The PLANETARY REPORT

Volume XVI Number 4 July/August 1996

Comet Hyakutake

On the Cover:

Comet Hyakutake provided the best celestial show in decades when it passed by Earth on its way to swing around the Sun. In late March and early April, the comet grew so bright that it was even visible in the light-polluted skies of major cities in the northern hemisphere. This photograph, however, was not taken in a major city; the comet appears over Kenai, Alaska, where the city lights barely dimmed the comet's glowing tail. Millions of people around the world who rarely glance at the night sky were enraptured by the unexpected visitor. With luck, their interest will be captured again next spring, when comet Hale-Bopp—with the potential to be even brighter—flies through our neighborhood.

Photo: Bill Hutchinson

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From The Editor

Planet Earth has never been a focus for research at The Planetary Society. Countless other organizations devote their energies to the fragile environment that makes this planet unique. We have concentrated on an area where we could make a difference: on the exploration of planets beyond our own.

But an extraterrestrial perspective is crucial to understanding Earth and the teeming life-forms that make it unique. One particularly vexing mystery about life, in fact, could not have been solved without that perspective: the extinction of the dinosaurs.

Most scientists now implicate an asteroid in that extinction, and that link has brought The Planetary Society into this research arena. We've undertaken a series of expeditions where members can work alongside scientists. This project fulfills two of our goals: to advance science and to involve our members personally in that adventure. Here we report the results of the latest expedition. Later this year, a team goes to Gubbio, Italy, where scientists found the first evidence linking an asteroid to the dinosaurs. Join us as we unravel the mystery of the dinosaurs' demise, either by reading these pages or by joining an expedition. Either way is a unique benefit of Society membership.

—Charlene M. Anderson

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Members' **Dialogue**

SETI Debate

I would like to contest Ernst Mayr's conclusion that high intelligence is rare and not favored by natural selection. The fossil record shows that, over time, organisms as a whole have grown more complex, more organized and largely more intelligent. I'm not sure how to measure the "average" intelligence displayed in the ecosystem, but I am pretty sure that it has increased tremendously over the past 100 million years. Extrapolating this trend of increasing intelligence would suggest that it is not at all unlikely, but is favored by natural selection and will arise, given enough time.

Rather than seeing us as unlikely, I think that we are simply the first highly intelligent creatures on Earth.
—E. MARC COE,
Brick, New Jersey

I just finished reading the debate on SETI between Ernst Mayr and Carl Sagan. I noticed loopholes in both arguments. Mayr said that out of 20 civilizations, only one has developed the technology to send and receive signals. Therefore it is unlikely that there is another civilization somewhere like ours.

Though most civilizations have died off, the successful ones learned from the mistakes of predecessors and so were more advanced and more capable of survival. Wouldn't it be reasonable to assume that other planetary civilizations do the same?

Mayr made the point that high intelligence has arisen only once on our planet. How many times need it have arisen to qualify as significant? He also asked how survivors of earlier impacts would be selected to develop the technical know-how to prevent future impacts. The idea is not to be selected after the last impact, but to be selected before the next one.

One of Sagan's final responses was that Mayr conceded that there may be extraterrestrial intelligence. It seems to me that he is just flat wrong in saying that. While reading Mayr's discourse, I never once got the impression that he didn't believe that extraterrestrial intelligence exists, merely that it is improbable.
—RUSS BAIN,
Glendora, California

Mayr points out that "perhaps 50 billion species" originated on this planet, with "only one" evolving to civilization. He should have stated "only one, so far." A scant 65 million years ago, our ancestors were but primitive mammals. There are dozens, if not hundreds, of species at least that advanced today. Does Mayr believe if humans are exterminated by disease or environmental disaster *none* of these species will evolve high intelligence in the next 65 million years? And that is but 1 percent of the evolutionary time left to this planet. In fact, civilization evolved exceedingly quickly, once life moved onto land. We just happen to be the first example.

Mayr also chastises Sagan and others for misusing methodologies. However, so does he—in his application of probabilistic analysis to a biological system. For example, he points out the fragility of the chain of evolution that resulted in *Homo sapiens*. He also mentions the astronomical number of species that failed to achieve high intelligence. Yet, probabilistically, it is that very proliferation of false starts that increases the likelihood of a fragile chain eventually surviving.

His strongest point against SETI was the unlikelihood of our civilization aligning in time with another so we are listening at the moment they are broadcasting. True. But an advanced civilization might plant beacons able to broadcast for thousands or millions of years, long after their "short-lived" civilization had perished.

Of course we cannot guarantee success by searching, but we can guarantee failure by not.
—TERRILL L. BURLISON,
Kent, Washington

ERRATUM: The photo caption on page 12 of the March/April 1996 issue of The Planetary Report *stating that the floodwaters flowed "more than 18 cubic meters (600 cubic feet) per second" was incorrect. The correct figure is about 11 million to 17 million cubic meters (400 million to 600 million cubic feet) per second.*

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This year's expedition traveled farther from the center of Chicxulub than did the 1995 expedition. The team was able to study a wider range of materials blown out by the impacting asteroid. *Map: B.S. Smith*

The Planetary Society's BELIZE: ROSETTA STONE OF THE K/T BOUNDARY

by Adriana Ocampo

The mysteries surrounding the dinosaurs entice our imaginations. These magnificent creatures dominated the biosphere of our planet for over 150 million years, then came to an end 65 million years ago, with the close of the Cretaceous period in Earth's history.

Those of us who believe in catastrophism, or abrupt change, as I do, over uniformitarianism, or gradual change, as an explanation for the end of the Cretaceous period, embrace the idea that a key player in this mystery came from outer space. The ensuing catastrophic event produced such a dramatic change in Earth's environment that over 50 percent of the species living at the time, including the dinosaurs, perished.

The first suspicion that an extraterrestrial body might have been responsible for the dinosaurs' demise came in 1980, when Luis and Walter Alvarez, with Frank Asaro and Helen Michel, of the University of California, Berkeley, identified the element iridium in a worldwide clay layer marking the boundary between the Cretaceous (K) and the Tertiary (T) periods. Iridium is rare on Earth's surface, but common in solar system objects such as asteroids and comets.

As intriguing as this evidence was, scientists favoring an extraterrestrial culprit were left without the proverbial smoking gun to clinch the case. That is, until 1990, when a crater buried beneath the town of Chicxulub (pronounced *chix'oo lube*) in the Yucatán peninsula was identified as the probable impact site of an asteroid or comet 65 million years ago. For the first time, scientists had the opportunity to study a large—over 200 kilometers (120 miles) across—and well-preserved impact crater. Because it has been buried under 1,000 meters (3,000 feet) of sediments in a tectonically inactive region, the crater has been protected from erosion.

The main surface feature that distinguishes Chicxulub as a crater is a ring of sinkholes (*cenotes* in Mayan) that marks the floor of the buried crater. To study the Chicxulub crater, scientists would have to undertake a systematic—and very expensive—drilling program. Mexican scientists are now carrying out such a program on a limited basis.

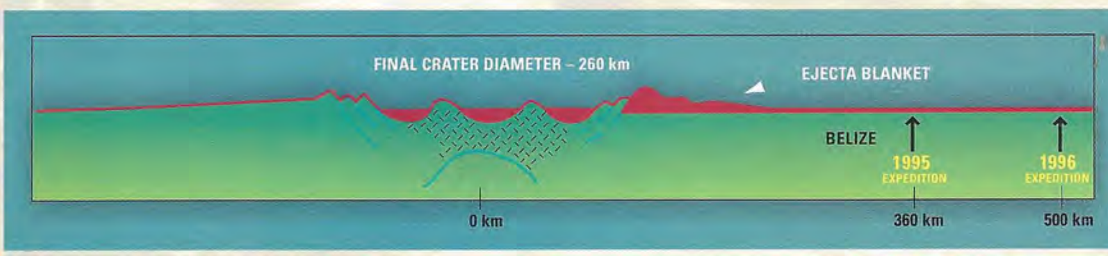
Our First Expedition to Belize

Another way to study the crater would be to find the ejecta blanket—that is, the rocks ejected from the crater by the force of the impact. If this blanket was found on the surface, there would be no immediate need to drill. Fortunately, we identified such a site in northern Belize, about 364 kilometers (226 miles), or two to three crater radii, from the crater. That was the destination of our first Planetary Society expedition, which took place in January 1995 (see the July/August 1995 *Planetary Report*).

That expedition proved fruitful. Among the discoveries of our team of Society members and professional geologists was a new species of crab, named *Carcineretes planetarius* after The Planetary Society. Like the dinosaurs, this species became extinct at the end of the Cretaceous. These marine crabs used to float in shallow coastal waters. Finding fossils in the sediments exposed in a limestone quarry on Albion Island in the Rio Hondo gave us insight into what the environment of Belize was like when the impact took place.

With the discovery of this new species of crab and other fossils—for example, a type of snail called a nereid—we were able to confirm that we had indeed found material dating from the end of the Cretaceous in a surface exposure of the ejecta blanket from Chicxulub in Belize. We found many more clues to the catastrophe: tektites (droplets of glass formed from rock melted by the impact) that matched the composition of the target rock in the Yucatán peninsula; striated boulders—one was 8 meters (26 feet) in diameter—

Seen in cross section, the Chicxulub crater might have looked something like this, with the blanket of material ejected from the crater flowing all the way to modern-day Belize. Today, the crater itself is buried under hundreds of meters of sediment. *Chart: B.S. Smith*



1996 Belize Expedition

The team traversed a landscape that looked like a Hollywood fantasy of a jungle. Above, team members prepare to explore a cave. At left, they canoe down the Macal River, where they discovered possible K/T exposures. In the center is a magnificent fold in Tertiary limestones.

Photos on this page: Adriana Ocampo and Kevin Pope

scarred as they were blasted out with tremendous force; and hinged pebbles (also called fracture pebbles) formed by a combination of plastic and brittle deformation caused by the explosion. All these confirm that the deposits in northern Belize must have been produced by something as tremendously violent as an asteroid or comet impact.

We Continue the Search

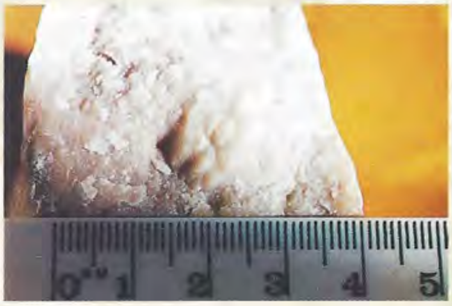
With this evidence in hand, we decided to find out how far the ejecta blanket extended in Belize, in the hopes of finding more clues to large impact crater processes. This proved to be very challenging, since in this tropical area rocks are rare, but beautiful and lush vegetation is plentiful. Our search led to the second Planetary Society Belize expedition, in January 1996. We began our work in the limestone quarry on Albion Island, and then extended our reach to the Cayo district of central Belize and the foothills of the Maya Mountains.

