The

PLANETARY REPORT

Volume XVIII Number 3 May/June 1998

If Worlds Collide

On the Cover:

Deer find repose in a bucolic alpine meadow nestled in Olympic National Park. But such scenes of seeming security and timelessness are illusory—as the dinosaurs discovered 65 million years ago when a comet or asteroid impact wiped them out. Earth resides in a swarm of smaller bodies, many with the potential to wreak havoc on civilization. We have discovered about 10 percent of the near-Earth objects, but one of the many unknown objects may at any time appear and pass through our neighborhood—as did comet Hyakutake just last year. Such as-yet-undiscovered comets may pose the greatest danger to life as we know it.

Deer photo: J. Lotter, Tom Stack & Associates
Comet Hyakutake: Johnny Horne

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From The Editor

It may not be explicit, but there is a theme running through this issue: life on Earth and its relationship to chunks of ice and rock from space. In 1980, as the Planetary Society was getting off the ground, Luis and Walter Alvarez and colleagues published their hypothesis that an asteroid or comet impact 65 million years ago triggered the extinction of the dinosaurs. With that paper, they helped solve a scientific mystery of long standing.

They also changed humanity's perception of life and its relation to the heavens. The evolutionary process that shaped our hands and brains was itself shaped by things falling from the sky. Life's earthly environment, after this recognition, can no longer be seen as separate from the larger environments of the solar system, the galaxy, and, ultimately, the universe.

And in this intellectual environment, the Planetary Society has thrived. We've focused many of our programs and projects on asteroids and comets, especially those that orbit in the same solar neighborhood as Earth. They may be small in size, but their importance cannot now be underestimated.

Relatively few people outside the scientific community and the Planetary Society fully appreciate our relationship to these small visitors. Recent headlines and even Hollywood movies notwithstanding, we have a lot of work to do to raise public awareness of our true place in space.

—*Charlene M. Anderson*

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Members' Dialogue

Shiva Impact

I appreciate your excursion (see "The Shiva Hypothesis: Impacts, Mass Extinctions, and the Galaxy" in the January/February 1998 issue of *The Planetary Report*) beyond the usual mission planning/mission results focus of *The Planetary Report.* Until reading that article I had not realized that there have been many mass extinctions of terrestrial life forms in our history. That these extinctions appear to occur cyclically is most sobering—the projectiles for the next bombardment are, likely, on their way.
—RON PATE, *Toronto, Canada*

Michael R. Rampino is correct in stating that the idea of periodicity of mass extinction and impacts is controversial. In his discussion of the extinction at the Cretaceous/Tertiary (K/T) boundary, however, he makes statements that are either out-of-date, incorrect, or have no published data supporting them.

First is the size of Chicxulub. The most recent estimates place it at 100 kilometers (62 miles) across, not 200 kilometers (see the November 20, 1997 issue of *Nature*). If this impact was such a killer, why did the Late Eocene, comparably-sized Popigai Crater in Siberia and the probably contemporaneous 80 kilometer (50 mile) Chesapeake Bay impact cause little or no extinction (see the July 24, 1997 issue of *Nature*)?

Second, a 75 percent extinction at the K/T boundary is an often cited figure, but there are no published data documenting such a percentage. It certainly varies from group to group, but for vertebrates, the best that we can say is that about 50 percent of the vertebrates (including all non-bird dinosaurs) became extinct in western North America. This is presently the only place where we have such records for vertebrates at the K/T boundary.

Third, the speculation of such events as acid rain and impact winter following the K/T impact fade when compared to the actual vertebrate record. Aquatic species would have been hardest hit by acid rain, yet most (75 percent of 49 species) survived the K/T boundary. Similarly, ectothermic vertebrates should have succumbed to impact winter, yet they too did well (66 percent of 61 species). During the K/T interval we also have one of the greatest sequences of volcanic eruptions in Earth's history (the Deccan Traps in India) and the largest loss of epicontinental seas and accompanying coastal habitats in the past 250 million years. Thus, the K/T impact takes its place, along with several other likely causes, as a necessary, but not sufficient, cause of extinctions at the end of the Cretaceous.
—J. DAVID ARCHIBALD,
San Diego, California

Ejecta from the Chicxulub crater (with a documented rim diameter of 180 kilometers, or 112 miles) mark the K/T boundary worldwide. Archibald quotes the diameter of the initial *cavity formed on impact, which quickly expands into the much larger final crater. The smaller Popigai and Chesapeake craters (which produced one-tenth the energy of the K/T explosion) occurred during a time of lesser faunal turnover and abrupt global cooling. The published 45 percent genus-level K/T marine extinction translates into a 75 percent loss of species. As Archibald knows, the vertebrate fossil record is harder to read. Of one thing we can be sure: following the Chicxulub blast, the dinosaurs were gone forever from the planet.*
—Mike Rampino

No Metric!

I'd like to comment on D. T. Bath's "Go Metric" letter in the January/February 1998 column suggesting you use metrics in the body of your articles for those with "deeper interests," whatever that means, and footnote "old terms" (imperial)—I guess that implies shallow interest? As a former *Mercury*, *Gemini*, and *Apollo* worker keenly interested in space exploration but, alas, an "old term" imperial "layperson," I nonetheless think Bath hit on a great idea when he (or she) said 1,000 and 2,250 degrees Fahrenheit to laypeople was just "damned hot." Right on!

But I propose we take Bath's great idea further—make everybody happy and footnote *both* metric and imperial measurements and for the article body coin new measurements we all understand. For example, as D. T. suggested, use "damned hot" and call it DH for anything, say, over boiling; anything over 500 miles (? kilometers) DF (damned far); less than a second, DQ (damned quick). You get the idea.
—CARL L.WOLARY JR.,
Oviedo, Florida

By using both metric and English units you are being fair to *all* of your readers. Moreover, placing the two systems' values side by side actually facilitates the reader's comprehension of both systems.
—CHRISTOPHER FRY,
Fort Worth, Texas

From the many letters we received on the metric conversion issue, it appears those of you who like The Planetary Report*'s current format are in the majority (about 6 to 1). We'll keep things the way they are.*
—Charlene M. Anderson

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OPINION:

THE GREEN SPACE PROJECT

This image, showing Earth as a fragile and lonely oasis in space, came from the Near-Earth Asteroid Rendezvous spacecraft as it swung by in January on its way to asteroid Eros. Here we see the south polar regions of Earth and its Moon from a distance of 400,000 kilometers (250,000 miles). For display purposes, the Moon appears five times brighter than it would to the human eye and is positioned closer to Earth than it actually is.

Image: The Johns Hopkins University Applied Physics Laboratory/NASA

BY KIM STANLEY ROBINSON

I often notice a distrust or antipathy between the environmental movement and the space community that I think is bad for both, but worse for the space community. I hear it in conversations and conferences, and read it in articles and books: space advocates dismissing environmentalism as alarmist, backward-looking, wilfully ignorant, or holier-than-thou; environmentalists accusing the space program of being elitist, irrelevant, polluting, and escapist. Both sides attempt to make their case to the culture at large, and the distortions involved do neither side credit. The space advocates seldom acknowledge that except for environmentalists' unfortunate hostility to the space program, they are mostly right. On the other hand the environmentalists involved, particularly those in the deep ecology movement, exhibit a hostility to human activity above the atmosphere that seems religious in its abhorrence. And it doesn't help to say that these are just the extremists on both sides, because very often the extremists set the tone of the entire discussion. Besides, even some moderates on both sides harbor surprisingly hostile views of the other.

Like many members of the Planetary Society, I suspect, I consider myself both an environmentalist and a space advocate. I think we who consider ourselves as both should try speaking to the general population to make clearer our feeling that the two positions are not antithetical but actually reinforcing, and parts of the same larger project. And I think by and large the burden of persuading the general populace of this "combined position" lies on those of us most actively part of the space community.

Why? Because environmentalism makes intuitive sense; we experience environmental problems with our own bodies, and hear about it every night in the news. We live on this planet, and we know that in the next century it is possible that humanity will overshoot the Earth's carrying capacity—not just as a matter of sheer numbers, but as a combination of population and consumption patterns. Of course no one can know the future, and the question of carrying capacity is notoriously vexed, but it appears that just as a matter of food production we may not be able sustainably to feed many more billions than we already have. It does no good to point to the remarkable gains we have made in crop productivity in the last century, for that is no guarantee that

> "Like many members of the Planetary Society, I suspect, I consider myself both an environmentalist and a space advocate."

the process will continue at the same pace. Science after all is not magic. In this dangerous situation—a kind of choke point in history—environmentalism is simply right, and needs little defense, except against capitalist fundamentalists intent on their religion of perpetual growth and profit.

The rightness of the space program, however, is not so obvious. In fact you might call it counterintuitive. Problems on Earth? Go into space! It sounds wrong. And it doesn't help that our space efforts are expensive, that they require exotic materials which can't be produced without some pollution, and that they are sometimes involved with the military, an institution that is among the Earth's worst polluters. And of course it doesn't help either that there are a few space advocates out there proclaiming that it's a good idea to go into space so that if (or when) we destroy the Earth's environment we will then have somewhere else to live; the damage this silly notion does is incalculable. Given all these factors, and the fact that no one lives in space, it is not surprising that the space program's constituency is relatively small and its budgets perpetually pinched.

Nevertheless I think the space community can make a strong case for itself as a very helpful part of the environmental movement—for space science as an Earth science. This case could begin by reminding people of the origins of our interest in space, by doing a kind of sociobiology of astronomy, clarifying its adaptive powers and therefore its evolutionary purpose. Ancient people studied the sky from the very start of consciousness, trying to tease out patterns and understand what might be happening, not just to satisfy their curiosity but to survive better in the world. This effort was adaptive or it wouldn't have lasted, and indeed in their attention to the round of the seasons, to help calculate planting times and the relocation of flocks and so on, it may be that the ancients were even more interested in space than we are, because it helped them to get one of the few handles they had on the larger questions of their environment. Astronomy, in other words, has been an environmental science from the very start.

Now we use it to understand not just the universe but also our interventions in it, and the space community should

"Astronomy, in other words, has been an environmental science from the very start."

never cease to emphasize its accomplishments in helping to manage our presence on Earth. The role of Venusian atmospheric studies in the discovery of the damage to our ozone layer should be made more widely known. The many ways that we monitor Earth's weather and climate from space should be emphasized. Both the importance of the collection of Earth data, and the power of comparative planetology to explain why Earth is the way it is, should be made clearer. In these ways the space community could make a stronger case for itself as an environmental science, clarifying its role to the general culture and also to any hostile environmentalists willing to listen.

In thinking of itself as part of the environmental movement, the space community might also have to look more closely at its own practices. The manufacture of rockets, satellites, telescopes, and all the rest of the sophisticated equipment involved is heavily industrial, so one has to ask how much pollution is created by this work and whether innovative technologies might not make the whole process cleaner. Something like this happened at the National Science Foundation (NSF) when it was challenged on its environmental practices in Antarctica; NSF responded by creating a rigorous set of guidelines that in effect made the US program in Antarctica an experiment in clean living. NASA could do something similar and lead the way toward making space another experiment in clean living, by mandating certain standards more stringent than the Environmental Protection Agency already requires for NASA's contractors. Private industry could also look for ways to lead in cleaner space technologies.

