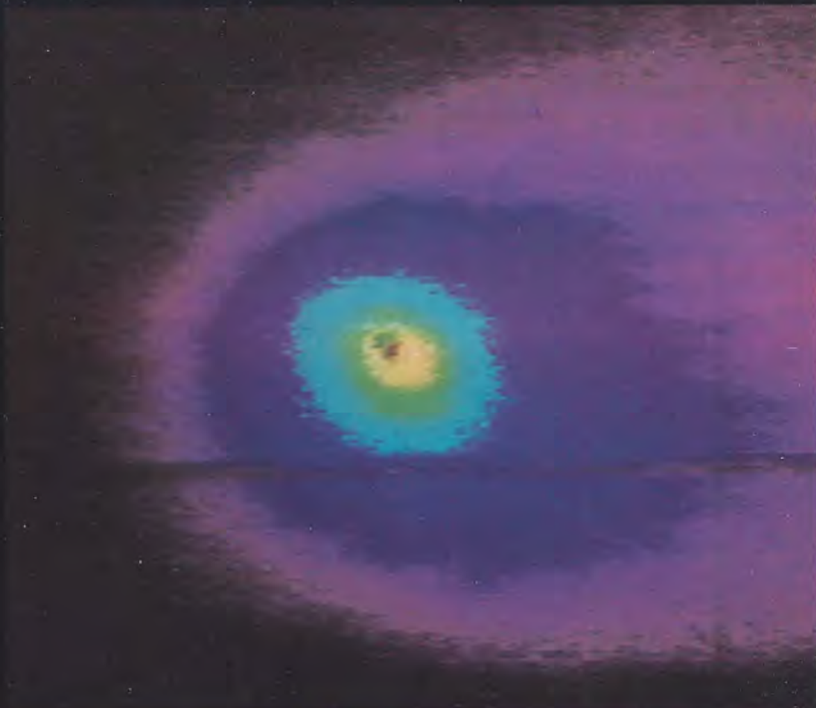
LEFT: Giotto's Multicolor Camera took this image of the comet's nucleus on March 14, 1986 when it was 20,000 kilometers from its target. The dark object near the center of the image is the comet's nucleus, which would appear to our eyes as velvet black. The "dirty snowball" hypothesis of Fred Whipple (see the July/August 1985 Planetary Report) appears to have been borne out by the spacecraft data, although the nucleus is darker than expected. A crust of organic (carbon) compounds probably covers the ice and dust. The surface temperature is about 60 degrees Celsius (140 degrees Fahrenheit). A dust jet, erupting from the sunlit side of the comet, appears here as the lightest region. This image covers an area about 125 x 125 kilometers.

ABOVE: The bri
color image of c
brightness level
Giotto's camera
the brightest ob
it focused here
than the nucleu
side in this imag
about 1,500 kilo
IMAGE: Max Planck In
Richard Berry, Astron

T LAST! *Vega* and *Giotto* Photograph the Nucleus of the Comet

e penetrated the coma of a comet to send back images
round the Sun on its 1986 pass through the inner solar
t it. Three of them flew through the dusty coma and past
h 9 and *Giotto* on March 13. Meanwhile, *Suisei* and
gen cloud surrounding the comet from hundreds of

cooperation. The *Vega*s were built and operated by the
ropean nations, and carried instruments designed in the
rman Democratic Republic, Austria, Poland, France, the
tes. The European Space Agency's *Giotto* made the
elp of the *Vega* team and the NASA Deep Space Network
her these spacefaring nations increased everyone's
vith Halley's Comet.
hypothesis of the comet's nucleus was confirmed, and
dark as black velvet. The nucleus was both larger and
es represent only early, rough data; scientists will
information with data gathered by other instruments on
Comet.