Some of the most puzzling things that we found were rounded limestone pebbles with highly polished surfaces marked with striations or grooves. We affectionately called them Pook's pebbles, since they were first found in the jungle on Pook's Hill, near Teakettle village in central Belize. Their origin and how they were deposited there are still the subject of much of our research. We believe that they are related to the impact, and that they were deposited via debris-flow mechanisms triggered by the impact. But there is much yet to be understood about them. Pook's Hill is over five crater radii away from Chicxulub, and impact models tell us that such features should only be found closer to the crater. We might still be on the ejecta blanket from Chicxulub, or we might have found the ejecta blanket from a secondary crater.

In the style of a well-developed detective story, Belize is showing us that we know very little about large impacts and how they might affect our biosphere to cause a mass extinction. But the clues are there. With every sample that Planetary Society team members brought back from Belize, we are gaining a greater understanding of Earth, its biosphere and planetary evolution.

Adriana Ocampo is a planetary geologist at the Jet Propulsion Laboratory in Pasadena. This research is funded by NASA's Exobiology Program and The Planetary Society.

One of the team's favorite spots was Pook's Hill, location of one of their "hotels" and some peculiar pink pebbles that seem to have been altered by impact processes. At bottom right is the jungle side of the hill; on the top right is the rocky side, where the Pook's pebbles were found. (For a close-up of one of these pebbles, see page 9.)



Within this fragment of dolomite is a well-preserved Late Cretaceous crab, named* Carcineretes planetarius *in honor of The Planetary Society.

GEOLOGY AND CLIMATE CHANGE: MECHANISMS OF EXTINCTION

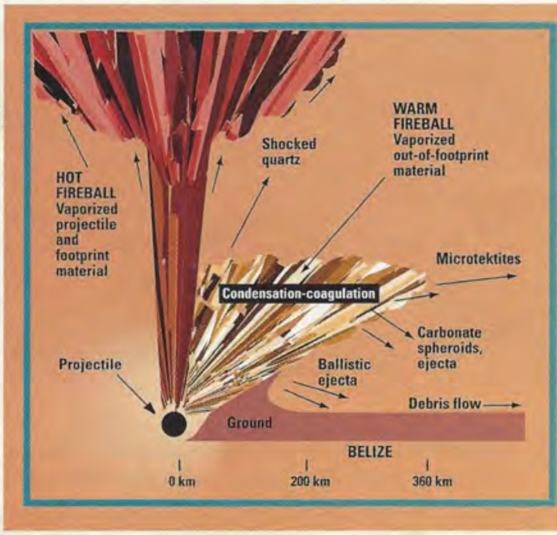
by Kevin Pope

The giant meteorite impact that formed the Chicxulub crater was one of the largest in Earth's history. Only Sudbury crater in Canada and Vredefort crater in South Africa are perhaps as large. It is difficult to study a crater like Chicxulub, which is deeply buried by sediment, so we chose to look for other evidence of the impact that killed the dinosaurs. In Belize, we found rocks ejected from the crater preserved at the surface. These exposures of ejecta deposits are the closest known to the Chicxulub impact site. The tremendous size of the Chicxulub impact, the proximity of Belize to the crater, and the excellent preservation of the ejecta deposits found in Belize make this Planetary Society research unique among impact crater studies.

One of our most exciting discoveries was that the ejecta contained millimeter- to centimeter-sized spherical bodies (spherules) of carbonate rock. Some of these spherules are made of the mineral calcite (calcium carbonate, $CaCO_3$), which forms fiber-like crystals radiating out from the center of the spherule. Others are made of the mineral dolomite (calcium magnesium carbonate, $CaMgCO_3$), which commonly forms concentric bands of large and small crystals around fragments of dolomite rock. Where did these strange balls of rock come from? Our current hypothesis is that they formed as material within the expanding plume of rock vaporized by the impact condensed and coagulated into larger particles. The spherules ultimately fell like hail on Belize.

A Lethal Plume

The vapor plume rising over the Yucatán landscape 65 million years ago must have been an awesome sight. When the incoming asteroid or comet struck, so much energy was released as heat that it instantly vaporized rock. Computer models suggest that the Chicxulub impact would have vaporized rocks within 6 to 12 kilometers (4 to 7 miles).



Based on evidence collected by Planetary Society expeditions and others, this chart shows some of the effects of the Chicxulub impact that might explain the rocks so far uncovered. (The "footprint" is the target rock directly within the path of the projectile.)
Chart: B.S. Smith

These rocky vapors were composed of trillions of tons of sulfur dioxide (SO_2) gas, carbon dioxide (CO_2) gas and water (H_2O) vapor once peacefully contained in a 3-kilometer-thick (2-mile) layer of carbonates and sulfates at the impact site. Superheated to thousands of degrees Celsius, these gases expanded rapidly, eventually encircling Earth.

Many scientists believe that these gases, along with soot and dust ejected into the atmosphere, caused climate changes that ultimately helped kill off over 50 percent of the living species following the impact. Especially lethal was the sulfur dioxide, which formed sulfuric acid (H_2SO_4) clouds in the stratosphere. These clouds could have blocked sunlight, preventing photosynthesis for a few months and cooling Earth's surface to near freezing for about 10 years. In addition, the sulfuric acid production would have depleted ozone (O_3) and also would have led to years of severe acid rain.

Another proposed cause of the mass extinctions is greenhouse warming from carbon dioxide released by the impact, although recent impact models indicate that this warming was probably less than a couple of degrees Celsius. Furthermore, our discovery of carbonate spherules in Belize suggests that some—perhaps much—of the carbon dioxide vapors did not reach the stratosphere. Instead, these vapors combined with particles of calcium oxide (CaO) or magnesium oxide (MgO) that had also been carried aloft in the plume. They coagulated into carbonate particles and fell.

If this proves correct, then greenhouse warming can be exonerated as the cause of the mass extinctions at the end of the Cretaceous period. Impact "winter" caused by the vaporization of sulfate rocks remains the favored theory.

Kevin Pope is a geologist who has worked in Belize for over 10 years. His studies of the climate effects of the Chicxulub impact are supported by the NASA Exobiology Program.

These calcite spherules show dramatic evidence of the unusual processes that shaped them. Above are the rounded forms taken by the vaporized or molten rock as it cooled and crystallized. At the right is a close-up of the crystals showing the radial growth form, which tells us they grew rapidly.
Photos: JPL/NASA

IMPACT PROCESSES: RECONSTRUCTING THE EVENTS

by Michael Rampino

Left: Mike Rampino scrapes away at an ejecta blanket exposure in Cristo Rey.

Below: This weathered exposure gives a good view of the K/T boundary. At the bottom is the Late Cretaceous Barton Creek dolomite. Just above the pen is a spheroid bed of rounded rocks formed in the blast, and on top of that is the ejecta bed.

Photos on this page: Adriana Ocampo and Kevin Pope

Below: In this wider view, the K/T boundary begins near the head of the person at far left and continues to the top of the picture.

Sixty-five million years ago, an asteroid or comet 10 kilometers (6 miles) in diameter, traveling at between 20 and 60 kilometers (roughly 10 and 40 miles) per second, slammed into what is now the Yucatán peninsula of Mexico. The result was clearly a global catastrophe. The impact energy (equivalent to the explosion of 100 trillion tons of TNT), which was converted into shock waves and heat, blasted a giant impact crater and hurled massive amounts of melted, fragmented and vaporized rock into and above the atmosphere.

Upon atmospheric reentry, this debris was heated to such an extent that Earth's surface became a broiler, igniting forests worldwide. The sky went dark as the dust and soot slowly settled on the burnt landscape. In the Gulf of Mexico/Caribbean region, the impact set off destructive earthquakes and tremendous tsunami waves, washing away entire coral reefs and sweeping low-lying coastal areas clean. The aftermath of the impact may have included a global cloud of sulfuric acid droplets, blasted from the target rocks at Chicxulub, that cut down incoming sunlight and cooled Earth for decades. Not surprisingly, when the dust cleared, most of the species of life on land and in the sea, including the dinosaurs, were gone.

This remarkable story has been pieced together through a combination of extensive geologic fieldwork, carefully executed laboratory analyses and sophisticated computer modeling. The decade and a half since the discovery of impact evidence by the Alvarez group has seen a steady confirmation of the impact scenario, with scientific sleuthing that culminated in the location and dating of the Chicxulub crater just a few years ago by several groups.

Storms of Rock

The Planetary Society's expeditions to Belize have provided a unique look at the by-products of one of the most dramatic processes set in motion by the massive impact—ballistic debris flows. During the impact, fragments of the target rocks were splashed upward and outward from the crater at high velocity. This debris traveled in arcing paths, eventually falling back to Earth. Imagine a curtain of such debris, sweeping rapidly outward from the impact site, violently striking the ground, tearing up the surface rocks and moving outward as a ground-hugging flow of mixed ejecta and local rock. Such storms of rock would have leveled everything in their paths, burying the countryside under tens of meters of debris, until finally the flows ran out of steam hundreds of kilometers from the crater.

The Belize localities are the closest that scientists can get to the Chicxulub crater to study the ejecta without having to drill through a thick cover of younger rocks. What we found there—chaotic deposits of fragmented rock showing clear signs of rapid flow and containing strange boulders and cobbles showing marks of violent collision, smooth facets, striations and a mirror-like polish—told us that we had hit the jackpot. During the 1996 expedition, we spent two weeks climbing over some of the most unusual deposits on Earth, collecting samples, recording data and happily arguing about what it all might mean.

We have compared our samples from the Chicxulub debris flows with the debris of other known impacts, such as that of the 30-kilometer-diameter (19-mile) Azuara impact structure (about 35 million years old) in Spain and the 26-kilometer-diameter (16-mile) Ries impact structure (15 million years old) in Germany. There are remarkable similarities, although the scale of the Chicxulub deposits is so much larger. It will take considerable laboratory analyses and additional fieldwork in Belize to unravel the origin of the features that we observed, and the information gained from our studies will help in creating computer simulations of the violent processes by which these materials are ejected from impact craters.