It would also be interesting to try to do a fuller cost/benefit analysis of these matters. In such an analysis, industrial pollution, use of non-renewable resources, and other environmental factors in the space program would be included as part of its costs, and long-term advantages of all kinds, including very long-term and "uneconomic" advantages, would be included when calculating its benefits. This kind of inquiry would expose the falsity of much contemporary economics—revealing how much is omitted, how much is fabricated, how often the numbers are presented as essential and universal facts, like the speed of light, when actually they are the result of calculations filled with hidden value judgments. New attempts at more illuminating kinds of full cost/full benefit analyses of our efforts in space would at least reveal some of these value judgments, and allow for a real discussion of them. Such attempts might also help to increase the usefulness of cost/benefit analysis generally.

This exercise might accord in some ways with the May 15, 1997 article in *Nature* by R. Costanza and others, who assessed the annual economic value of all natural goods and services at some $33 trillion a year, or more than twice the annual monetary value of all GDPs (Gross Domestic Product) combined. The process used to arrive at this valuation played economics against itself to show that even in economists' own terms the environment is not just an "externality" but a "bio-infrastructure," much more important than traditional economics admits. At the same time, it was also kind of a joke, revealing the absurdity of the whole notion of putting a money value on the ecosystem as a whole, for on consideration one sees that Earth's natural processes are invaluable and irreplaceable, their "scarcity value" peeling off to infinity. They are our communal body and life.

Applying a similar analysis to the space program could lead us, I think, to improvements in the space program as an aspect of environmental science and also to the realization that both the space program and the environmental movement are part of a larger utopian project that is not finally economic in its goals—a project that we could call permaculture, an attempt to invent a long-term, sustainable culture —which might also be called science itself. All these enterprises are trying in their various ways to better the communal situation on Earth, for the sake of all humans, all our descendants, and all the other living things on the

"[T]he space program and the environmental movement are part of a larger utopian project that is not finally economic in its goals . . . ."

planet, combining together as Earth's biosphere, a kind of supra-organism or family. Going into space gives us a higher angle on the problem, but the problem has to be kept in focus, so that those pursuing different solutions to it can see that they are part of the same work.

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*Kim Stanley Robinson is a novelist whose trilogy on terraforming—*Red Mars, Green Mars, *and* Blue Mars*—has won Nebula and Hugo awards and high critical acclaim.*

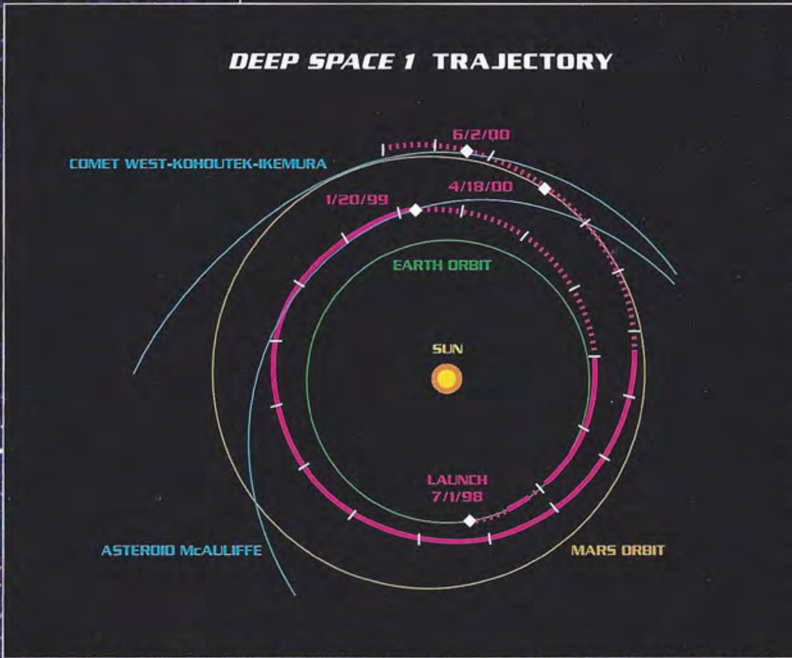
DEEP SPACE 1: Exploration Technology for the 21st Century

by

Robert M. Nelson

and

Marc D. Rayman



Above: Deep Space 1 *will fly by the asteroid McAuliffe in January 1999, slip past Mars in April 2000, and approach comet West-Kohoutek-Ikemura in June 2000, demonstrating along the way the possibilities of solar electric propulsion. New technology is the focus of this mission. As a bonus, it will collect data from some of the smaller and lesser-known objects in our solar system.*

Painting: JPL/NASA

Left: Deep Space 1*'s trajectory around the Sun will provide ample opportunity to test the solar electric propulsion system (SEP). The ticks on the spacecraft path mark 30-day intervals; the solid portion indicates the SEP is thrusting.*

Chart: JPL/NASA; modified by B.S. Smith

This summer NASA takes a revolutionary step when it launches *Deep Space 1 (DS1)*. During its flight, the spacecraft will visit asteroid 3352 McAuliffe, the planet Mars, and comet West-Kohoutek-Ikemura. But its primary goal is not to study these fascinating bodies; rather, as a member of the New Millennium program, its job is to pave the way for future, even more exciting, space science missions.

NASA has already flown missions to asteroids, comets, and Mars, so what makes *DS1* unusual? It will demonstrate a dozen technical innovations that will serve as foundation technologies for the next generation of deep-space missions. Foremost among these new technologies will be solar electric propulsion (SEP), which will enable a whole class of ambitious missions that are simply impractical or unaffordable with the standard chemical propulsion available today.

A Test Drive

DS1 will be launched from Cape Canaveral on the first Delta 7326 rocket, a low-cost member of the Delta II family. *DS1* is so small that even this economy-class launch vehicle will be able to carry a second spacecraft at the same time—SEDSAT-1, an Earth orbiter built by students at the University of Alabama in Huntsville.

Once in space, *DS1* will be checked out and certified by the mission operations team, and then the SEP system will begin thrusting. Instead of burning a strong, short pulse of chemical propellant, followed by a long interplanetary cruise, the SEP system will sustain a tenuous but very high-velocity stream of ionized xenon. This stream will create a gentle, steady thrust that will propel the spacecraft almost continuously during interplanetary cruise.

Although the thrust of SEP is small, its advantage accrues because the exhaust velocity of the ion rocket is many times greater than the exhaust velocity of a conventional chemical system. The bottom line is that SEP requires far less propellant than a chemical rocket to deliver the same payload mass to a target. It takes time for the gentle thrust to build up high spacecraft velocity, so SEP is appropriate only for missions requiring high energy or long trips.

Within a month of launch, *DS1* will have accomplished most of its major objectives, and we will have assessed its payload of advanced technologies. If a technology fails during the flight, even if it causes the loss of the spacecraft, we may still regard the mission as a success if it achieves the program goal of reducing the risk for future science missions. It is in these future missions that the real science return of *DS1* will be found. But this high-risk project will attempt to return science during its test flight.

Depending upon the exact date of launch and the performance of the new technologies, the plan for *DS1* is to fly by asteroid 3352 McAuliffe about January 20, 1999 and by comet West-Kohoutek-Ikemura on June 2, 2000. An encounter with Mars about April 20, 2000 will provide a small gravity assist and present another opportunity to validate technologies and conduct science observations.

The flight of *DS1* will test new autonomy technologies, solar concentrator arrays, and a variety of telecommunications and microelectronics devices. Autonomy, which in this case means the ability of the spacecraft to make its own decisions, can help reduce the heavy burden on NASA's Deep Space Network (DSN). As more and more probes are sent into space in the coming years, it will be harder for the DSN to communicate with all of them as frequently as it has done in the past. With autonomy technologies allowing spacecraft to operate for longer times without detailed instructions from Earth, the precious resources of the DSN can go further. In addition, by placing more responsibility on the spacecraft, we reduce delays caused by signal travel times and limited communications rates. Despite the potential advantages, it is easy to see that onboard decision-making systems entail risk for the first user. If the autonomy systems on *DS1* perform as planned, future mission teams can be more confident about leaving important decisions to the spacecraft.

One of the powerful autonomy technologies on *DS1* is the navigation system. It uses images of main-belt asteroids viewed against the background stars to compute the spacecraft's position. As the spacecraft travels, foreground objects (the asteroids) will appear to move relative to the background stars. The apparent shift, or parallax, gives the navigation system information from which to triangulate the spacecraft position. The navigation system then uses positions calculated at earlier times to determine trajectory, making allowances for SEP thrusting, gravitational pulls of the Sun and planets, and other forces. If the navigation system finds that it is off course, it can make a course correction by adjusting the direction or duration of SEP thrusting.

A New Focus: Instrument Versatility

In addition to these engineering systems, two scientific instruments will also be validated aboard *DS1* for the first time in space: the Miniature Integrated Camera Spectrometer (MICAS) and the Plasma Experiment for Planetary Exploration (PEPE). MICAS has two visible-light imaging channels, an ultraviolet imaging spectrometer, and an infrared imaging spectrometer. MICAS will return images and spectra of Earth and the Moon as well as various stellar and planetary calibration targets. Data from these familiar targets will help validate our re-engineering of diverse instrument capabilities into one small package. MICAS will go on to study the other solar system bodies on *DS1* 's itinerary.

PEPE will measure plasma, the ionized gas that constitutes an important part of the environment in space. Measurements from PEPE will tell us not only about the flow of plasma near various target bodies but also about the effects of SEP effluents. The SEP emits positive xenon ions and, to keep the spacecraft electrically neutral, negatively charged electrons. These particles may form a complex plasma around the spacecraft as they interact with the solar wind. Indeed, a key validation question for *DS1* is whether meaningful solar wind measurements can be made while operating an SEP system.

MICAS and PEPE represent a new direction in the evolution of science instruments for interplanetary spacecraft. These two instruments have capabilities from five instruments that typically flew on deep-space missions in the past. MICAS performs as an imaging system, an ultraviolet imaging spectrometer, and an infrared imaging spectrometer. PEPE combines the functions of an ion analyzer and an electron spectrometer. Although the integrated instruments do not have the full capability of the instruments they replace, the advantage that MICAS and PEPE bring in savings of mass and power makes them highly desirable technologies in the era of faster, better, cheaper missions.

DS1 and later New Millennium missions contribute directly to NASA's new approach to solar system exploration. SEP provides faster access to farther destinations. Autonomy reduces the cost of such missions. Advanced microelectronics and telecommunications devices allow small spacecraft to conduct these missions, carrying a new generation of compact instruments.

The New Millennium program will give NASA the ability (technically and fiscally) to launch many missions per year rather than a few per decade. We may find that the next time an intriguing and unexpected visitor such as comet Hale-Bopp graces our skies, we will have a ready supply of probes to greet it. By taking risk with missions such as *DS1*, NASA is preparing for the time when humankind's robotic (and, eventually, human) emissaries to space will be routinely reporting back exciting new findings from throughout the solar system and beyond.