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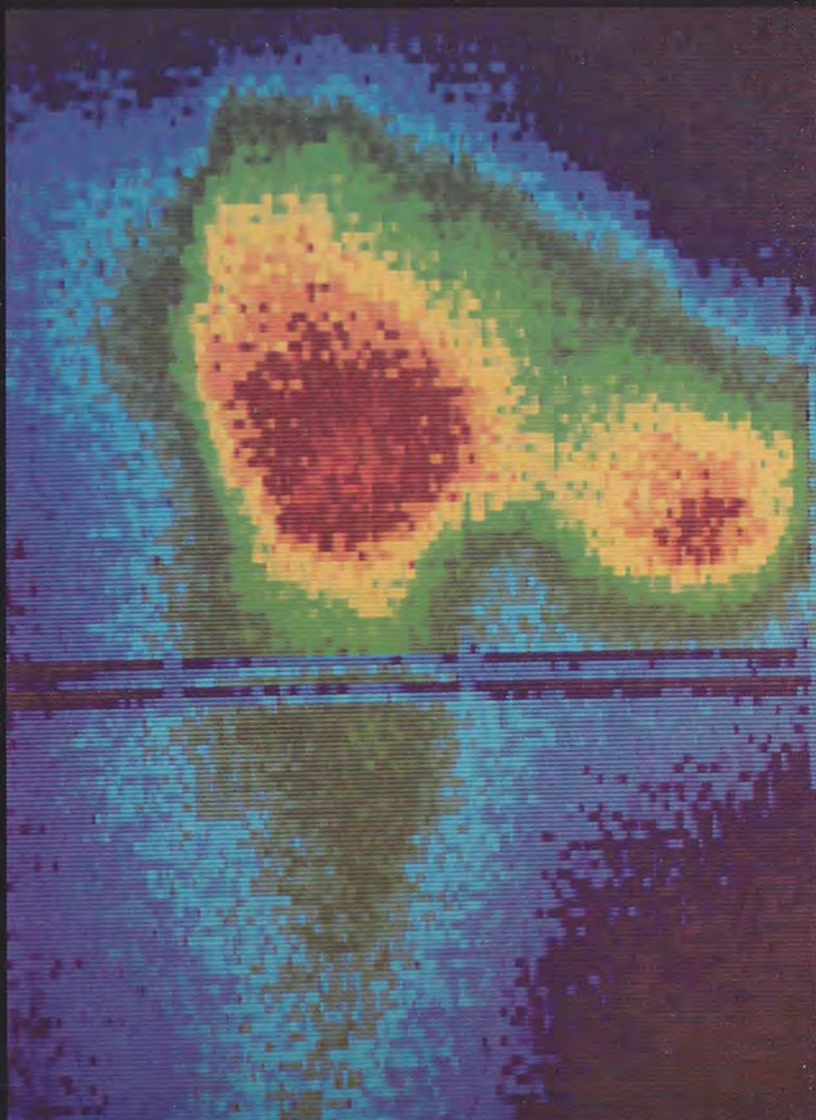
itut fur Aeronomie, courtesy of
ny magazine



ABOVE RIGHT: Two days before encounter, and 14 million kilometers from its target, Vega 1 returned its first image of Halley's Comet. The coma, or atmosphere of dust, surrounding the comet's nucleus is clearly visible. Although it may appear that the familiar comet tail is streaming out to the right side of this image, that is actually the direction of the Sun, and the tail extends in the opposite direction. The Sun warms the icy nucleus, and it releases dust to form an atmosphere on the sunlit side. The light reflects off these particles, as recorded here by Vega 1.

RIGHT: The shape of the comet's nucleus was revealed by Vega 2 in this image taken at closest approach, only 8,000 kilometers away. The nucleus nearly fills the image area, about 15 kilometers across. If we could see the peanut-shaped nucleus with our eyes, it would appear as black as coal. The colors here indicate brightness, the highest intensities appearing red, the lowest, blue. A dust jet, seen here in green and blue, extends downward from the nucleus. Both Vega spacecraft passed through such jets as they flew by the comet, and many instruments (as well as 80 percent of the solar cells) on Vega 2 were knocked out by impact with the dust.

IMAGES: Institute for Space Research, Soviet Academy of Sciences

News & Reviews

by Clark R. Chapman

Science and technology are often portrayed as cut-and-dried, rational enterprises, carried out by objective men and women. Yet, they are human activities too, deeply affected by the subjectivities, emotions and uncertainties of human existence. In this column, I'll consider a couple of recent magazine articles dealing with the speculative side of science, and then I'll dive into the murky realm of political and economic opinion.

Oil Crisis Solved?

One of the most fascinating space scientists of our times is Professor Tommy Gold of Cornell University. Gold is featured in the cover story of the February *Atlantic Monthly*. An ex-ski instructor and an early proponent of the so-called steady-state theory of the universe, Tommy Gold is always pursuing big issues with absolute disregard for conventional wisdom. Recently he has been debunking the conventional view that our planet is running out of fossil fuels.

Gold would have us believe that in the depths of Earth there is an inexhaustible supply of oil and natural gas. He thinks much of our economically vital hydrocarbons are of primordial origin — dating from the earliest history of our solar system — rather than being of fossil, or biological, origin. Gold has been pursuing these ideas, to the consternation of petroleum geologists, for quite a few years now.