A Need to Reexamine

Moreover, these unusual deposits may have a significance that goes far beyond the events at the Cretaceous/Tertiary (K/T) boundary. Similar deposits occur in the geologic record, and they have been interpreted as the products of ancient glaciation primarily because of the presence of large boulders and scratched and polished stones resembling those found in deposits of the most recent ice age. The discovery that impact debris can have analogous features casts doubt on the interpretation of some of these deposits as glacial in origin. In reality, they may be impact debris, or the products of debris flows generated by other violent processes. Further study of the Belize material and other known impact debris will enable geologists to develop better criteria for distinguishing impact ejecta from true glacial deposits in the geologic record.

Michael Rampino is an associate professor in the Earth and Environmental Science Program at New York University, and a consultant at NASA's Goddard Institute for Space Studies in New York City.

MINERALOGY: CARVED IN STONE

by Alfred G. Fischer

The members of The Planetary Society's 1996 expedition to Belize have delightful memories of fascinating landscapes, interesting people and fellowship—and the tantalizing problems involved in trying to interpret rocks in the field. Here I write about the aftermath of the expedition, getting at the story of what happened after the Chicxulub impact by working on the Belizean rocks in the laboratory. We have a long way to go before the story of what happened there is complete, but some things (and some questions) have been clarified.

The rocks called hinged pebbles (see page 5) proved particularly interesting. The force of impact seems to have cracked them, healed the crack, encrusted and then polished them before they came to rest in the ejecta blanket. Similar rocks are found at other, well-studied impact sites.
Photo: Adriana Ocampo and Kevin Pope

We now have no doubt that the deposits we studied, from around the Cretaceous/Tertiary boundary in the Albion Island quarry in northern Belize, and in the flanks of the Maya Mountains in central Belize, contain ballistic ejecta—that is, material blasted out by the force of the impact. At Albion Island, we found clay shards containing relict vesicles—holes left by gas bubbles formed while the rocks were melted. These shards are surely altered glass, most likely derived from the Chicxulub impact.

The 1995 Planetary Society expedition provided evidence that Albion Island had been land at the time of the impact, probably an island much like the Bahama Islands, which are emergent parts of the Bahama Bank. We were able to verify that the deposits exposed in the Albion Island quarry were near 65 million years old and corresponded at least roughly to the boundary between the Cretaceous and Tertiary periods, but tangible evidence of an impact origin, other than glass, had been tenuous. By the end of our 1996 visit there, we had found, in a layer we interpret as the ejecta blanket from the Chicxulub impact, two rock specimens that provided more solid evidence.

New Data From Northern Belize

One specimen from the Albion quarry is a small, steeply conical piece of dolomite, with a fan of striations radiating out from one side of its pointed top. This resembles shatter cones, structures found in rocks surrounding meteorite impact sites, though it lacks the "horsetail" structure of striations in typical shatter cones. Furthermore, near its top this specimen has embedded within it angular chips of another kind of dolomite that penetrated it, plus the tracks of other chips. At some stage in its history, this rock had the consistency of putty, allowing other rock chips to become embedded in it. Did this happen under the enormous pressures generated during the initial stages of ejection? Or did it happen in a micromoment when intense shock broke the molecular bonds and turned the dolomite rock into a tough jelly?

The other specimen, also from the Albion quarry, is a piece of red chert (flint), a rock normally composed of microgranular crystals of quartz. When viewed in thin section under polarized light, this chert is found to be an interlocking mosaic of spherulites, bodies composed of fibers of quartz (chalcedony) radiating out from the center. That is the structure formed when a glass, such as obsidian, crystallizes rapidly. Here the chert was, for an instant, turned into silica glass by a shock that completely disrupted the molecular bonds. It rapidly recrystallized into spherulites by radial growth of chalcedony fibers from randomly scattered "seeds." Similar but larger spherules of calcium carbonate previously found in the Albion quarry had initially been interpreted as accretionary, pea-sized globes of limestone called "pisolites." These are now viewed as formed by recrystallization of limestone, most likely in response to shock-melting.

We thus have every reason to think that these specimens were blasted out of an impact crater on a ballistic trajectory, and then became incorporated into a debris flow that carried them some additional distance. It seems likely that they came from the Chicxulub crater some 350 kilometers (200 miles) to the north.

A remaining question concerns the blocks of ordinary dolomite in the layers we consider to be part of the ejecta blanket thrown out by the impact. These do not reveal such evidence of intense shock, but many are marked with facets and striations (grooves). How many of these were blasted out of the crater, and how many were merely swept up by the ejecta blanket as it rushed over the Yucatán region? Did the faceting and striations occur as the rocks were flying out of the crater, or were they cracked and grooved as the mass of debris flowed across the countryside? We also have questions about the matrix of the sedimentary layer that we believe to be the debris flow: Did this dolomite crystallize out of the cloud of vaporized rock thrown up by the impact, or is it merely soil that had accumulated over the Yucatán region, and rock ground up during transport?

Discoveries in Central Belize

During the 1995 expedition, Adriana Ocampo and Kevin Pope had found in central Belize, on the north flank of the Maya Mountains, a sedimentary layer containing polished pebbles and cobbles. They suspected it might be part of the ejecta blanket thrown out by the Chicxulub impact. Here the 1996 expedition gathered a rich harvest.

These are rounded pieces of limestone and marble, rarely dolomite, containing some chert nodules. They superficially resemble stream-rounded or beach-worn cobbles and pebbles, but many of them have flat and commonly striated facets, rounded hollows, and deep pockmarks. Some have been split

From top: This conical piece of dolomite (a) with striated faces seems to be a shatter cone, a rock typically found surrounding impact sites. (Scale bar on rock is 1 centimeter in length.)

The expedition team found beds filled with glass spheroids (b) formed by the shock and heat of the impact explosion.

This pink rock (c) is a Pook's pebble, named for its discovery site. Its beach-worn look is the result of impact processes, as evidenced by the impact pit in its side. (Scale bar on rock is 1 centimeter in length.)

Pook's Hill was also the site of mud balls—matrix-coated boulders (d) wrapped in finer material before being deposited among the impact debris. Photos: Adriana Ocampo and Kevin Pope and displaced along the fracture, and most have been polished in places. These rocks include tan limestones—lithified shallow-water carbonate sands that retain their original shell fragments, accreted ooids (tiny, rounded carbonate rocks), and the microscopic skeletons of planktonic animals and algae. But the more battered ones have recrystallized into marbles with crystal sizes diminished from those in the limestones—the process of mosaicism associated with shock. Growth of radially structured spherulites, both in the carbonate and in the cherts, repeats the pattern found in the Albion quarry—crystallization from patches that melted under shock.

As yet we have no precise data on when these limestones were first laid down. Once we have properly prepared a suitable amount of well-preserved fossils, we can begin paleontological studies to fix their age. The pebbles and cobbles bear evidence of shock and ballistic transport, but we have much to learn about the conditions that shaped them. Mineralogical and compositional investigations may give us more definitive evidence of the pressures and temperatures these rocks encountered. Further studies will clarify the sequence of events.

Puzzles

One factor that puzzles us is the difference between the deposits we found in northern and central Belize. In the north, the matrix of the layers and the ejecta are mainly drab-colored dolomite. In the central region, the ejecta are limestone and marble in a matrix ranging from drab or red clay to limestone. Altered glass, common in the deposits in northern Belize, is rare or absent in central Belize.

Were these deposits derived from the same impact crater? We know from images of Mars and other bodies that several lobes can be ejected from a single crater, and our observations would imply that such lobes result from different domains and stages of ejection. An alternative explanation is that the ejecta of central Belize came from separate impacts, most likely related to Chicxulub. Either the impactor had broken into pieces before striking Earth, or a large mass ejected by the primary impact formed a crater of its own.

We can answer some of our questions with further laboratory study, now being carried out with the help of NASA. Other questions will no doubt emerge. In the meantime, we are delighted to pass along this candid progress report, with gratitude to the ever-enthusiastic members of our expedition and to The Planetary Society.

Alfred G. Fischer, long associated with Princeton University, is now professor emeritus of geology at the University of Southern California in Los Angeles. His studies have focused on the history of the outer Earth in terms of the interactions between physical and biological processes.

STRATIGRAPHY: LAYERS OF EVIDENCE

by David T. King, Jr.

In the foothills of the Maya Mountains, and in the Cayo district of central Belize near Belmopan, the capital of Belize, Planetary Society team members studied a sedimentary layer 30 meters (100 feet) thick. We believe this layer to be a remnant of the debris ejected by the impact that ended the dinosaur era.

Whatever the mechanism, or the exact sequence of events, it's startling to imagine how such a thick blanket of rock could be laid down over such a vast area—the Yucatán peninsula and adjacent parts of Central America —in such a brief time. Calculations show that the debris flow from the Chicxulub crater would have moved at about 300 meters (1,000 feet) per second. That puts its arrival time in Belize at only 15 to 18 minutes after the impact.

Few locales on Earth afford the opportunity to study such a massive, rapidly deposited body of rock. The layer we examined lies between a bed of Late Cretaceous Barton Creek dolomite and the overlying Early Tertiary El Cayo Group carbonates. To study this boundary layer, we measured 21 stratigraphic sections (Figure 1, page 11) to determine the nature and sequence of the rock layers. Thirteen sections spanned the ejecta layer.

Most of the boulders the team examined in the K/T layer during the 1996 expedition came from local bedrock. But the polished boulders in the center are not from Belize. They seem to have been blasted out from somewhere else and carried to Belize by the impact.
Photo: Adriana Ocampo and Kevin Pope

To gain an internal view of this layer, we constructed a correlation among the 21 sections (Figure 2). A glance at the correlation shows that individual beds appear in all the stratigraphic sections. There are as few as five to perhaps as many as 10 beds in any given part of the layer.

Figure 1

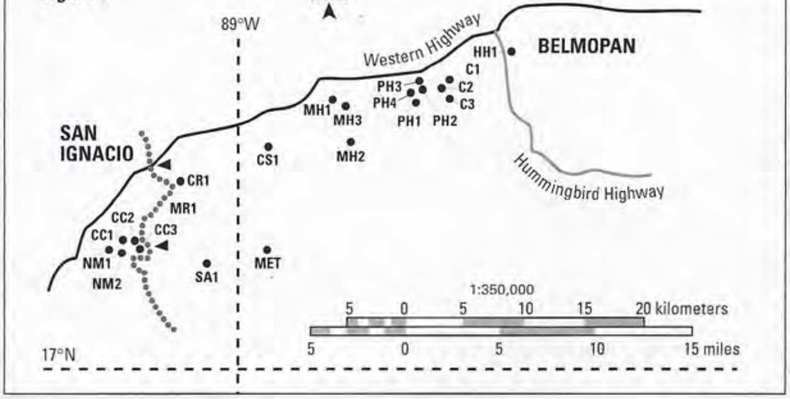


Figure 1: Measured stratigraphic sections in the Cayo district, Belize. All sections are located by a dot, except the Macal River section (MR1), which is along the river (dotted line) between the black triangles.