Robert M. Nelson is a Research Scientist at NASA's Jet Propulsion Laboratory and the Project Scientist for DS1. *Marc D. Rayman is the* DS1 *Chief Mission Engineer and Deputy Mission Manager.*

New Millennium

A major criticism levied against the NASA of past years was that the agency was unwilling to take even prudent risks with innovative technologies for deep-space missions.

NASA Administrator Dan Goldin has since encouraged his agency to take greater risks in developing new missions. However, NASA managers are rewarded for mission success, not for taking risk. Thus, they tend to be most comfortable with missions that use components with a long heritage and that use systems configured to ensure the greatest possible redundancy, maximizing the possibility of a "work around" should a component fail. This approach is sometimes called "both belt and suspenders" project management.

The organizational logjam began to clear when Goldin's Associate Administrator for Space Science, Wes Huntress, spearheaded development of the New Millennium program, managed for NASA by the Jet Propulsion Laboratory. New Millennium's purpose from the outset was to carry out final validation of technologies so that they could be used on future missions without stigma of risk.

DS1 will validate a dozen new technical concepts. Next in line, *Deep Space 2* includes two microprobe impactors with instruments designed to survive a hard slam into the surface of Mars (equivalent to 80,000 times the force of Earth gravity). Other missions will demonstrate tandem flying in space for optical interferometry, sampling and return techniques, and other critical technologies.

Once the technologies from *DS1* and the other New Millennium test flights have been demonstrated in space, they can be included on future science missions without undue fear of failure by systems with important, but unproven, new capabilities.
—RMN and MDR

The Mars Rock: Some of Its Chemistry Is From Earth

by Gene McDonald

Results from two recent studies of the meteorite ALH84001 are lending support to skeptics who doubt that the headline-making rock contains evidence for life on ancient Mars. Debate continues, but on this much the scientists agree: ALH84001 is a fragment of Mars—a meteorite found in Antarctica in 1984 and determined by mineralogical and chemical analysis to be a visitor from the Red Planet.

In August 1996, a group of scientists led by David McKay of NASA Johnson Space Center published a paper in *Science* in which they observed that the meteorite, 3 to 4 billion years old, contains carbonate minerals, which normally precipitate from liquid water. The team also noticed grains of the mineral magnetite that were similar in size and shape to those produced by certain bacteria on Earth. McKay and colleagues also detected organic molecules known as polycyclic aromatic hydrocarbons (PAHs) associated with the carbonates. Using a scanning electron microscope, they saw small, elongated structures that are suggestive of fossilized bacteria.

From this concatenation of data, the McKay team concluded that "considered collectively" these observations "are evidence for primitive life on early Mars." Since publication of this paper, most of the discussion within the scientific community has centered on two topics. One issue is whether the carbonate minerals formed from water at temperatures less than 100 degrees Celsius (212 degrees Fahrenheit), low enough for life to exist, or at temperatures of several hundred degrees, much too high for life as we know it. The other question is whether the elongated structures, which are around 100 nanometers (4 millionths of an inch) long, are large enough to have once contained the molecular machinery that a living cell needs to function. Typical earthly bacteria are ten or more times as large. No consensus has yet emerged on either of these two issues.

The January 16, 1998 *Science* brought forward a third line of inquiry—investigations into the source of the organic molecules in ALH84001. As reported in two articles by separate groups of researchers, new evidence indicates that the meteorite's organic molecules are contaminants of terrestrial origin.

As the Amino Acid Turns

One of the articles, authored by J. L. Bada, D. P. Glavin, G. D. McDonald, and L. Becker, reports on their search for amino acids, a class of organic molecules central to terrestrial biochemistry. To get amino acids out of a sample from the rock, Bada and colleagues used a dilute hydrochloric acid solution to dissolve the carbonate minerals, leaving behind any organic compounds associated with them. The researchers then analyzed this extract using liquid chromatography, a procedure that separates amino acids that are more water-soluble from those that are less water-soluble. (The dissolved amino acids travel through a column of porous silica that has a layer of a hydrocarbon compound to slow down the less water-soluble amino acids. Particular amino acids can then be identified by the time it takes them to pass through the column.)

The team looked for amino acids found in life on Earth and also for other amino acids not found in terrestrial life but abundant in carbon-containing meteorites (carbonaceous chondrites) that have struck Earth and Mars throughout time.

The researchers found low levels of a few amino acids used by life on Earth but detected no non-biological amino acids. The distribution of amino acids in the meteorite was similar to that in Antarctic ice, and the biological amino acids were almost entirely of the same "handedness" as amino acids used in proteins on Earth. (An amino acid is either right-handed or left-handed according to whether its chain of atoms corkscrews in one direction or the other. Amino acids associated with terrestrial life are all left-handed.) By contrast, in carbonaceous meteorites, we find equal amounts of amino acids with each handedness. While it is possible that this amino acid signature could be the result of Martian biology, Bada and colleagues concluded that the most likely source of the amino acids is contamination by earthly biological material during the meteorite's residence in the Antarctic.

Telltale Kinds of Carbon

The second paper, authored by A. J. T. Jull, C. Courtney, D. A. Jeffrey, and J. W. Beck, describes their analysis of carbon isotopes in the organic material and in the carbonate minerals of ALH84001. Jull and colleagues fractionated the meteorite's carbon (that is, they separated the organic-associated carbon from the carbonate-associated carbon) by heating samples in 100-degree increments from room temperature to over 700 degrees Celsius (about 1,300 degrees Fahrenheit). Most organic carbon combusts to carbon dioxide at temperatures below 400 degrees Celsius (about 750 degrees Fahrenheit), while carbonates combust at temperatures about 450 degrees Celsius (840 degrees Fahrenheit) or above. The researchers then tested the lower-temperature (organic) fraction of the carbon for its ratio of carbon-13 to carbon-12. The ratio for these two isotopes in ALH84001 was indistinguishable from the ratio in terrestrial biological material.

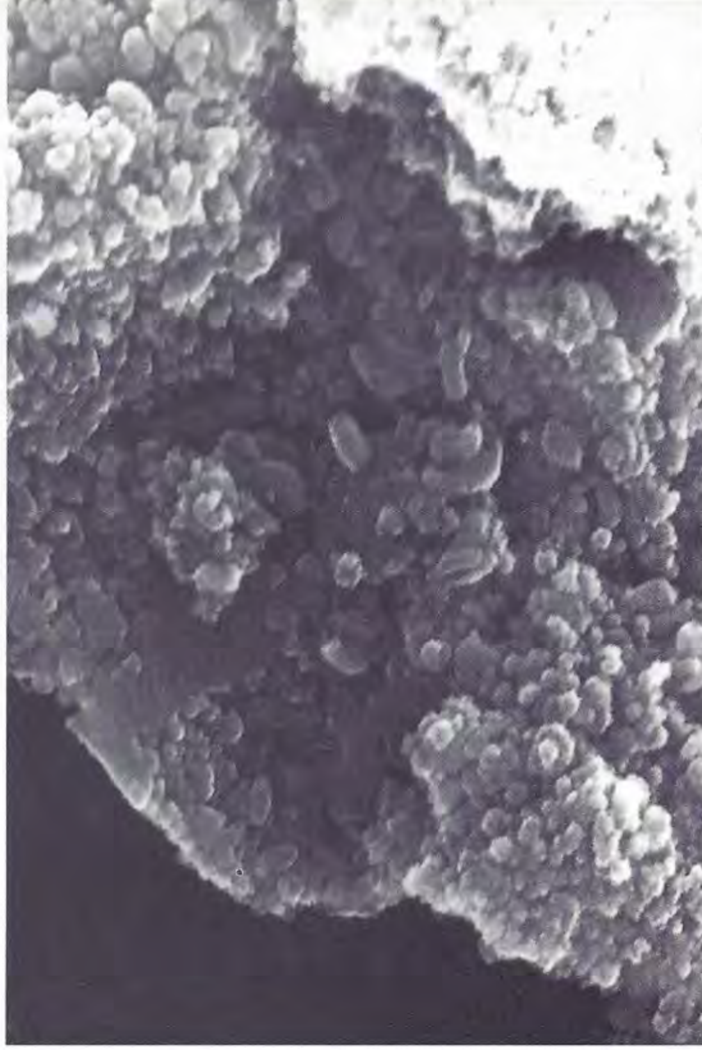
More important, this fraction also contained significant amounts of carbon-14, the isotope widely known for its use in dating archeological artifacts. From carbon-14's half-life of 5,715 years, Jull and colleagues determined that the radiocarbon age of the organic material in ALH84001 is between 5,000 and 12,000 years.

We know the meteorite was ejected from Mars about 14 million years ago, as measured by cosmic-ray damage to the meteorite. We know also that it has resided in the Antarctic for some 13,000 years, as measured by decay of radioactive elements produced during the meteorite's time in space. Therefore, the carbon-14 evidence indicates that the organic material must have contaminated the meteorite after it arrived on Earth.

The team noted that a small fraction of the total carbon in ALH84001 combusted at temperatures intermediate between organic and inorganic carbon, and it is still unclear whether this fraction was organic or inorganic. This intermediate fraction did not contain carbon-14, which indicates that it was extraterrestrial.

We don't completely understand the source of all the organic material in ALH84001. However, the recently published studies make it clear that most of the organics in this meteorite are terrestrial contaminants rather than residues of life on Mars. If there is any Martian organic carbon in ALH84001, it will probably be very difficult to isolate from the contaminants and even more difficult to identify unambiguously as extraterrestrial. We may never completely resolve the provenance of all the organic material in ALH84001, but the simplest and most plausible explanation for what we've observed remains contamination from the Antarctic environment.