David Osborne's story in the *Atlantic* about Tommy Gold seems to be a plausible portrayal of many debates in science, when new ideas clash with the traditional underpinnings of a well-established science. Osborne compares Gold with Alfred Wegener, who was the lonely advocate of continental drift many decades before the intellectual revolution in geophysics that brought sudden acceptance of the plate-tectonics perspective of Earth's geology. Wegener was not the first, nor the last, "crack-pot" to challenge the scientific establishment, to be ridiculed, but ultimately to be vindicated.

That does not mean, however, that every eccentric idea is right, nor that every debunking by establishment scientists is mere close-mindedness. Maybe Tommy Gold has found a panacea to the energy crisis. Then again, maybe he is an astrophysicist out of his depth, trying to address a geological question far from his field of expertise.

While Osborne's article is a fundamentally good one, I fear that it is inherently unbalanced, and that the *Atlantic* is exhibiting a lack of balance in printing it. Is it truly good journalism to treat two opposing sides equally, when they are inherently unequal? Should Gold and his few supporters get equal treatment in opposing whole established scientific fields? I think Osborne talked with Tommy a little too exclusively. Early in the article, Osborne mentions some of Tommy's earlier controversial assertions, some now thought to be right, others wrong. He quotes as a chief example of Tommy's "correct" ideas his 1960's advocacy of dust on the Moon. Of all lunar scientists I know, Tommy is the only one who thinks his dust ideas were proved right by *Apollo*. The astronauts' shallow footprints in lunar soil were a far cry from Tommy's often expressed fears that the Lunar Landing Modules would sink out of sight into seas of dust.

In this year of 1986, with *Voyager's* historic Uranus encounter and international exploration of Halley's Comet, it is a shame that when *Atlantic* chooses to print a planetary article once or twice a year, it picks one on the fringe.

Wandering Poles on Mars

Before plate tectonics, the term "polar wandering" conjured up the once disreputable ideas of continental drift. Now incorporated into accepted models of plate tectonics for Earth, the term — applied to the planet Mars — is again controversial. Unlike *Atlantic, Scientific American* has paid its dues with scores of centrist articles about planetary science. So I have no complaint that it gave some pages of its December 1985 issue to Peter Schultz's arguments that the entire crust of Mars may have shifted with respect to its spin axis. Schultz, a sharp-eyed interpreter of planetary photographs and a professor at Brown University, believes the Red Planet's equator may once have been near a pole. Unlike Osborne's "balanced" commentary, Schultz's article is pure advocacy. But the logic is tight and the illustrations pertinent. So long as readers recognize that there *is* another view, this article is highly recommended.

Politics of Space

Scientific American occasionally ventures beyond the realm of scientific speculation to the even shakier world of political opinion. In its January issue, the eminent space physicist and Planetary Society Advisor, James Van Allen, argues about the goals and costs of the space program in the era of the space station. Planetary Society members, whatever their personal views about the relative merits of unmanned spacecraft versus astronaut-inhabited vehicles, would do well to consider Van Allen's views, based as they are on his many decades of involvement with the space program.

Writing before January's tragic explosion of the *Challenger*, Van Allen recalls the history of selling the shuttle in the early 1970's, and claims that it has always been an economic failure. He documents the number of planetary and astrophysics programs, and Earth-orbital science and applications missions too, that have been cancelled or delayed by development delays and the financial pinch of the Space Transportation System. He fears that today's promotion of the cost-effectiveness of a space station is similarly wildly unrealistic.

One must remember, however, in reading Van Allen's article that, while it is written by a scientist, it is mainly an opinion piece. As Van Allen writes himself, we cannot rerun history and see what the space program would look like today if different decisions had been made a decade or two ago. He offers facts and figures, but his interpretations of them will be disputed. Van Allen is probably not too far from the mark in explaining that the recent cost of launching things into space has been fully 20 times what proponents of the shuttle were promising back in the early 1970's. Van Allen's conclusion that the shuttle has been a failure would presumably be augmented by the enormous disruption of the space program due to the recent tragedy.

On the other hand, the public has loved the shuttle, exulted in its triumphs, and wept after its tragedy. The outpouring of positive hopes for the manned space program in the aftermath of the shocking loss of seven astronauts pays tribute to the depth of public identification of the space program with the historical exploratory traditions of the American people. It is difficult to quantify the value of adventure and pride in cold, budgetary terms.

In the November/December 1985 Planetary Report, *Clark Chapman stated that he would stay home in Tucson, Arizona this spring, rather than go on a cruise to see Halley's Comet. But he went on The Planetary Society cruise after all.*

World Watch

by Louis D. Friedman

In 1964 I began working on missions to explore comets. Since 1974 I have worked on every proposed mission to fly to or through Halley's Comet, including those of the United States, Europe, Japan and the Soviet Union. Because of this background, I felt privileged to "ride" three spacecraft through Halley's Comet in early March, at the Institute for Space Research in Moscow and at the European Space Operations Center in Darmstadt, Federal Republic of Germany. Later this year we will give you the scientific details of the missions in a special issue of The Planetary Report. For now, we can only briefly comment on the cometary successes of scientists from over a dozen nations who worked together to explore an old world, now newly seen.