Figure 2

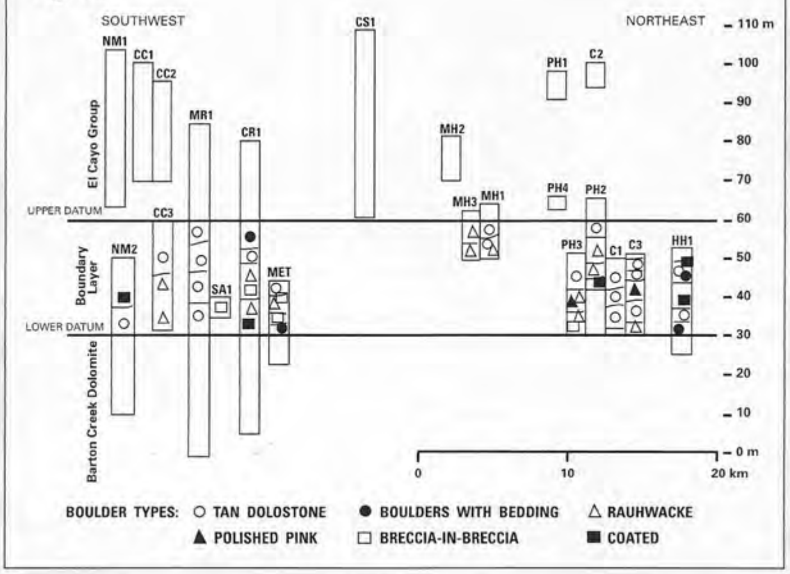


Figure 2: This chart gives the correlations among the 21 measured sections. Bedding contacts are indicated by lines drawn across the section column (e.g., there are four beds in section MR1).

Charts: D.T. King, Jr.; redrawn by B.S. Smith

Making the Beds

Each bed has both common and distinctive characteristics. Beds range from 3 to 10 meters (10 to 30 feet) thick, and the thickness can vary along a single outcrop. The rocks making up the beds, from the finely ground matrix to boulders 8 meters (26 feet) across, are poorly sorted. Many of the beds show evidence of flow lamination—thin, parallel layers of sediment indicating laminar rather than turbulent flow conditions—in their upper third.

We found six main types of boulders: tan dolostone boulders, boulders with bedding (these had internal stratification or beds), matrix-coated boulders, rauhwacke ("rough-rock") boulders, breccia-in-breccia boulders (these large blocks contained angular fragments of limestone and dolostone) and polished pink carbonate boulders. The first five types come from the local Late Cretaceous bedrock. The polished pink boulders do not seem to come from Belize. They may have been blasted out in the impact and carried to Belize along a suborbital trajectory.

From our studies of the beds and the materials within them, we suggest several conclusions. First, the textures and sedimentary structures within each bed are consistent with some type of debris-flow deposition. Second, the similarities of materials within the beds suggest that a common process formed each one. Third, the strata within the debris flow suggest that the separate layers were (1) moving at different speeds, (2) following different paths, (3) deposited at different times or (4) generated from different locations.

All this makes it certain that, whatever happened after the asteroid struck the Yucatán, the materials that were blasted out followed yet-to-be-understood paths to their final resting places. It is possible that secondary impacts of rock blasted out of the original crater played a role in determining the final stratigraphy of the ejecta layer. Large boulders blasted out by the impact may have rained down on Belize in a sort of carpet bombing. This may explain why the flow deposits contain so much local rock, and why they appear to have come from different directions at different times.

From our study of ejecta blankets, we hope to learn more about how the impacts of objects from space have shaped the face of Earth. As this is the largest impact event known in the inner solar system with an age less than 3 billion years, it is a potential source of useful information about much older terrestrial impacts and their ejecta layers. Similar internal stratigraphy of ejecta blankets may eventually be encountered on geological expeditions to Mars.

David T. King, Jr., is an associate professor of geology at Auburn University in Alabama. His specialty is stratigraphy, and he also researches dinosaurs and the K/T boundary.

The expedition team paused for a tour of a conservation area given by the director of the Belize Zoo (center, back row).

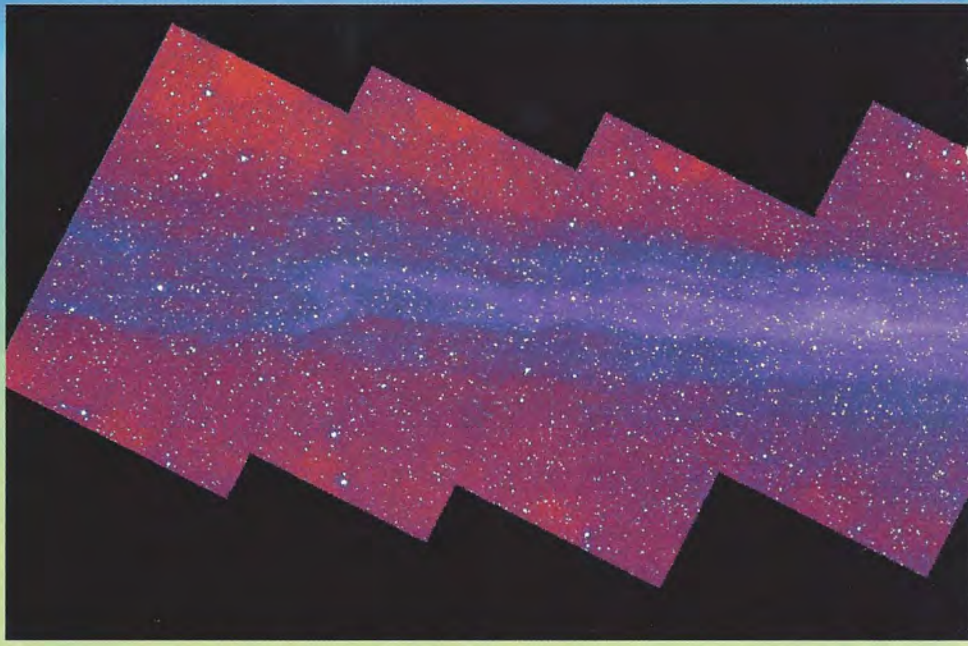
Photo: Adriana Ocampo's camera

Comet Hyakuta

Comets are the solar system's long-distance travelers. We know a few rather well, such as comet Halley, which reappears regularly every 76 years. Such short-period comets are predictable, making it possible for astronomers to prepare for each apparition. But other comets are unexpected visitors, traveling paths that last took them by Earth before there were human observers capable of recording their visits or predicting their returns for whatever progeny might follow.

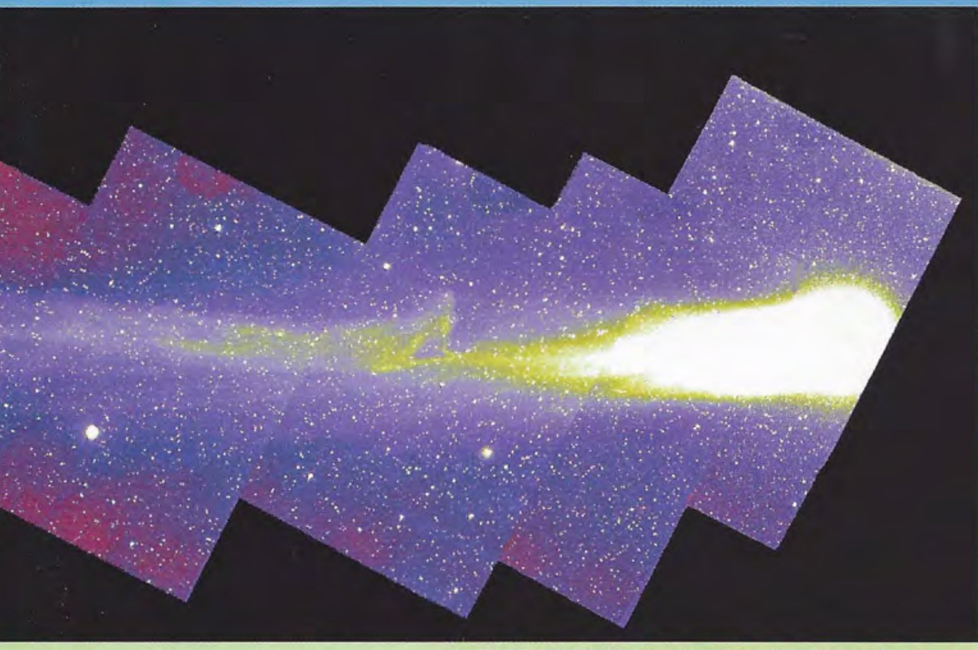
This is the story of comet Hyakutake, which last flew by Earth some 17,500 years ago—well before the lifetimes of the earliest known astronomers. It was first noticed on January 31 of this year by amateur astronomer Yuki Hyakutake, who systematically searches the sky with giant binoculars. In only two months, this unexpected visitor had grown into one of the most spectacular comets of the 20th century. Comet Hyakutake quickly passed through the inner solar system, and it will not return again for an estimated 29,500 years. The planets it passed on this trip—particularly giant Jupiter—perturbed its orbit and sent it on an even longer journey round the solar system than before.