Gene McDonald, a contributor to one of the Science *articles described here, is a Research Scientist with the Astrobiology Group at the Jet Propulsion Laboratory. In the March/April 1998 issue of* The Planetary Report, *he contributed the first article in our new column, The Stuff of Life.*



Earthly Contaminants Don't Rule Out Martian Life

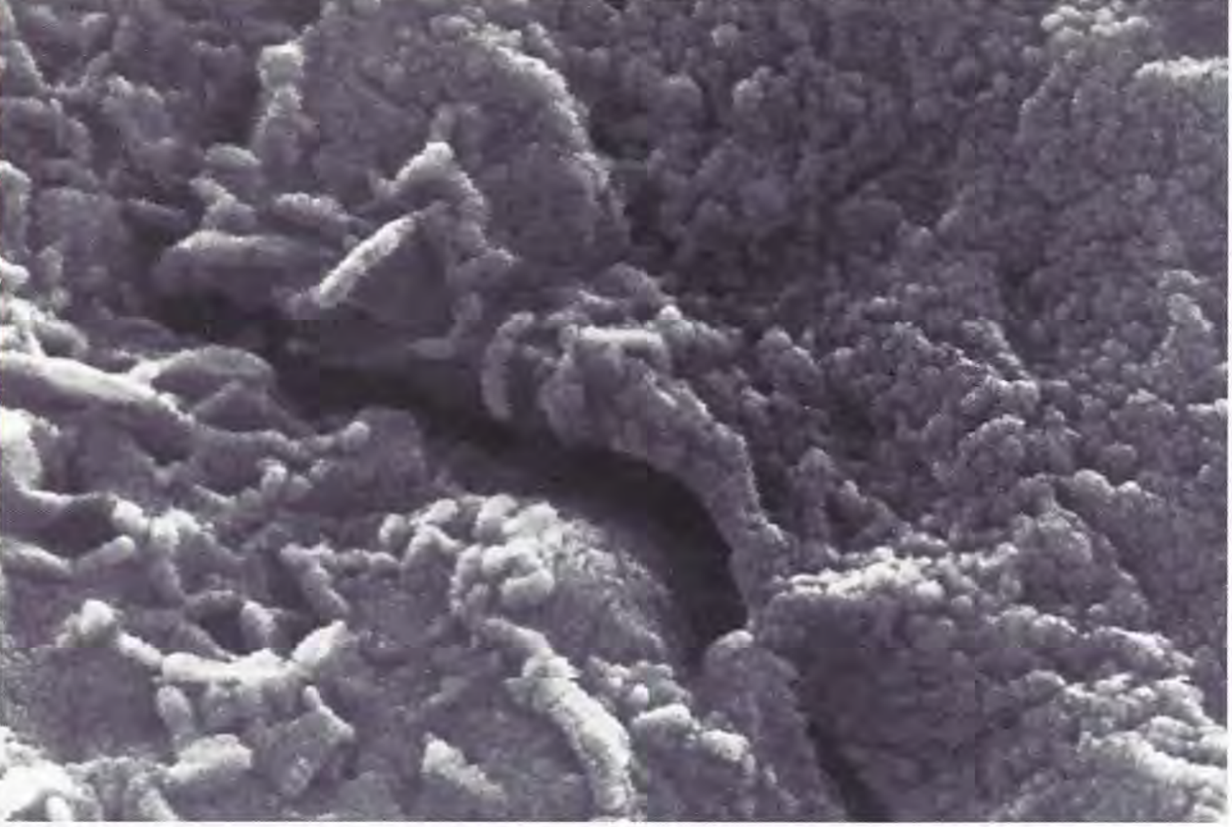
by David S. McKay, Everett K. Gibson, and Kathie L. Thomas-Keprta

The Bada and Jull papers are extremely interesting and give us additional insight into the history of this Martian meteorite, but they do not invalidate our original hypothesis that ALH84001 contains possible evidence for early life on Mars.

First, the amino acids detected by Bada and colleagues may very well be contamination from Antarctica. However, the fact that they are left-handed molecules does not prove that they are from Earth and not from Mars; Martian organisms may have produced left-handed amino acids similar to those produced by terrestrial organisms.

PAHs as Biomarkers

An important point is that our group analyzed for polycyclic aromatic hydrocarbons (PAHs), not amino acids. PAHs have been shown to be a natural decay product of dead organisms on Earth, so they are just as much a biomarker as amino acids; both types of organic molecules can form either by non-biologic processes or biologic processes. Furthermore, extensive testing by the Stanford University members of our original team show that PAH levels in Antarctic ice and in other kinds of meteorites from the Antarctic are much lower than PAH levels in ALH84001.



***Far left:* These egg-shaped structures in the Martian rock look intriguingly like bacterial fossils, but this resemblance was not the only evidence the NASA/Stanford University team put forward to support their hypothesis. They also found polycyclic aromatic hydrocarbons (PAHs), a common residue of life, within the meteorite ALH84001.**

***Left:* Within meteorite ALH84001, carbonate deposits were formed when water filled fractures in the rock. Within those deposits were tiny structures that, at least superficially, resemble bacterial fossils on Earth. The terrestrial fossils often appear in limestone, a familiar carbonate form.**

Images: Johnson Space Center/NASA

In addition, PAHs are much less water-soluble than amino acids, so PAHs are less likely to be transported through meltwater movement. It is not surprising that the bulk meteorite contains soluble components from Antarctic meltwater; it is likely that during the Antarctic summer this meteorite may even have been soaking in a puddle of meltwater. However, careful work by George Flynn at the State University of New York, Plattsburgh, using instruments at Brookhaven National Laboratory, found that the chlorine to bromine ratio in the carbonate globules and their rims was about 10,000 to 1, which is nearly 100 times that of Antarctic ice. These results suggest that the carbonate globules have not been significantly contaminated by soluble chlorine or bromine salts while in Antarctica. Otherwise, the ratios should be similar to that in the ice.

The source of the PAHs remains a mystery, and our original interpretation that they are inherent in the meteorite and come from Mars remains valid. We also emphasize that our original work concentrated on the carbonate globules, which were indisputedly formed on Mars. The Bada group analyzed chunks of the meteorite and did not attempt to separate out the carbonate globules. Consequently, it is not clear whether their amino acids are mainly near-surface contamination or are also present in or on the carbonate globules. We found that the PAHs were most abundant on surfaces rich in carbonate globules and were nearly absent from the outer crust.

The Mystery Component

The presence of carbon-14, as discussed in the paper by Jull and colleagues, clearly demonstrates that a significant part of the organic carbon in this meteorite is terrestrial contamination. In fact, every Antarctic meteorite ever analyzed contains some carbon-14 acquired in the ice fields. Many have secondary minerals, including carbonates that clearly formed in Antarctica.

However, in the acid-resistant residue of the Martian meteorite the Jull team found a carbon-rich mystery component that did not contain carbon-14 and therefore was not a terrestrial contaminant. Furthermore, this mystery component displayed an intriguing combination of features: it had a carbon-12 to carbon-13 ratio characteristic of organic carbon made by organisms on Earth, but was at the same time relatively heat resistant, combusting only at 450 degrees Celsius (840 degrees Fahrenheit) or higher temperatures. Its carbon-12 to carbon-13 ratio was quite different from that of the Martian carbonates in the meteorites. While this mystery component made up at most 20 percent of the total organic carbon, its demonstrably pre-terrestrial origin and its similarity to biologically produced organic carbon on Earth actually lends new support to our hypothesis. Does this carbon-rich material include the PAHs originally found by us? Was this carbon-rich material produced by the decay of Martian organisms? No one yet has those answers.

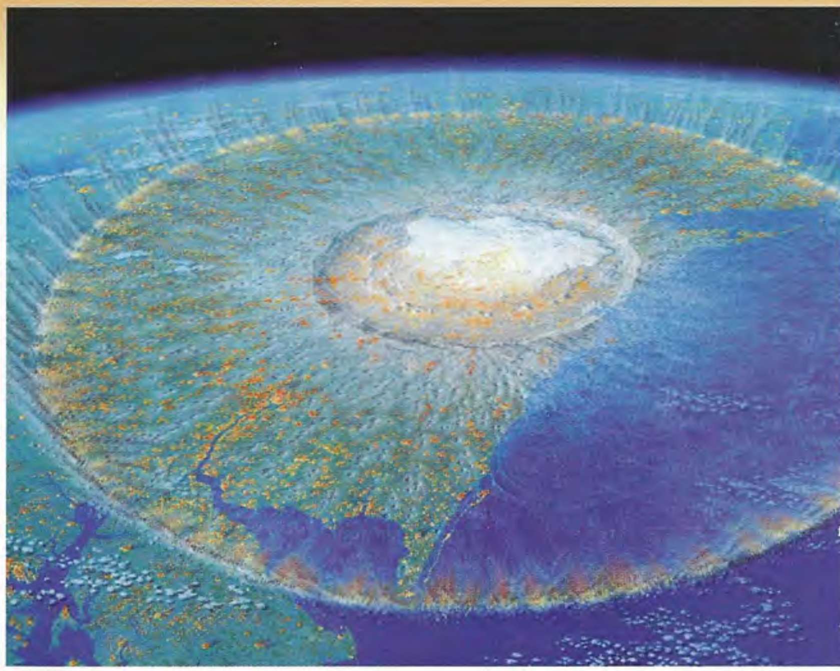
We agree that this is an extremely complex rock with a complicated history. Nature is not always simple. However, that should not deter us or anyone from trying to sort out the true Martian properties from terrestrial contamination. The presence of significant Antarctic contamination makes it more difficult, but not impossible, to determine whether this rock contains Martian biomarkers.

In summary, neither of these papers detracts from our original data or invalidates our original hypothesis; they only make the story more complex and challenging. The ultimate answer may have to await the return of Mars samples in the next decade. Until then, we argue that the study of Martian meteorites will continue to provide important clues to the possible early presence of life on Mars.

David S. McKay and Everett K. Gibson of NASA Johnson Space Center, Houston, and Kathie L. Thomas-Keprta of Lockheed Martin Corporation, Houston, are members of the team whose 1996 article in Science *identified the evidence for early Martian life contained in ALH84001.*

DEEP IMPACT

FILMING A COSMIC CATASTROPHE



By Charlene M. Anderson

We do meteoroids, not movies. In this magazine, we report on humanity's efforts to explore other worlds and understand our place in the solar neighborhood. We often cover comets and their close relatives, asteroids—objects that have the potential to affect life on this planet.

Through the Planetary Society's various asteroid projects, we have sought to advance scientific investigation of these objects. Through public education and advocacy, we have tried to teach people about the role of comets and asteroids in Earth and solar system history and to raise awareness among those who control the funds for scientific research.

Meanwhile, Dreamworks and Paramount Studios are releasing a major film, *Deep Impact*, about the people of Earth reacting to a comet bearing down upon them. The film's producers—Society Director Steven Spielberg and Joan Bradshaw—granted the Planetary Society an exclusive preview of their script.

This preview occurred after shooting had begun, so we had no influence on the movie's scientific and technical accuracy. However, our reading touched off some lively "what if?" and "could it happen?" discussions that Society members may find interesting.

The Planetary Society named three internal reviewers: James D. Burke, an engineer and technical editor of *The Planetary Report* (and near-legend in some corners of the space program); Andre Bormanis, a physicist, science consultant to the *Star Trek* television series and films, and sometime consultant to the Society; and myself, editor of *The Planetary Report*.

The script contained no fatal flaws. Compared to other films with similar themes, any mistakes were minor. However, much will depend on how the visual effects are handled. In some areas, such as the depiction of a special propulsion system, we can't say anything about accuracy until we see the finished product.

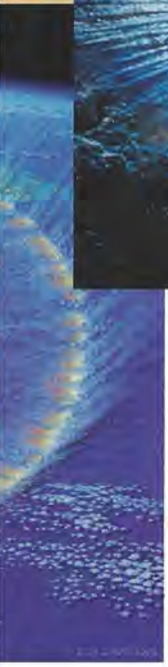
We make no final pronouncements on *Deep Impact*. There has been a lot of comet exploration, observation, and study in recent years, and our readers have been along for the ride. Better than most of the movie-going public, you can judge for yourself.