MOSCOW — On March 6, *Vega 1* flew through Halley's Comet, followed on March 9 by *Vega 2*. They passed within 8,900 and 8,000 kilometers, respectively, from the nucleus. Carrying 16 experiments from 10 nations, the spacecraft relayed to Earth the first images of a comet's nucleus. In the *Vega 1* images, the nucleus was barely visible through a dust "cocoon." It wasn't until *Vega 2* arrived three days later — when the comet was slightly less active — that scientists could be certain they had indeed seen the nucleus.

The encounter was punctuated by several dramatic moments. During *Vega 1*'s flight through the comet, John Simpson of the University of Chicago detected a dust jet striking his dust-counting instrument onboard the spacecraft. As *Vega 2* neared its closest approach, dust apparently struck and damaged a microprocessor controlling the television camera. The microprocessor failed 32 minutes before encounter, leaving barely enough time for controllers on Earth to contact the spacecraft and implement a back-up mode of operation. The Soviet-Hungarian imaging team responded quickly and, fortunately, the spacecraft transmitted its best images in this mode.

Overriding even the science was the visible evidence of international cooperation. Visitors from many nations, including a delegation from NASA and Dr. Carl Sagan and myself from The Planetary Society, witnessed the encounters. Members of the American press were also there, and the Society was able to arrange for ABC News' "Nightline" to broadcast the encounter live for the American public.

As a memorial to astronaut-teacher S. Christa McAuliffe, Academician Roald Sagdeev, the Director of the Institute for Space Research, suggested that The Planetary Society organize a visit to the Institute for schoolchildren from several countries. Children from the Anglo-American School in Moscow joined with Soviet students to tour the Institute as data from the *Vegas* were being received. The children met, mingled and listened to Soviet and American scientists describe what they were learning about Halley's Comet.

DARMSTADT, WEST GERMANY — After the *Vega* encounters, the scene shifted to the much smaller European Space Operations Center where 2,000 people stood by as the *Giotto* spacecraft flew within 550 kilometers of the comet's nucleus on the morning of March 14. Again, Halley's Comet provided great drama when something (probably a dust particle) hit the spacecraft just at closest approach and caused it to lose its radio lock on Earth. But before the collision, *Giotto* took the best pictures yet of the nucleus, while its nine other instruments measured the comet's composition and environment. Surprising many, the spacecraft survived the encounter and within 35 minutes of the collision it was again communicating with its Earth-based controllers. However, the camera and several other instruments were damaged by the impact.

By the time of this fourth encounter with the comet (the Japanese *Suisei* flew within 151,000 kilometers of the nucleus on March 8), the remnants of Halley's mystery were being stripped away. The peanut-shaped nucleus — darker and warmer than expected — was now familiar to us. The dark color is probably due to carbon and organic compounds.

The success of international cooperation was cited by all the experimenters in their reports. Without the multinational efforts on *Vega* and *Giotto*, the harvest of data would have been much poorer.

MOSCOW AND DARMSTADT — The Inter-Agency Consulting Group (IACG) of the space agencies of the USSR, Europe, Japan and the US met during both the *Vega* and *Giotto* encounters to review their success with Halley's Comet and their plans for the future. In the Pathfinder project, *Giotto* was targeted closer to the comet using *Vega*'s pictures and the NASA tracking network, reducing the navigational error from hundreds of kilometers to about 40. (Pathfinder was first reported to the public by one of its originators, Society Advisor Jacques Blamont, in the March/April 1981 *Planetary Report*.) The European Space Agency's space science director, Roger Bonnet, called it the greatest example of space cooperation.

The IACG agreed to continue coordination and to look at immediate projects in the International Solar Terrestrial Program, in future planetary missions and in radio astronomy. NASA Associate Administrator Burt Edelson said, "The success of the IACG with Halley's Comet underscores the importance of international cooperation in space science. We must build on this for the future."

WASHINGTON, DC — Tempering the excitement of the great spacecraft achievements at Uranus and Halley's Comet, NASA continues to struggle to recover from the *Challenger* disaster. The presidential commission investigating the accident will report soon, but even before its report many questions about NASA procedures were being raised in hearing testimony and press reports.