Although it was unexpected, comet Hyakutake was not unobserved. Millions of people watched its progress across the night sky. Thousands of astronomers, both amateur and professional, studied and photographed it. While we don't know what earthly civilization might see Hyakutake the next time round, there might be surviving records from this civilization to help them prepare their observations. We share here a few of the images that will help us remember this celestial traveler.
—*Charlene M. Anderson*



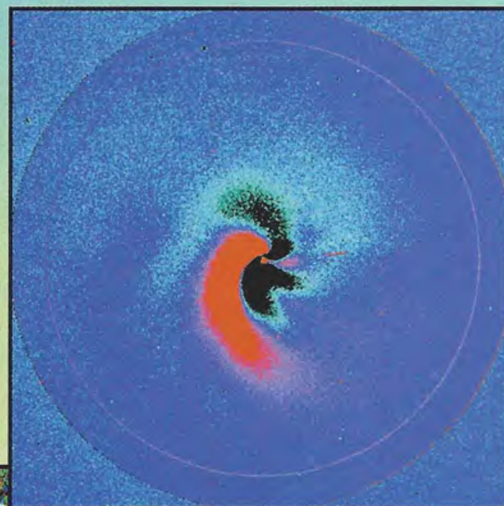
By piecing together high-resolution images of the comet, astronomers at the University o and all the streams, kinks and knots typical of a cometary tail are easily seen. For examp disconnection event, where a piece of the tail appears to have broken off the nucleus. Sc a gust in the solar wind, but images from the Hubble Space Telescope showed that a frag this may have caused the disconnection event. (The spiral galaxy M101 also appears in t one of ionized gas or plasma and one of dust. The dust tail on this comet was hardly noti This mosaic covers the width of 60 full Moons, showing what an impressively large objec
Mosaic: James M. De Buizer and James T. Radomski, with R. Scott Fisher and Robert Pina, University

ke: A Very Pleasant Surprise



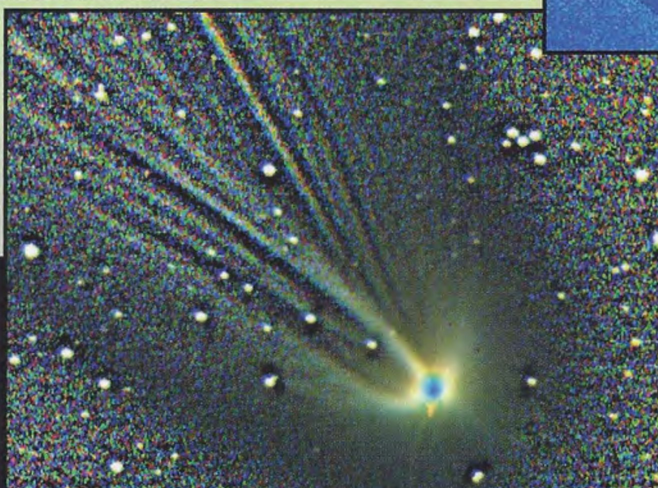
Florida produced this finely detailed portrait,
, the third panel from the right contains a
ntists first thought that this was caused by
ent broke off the nucleus on March 24, and
s panel.) Comets usually display two tails:
able and all you see here is the plasma tail.
Hyakutake became.

Florida; copyright 1996 University of Florida



The comet appears very different in this image taken by the European Southern Observatory's New Technology Telescope in La Silla, Chile. Here the focus is on the inner coma of comet Hyakutake and on the jets of dust spewing from its relatively tiny nucleus at the center of the image. The nucleus' rotation is also apparent as the jets curve in response to its motion. The dust is freed from the frozen nucleus as the comet heats up as it nears the Sun. The stream of ionized particles flowing from the Sun, known as the solar wind, "blows" the dust in the anti-solar direction, creating the bright tail easily seen from Earth.

Image: Olivier Hainaut, Richard West, Manuel Pizarro and Vicente Reyes, from the European Southern Observatory



New technologies are changing the way we see comets and other celestial objects. This image was taken with a reflector telescope—a technology a few centuries old. But instead of a human eye recording the comet, in this case a camera using charge-coupled devices produced this image. Three 60-second exposures were added together, and then a computer processed the image to bring out the dust jets streaming from the comet. No naked human eye ever saw a comet this way, but with these new technologies, we can now view these objects in many different ways.

Image: Tim Puckett

A quiet pond reflects bright stars and the planet Venus as comet Hyakutake sinks into the glow of Kansas City. The constellation Orion appears to the left, Venus to the left of center and the comet to the right of center. Photographer Vic Winter took this beautiful shot while standing knee-deep in mud as the temperature dropped into the vicinity of 30 degrees Fahrenheit.

Photo: Copyright 1996 Vic Winter

Why Near-Earth Objects?

by Carl Sagan

There's more than the thrill of discovering new worlds to justify our exploration of the solar system. There are solid scientific—and often social and political—reasons for undertaking such difficult and expensive endeavors. But these reasons are not often pulled together to increase the force of our advocacy for planetary science. NASA Administrator Dan Goldin asked Planetary Society President Carl Sagan to do just that to help him make the case for studying near-Earth objects (NEOs). Here are Dr. Sagan's points.
—Charlene M. Anderson

■ A population of some 2,000 small worlds more than 1 kilometer (0.6 mile) in diameter orbits the Sun very near Earth. Some have arisen from the main asteroid belt; others are dead or dying comets deriving ultimately from the outer solar system. Most NEOs are gravitationally perturbed into and out of near-Earth orbits on timescales of 10 million to 100 million years.

■ NEOs therefore represent a convenient opportunity to study small worlds at much less cost than missions beyond Mars orbit.

■ NEOs present fairly pristine samples of the early planetesimals that built the planets—with clues to conditions in the solar nebula from which the solar system formed. Some NEOs have undergone more physical and chemical processing than others.

■ The dumbbell shape of some NEOs (e.g., Toutatis) raises the intriguing possibility that we are seeing here remnants of the accretion of planetesimals, and therefore the processes that led to the building of Earth and of the planets.

■ Some NEOs are carbonaceous. Organic molecules of cometary and/or asteroidal origin played an important role in the origin of life on Earth around 4 billion years ago. Comets entering Earth's atmosphere today have their organic molecules largely destroyed or modified thermally. Microscopic particles of cometary debris collected in the stratosphere represent so little cumulative mass that it is very difficult to determine their organic chemistry. The study of carbonaceous NEOs may therefore provide important clues to the origin of life.

■ While many meteorites have been collected on Earth, we are unable to relate these meteorites to the physics, chemistry and history of any specific solar system asteroids or comets. We do not even clearly understand how meteorites are connected to the different asteroidal and cometary populations. It is possible that a weakly coherent class of NEOs exists that never survived entry into Earth's atmosphere and is unknown to us.

■ The dinosaurs and 75 percent of those species then on Earth seem to have been rendered extinct by the impact of a 10-kilometer-diameter (6-mile) NEO some 65 million years ago. The Tunguska event of 1908 in Siberia, the recently declassified United States Air Force data on small objects entering Earth's atmosphere, and particularly the impact of some two dozen fragments of comet Shoemaker-Levy 9 with Jupiter all underscore that dangerous impacts may occur today. The best estimate of the probability of a civilization-threatening collision in the next century is nearly one in a thousand.

■ A program to inventory all large NEOs is needed to determine not only orbital elements but also something of the physical and chemical properties of the inventoried NEOs. Ground truth on the NEO is needed to calibrate remote observations. Transponders may have to be emplaced on potentially dangerous NEOs.

■ The population of NEOs probably ranges from highly coherent objects to weakly cohesive fluffballs. If the time ever comes when it is necessary to deflect or disintegrate a NEO on an Earth-impact trajectory, it will be essential to have in situ experience with the various populations of NEOs. For example, the coupling constant in the use of standoff nuclear weapons may be highly variable from NEO to NEO.

■ The dangers presented by NEOs over the next century probably provide another coherent justification for the development of long-duration human spaceflight capability. Some NEOs are easier to get to than the Moon. Some round-trip missions to interesting NEOs with as much as a 30-day stay time on the NEO surface take less than a year. In general, missions to NEOs are intermediate in difficulty and risk between lunar and martian missions.

■ As for Mars, robotic and human missions to NEOs provide an opportunity for the development of rover, telepresence, return-sample and virtual reality space technologies and provide a justification for space-station and other means of investigating long-term human survival in space. Likewise, observations and missions to NEOs are intrinsically international because everyone on Earth is equally at risk from the impact of a large NEO. (The language of the House Science and Space Committee's proposed legislation for a program like Spaceguard mandates it be done internationally.)

■ NEOs represent a new and unknown environment for exploration—in many respects, more tantalizing than the partially explored Moon.

Carl Sagan is the David Duncan Professor of Astronomy and Space Studies and Director of the Laboratory for Planetary Studies at Cornell University.

World Watch

by Louis D. Friedman

Paris—The European Space Agency's Space Science Advisory Committee has rejected the proposed 2003 Intermarsnet mission plan, which was to have been a cooperative ESA/NASA venture. Instead, the committee selected COBRAS/SAMBA, an astronomy mission to measure the cosmic background infrared and microwave radiation.

The Intermarsnet mission plan had called for a network of three NASA landers carrying seismometers and meteorology instruments, as well as other instruments, to be placed on the surface of Mars. The launch vehicle was to have been an *Ariane 5,* and the science experiments were to have been European and American.

NASA will now redirect its 2003 Mars Surveyor mission to be a precursor to a Mars sample return in 2005.

ESA's rejection of Intermarsnet was accompanied by a recommendation for a 2007 planetary mission, which might turn out to be participation in an evolving international Mars sample return program.

Mainz—At a May meeting of the International Mars Exploration Working Group, Russian space scientists described a Phobos and Mars sample return mission study. Two concepts were described—one, a launch on the large *Proton* rocket, and the other, a Mars-only sample return launched on the smaller *Molniya* rocket. The latter mission could include a solar electric propulsion (SEP) stage now being developed for a late 1997 test flight from the *Mir* space station.

The development of this stage is part of a NASA-funded American–Russian initiative for space science from the space station.

Washington, DC—NASA is on its way to fulfilling Dan Goldin's vision of several launches per year to the planets. The Mars Surveyor, Discovery and New Millennium programs, plus the Pluto Express and the Origins program (this will search for evidence of life-bearing planets in the universe), as well as the post–space station development of human flight capability, bode well for planetary exploration.

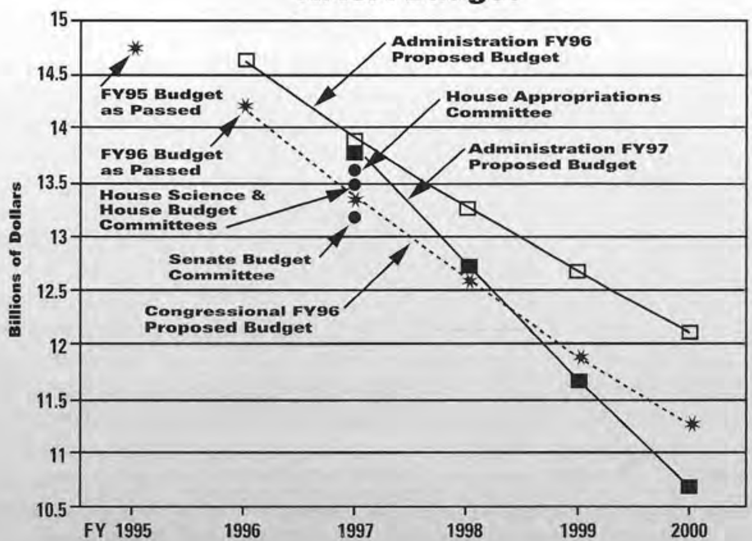
Nevertheless, a dark cloud has moved over the horizon, threatening to obliterate the vision. Both the Clinton administration's proposed budget and Congress' guidelines for 1998 and beyond imply that space science and planetary exploration will go out of business. The accompanying graph starkly foretells the problem.