After reading the script, I asked the filmmakers and their consultants many questions about the making of *Deep Impact* and checked some of their statements with leading scientists in comet and asteroid research and hazard analysis. Here is an overview of what everyone had to say.

Why try to portray the science correctly?

Filmmakers usually elevate "dramatic necessity" over scientific accuracy in the stories they tell. And some are simply blatant in rewriting reality to suit their purposes. Executive producer (with Steven Spielberg) Joan Bradshaw was adamant that "we could get the science right and still make a movie.

"We were aiming to make a dramatic film with the same emotional impact as *On the Beach*," she explained. "You have to at least root the movie in fact because people are so educated today."



***Above:** In designing their version of a comet impact, the* **Deep Impact** *special effects team tried for the most dramatic effect possible while remaining within the realm of possibility.*
Image: Paramount Pictures and Dreamworks L.L.C.

Left:** As one of* **Deep Impact's consultants pointed out, we humans have no first-hand experience of large comets striking Earth. But with numerical modeling, scientists can get some idea of how such an event might appear. Noted astronomical artist Don Davis referenced scientific modeling in his rendition of a cometary impact. Don is known for painstakingly accurate portrayals of planetary scenes.* *Image: Don Davis*

Deep Impact consultant Gerry Griffin, former director of Johnson Space Center (JSC), was more blunt: "None of them [the filmmakers] wanted to look stupid." Griffin, who served as a consultant on *Apollo 13* and *Contact*, said of these filmmakers: "They went overboard to get it as close as they could—I was pleased with that."

What role did scientific consultants play?

The *Deep Impact* producers hired several consultants from the world of space science and engineering: Joshua Colwell of the University of Colorado, Boulder, who specializes in the study of small, solar-system bodies; Gerry Griffin, who served in mission control during the *Apollo* missions and became head of JSC; Chris Luchini of the Jet Propulsion Laboratory (JPL), who studies how to model and visualize comets; and David Walker, a former astronaut who flew four space shuttle missions.

During pre-production, Gene and Carolyn Shoemaker worked with the filmmakers and found their brief experience with the movie "kind of impressive, intriguing. We really had good hopes for the film." However, an automobile accident in Australia last summer, which killed Gene and left Carolyn in the hospital, ended their involvement.

The consultants, according to Colwell, told the filmmakers "where it was firmly grounded in science, where it was more speculative, and where it was just wrong." For example, the original conception had the astronauts "loping along as if they were on the surface of the Moon," which has a gravity about one-sixth of Earth's. But, as Colwell explained to them, a comet's gravity is a small fraction of that fraction, and their astronauts would appear to be nearly floating over the comet surface.

Bradshaw said, "The scientists were available to us as we made the movie. When we were shooting things related to their expertise, we had them around or available." According to Colwell, "We were changing lines on the day of shooting."

How was the film's comet discovered and named?

In the script, a teenage boy discovers a comet while on a school field trip. He sends a picture taken through a six-inch telescope to a professional astronomer, who somehow determines the comet is going to collide with Earth. The comet is named after both of them, "Wolf" for the astronomer and "Biederman" for the boy. This scenario is both unlikely and incorrect.

"The comet would simply be called Biederman," explained Bormanis. "Wolf's name would not be added because he simply confirmed the discovery." Bormanis observed further, "It's unlikely that a comet visible from a state park in Virginia [site of the field trip] would go unnoticed by other astronomers for even a few days, let alone months." However, that is what happens in the film.

Carolyn Shoemaker also pointed out this problem to the filmmakers. "My first concern was the way they were handling the discovery."

Through our long association with Eleanor Helin and the Planet-Crossing Asteroid Survey, Planetary Society members are familiar with the naming of comets and asteroids. Comets are named for their discoverers. Asteroids are named by their discoverers after the orbit has been determined. Society members have helped Helin name a few asteroids, including Bonestell, to honor the influential astronomical artist, and Nereus, the current target of a planned Japanese sample-return mission, *Muses C*.

How is humanity's impending doom described?

The president of the United States breaks the news to a stunned world. As played by Morgan Freeman, he is a figure with authority and presence. But, like many true-life politicians, he doesn't always get his facts right. And sometimes he stretches the truth.

To focus on one instance, the president states that comets in the Kuiper Belt (see the January/February 1994 *Planetary Report*) sometimes get "bumped" like "billiard balls" into Earth-crossing orbits. This imagery is a bit misleading. Gravitational perturbations from larger bodies, such as Neptune, are the most likely culprits in this scenario.

Savvy viewers will also notice that the president confuses meteors and meteorites. Such objects are comets, asteroids, or dust while traveling through space; as they burn through Earth's atmosphere, they are called meteors; when they strike the ground, they become meteorites.

In another address, the president flatly states that after the impact all plants will be dead within four weeks, all animals in a few months, and Earth will be uninhabitable for two years. However, with myriad variables to consider, there's no way to put definite times on such events. And we should keep in mind that we are all descendants of creatures that survived a similar event 65 million years ago. In addition, as Colwell points out, our ability to evaluate such an impact is limited:

Here is Hollywood's version of a comet's surface, created by the artists and technicians of Deep Impact. The surface appears much brighter than it would in reality; as to its roughness, we just don't know how well it was simulated. To portray people working in the comet's low gravity, the actors were suspended by wires. Photo: Myles Aronowitz, Paramount Pictures, and Dreamworks L.L.C.

This is about the best image we have of a comet's surface, a view of Halley's comet as seen by the Giotto spacecraft in 1986. Violent and powerful jets erupt from the sunlit side. The comet's irregular shape is also evident. But how would a comet appear to a human on its surface? We can as yet only imagine. Image: Max Planck Institut für Aeronomie/ESA

"There is fortunately not a lot of first-hand knowledge."

The writers cleverly extricate themselves from these problems by having the teenage hero say that "the president didn't explain this very well."

Why was the Orion propulsion system chosen for the spacecraft?

Orion was an idea for using a series of small nuclear explosions to propel spacecraft through the solar system. In the late 1950s and early 1960s, some of the best scientific minds on Earth worked on this project. Although a prototype using conventional explosives did fly, the nuclear-powered Orion was never developed. The prototype now hangs in the Smithsonian's National Air and Space Museum.

The script required a spacecraft to carry a human crew quickly to the comet, but, as Griffin explained, "We have no propulsion system capable of getting them to a comet. The old Orion system was Gene Shoemaker's idea. So we assumed it had been developed, and we scaled it up."

Would Orion be a good choice for the mission? Ted Taylor of Princeton University, who headed the Orion project, said there are now "much better choices than Orion," such as solar electric propulsion, which is soon to be demonstrated on the *Deep Space 1* mission (see page 6).

The portrayal of Orion was one of Burke's greatest concerns—he worked on the original Orion project. From reading the script, we couldn't tell how it would work or what it would look like, for that will be determined by the special effects, which were not completed when this article was prepared. In places, the script seemed to indicate that Orion used a series of pulsed explosions to put-put-put through space—which would be correct. In other places, it seemed to take off with one big bang, the acceleration from which, Burke pointed out, "would instantly turn the astronauts to jello."

But if the effects are done correctly, what might an Orion-powered spacecraft look like to observers on Earth? Taylor described the possibilities: "Most of what you'd see would be images, not of the explosions themselves, but of their effects on the upper atmosphere—flashes of multicolored light." It might be possible to see "the expanding explosion of each pulse, something like a bright cone. It might even be blinding."

Taylor added an interesting sidelight: "There was a time when Arthur C. Clarke planned to use Orion in *2001: A Space Odyssey*. But they decided the special effects would be too complicated." We'll see how the makers of *Deep Impact* do.

What greets the astronauts as they approach the comet?

All three Society reviewers raised their eyebrows at dialogue indicating that apartment-building-sized chunks menaced the spacecraft as it approached the comet. Common wisdom holds that a cometary nucleus is surrounded by gas and dust —meaning tiny bits of rock.

I queried Luchini on this point. He referenced recent work by Steve Ostro of JPL and others who had made radar observations of comet Hyakutake. Their results indicated that pebble-sized rocks make up much of the mass of the comet's dust coma. "This is cutting-edge science," he said, and he's "very proud of getting it into the film."

I pursued the topic of comet fragments with John Harmon, a senior research associate and assistant director of the Arecibo Observatory, where much of the radar work on comets is done. He reported that their radar detected golf-ball-sized chunks coming off Hyakutake. To be detected by radar, the pieces have to be both big enough and numerous enough. Even if they existed, Arecibo couldn't see larger chunks because there wouldn't be enough of them.

However, the strength of the gas jets coming off Hyakutake were powerful enough that they "could have blown off stuff tens of meters in size." Harmon said that an apartment-building-sized chunk was "not a wild conjecture, but it may not be typical of most comets."

How is an object of very little gravity portrayed?

No one knows exactly how comets are made or what gravitational effects they might exert on landing spacecraft and probing humans. The Near-Earth Asteroid Rendezvous recently measured the density of the asteroid Mathilde and found it to be much lighter than expected with a reading only 1.3 times the density of water. (See Factinos, page 21.) Although they are close relations, asteroids seem to be made mostly of rock, while comets are mostly ice. So a comet would be even less dense and exert even less gravity.

The filmmakers knew they would have trouble portraying this aspect of a comet. Said Bradshaw, "We were most speculative in the landing on the comet, and Gene had told us we would have to be. In the end, we didn't make it outside the realm of possibility."

The final portrayal was affected by a consultant's advice. "In the initial script," Luchini reported, "the comet was denser than plutonium," if one judged by the gravity it exerted. "I settled on a specific gravity of about 1 [the same as water], which is more or less reasonable."

The script calls for astronauts to work with equipment on the comet's surface. "I did explain to them," Luchini related, "that it would take about 45 seconds for an object to drop one meter, which of course they couldn't do. They have to keep people in the theater."

What will the comet look like close up?

Almost everyone I talked to pointed out that no one has ever seen a comet up close. We can only make educated guesses on how one might look based on spacecraft flybys and Earth-based observations. The *Deep Impact* consultants didn't always agree on what the comet should look like. Colwell remembered that he visited the comet set with Gene Shoemaker, and "Gene thought the surface was too rough. I thought it was pretty good."

We do know that despite the bright appearance of their heads and tails in the sky, the nuclei of comets are among the blackest objects in the solar system. "Cometary dust has an albedo of 3 to 4 percent," Luchini pointed out, meaning that it reflects only 3 to 4 percent of the sunlight falling on it. This posed a major problem for the filmmakers in portraying scenes at the comet's nucleus. "If done correctly, it would have looked like they were filming on the inside of a bag of charcoal briquets."

But the consultants' opinions were not always limiting to the filmmakers. Colwell speculated that because a comet's gravity is so low, delicate ice formations would be able to grow to respectable heights on its surface. It "could have lots of fairy-castle-like structures caused by outgassing," he said.

Could nuclear energy save life on Earth?

In the story, the astronaut-heroes twice use nuclear devices in their attempts to divert the comet. In the first attempt, the astronauts bury bombs deep in the comet, hoping the explosions will divert its orbit. As Bormanis pointed out, "Burying the nukes, as opposed to detonating all of them above one side of the comet, seems like a dubious tactic for deflecting the comet. Simply blowing the comet apart won't change the trajectory of its center of mass."