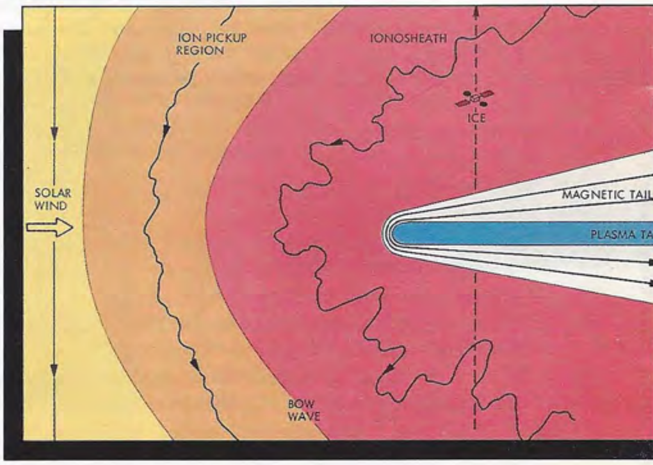
President Reagan named former NASA Administrator James Fletcher to resume control of the agency. NASA indicated that about $3 billion will be needed to replace the lost shuttle and cover additional costs due to delayed payloads. They have also stated that no more than nine launches will be possible in 1987 — and even this number is optimistic. The ramifications for space exploration will be profound, with *Galileo*, *Ulysses* and the Hubble Space Telescope all stuck on the ground, and a backlog of the equivalent of at least 24 fully loaded shuttles expected to accumulate by 1990.

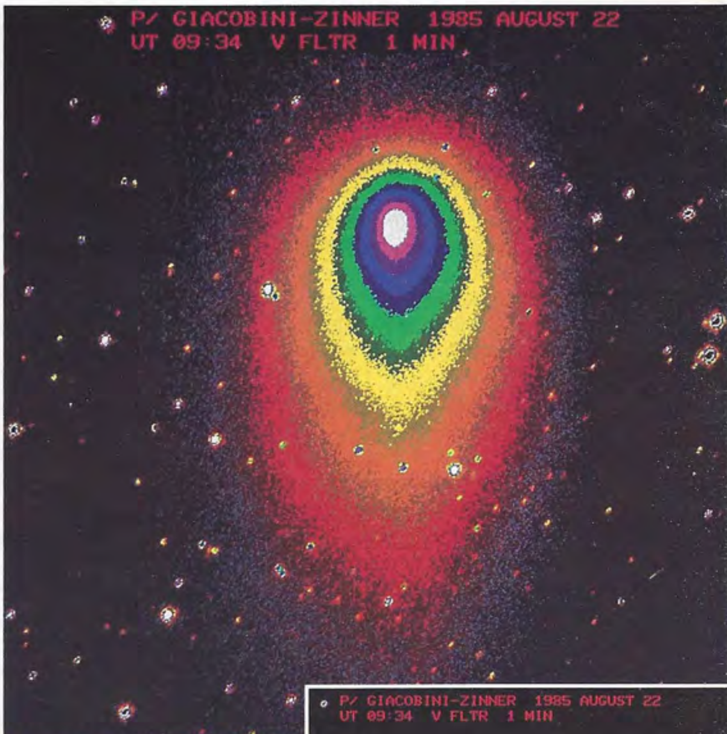
The National Commission on Space, headed by Dr. Thomas O. Paine, will also report soon on its recommendations for the United States' goals in space. In the next few months, we can expect a great deal of discussion about these goals, and what NASA will have to do to reach them.

Louis Friedman is the Executive Director of The Planetary Society.

Visiting a

TOP: The interplanetary magnetic field, frozen into the solar wind, encounters a cometary ionosphere. This interaction slows the solar wind in the vicinity of the comet. MIDDLE: The field lines then drape around the comet, forming a long magnetic tail. Plasma is trapped between the regions of oppositely directed field lines. BOTTOM: The ion tail becomes visible when enough plasma has become trapped between the magnetic tail lobes. Here, an image of a comet's dust tail is overlaid on the ion tail. IMAGES: Produced at the JPL Computer Graphics Laboratory from a simulation by R.S. Wolff and J.M. Goldsmith





Comet Giacobini-Zinner appears here in two pictures created from the same exposure. The colors in the image above are computer-generated to display different levels of light intensity. The image to the right shows the comet as a human eye might see it looking through a telescope. IMAGES: Uwe Fink, Lunar and Planetary Laboratory, University of Arizona

Comet

ICE Flies Through Giacobini-Zinner

by Edward J. Smith

As it flew through Comet Giacobini-Zinner, the ICE spacecraft detected several different plasma regions associated with the comet, as illustrated here. The lines with arrows represent the directions of the magnetic fields.
ILLUSTRATION: JPL/NASA

On September 11, 1985, a spacecraft flew through a comet for the first time when the International Cometary Explorer (ICE) passed through the tail of Comet Giacobini-Zinner, coming within 7,800 kilometers of the nucleus. The intercept was a scientific success and the spacecraft survived the dust hazard, which proved to be less than forecast by pessimists. It was an exciting event, the intercept alone ensuring a place in history for both the spacecraft and the comet. But the most important aspect of the encounter was the new scientific information obtained.