The details have been set forth in several Planetary Society statements and letters to our members. (If you would like copies of these materials, you can find them on the World Wide Web at http://planetary.org/tps/, or you can ask us to send you the information via mail.) Similar statements have been influential in the past during congressional consideration of the NASA budget. This year, as in the past, letters from the Society and our members have been cited in congressional debate.

We encourage all of you to write to Congress and to President Clinton, citing your support for planetary exploration and the search for extraterrestrial life. We need to be heard now even more than in the past.

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

NASA Budget



Various budget plans for NASA (1997 dollars). The budget being considered in calendar year 1996 by Congress is for fiscal 1997 (FY '97), which begins on October 1, 1996. The three lines show the budget passed by Congress last year (FY '96) and the administration's proposals for last year (FY '96) and for this year (FY '97). Dots indicate individual congressional committee actions on the FY '97 budget. Projections for fiscal 1998–2000 are also included.

Graph: Louis D. Friedman, redrawn by B.S. Smith

News and Reviews

by Clark R. Chapman

A century ago, scientists were accustomed to a deliberate pace for research. For years, even decades, they patiently checked and rechecked their work before publishing results in long articles or books. By the time of *Apollo, Viking* and *Voyager,* the lonely research by individuals had been replaced by "big science." The world was eager to hear the results, and the media became ever more demanding. Scientists were no longer afforded the luxury of contemplation, but were thrust into live news conferences while the data had been on Earth for only a day or two.

Voyager scientists were uncomfortable about reporters' demands for instant science. Yet when the chief data were pictures, depicting radically new landscapes, it was easy enough for scientists to describe what was there for all to see. When asked to speculate about why Ganymede had grooves or why Triton had geysers, they sometimes offered theories, though those theories rarely survived more intensive research. Still, it worked OK. The press and the public were satisfied by neat new pictures and accompanying sound bites, and the longer-term purposes of science were satisfied by post-mission data analysis programs, through which NASA funds mission and non-mission scientists to figure out what all the data really mean.

Last December, *Galileo*'s probe blasted (at more than 100,000 miles per hour) into Jupiter's atmosphere in one of the premier technological accomplishments of NASA's planetary exploration program. Parachuting a collection of high-tech instruments, the probe radioed back an hour's worth of meteorological observations and samplings of the giant planet's atmosphere to a depth of 100 miles. The mission was conceived in the 1970s to literally take the temperature and sample the composition of the body that contains over 70 percent of the mass of all the planets combined. Huge, gaseous Jupiter would be the most representative planet for testing theories of how the planets formed—or so it seemed a quarter of a century ago.

Two weeks after probe entry, with some data still dribbling in from *Galileo*'s small antenna, the scientists who had designed and built the instruments two decades ago, and had nursed them through the *Galileo* project's long, turbulent history, were scheduled to tell all at a press conference at NASA's Ames Research Center. Mercifully, the impasse between the president and Congress closed down the government, including NASA, delaying the press conference for a month. Even after a month, the probe scientists were ill-prepared for the inquisitive press.

They waited for their 15 minutes of fame, but they had no pictures to show. The stream of data was difficult to calibrate, and months and years of analysis would be necessary before a responsible report could be written. Yet the world wouldn't wait. So, in January, the scientists sat on a stage, offered no results, but invited reporters to ask questions anyway. Used to being fed an announcement to serve as a foil for their questions, the journalists were dumbfounded. An hour later, the press conference was over, but the world had learned virtually nothing about Jupiter. One reason was that the *scientists* had not yet learned much about Jupiter. But the media had a few sound bites, and the evening news shows treated *Galileo*'s achievement with due respect.

The pressure to produce continues unabated, and the ensuing months have begun to reveal some results about Jupiter that may stand the test of time. The most pressing requirement for the probe team was to write articles for a special section in the May 10th issue of *Science* magazine. Brief summaries of these articles can be found at a Web site with a long URL: http://science-mag.aaas.org/science/scripts/display/short/272/5263/837.html. Your local library may have the complete issue (a pretty Infrared Telescope Facility picture of Jupiter is on the cover), with the full articles plus an overview by Richard Kerr. You could also look at the illustrated, nontechnical summary at http://ccf.arc.nasa.gov/galileo_probe/htmls/Science_summary.html.

Jupiter, it turns out, is very different from the target envisioned in the 1970s. Years ago, *Voyager* and modern ground-based astronomy had revealed the complexity of this world—a single probing could hardly represent such a heterogeneous world. And, indeed, as luck would have it, the probe penetrated an anomalously hot "hole" in Jupiter's cloud deck. So the resulting surprises—absence of cloud, absence of water, strong winds—could reflect an exceptional place, as if an Earth probe just happened to land on Mount Everest, or in Washington, DC. But comparison of the measurements of the various instruments is beginning to suggest that Jupiter may be quite different from what most of the experts had thought.

Watch the story develop on the Web. The Web provides the instant gratification of our ever more impatient, fast-paced culture. However, the postings will be continually updated as the research matures—*if* NASA provides the funds to the scientists to ensure that the careful scientific work is done over the next years. It used to be that instant science—the press-release pictures and accounts from the early press conferences—was all that penetrated the public's consciousness. Now there is an instant medium that, if managed properly, may provide public awareness of the continually evolving research.

Clark R. Chapman, as a member of the Galileo *imaging team, will be studying images to be taken by the orbiter's camera until the end of 1997.*

Society News

Celebrate *Viking's* 20th Anniversary

On July 18 and 19, 1996, at the National Academy of Sciences in Washington, DC, there will be a celebration of the 20th anniversary of the *Viking* mission to Mars. This tribute to *Viking*, cosponsored by The Planetary Society and NASA, will include evening lectures by Carl Sagan and NASA Administrator Daniel Goldin and an all-day symposium on Mars exploration. For details, please contact me by phone at 818-793-5100; by e-mail, tps.sl@genie.com.
—Susan Lendroth, Manager of Events and Communications

Mars Madness

Do you want to be there in person as the powerful *Proton* rocket rises from its launchpad this November 16, sending *Mars '96* on its long-awaited trek to the Red Planet? Then come with us to Russia and the Baikonur Cosmodrome in Kazakhstan. Or would you like to be at Cape Canaveral as Mars *Global Surveyor* begins its adventure? Our tour to Orlando, Florida, and the Kennedy Space Center (November 2 to 9) will take you there. For information, call me at Society headquarters or send e-mail to tps.cj@genie.com. Don't miss this chance to witness our return to Mars.
—Cindy Jalife, Manager of Program Development

For Comet Watchers

We have *two* new tours in the works, and they're both focused on the 1997 arrival of comet Hale-Bopp. Both trips will take place March 22 to 29, when the comet is expected to be at its most spectacular. One trip will take us to Hawaii, where we'll comet-watch with planetary scientist Steven Edberg of the Jet Propulsion Laboratory by night and explore the islands by day. The second is tentatively scheduled for Fairbanks, Alaska. We'll have the special pleasure of viewing the comet with Alan Hale, its codiscoverer. If you want to know more about either of these tours, contact me at Society headquarters. *—CJ*

Open House at ISAS

The Institute of Space and Astronautical Science (ISAS) in Japan will host its annual open house on Saturday, August 3, 1996. And we'll be there, with Planetary Society exhibits featuring such special projects as Red Rover, Red Rover and *Visions of Mars*. Phone 0427-51-3911, extension 2204, for information; the address for ISAS is 3-1-1 Yoshinodai, Sagamihara, Kanagawa. *—SL*

Share Your Photos

Did you capture a photograph of comet Hyakutake that you are especially proud of? Do you want to share it? The Planetary Society would like to collect some striking portraits of the comet for possible use in future publications or videos. If you want to participate, please send your work to me at Society headquarters. We prefer prints or slides over digital formats, unless you have a large, high-resolution image.
—Donna Stevens, Assistant Editor

Countdown With *Galileo*

The Society is counting down to Planetfest '97 with a series of events tied to *Galileo*'s encounters with the moons of Jupiter. Here's a preliminary list:

- July 25, 1996, Pasadena, California
- October 26, 1996, Tucson, Arizona
- December 4, 1996, Providence, Rhode Island
- January 22, 1997, Honolulu, Hawaii
- March 1997, Davenport, Iowa

If you live in the area of a scheduled event, you'll be notified by mail. You may also contact us for details on any event of special interest to you. *—SL*

Feast of Events in Great Britain

The Planetary Society will be participating in the 1996 COSPAR (Committee on Space Research of the International Council of Scientific Unions) conference at the University of Birmingham July 14 to 20. We'll have a display at the conference, as well as a Red Rover, Red Rover demonstration at the Birmingham Museum of Science.

Society Executive Director Louis Friedman will host an evening event on July 20 in Birmingham; on September 21, he will speak at one of many Society events celebrating National Astronomy Week. For information, contact me via e-mail (hn81@dial.pipex.com) or telephone (0121-356-5446).
—Andy Lound, Regional Coordinator

Ride 'em, Rover

Rovers from around the world will be showcased at the February 1, 1997, Rover Roundup on the beach in Santa Monica, California. This event is sponsored by The Planetary Society in cooperation with NASA and several other space agencies. A three-day international conference on mobile planetary robots will precede the public event.

If you are interested in the technical conference Call for Papers, contact India Wadkins at Society headquarters. Details of the public event will be available later. *—SL*

More News

The Mars Underground News:
United States presidential candidates and space…the Planet-B mission…images of Mars.

The Bioastronomy News:
Preparing for an extraterrestrial signal…how to respond to signals…the ongoing search for extraterrestrials.

The NEO News:
Spacewatch…more Hyakutake news…discoveries of new objects.

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

Basics of Spaceflight:

Electrical Systems

by Dave Doody

In the previous installment, we looked at propulsive power, which is provided to a spacecraft by its chemical-burning launch vehicle, augmented by onboard propulsion systems. (See the March/April 1996 *Planetary Report*.) But interplanetary spacecraft also need electrical power to operate valves, computers, radio transmitters and receivers, data storage devices and a host of sensors and instruments. How does a spacecraft meet these electrical power needs?

Voltage and Current

First, let's describe two basic measurements of electrical power: voltage and current. We can compare electrical voltage with water pressure. The 12 volts (V) in your automobile is a relatively low electrical pressure. Low water pressure could be used in, say, a drinking fountain. The 120-volt service in United States homes provides a higher electrical pressure. If you were to increase the pressure in your drinking fountain tenfold, the water might squirt across the room when you went to take a sip (our office used to have one that did nearly that).