In the second attempt, the comet breaks into many small pieces, as it might if the body's internal consistency resembled a rubble pile—which accords with current theory but did not appear to be the case in the first attempt to explode the comet.

Alan Harris of JPL has studied various proposals for using nuclear devices to deflect or destroy hypothetical comets or asteroids on impact trajectories to Earth. I described to him the results of the explosions as portrayed in the script and asked if this outcome was possible. "It depends on the bomb and where you place it," he said. "It's not so implausible as to be an objection."

Were the consultants satisfied with the science in the film?

"As far as I know about it, yes," said Colwell. But a lot will depend on the special effects, which he hadn't seen yet. "I'm hopeful and a little bit fearful."

"Within limits, the physics and details of the comet are plausible," Luchini feels. "There are decisions people make in the movie that I wouldn't make, but then there wouldn't have been a movie."

Gerry Griffin enjoyed the experience. "As an engineer, I found it neat not to have to color inside the lines all the time. You can use shades of gray; you can let your imagination go a bit."

Charlene M. Anderson is Director of Publications for the Planetary Society.

Scientists searching for traces of the giant impact that wiped out the dinosaurs discovered evidence that tsunamis ravaged landscapes many hundreds of miles inland from the impact site. In 1993, a much smaller wave generated by an earthquake swept across Japan's Okushiri Island, shown here. When the water subsided, the town of Aonae was gone. More than 120 people were killed by this wave. A comet-generated tsunami could have thousands of times the destructive power.
Photo: Dennis J. Sigrist; National Geophysical Data Center/NOAA

The STUFF of LIFE: Why Water?

by Christopher Chyba

Life as we know it on Earth is utterly dependent on liquid water. Organisms living in oceans and fresh water literally swim in it, but even plants and animals living on land maintain an internal liquid environment, bathing their cells in sap or plasma—both of which are mostly just water. Land creatures have in effect found a way to carry their ocean along with them. The concentration of water inside a kangaroo rat living in the desert is nearly the same as that found in fish living in the sea.

Life on Earth, especially microscopic life, is remarkable for its ability to adapt to many environments that appear hostile from a human point of view. For example, some bacteria at deep-sea vents are quite happy at temperatures nearly equal to the boiling point of water at Earth's surface. Other species of bacteria have adapted to survive the levels of radiation common in the cooling water of nuclear reactors.

But terrestrial life cannot adapt to a total absence of liquid water. The individual cells making up organisms on Earth range from around 60 to 95 percent water. Organisms must replenish this internal water, either directly from the environment or through the breakdown of organic molecules. For example, the desert kangaroo rat doesn't need to drink; instead it uses oxygen to break down carbohydrates (sugars are simple carbohydrates) to produce its own water supply.

If a desert is too harsh—if water is too hard to come by—organisms can't maintain their internal water concentration, and they are forced into a state of repose, or they die outright. Some soils in dry Antarctic valleys, which are among the harshest deserts on Earth, appear to be sterile altogether. For terrestrial life, there appears to be a limit beyond which adaptation just isn't possible, and that limit is set by water.

Because liquid water is indispensable to terrestrial biology, much thinking about extraterrestrial life really amounts to thinking about liquid water. The definition of the "habitable zone" for life around a star is commonly given as that range of distances from the star within which liquid water could be stable on a world's surface. In our solar system, Jupiter's moon Europa lies well beyond the habitable zone, but tidal heating may nevertheless sustain an ocean of liquid water beneath Europa's cover of ice. Because of the possibility of liquid water, Europa is becoming a focus for exobiology. As a practical matter, with life as we know it on Earth as our model, the search for life in the solar system begins with the search for liquid water.

Advantages of Liquidity

Why is water so essential, and could extraterrestrial biologies have found ways around this terrestrial limitation? Because our understanding of life is restricted to terrestrial examples (so far!), it is difficult to distinguish between characteristics that are necessary for life in general and those that are contingent on the peculiarities of Earth's environment and history. It is difficult even to define what is meant by "life" in a general sense. This indefiniteness makes it easy to speculate about biologies that could avoid many of the requirements faced by life on Earth. On the other hand, there are so few constraints on these speculative biologies that they are of limited use.

It is clear that the liquid phase of matter (as opposed to solid or gas phases) offers important advantages as an internal medium for life forms. In liquid, molecules may dissolve and chemical reactions occur. The liquid environment allows movement of key molecules from one location to another. As a result, chemical reactions can be sustained by an ongoing supply of the necessary ingredients, key products of reactions can diffuse or be moved to wherever they are needed, and wastes can be eliminated.

As an internal medium, a gas might provide some of these same advantages, but life in the gas phase would face enormous difficulties keeping itself confined. Moreover, in a gravitational field, any large, heavy molecules would naturally settle out of the background gas and so would become unavailable for further reactions. Analogous problems exist in principle for chemistry in liquid solution, but they are far less severe.

. . . and Solvency

Water is a very good solvent for certain molecules—so much so that water is sometimes called the "universal solvent." To understand why, consider the structure of the water molecule (H_2O), which consists of two hydrogen (H) atoms bonded to a single atom of oxygen (O). The hydrogen atoms each have one orbiting electron and the oxygen has eight. But the oxygen atom exerts a much stronger attraction for electrons, with the result that the electrons, even those originally from the hydrogens, spend more of their time near the oxygen end of the water molecule than near the hydrogen ends.

Since electrons are negatively charged, the oxygen end of the molecule, with its electron excess, acquires a partial negative charge. The two hydrogen atoms, largely deprived of their electrons, acquire partial positive charges. Because the molecule has these positive and negative ends, chemists say H_2O is a "polar" molecule. If another type of molecule, called a solute, is put into the water, the hydrogen atoms can form weak bonds (so-called hydrogen bonds) with any negatively charged ends of the solute molecules, because opposite charges attract. Water is therefore a good solvent for any solute molecule that is polar.

Other good polar solvents with similar properties exist, for example, liquid ammonia (NH_3). But ammonia is not liquid at the temperatures of the Earth's surface. In this sense, water is the best solvent for life on Earth, and probably for any Earth-like planet within the habitable zone of its star. On much colder worlds, where ammonia would be a liquid but water would be frozen into ice, ammonia might be the "obvious" choice for a solvent. Keep in mind that the rates of chemical reactions slow down exponentially with lower temperatures, so any biochemistry on cold worlds would proceed far more slowly than on Earth.

Liquid hydrocarbons (perhaps on Titan?) might also serve as solvents for life. But hydrocarbons are non-polar molecules (they do not have oppositely charged ends), so any such biochemistry would be radically different from that of terrestrial life and would rely on something other than hydrogen bonds.

Bending Enzymes

Water molecules react to the presence of non-polar solutes by arranging themselves into cages around the solutes, herding the non-polar molecules together. This property of water turns out to be extremely important for biology, because terrestrial biology relies on certain types of proteins, called enzymes, which catalyze chemical reactions. The enzymes make the reactions run much faster than they otherwise would. Critical to enzymes' ability to catalyze reactions is their three-dimensional shape, which water plays a role in forming.

The enzymes are made by linking together smaller molecules called amino acids, which have side groups of atoms that may be polar or non-polar. The result is that different amino acids in the chain making up the enzyme will be pushed and bent around according to their charge by the surrounding water molecules, forcing the enzyme into a specific three-dimensional shape. In this way water is crucial to the ability of enzymes to assume the right catalyzing shape and, therefore, to make biochemical reactions proceed in the cell.

Water Worldwide

Considered at a larger scale, water has a number of other remarkable properties. For example, the solid phase of water, ice, is less dense than liquid water, so ice floats rather than sinks upon freezing. (Ammonia, incidentally, does the opposite, as do nearly all substances.) This means that when lakes freeze over, they freeze from the top down. If ice were to sink, a layer of ice might instead accumulate on lake bottoms year after year, remaining insulated from melting during the summer by the overlying water. Eventually the lakes could completely fill with ice. Instead, the surface ice layer, because of its buoyancy, simply melts off every season.

Water has one of the highest specific heats of any substance known, which means that a lot of energy is required to make the temperature of water rise a small amount. The result is that Earth's oceans act as a major moderating influence on the climate: energy fluctuations (for example, between day and night) have far less impact on our temperature than they would on a less watery world. In the absence of water, temperature fluctuations would also be greater with changes between the seasons.

All these properties of water have the effect of moderating the terrestrial environment. Perhaps it is no surprise that these effects seem pleasant to creatures such as ourselves that have evolved on a planet covered with water. Yet it is hard to see how the existence of these moderating influences represents any absolute requirement for life. To the contrary, it could be that evolution might proceed more quickly in more challenging environments.

Water's three phases—solid, liquid, and vapor—are dramatically demonstrated in the geyser-hewn landscape of Yellowstone National Park. Earth's ability to maintain water in all three phases is one reason life has flourished on this planet.
Photo: Terry Donnelly, Tom Stack & Associates

Beware the Hydrocentric

We should be wary of some of the biochemical arguments for the inevitability of water for life. Certainly it seems as though some sort of solvent is needed for biology, and for many worlds this necessity will lead almost inexorably to water. But if we were all ammonia-solvent-based creatures living on some much colder world, we could easily tick off reasons why water might seem to be a terrible solvent for life, as well as for its origin.

For example, water attacks proteins as well as nucleic acids (the biomolecules of metabolism and heredity, respectively). Put a protein into solution in water and the water begins to break the protein into its individual amino acids. Water-based life must therefore fight a constant battle against destruction. And this property of water poses a crucial, and still largely unsolved, problem for the origin of life: proteins are necessary for all life on Earth, but how could these molecules have formed in the seas of pre-biotic Earth, since water acts not to link amino acids together but rather to split them apart? We should not lose sight of the fact that while water presents many advantages to life, it poses its own challenges as well. On Earth, at least, through mechanisms that remain poorly understood, these challenges were overcome. What solutions—if any—were found on Mars or Europa?

Christopher Chyba is a planetary scientist at the University of Arizona's Lunar and Planetary Laboratory, where he teaches a graduate seminar in the origin of life. Professor Chyba chairs the Editorial Advisory Board for The Planetary Report.

News and Reviews

by Clark R. Chapman

Sometimes good articles appear in obscure places. Few Planetary Society members read the *New York University Environmental Law Journal*, but its 45-page article (vol. 6, no. 1) on legal aspects of the asteroid impact threat and potential countermeasures is a "must read." Meanwhile, two movies coming soon to your local theater are sure to make cosmic impacts a topic of interest to many. Dreamworks' *Deep Impact* opens May 8 (www.deep-impact.com), followed on July 1 by *Armageddon* (www.movies.com/armageddon/), starring Bruce Willis. Both films deal with horrifying impacts by comets and asteroids.