When an active comet is visible in the night sky, it is made up of three major parts: dust, neutral gas and plasma. The plasma is an ionized gas of electrically charged atoms and the electrons which have been removed from them — for example, by the absorption of ultraviolet sunlight. Plasmas are unfamiliar to many people, although they are found in combustion, in gaseous discharges (neon tubes, fluorescent lamps and photoflash units) and in laboratories devoted to thermonuclear research. However, in space, where gases are typically both hotter and much less dense than at Earth's surface, plasmas are the norm. ICE is essentially a space plasma physics laboratory.

In a comet, plasmas form the long ion tail. In photographs, comets often exhibit two tails — a yellow, curving tail of dust and a straight, often blue tail of cometary ions. The ion tail can change rapidly, disconnecting from the nucleus and then regrowing, or propagating helical structures along the tail. The formation and dynamics of the tail is a plasma physics phenomenon. Other cometary activities assuredly also involve plasma processes, and identifying and understanding these phenomena was a major goal of the ICE mission.

Plasma structures other than the ion tail have been difficult to identify from ground-based observations alone. It has also proven difficult to derive quantitative information (field strengths, densities, temperatures, velocities) from remote observations. So it was essential that we send a spacecraft through a comet to prove the known structures and to look for plasma features which we suspected or were unaware of.

As it travels into the inner solar system and is heated by the Sun, a comet's solid, icy nucleus emits the neutral gas that becomes the plasma. The nucleus' gravity is too weak to hold the escaping neutral atoms and molecules, which flow outward in all directions at a nearly constant speed (about one kilometer per second). Since sunlight continually falls on the neutrals, they eventually become ionized. This photoionization is a relatively slow process, taking up to 10 days, so many ions are created at great distances from the nucleus (about a million kilometers).

The cometary neutrals and ions do not expand into a vacuum. The solar corona is also a prolific source of plasma. This outermost atmospheric region of the Sun is very tenuous and extremely hot, with temperatures exceeding a million degrees. Despite the Sun's gigantic gravity field, it cannot hold the solar plasma, which flows outward at very high speed (about 400 kilometers per second) as the solar wind. The corona is threaded by magnetic fields originating at the solar surface and extending to high altitudes. Space plasmas typically behave like perfect electrical conductors. As a consequence, the coronal magnetic fields are carried off by the solar wind ions and electrons to form the all-pervasive interplanetary magnetic field.

The solar-wind magnetic field exerts a dominant force on charged particles in space. This force binds solar wind particles together so that they behave collectively rather than as individual particles, giving rise to gross behavior similar to that of a normal gas or fluid. When a cometary ion is created, the magnetic field immediately accelerates it up to the same speed as the solar wind. But the added mass of the cometary ions tends to decelerate the solar wind. The magnetized solar wind eventually reaches a place near the comet where it cannot exert enough pressure to push aside the cometary ions being created near the nucleus. At this point, the solar wind is deflected to flow around the comet.

ICE carried instruments to measure the solar wind, cometary ions and electrons, and the magnetic fields and waves generated within the plasma. The measurements show that ICE passed through at least four distinct plasma regions surrounding Giacobini-Zinner. Near a million kilometers from the nucleus, the spacecraft passed from the unperturbed solar wind to the transition region. This passage was marked by the appearance of energetic particles representing cometary ions accelerated to solar wind speeds, and by the generation of magnetic waves over a broad band of frequencies.

A hundred thousand kilometers from the comet, the spacecraft entered the ionosheath, a region where all plasma parameters became increasingly irregular. The density, temperature and speed of the solar wind (now contaminated by heavy cometary ions), the magnetic field strength and the intensities of the plasma waves all began to vary rapidly from very low to very high values. This is characteristic of a form of turbulence unique to plasmas. The outer boundary of the ionosheath represents a form of bow wave like that of a pier in a swiftly flowing river. As the spacecraft neared the comet, the plasma dramatically slowed and the magnetic field lines began to drape around the comet, which was acting as an obstacle to the plasma flow.