The other electrical measurement, current, is analogous to the water's flow rate. The small pipes in your drinking fountain carry a small current of water—only a few liters or so per minute. Large pipes supplying a fire hydrant can carry a substantially higher current, perhaps thousands of liters per minute.

You could vary the flow rate somewhat in your drinking fountain by changing the pressure, and this is true in electrical circuits as well: Increase the voltage supplied to a lightbulb, and more current will flow through it. But only until it breaks. You wouldn't trust drinking-fountain-sized pipes to fight a fire. And guess what? It takes larger-diameter electrical wires to safely carry a larger electrical current.

Electrical current is measured in amperes (A). The 12-volt fan in your automobile might consume half an ampere at its low setting, and 2 amperes on high. Volts multiplied by amperes gives a convenient single measure of power: watts, abbreviated W.

Roughly 300 to 1,500 watts (1.5 kilowatts, kW) of electrical power was required by the systems aboard spacecraft like *Magellan,* which mapped Venus; *Galileo,* now exploring Jupiter; *Cassini,* the Saturn spacecraft; or the *Voyagers,* traveling in the outer solar system. But what power source can supply a spacecraft for years, or even decades? Batteries just won't last that long, notwithstanding the pink bunny advertisements seen so frequently on US television. Batteries did power *Galileo*'s atmospheric probe, but it only had to run its instruments and transmitter for a little more than an hour—an appropriate task for batteries. There are two realistic choices to meet the long-term demands of interplanetary spacecraft: photovoltaics and radioisotope thermoelectric generators (RTGs).

Photovoltaics

As the name suggests, photovoltaic materials have the wonderful, seemingly magic ability to convert light to electricity. You might have a desktop calculator that runs on ambient light by using a photovoltaic cell. Crystalline silicon and crystalline gallium arsenide are two typical choices of photovoltaic materials for deep space applications. Gallium arsenide crystals are grown especially for photovoltaic use, but silicon crystals are mass-produced for the microelectronics industry and are less expensive. Gallium arsenide is notably tougher and more efficient.

Crystalline ingots of either material are sliced into wafer-thin circles, and then some metal is deposited onto each surface: a thin grid on the Sun-facing side, a flat sheet on the back. Connect one wire to each metal surface, and you have an electrical power source—a photovoltaic cell. When the cell is exposed to direct sunlight at Earth's distance from the Sun (1 astronomical unit, or AU, which is equivalent to 150 million kilometers or 93 million miles), a current of about 1 ampere, at a quarter of a volt, can be produced by a typical 6-centimeter-diameter (2.4-inch) silicon cell. (Operating closer to the Sun creates more power.)

These cells are trimmed into appropriate shapes and sizes and cemented onto a substrate. Electrical connections are then made among all the cells to provide an output suitable to power a spacecraft. These assemblies are called solar arrays. In flight, the cells absorb sunlight and get quite warm, so a solar array's cement and substrate have to be thermally conductive to help dissipate the heat.

Photovoltaics are only practical for spacecraft operating relatively close to the Sun. *Magellan* used solar arrays, as will Mars *Global Surveyor*. Topex/Poseidon, the Hubble Space Telescope and most other Earth-orbiters also use solar arrays. Generally, solar arrays for interplanetary spacecraft are designed to be movable appendages, and the spacecraft's computers keep them pointed toward the Sun. Prolonged exposure to sunlight causes photovoltaics' performance to degrade in the neighborhood of a percent or two per year; this degradation happens more rapidly if the cells are exposed to gas, dust or particle radiation from solar flares.

Spacecraft that have solar arrays are usually equipped with rechargeable batteries. The batteries are recharged whenever the solar arrays are in sunlight. But when the arrays are shadowed by the planet, or when they are pointed away from the Sun during spacecraft maneuvers, the batteries take over, discharging to power the spacecraft until the

Sun returns to the arrays. Nickel–cadmium (NiCad) batteries, not unlike the ones in a portable electric shaver (but larger), are frequently used in spacecraft. After hundreds of charge–discharge cycles, NiCad batteries degrade in performance, but they may be rejuvenated by carefully controlled deep discharge and recharge cycles, an activity called battery reconditioning.

RTGs

Beyond the orbit of Mars, the Sun's light is too weak to be practical for generating power with solar arrays. Craft bound for Jupiter and the planets beyond carry their own sources of power: radioisotope thermoelectric generators. RTGs contain pellets of plutonium 238 in the form of an oxide pressed into ceramic pellets. As the radioactive plutonium decays, it produces heat, and this is converted into electricity by an array of thermocouples made of silicon–germanium junctions. Any waste heat is radiated into space by an array of metal fins.

The very name *plutonium* conjures images of extreme hazard, and the possibility, although extremely remote, of an accident releasing this element into Earth's atmosphere has not been ignored by spacecraft engineers. In the US space program, RTGs are designed to survive launch accidents without releasing the plutonium, and these designs have been tested by the US Department of Energy. In fact, the prelaunch procedures for RTG-carrying spacecraft are so rigorous that the office of the president of the United States must be satisfied of their safety and approve each launch.

RTGs must be located on the spacecraft in such a way as to minimize their impact on particle-detecting and infrared-detecting science instruments. *Galileo*'s RTGs are mounted behind reflective shields to shade the near-infrared mapping spectrometer from the heat they radiate. Much of the spacecraft's mass shields *Galileo*'s high-energy particle detector from the RTGs' gamma radiation. RTG performance degrades in flight just slightly faster than what is normally expected for photovoltaic sources, except that RTGs are much more rugged and therefore more reliable under harsh conditions.

Regulating Electricity in Space

Virtually every electrical or electronic component on a spacecraft may be switched on or off via commands sent from Earth (see the Basics of Spaceflight column in the November/December 1995 *Planetary Report*). This is accomplished using solid-state or mechanical relays that connect or disconnect the component from a common distribution circuit, frequently called a main bus. On most interplanetary spacecraft, you have to power off some components before you can switch others on, in order to keep the electrical load within the limits of the supply. Voltage and current are measured and telemetered from the main bus and other points in the electrical system, including many if not all spacecraft components and instruments. This information is very helpful in making sure systems and instruments are working properly, as well as in troubleshooting when problems arise.

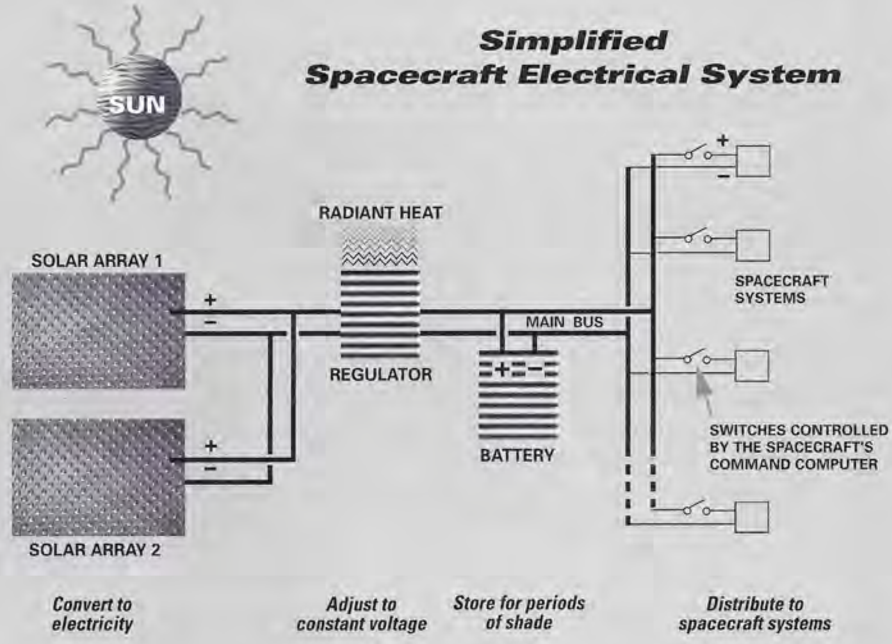


Chart by Dave Doody; redrawn by B.S. Smith

It's important for a spacecraft's computers, instruments, and other components to have a precise, constant voltage. To do this, the electrical power source is typically designed to produce a slightly higher voltage than needed, and this supply is fed to a regulator. The regulator converts the excess electrical energy into heat, most of which is radiated away into space via a radiating plate, and a controlled voltage is supplied to the main bus. *Magellan,* working at Venus' distance from the Sun, had to be operated very carefully to be sure all its components were kept within the right temperature ranges. Once in a while, it was convenient to point its solar arrays slightly off from the Sun so they would produce slightly less electrical power, thus causing the regulator to produce a bit less heat!

Typically, spacecraft power supplies are designed to provide about 28 volts DC (direct current). With DC, the polarity, or direction of current flow, is constant. Some instruments or components, however, may require higher or lower voltages, or they may require alternating current (AC; here the direction of current flow reverses, perhaps 400 times per second). These special needs are met by small, efficient power converters, which take in the normal spacecraft electrical supply and provide the required output. You may have used a similar kind of power converter in an airplane if you plugged your shaver into an outlet in the lavatory.

In the next issue, we'll look at how interplanetary spacecraft deal with the effects of extremely hot and cold temperatures in their environment.

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

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

Questions and Answers

If the Search for Extraterrestrial Intelligence (SETI) was based on Mars (or Alpha Centauri) and aimed at Earth, would it detect any of the signals that it is now searching for? If so, which types of intelligent signals would it select for further scrutiny?
—Tom and Joe Parkinson, Toronto, Canada

If there were Martians and they had a SETI program, they would have no difficulty detecting Earth's radio and television transmissions. Human SETI projects are able to pick up the feeble transmissions, from beyond Pluto, of the Pioneer spacecraft, whose transmitter uses a few watts of power, similar to what a refrigerator lightbulb uses. Earth has many transmitters using thousands to millions of watts. These should be easy for Martians to detect. For example, the giant Arecibo radio telescope in Puerto Rico has a million-watt radar transmitter. It's used to bounce radio signals off planets, moons, comets and asteroids. It's so powerful that it could detect a steel golf ball on the Moon.

They'd be able to learn something about our civilization. They'd discover that our planet rotates every 24 hours, and that there are great concentrations of transmitters in certain regions. They would even deduce something about politics when they found over a hundred languages, with most confined to particular areas.

If there are Alpha Centaurians, their SETI will probably only observe our most powerful transmissions, such as the television and military radar of the United States and Russia. Beyond the nearest stars, the distances are so great that the transmissions get buried in cosmic noise. However, a signal *beamed* at its target could be detectable much farther away. A civilization no more advanced than ours could build a transmitter that we could detect anywhere in the galaxy.