The topic was hardly heard of until the 1980s, although a few prescient scientists (like Ralph Baldwin and Ernst Öpik) and science fiction authors (like Arthur C. Clarke and the Jerry Pournelle/Larry Niven duo) had written about it. Now Hollywood studios have spent tens of times as much on its entertainment virtues as NASA and all other world agencies have spent doing anything about the hazard. Indeed, Australia recently closed down its small, but significant, telescopic program of searching for NEOs (Near Earth Objects).

Now, Michael Gerrard, partner of a New York law firm and environmental law expert, and his associate Anne Barber have combed the literature about the impact hazard and added their own professional insights about how national and international laws and treaties might affect programs of "planetary defense." Their footnotes are extensive, and their summary of the technical background is well balanced and nearly flawless.

Only sharp lawyers could find the slender legal hook that might justify dealing with the impact hazard. The so-called Outer Space Treaty of 1967 requires that signatory nations inform all others of "any phenomena they discover in outer space, including the moon and other celestial bodies, which could constitute a danger to . . . astronauts" and that they "shall render all possible assistance [to astronauts] in the event of accident . . . ." If a cosmic body should crash, few of us on the ground would have any legal recourse—although insurance companies should pay those covered by broad "umbrella" policies. But if there were a threat to Senator John Glenn, even on the ground, then there might be legal justification for protecting him and thus us as well.

The authors provide dispassionate legal analysis of such other international treaties as the Partial Test Ban Treaty, the Anti-Ballistic Missile Treaty, and the Space Objects Liability Convention, as they might impinge upon planetary defense—which would include generalized defensive programs as well as any emergency program responding to the (extremely unlikely) discovery of a cosmic body headed towards us. Then there are the stiff requirements of the National Environmental Policy Act, which mandates Environmental Impact Statements (or FONSIs: Findings of No Significant Impact) for numerous NASA missions, including the *Galileo*, *Ulysses*, and *Cassini* launches of plutonium-based power generators.

With no disaster immediately impending, Gerrard and Barber doubt that efforts to mount defensive nuclear arsenals or to practice defensive technologies by blowing up small asteroids would pass legal scrutiny. (They sought the opinion of H-bomb creator Edward Teller, who wrote them a reply expressing different views.) However, if a threatening object were actually found to be headed toward Earth, different legal standards would apply. Indeed, the inherent right of a nation to defend itself—embodied in the United Nations Charter—should supersede all treaties and permit otherwise prohibited use of nuclear weapons in space.

Despite legal controversies concerning astronomical observatories (like preserving squirrel habitat on Arizona's Mt. Graham), Gerrard and Barber doubt that astronomical surveys would be encumbered by legal constraints. In the end, they argue that the United States and other nations should establish consistent funding for NEO discovery and tracking.

As yet there is no evidence that any comprehensive NEO assessment will happen. The few NEO search programs now in existence are supported inadequately, when measured against the Spaceguard Survey recommendations of the Shoemaker Committee after the epochal crash of comet Shoemaker-Levy 9 into Jupiter. Gerrard and Barber note that, by analogy with criteria applied towards some other hazards, expenditures upwards of $10 billion a year might be justified for dealing with the impact hazard, thousands of times more than is now being spent.

I, for one, am ambivalent about the degree to which society should deal with a hazard that potentially exceeds all others (by threatening civilization, or even our species) but that has such a remote possibility of occurring within our lifetimes. One might argue that we should protect future generations, but, as Gerrard and Barber say, there is little we can do now about asteroids to significantly affect future generations, who will surely have far superior technology to deal with any cosmic threat. (By contrast, what we do now in managing radioactive waste dumps *will* affect future generations.)

The least we could do is responsibly assess what asteroids and comets are out there and whether anything is headed our way, which we can do with comparatively modest funding. It seems obscene that tens of millions should be spent on impact entertainment while only a pittance is spent to address our survival.

Clark R. Chapman, along with co-author David Morrison, is partly responsible for bringing the impact hazard to public attention in the 1989 book Cosmic Catastrophes.

World Watch

by Louis D. Friedman

Moffett Field, California—In early March, scientists on the *Lunar Prospector* mission announced the first clear evidence of ice on the Moon. Back in the early 1960s, Society President Bruce Murray predicted ice in permanently shadowed areas of the lunar poles. He reasoned that if cometary impacts deposited water on the Moon, most of the water would quickly sublime away when exposed to sunlight in the airless environment. But in deep polar craters, where the sun never reaches the surface, ice could survive.

Lunar Prospector found the ice in low concentrations, spread over both polar regions as crystals embedded in the lunar soil. From this discovery, scientists will learn more about the role of cometary impacts in the evolution of the terrestrial planets. The popular press treated the finding with a great deal of sensationalism, although the scientists reported that their data indicated only "the presence of water ice in very low concentrations."

In fact, the amount of ice discovered was disappointingly small. Many were hoping that enough water would turn up to give credence to the idea of a lunar base for future human activities. The 0.3 to 1 percent found in the soil, spread over large areas, amounts to just a few ice crystals. This will hardly be a resource for a lunar base.

Nonetheless, the result is scientifically significant and is one of a string of recent accomplishments in the NASA planetary program.

Tokyo—The Institute of Space and Astronautical Sciences (ISAS), the organization responsible for science missions in the Japanese space program, has announced its 10-year schedule. This year ISAS will launch *Planet B* to explore the upper ionosphere and atmospheric regions of Mars. The mission is scheduled to launch on July 4, 1998, one year to the day after the landing of the Carl Sagan Memorial Station (*Mars Pathfinder*). Although the mission launches in the summer, it does not leave Earth orbit until December 20, using the time between to swing by the Moon twice and pick up the velocity needed for the trip to Mars. *Planet B* will reach Mars in October 1999.

In 1999, the Japanese will launch *Lunar A,* an orbiter with three penetrators (originally scheduled for 1997), and in 2000, *Astro E*, an x-ray satellite. In 2002, *Muses C* launches for a rendezvous with and sample return from a near-Earth asteroid. This mission will include a nano-rover being developed at the Jet Propulsion Laboratory (JPL).

The Planetary Society is working closely with JPL on education outreach for their nano-rover and with ISAS on other educational programs.

Two missions are scheduled for 2003: *Selene*, an orbiter and a lander bound for the Moon, and *Astro F*, an infrared observatory in Earth orbit. *Selene* will be a cooperative mission between the two principal Japanese space organizations, ISAS and NASDA. Other missions under consideration include *Solar B*, which is a solar physics mission for 2004, and a Mercury orbiter for 2005.

Paris—The European Space Agency (ESA) has received more than 30 proposals for scientific instruments for the *Mars Express* orbiter and possible landers. The orbiter will almost certainly include duplicates of the imaging system and infrared instruments that were lost on the ill-fated Russian mission *Mars '96*. Other instruments may include a sounding radar (including one proposal in cooperation with NASA) and instruments to measure fields and particles.

At least two lander packages have been proposed: one concerning exobiology and another setting up a seismic and weather monitoring network on the planet.

However, the landers are not in the ESA budget and will require funding from outside the agency, perhaps from national agencies or budgets. As of this writing, their inclusion on the mission is very much in doubt.

Pasadena—In its latest phase of aerobraking down toward a mapping orbit, *Mars Global Surveyor* returned spectacular data, including new close-up images revealing details on the Martian surface smaller than five meters across! Some of these images show clear evidence of past rivers and lakes.

In mid-March, *Mars Global Surveyor* began a six-month period of no aerobraking, which will permit its orbit to swivel around the planet and will bring the spacecraft to its south-to-north mapping configuration. The spacecraft continues to take data at the lowest point in its orbit. This periapsis altitude is only 170 kilometers (about 110 miles), and thus extremely high-resolution images of selected areas on Mars will come to us in the next few months.

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

Questions and Answers

If further research finds that life did, in fact, exist on Mars billions of years ago, how will that alter the calculated probability of other intelligent life in our galaxy capable of radio transmission?
—Byron Weber,
Los Angeles, California

If Earthlings found that life arose independently on Mars, that would mean life originated on two out of nine planets in our solar system and is therefore extremely likely to get started on many other planetary systems. Even without understanding the detailed mechanism of how prebiotic molecules evolved into early life forms, we would know that life starts easily and would predict our galaxy to be teeming with life.

However, primitive life may not necessarily evolve into technological civilizations that transmit radio waves, so we'd still be uncertain about the probability of success of our radio Search for Extraterrestrial Intelligence (SETI) programs.

Another possibility is that Earthlings might confirm that there was life on Mars but that this life originated on Earth and then traveled over to Mars via meteor, or perhaps vice versa (life here on Earth getting its start on Mars). In such a case, we are really back to only one known instance of life, making it difficult to predict the incidence of life elsewhere.
—DAN WERTHIMER,
University of California, Berkeley

Did ancient water once flow here? Mars Global Surveyor*'s camera captured this canyon image on January 8, 1998. It shows Nanedi Vallis, one of the valley systems that cuts through the cratered plains of Mars' Xanthe Terra region. The area covered in this picture is about 10 kilometers (6 miles) by 19 kilometers (12 miles): features as small as 12 meters are visible.*

This canyon's origin is enigmatic. Some features, such as the terraces within the canyon and the small channel (both seen near the top of the frame), suggest continuous flow of some fluid—such as water. Other aspects, such as the lack of a pattern of contributing smaller channels surrounding the canyon, suggest formation by collapse. It's likely that continual fluid flow and *collapse are responsible for this canyon's formation. Further observations by* Mars Global Surveyor*, especially to the west of this image area, will shed more light on these processes.* *Image: MSSS/NASA*

Could extraterrestrial signals be detected in any range of frequencies? Maybe the way extraterrestrials communicate is completely different from ours and they transmit in the visible spectrum instead.

Maybe this is why we have not received a strong signal yet.
—Carlos A. Correa and Vincent Lopez,
Buenos Aires, Argentina

Nature places some limits on the frequencies a civilization could use, if they are electromagnetic signals such as radio or light waves. Very low frequencies are reflected by the thin ionized gas in the Milky Way galaxy and are also subject to interference from cosmic rays, which generate a lot of radio noise. Light waves, which have higher frequencies, can be absorbed by dust clouds in space, although these are patchy, allowing us to see much of the Milky Way with our eyes.

All known forms of radiation decrease with distance because the energy spreads out over a greater and greater area, even if you use a laser to beam the energy. Any real laser will have a beam in the shape of a cone, which causes the energy to decrease as the inverse of the square of the distance, the same as with radio. (In a laboratory, the laser beam can be made fantastically parallel, but over the huge distances of outer space, the beam spreads out in a cone.)

However, you are right that civilizations might use light to communicate, and several searches for extraterrestrial intelligence have looked for light or infrared signals from space, with no luck so far.
—TOM McDONOUGH,
SETI Coordinator

In 1996 the Jet Propulsion Laboratory tested the* Mars Pathfinder *in Grant County, Washington. The terrain was superb—take away the flora and it looks like Mars.