The comet's tail, penetrated 16 thousand kilometers (10 thousand miles) from the nucleus, consisted of two distinct regions. The thin central region (about a thousand kilometers across) was filled with a high-density, low-temperature plasma with a very weak magnetic field. This feature is an ion tail formed by cometary plasma flowing downwind. Apparently the solar wind is excluded from this region.

Surrounding the ion tail was a magnetic tail about ten thousand kilometers thick. On one side of the ion tail, the field pointed away from the Sun, while on the other side it pointed toward the Sun. This topology is the final state in the draping of the interplanetary magnetic field around the comet. In this region, the magnetic field was most intense and there was a distinct reduction in plasma, whether of solar wind or cometary origin.

I hope that this brief overview conveys a sense of the complexity of the interaction between an active comet and the solar wind. Within the different regions traversed, ICE obtained an extraordinarily rich data set. Its detailed observations pose many challenging questions. Is the bow wave actually a shock? What physical processes cause the surprisingly strong turbulence? What balance of forces accounts for the structure of the comet tail? If a successful experiment raises more questions than it answers, the Giacobini-Zinner encounter was certainly a scientific success. Scientists throughout the United States and Europe are now striving to answer these questions and are anticipating further clues from the encounters of Soviet, European and Japanese spacecraft with Halley's Comet.

Edward J. Smith is a research group supervisor at JPL and the principal investigator on the magnetic field experiment on ICE.

SOCIETY NOTES

ON TO MARS

The prospect of a human mission to Mars continues to generate excitement. "Let's Go to Mars Together," the February 2 cover story in *Parade* magazine by Planetary Society President Carl Sagan, brought more than 1,000 requests for more information to the Society. A similar amount of mail was sent to those in the Congress and the Administration now considering the future of space exploration.

In the article, Dr. Sagan called on the two major space-faring nations — the United States and the Soviet Union — to "blaze the trail to Mars and beyond, on behalf of every human being."

The overwhelming majority of letters to the Society applauded Dr. Sagan's proposal. Schoolchildren discussed the proposal as classroom projects and several senior citizens rewrote their wills, leaving portions of their estates to the Mars Fund. One intrepid youth, avid for a journey to Mars, wrote that his father would gladly pay $100 for him to travel to Mars — and stay there!

If you wish to further the Society's efforts to encourage a human mission to Mars, please send a contribution to: "The Mars Fund," The Planetary Society, 65 N. Catalina Avenue, Pasadena, CA 91106.

CHICAGO EVENT PACKED

Once again, Chicago area members have overwhelmingly supported a Planetary Society event. On February 25, The Field Museum of Natural History's Simpson Theater was sold out for Richard Terrile's discussion of the *Voyager 2* encounter with Uranus. Dr. Terrile of the Jet Propulsion Laboratory is a member of the *Voyager* Imaging Team. A second lecture had to be scheduled to accommodate the overflow crowd.

The Society thanks members Teinya Prusinski and Linda Low for organizing this successful event.

ASTEROID SEARCH FUNDED

The Planetary Society recently continued its grant for funding Eleanor Helin's highly productive search for Earth-crossing asteroids. A research scientist at JPL, Helin conducts most of her search with the Schmidt telescopes at the Mount Palomar Observatory. Her Asteroid Search Project is the most successful ever, and is responsible for the discovery of half of the known near-Earth asteroids.

The project is primarily funded by NASA, with help from The Planetary Society, and is coordinated by the World Space Foundation.

FINANCIAL STATEMENT COMPLETED

The Price Waterhouse audit of our complete 1985 financial statement resulted in an unqualified opinion with no qualifications, finding our statements in conformity with generally accepted accounting principles. A one-page summary is available upon request.

INFORMATION LINES

The Planetary Society's telephone information lines are open 24 hours a day with news on upcoming events. From west of the Mississippi, phone 818/793-4294; from east of the Mississippi, phone 818/793-4328.

To Solve Your Membership Problems

Have you ever had a problem with your Planetary Society membership? Cindy Grisanti, our Data Processing Manager, is the person who makes sure that all membership information is put correctly into our computer. Cindy sometimes has problems with your problems, and she has some hints to help you avoid them.

— Put your membership number on all correspondence. This number is printed on your membership card and above your name on the magazine label. Including it will make it easier for Cindy to find your name in the computer.

— Send Cindy a "change-of-address" card when you move. Since *The Planetary Report* is mailed at the third-class, non-profit rate, the Post Office will not forward it or return it to us. We have no way of knowing if you've moved unless you tell us. So if you don't want to miss any issues, send us your new address.

— When ordering gift memberships please include a check or your credit card number. Sometimes we never receive payment for a gift membership — even after billing the giver — and we don't like to cancel gifts, nor can we bill the recipient.