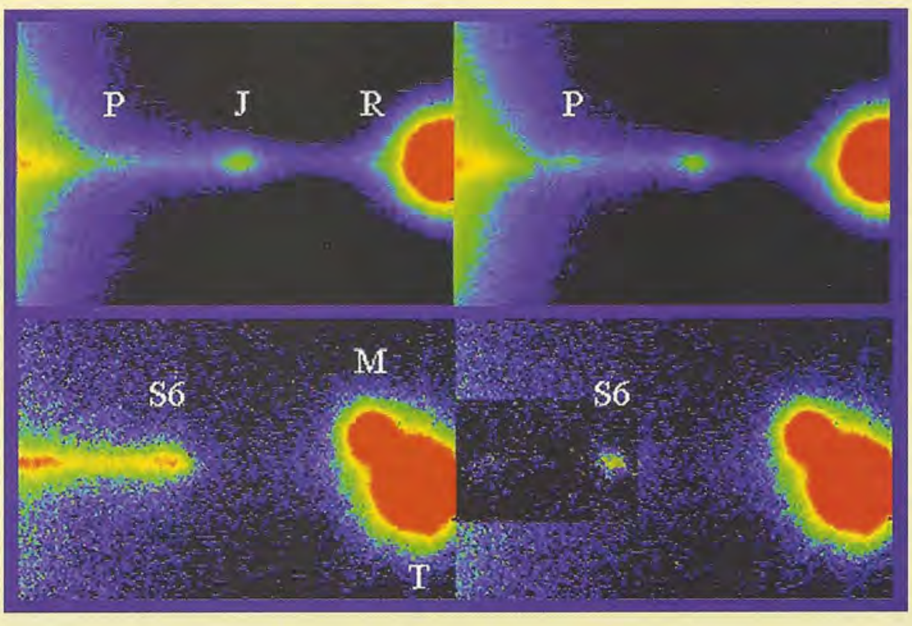
If they are more advanced, it's even possible that they might be able to detect our most powerful television and radar signals even though these are not beamed at them. One trick would be to use their star as a gravitational lens. If they put a receiver at the right location,

Factinos

Rather than finding some new saturnian moons, as some researchers originally reported, the Hubble Space Telescope (HST) may have instead seen clouds of ice and dust orbiting the ringed planet. Some of that debris, however, may be the shattered remains of tiny satellites (see image below).

Last year, Amanda S. Bosh of Lowell Observatory in Flagstaff and Andrew S. Rivkin of the University of Arizona announced that during the May 22 ring-plane crossing, the HST detected two new objects that appeared to be moons (see the November/December 1995 issue of *The Planetary Report*). But after further studying the data, Bosh has now determined that only one of the bodies is a new moon. The other, named S3, has an orbit so similar to Saturn's F ring that it represents a small clump of material from the ring.

In HST images captured during the August 10, 1995, ring-plane crossing, Philip D. Nicholson of Cornell University and his colleagues detected two never-before-seen bodies, as well as S3. The team has concluded that none are moons. The objects must have been created during the last 14 years, because they are too big and bright for the *Voyagers* to have overlooked during their flybys of the



These false-color images show Saturn's inner moons, Pandora, Janus, Rhea, Mimas and Tethys, as seen by the European Southern Observatory's 3.6-meter (140-inch) telescope in La Silla, Chile. The upper panels show the western edge of Saturn's ring plane. The lower panels reveal the newly discovered body S6, which is believed to be a clump of debris, not a new moon. In the April 26, 1996, issue of* Science, *Philip D. Nicholson and his colleagues mentioned that S3 and S6 could well be the same clump in Saturn's F ring.

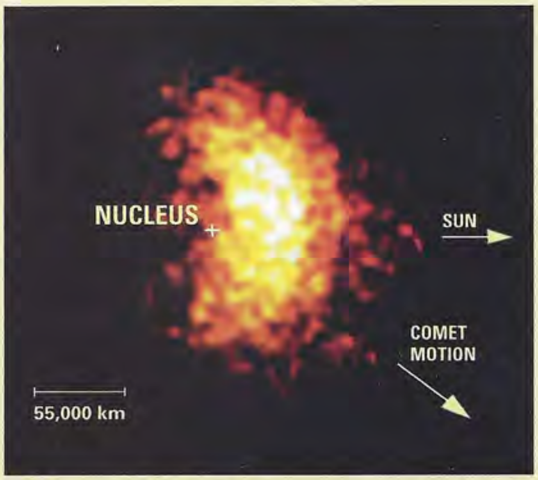
Image: European Southern Observatory

where our radio signals are focused by gravity, they might be able to eavesdrop on some of our routine transmissions even thousands of light-years away.
—TOM McDONOUGH,
SETI Coordinator

We often read that prolonged exposure to weightlessness is damaging to humans, and yet we know that there are plans to put people in orbit on the space station and perhaps on a flight to Mars. Why do we no longer hear of the torus-shaped space station or vehicle that creates gravity by rotating?
—L.S. Kypta,
Milpitas, California

As we gain experience in the joint US/Russian shuttle/*Mir* program and begin constructing the international space station, we are learning more about the effects of prolonged exposure to microgravity (weightlessness) on human beings. Our experience on these space stations will allow us to continue to develop and refine measures to offset the adverse effects of microgravity on bones, muscles, the cardiovascular system, the nervous system and other body systems. Research aboard the space station will also teach us much about how these systems work on Earth.

One of the key research components of the international space station will be a large centrifuge (but not large enough for humans) that will allow us to study how different levels of gravity affect living organisms. This may lead to the development of space stations and other vehicles that create artificial gravity by rotation like the torus-shaped space station you describe. But before the development of these spacecraft, we will have to become better at identifying the requirements for, and effectiveness of, other "simpler" measures to combat the effects of microgravity. We should also have a better understanding of the level of artificial gravity necessary to offset these effects.
—EARL W. FERGUSEN,
NASA Headquarters



A team of US and German astrophysicists has made the first ever detection of X rays coming from a comet. Their discovery of a strong radiation signal was made on March 27, 1996, during observations of comet Hyakutake using Germany's orbiting ROSAT satellite. Scientists had optimistically predicted an X-ray intensity that turned out to be 100 times weaker than what ROSAT detected. Strong changes in the brightness of the X rays were another surprise. These changes, typically a few hours apart, were visible from one ROSAT image to another.

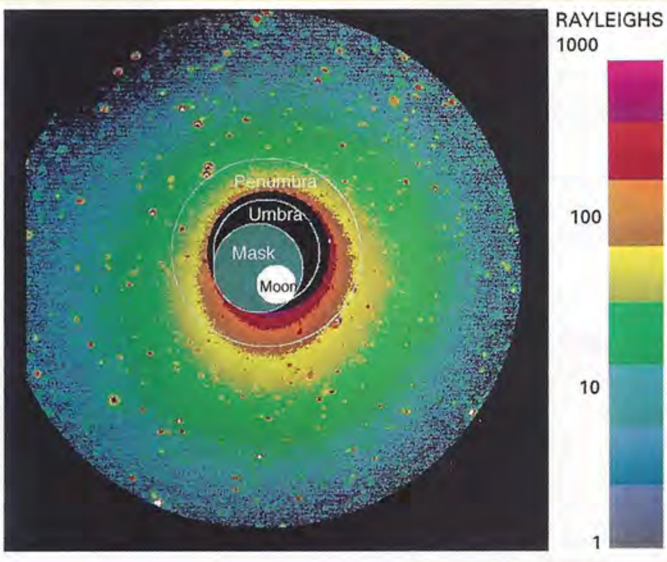
Image: C. Lisse, M. Mumma, NASA Goddard Space Flight Center; K. Dennerl, J. Schmitt and J. Englehauser, Max Planck Institute for Extraterrestrial Physics

planet in the early 1980s, says Nicholson. Also, the brightest of the three bodies is elongated, unlike a satellite.

Nicholson noted that all three bodies seemed to have disappeared by November 21, 1995, when the HST viewed Saturn again. Bruno Sicardy, a scientist from the Paris Observatory in Meudon, France, suggests that the objects, believed to lie near the F ring, disappeared precisely because of their location. Here Saturn's tidal pull could break off a piece of a small moon. This loose package of material would briefly form a cloud of debris bright enough to be seen by a telescope.
—from R. Cowen in *Science News*

The first detailed picture of the Moon's extensive atmosphere (see image at right) was released by researchers from Boston University. In the October 5, 1995, issue of *Nature*, Michael Mendillo and Jeffrey Baumgardner described their observations of the full Moon during the one-hour totality phase of a lunar eclipse at the McDonald Observatory in Fort Davis, Texas, in November 1993.

During the eclipse, the Moon was in Earth's shadow, and the normally bright, scattered moonlight was absent. This revealed a faint glow from sodium gas high in the lunar atmosphere. The scientists were surprised to find that this glow extends over nine times the radius of the Moon, to a height of about 14,000 kilometers (9,000 miles) above the surface. This is almost twice the size of the lunar atmosphere that the Boston team recorded in earlier observations when the Moon was at quarter phase (see the March/April 1995 issue of *The Planetary Report*).
—from Boston University



This image depicts a color-coded representation of the Moon's sodium atmosphere, which was observed during the total lunar eclipse of November 29, 1993. The brightest signals, showing the highest quantities of sodium, are magenta and red, while the faintest signals are depicted as blue. The full Moon's position is indicated behind the occulting mask in the telescope. The umbra (Earth's full shadow) and penumbra (partial shadow) are also shown.

Image: M. Mendillo and J. Baumgardner, Boston University

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—Sam Walter Foss, Librarian, 1858-1911

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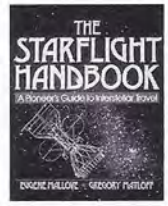

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This violent scene depicts the immediate aftermath of the Cretaceous/Tertiary impact 65 million years ago, when an asteroid smashed into Earth, ending the reign of the dinosaurs. Inside the crater, 30 minutes after impact, the ocean is pouring in through low spots in the crater's rim, cascading down broken, hot rock splattered with molten asteroid and ocean bottom material. Heat generated by the collision has turned many of these growing waterfalls into steam well before they can reach the crater floor, while ash and debris are vented into a widening plume that will soon enshroud the planet.

Don Davis created this "digital intermediate version" of a painting in progress on his Macintosh by first scanning a small black-and-white airbrushed piece and then coloring and refining the image in the computer. Don is currently producing animation and still images for the upcoming British TV show *The New Solar System*, as well as concept art and special effects sequences for various clients.

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