I know parts of eastern Washington were formed by the Great Spokane Flood 20,000 years ago. But how could liquid water have caused the terrain on Mars? Wasn't the Sun much cooler and smaller then? If the Sun was warmer, wouldn't Earth's oceans have evaporated?
—Ken Albertson,
Soap Lake, Washington

This is an excellent question, or rather two questions. Current stellar models tell us that since the early formation of the solar system, the luminosity of the Sun has increased. And this increase in luminosity probably did have an effect on the early atmospheres of the planets. But the terrestrial planets (Mercury through Mars) do not have their primordial atmospheres intact.

Again from stellar models, scientists believe that just after a star's formation there is a phase called the T-Tauri stage. During this stage of our Sun's development, most of the inner planets are believed to have had their primordial atmospheres of the lighter elements blown away. All of the inner planets (except Mercury) now have secondary atmospheres, which resulted from outgassing of volatile elements and compounds, such as carbon dioxide, from within the planet. Thus, the effects of the Sun's luminosity on the secondary atmosphere would happen only after the T-Tauri stage.

It is the atmosphere's insulating ability and the presence or absence of greenhouse gases that control the surface temperature of a planet. The combination of these two features is why the surface of Venus is hotter today than the surface of Mercury, although Mercury is closer to the Sun.

It is very possible that Mars once had a thicker atmosphere (possibly of carbon dioxide) than it does today. A thicker atmosphere and the presence of greenhouse gases would have made it possible for liquid water to exist on the surface of Mars for a long time.

But even if the early atmosphere of Mars was similar in composition and pressure to that of today, it might still have been possible to form the catastrophic outflow channels like those observed at the *Mars Pathfinder* landing site (Ares Vallis). If a large area of ground ice were located near a heat source, such as a volcano, then it would be possible to suddenly melt the ice and, depending on the area's slope, cause a catastrophic outflood and carve the channels.

This effect could also be accomplished by a large asteroid or comet impact, which could supply the heat as well as seismic activity needed to melt the ice and thus form the channels. Once the water was released, it would probably last only a short time on Mars' surface. But the water's stay on Mars' surface would most likely last as long (a few days or a week) as it took to carve the catastrophic flood channels in the Scablands of eastern Washington.
—ROBERT C. ANDERSON,
Jet Propulsion Laboratory

When trajectory specialists calculate trajectories for spacecraft such as* Voyager, Cassini, *etc., do they use Newtonian classical mechanics or Einsteinian relativistic mechanics? How small (or large) is the difference between the two?
—Doug Stephens,
Aurora, Colorado

The equations in the computer programs generally use Newtonian mechanics for trajectory calculations. Engineers take relativistic effects into account for some scientific studies involving the use of radio and optical tracking data. For typical navigation and engineering requirements, however, those relativistic effects are negligible (1 part in 10,000 million or so).
—LOUIS D. FRIEDMAN,
Executive Director

Factinos

Data obtained from last June's Near-Earth Asteroid Rendezvous (NEAR) flyby of the asteroid 253 Mathilde reveal that this carbon-rich, heavily cratered body is only about half as dense as rocky asteroids. Now two reports in the December 19, 1997 issue of *Science* indicate that the asteroid is highly porous, suggesting that it was either formed from loosely packed fragments or has been pulverized into a "rubble pile" by repeated impacts with other celestial bodies.

One study, led by Donald K. Yeomans of the Jet Propulsion Laboratory, determined Mathilde's mass to be about 110 trillion tons. Another study, led by Joseph F. Veverka of Cornell University, reveals Mathilde's size to be 48 by 46 kilometers (about 30 by 29 miles). Together the two teams' measurements show the asteroid's density to be only about 1.3 times that of water.
—from S. Perkins in *Science News*

A scientist who cast doubt last year on evidence that a planet exists around another star now says that the planet may be there after all. In 1995, Didier Queloz and Michel Mayer of the Geneva Observatory in Switzerland discovered the body after analyzing light from the star 51 Pegasi. It was the first planet discovered outside our solar system. (See the January/February 1996 issue of *The Planetary Report*.)

Their analyses indicated that 51 Pegasi was wobbling, apparently from the gravitational tugs of an orbiting planet. However, in February 1997 David F. Gray from the University of Western Ontario in Canada argued that the star was pulsing, which created the illusion of a planet-induced wobble. But now Gray has reported in the January 8, 1998 issue of *Nature* that new observations of the starlight have failed to find the trait that led to his conclusion, and "a planet may indeed be the best explanation."
—from the *Los Angeles Times*

Now that *Mars Pathfinder* geologists have had time to examine the wealth of information gathered by the spacecraft, they find that the landing site is not what they expected. At the December meeting of the American Geophysical Union, many *Pathfinder* researchers suggested that a single volcanic rock type lies behind the varied shapes, colors, and textures that the spacecraft observed. The evidence for this comes from *Sojourner's* direct measurements of the rocks' compositions and from the lander's camera.

"I think we can explain most of the elemental and spectral variations as just due to varying amounts of dust on the rock," says Scott Murchie of the Applied Physics Laboratory of Johns Hopkins University in Laurel, Maryland. The "rusty" sulfur-rich dust seems ubiquitous on Mars' surface, but where it came from is still a mystery.

However, not everyone on the *Pathfinder* science team is going for the one-rock story. Rover team member Henry Moore of the United States Geological Survey in Menlo Park, California has noted loose pebbles and rocks pocked by little holes—presumably left when smaller rocks fell out. To him these rocks look like conglomerates, sedimentary amalgamations of sand and pebbles from many different sources.
—from Richard A. Kerr in *Science*

Society News

Pathfinder Model Stars in BBC Science Show

A regional coordinator for the Society in Great Britain, Andy Lound, built a half-scale model of *Mars Pathfinder* and a radio-controlled model of *Sojourner,* both featured at the BBC Tomorrow's World Live Science Show at the National Exhibition Center in Birmingham, England. The show attracted more than 30,000 people.

The *Mars Pathfinder* model, built in Andy's dining room, incorporated foam board and other common household items.

The model spacecraft was "launched" on board a Toyota Carina 2 vehicle and, following two orbits of the exhibition center, made a successful landing, cushioned by air bags constructed from a pair of white linen bedsheets. After 20 minutes, the rover *Sojourner* was deployed. Despite minor mishaps—such as a power failure, solved by recharging batteries—the exhibit was a great success. The model *Sojourner* did five performances daily for five days.

The *Pathfinder* and *Sojourner* models will be used in a series of events in the United Kingdom, part of the national Mars Invades Britain program. Events will feature slide presentations and special displays.

—Susan Lendroth,
Manager of Events and Communications

More News

Mars Underground News:
Mars meteorite analysis update; new data from *Mars Global Surveyor* are adding to the life on Mars debate.

Bioastronomy News:
Australian conference focuses on SETI in the 21st century; views of the universe change as we discover and understand life.

The NEO News:
The Planetary Society teams with JPL on the *Muses C* nano-rover, set to visit an asteroid.

For more information on the Society's programs, call (626) 793-5100.

Mars Microphone Readies to Record

The Planetary Society's Mars Microphone has moved one step closer to recording the sounds of Mars. Included within a lidar instrument built by the Russian Space Research Institute for NASA's *Mars Polar Lander*, the microphone has been delivered from Russia for integration onto the spacecraft by Lockheed Martin Astronautics.

Developed by the University of California Space Science Lab for the Planetary Society, the microphone is funded by generous Society members. The lidar marks a landmark cooperative venture—part of Mars Together, signed by Vice President Al Gore and Russian Prime Minister Victor Chernomyrdin in 1994.

The *Mars Polar Lander* will launch in January 1999, following the launch of the *Mars Climate Orbiter* in December 1998. Educator's curriculum, information about upcoming Mars missions, and results of the Mars Microphone experiment will be posted on the Planetary Society's World Wide Web site: *http://planetary.org*. Information about the microphone is also available at the University of California team's site: *http://plasma2.ssl.berkeley.edu/marsmic/*.

—SL

U-HAUL Trucks Celebrate Rover Technology

This spring, U-HAUL rolled out 300 new trucks with colorful side-panel posters celebrating rover technology and the efforts of the Planetary Society in supporting rover science.

These trucks, part of U-HAUL's US and Canadian fleet, will have on both side panels a large, colorful image of a rover and an inset box that reads: "The Planetary Society—Pasadena. Rover Technology for Planetary Exploration."

"We're delighted to celebrate the success of *Pathfinder* in 1997 and recognize the Planetary Society's involvement in supporting and developing rover technology ," said Janet Cooper, public relations director for U-HAUL. While 300 trucks will roll out this spring, Cooper says that U-HAUL will probably add more trucks with the design over the next five years. The Planetary Society and U-HAUL will unveil the design in a special event June 2, 1998 at Society headquarters.

—Cindy Jalife,
Director of Membership and Programs

NEO Web Site Launched as *Deep Impact* Opens

Taking advantage of public interest in the film *Deep Impact*, the Society presents its newest electronic effort on the Web. The Planetary Society's NEO Page is dedicated to current research, tracking, and discovery of near-Earth objects. This site will provide the most current information and will coordinate additional stories with those published in the Society's special-interest newsletter, *The NEO News*.

The site will contain regular headlines of NEO interest and information about Society-sponsored projects, like the Belize Expedition and the Gene Shoemaker Near-Earth Object Grant program, as well as scientific perspectives on media representation of NEO science and the NEO threat.

Look for the link to The Planetary Society's NEO Page on our Web site: *http://planetary.org*.

—Bill McGovern,
Production Editor

New!

Mars Pathfinder Memorabilia

Panoramic View of Mars
This famous color image (shown below) offering a panoramic view from the Carl Sagan Memorial Station is accompanied by a "tour guide"-caption to help you navigate through the rocky landscape.
10" x 36" poster.
1 lb. **#328 $5.00**

***Pathfinder* Images of Mars**
This collection of 20 slides features some of the most notable *Pathfinder/Sojourner* images, including the color panorama and images of *Sojourner* at work. 20 slides.
1 lb. **#215 $7.50**

Carl Sagan Memorial Station T-Shirt
Wear a piece of history! This T-shirt captures *Mars Pathfinder's* successful July 4 landing with a color image of the undeployed rover on the Carl Sagan Memorial Station.
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1 lb. **#581 $14.00**

Planetary Miscellany

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Adults' M, L, XL, XXL. 1 lb. **#557 $18.00**

Future Martian T-Shirt
Children's S, M, L.
1 lb. **#565 $16.00**

Future Martian Romper
Size: 24 months. 1 lb. **#566 $16.00**

The Planetary Society T-Shirt
Adults' M, L, XL, XXL.
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Venus, that bright jewel that adorns our morning and evening skies, is, on its surface, a noxious inferno. No longer such a mystery since *Magellan* peered under her thick atmosphere, our planetary neighbor turns out to be quite the opposite of the swampy jungle once imagined by some. But this bleak, hot, bone-dry world is still geologically alive. In *Venus* by David Egge, a sulfur-spewing volcano contributes to the planet's opaque, battery-acid clouds.

David Egge's paintings have appeared in *Astronomy* and *Omni* magazines, as well as in *Cosmos*, the book and television series. When he isn't painting, David writes science fiction and creates music on his analog synthesizer.

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