Cindy will appreciate your help, and your membership problems will be solved more quickly.

DRAWING: S.A. SMITH

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For a written description of each item, see back issues of THE PLANETARY REPORT or write to The Planetary Society.

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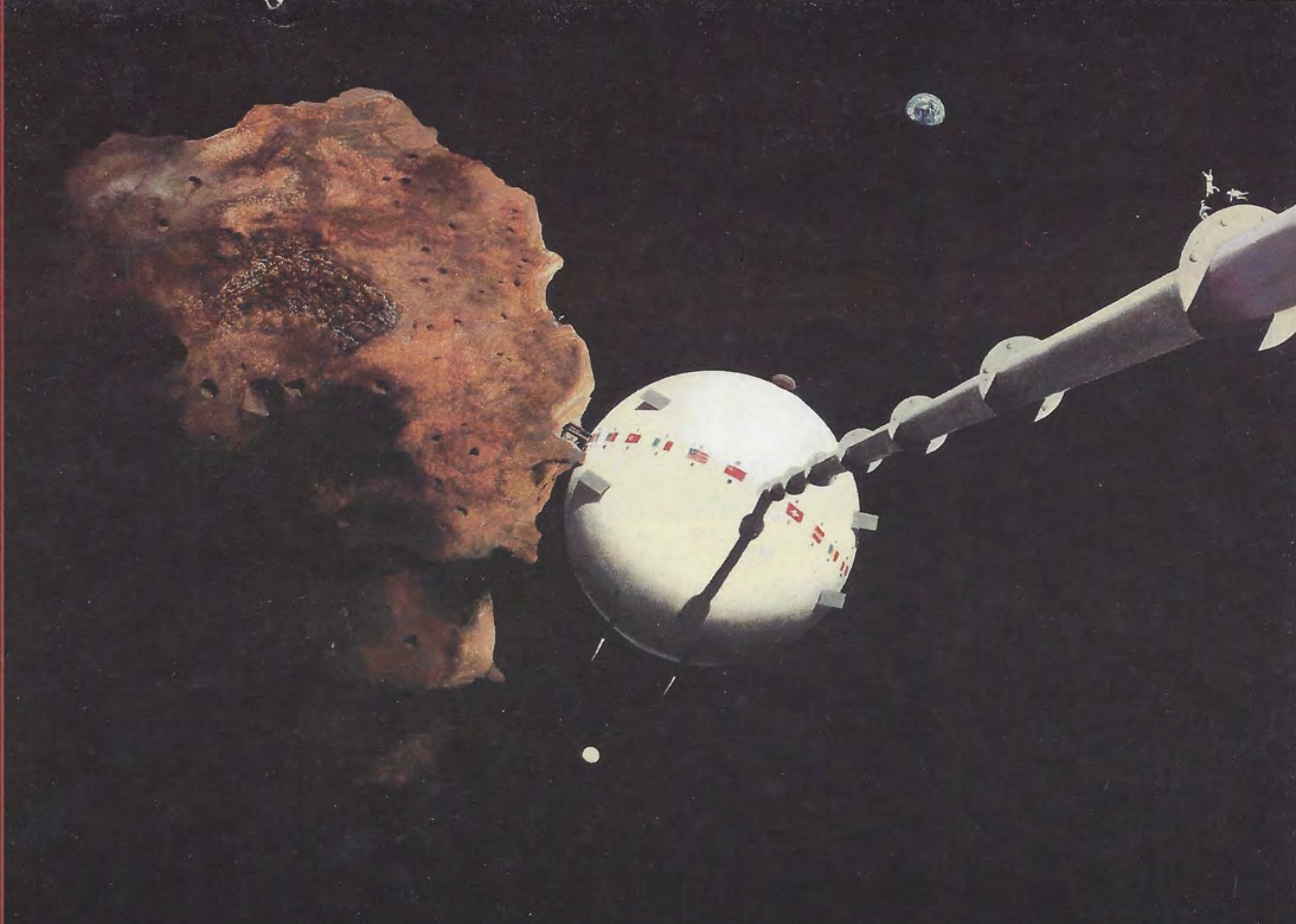

MINING AN ASTEROID — A space-based factory extracts raw materials from a near-Earth asteroid in this 1976 painting by Chesley Bonestell. The international facility conducts its operations beyond the Moon (bottom center), while the blue and white Earth hangs in the sky (upper right). Perhaps someday space pioneers will visit the asteroid Bonestell.

The Planetary Society and its members recently honored Chesley Bonestell, the dean of space artists, by naming an asteroid in his honor (see page 3).

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