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Planet Earth

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Editor, CHARLENE M. ANDERSON
Technical Editor, JAMES D. BURKE
Assistant Editor, DONNA STEVENS
Copy Editor, KARL STULL
Art Director, BARBARA SMITH

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COVER: An unexpected fruit of the Space Age is the growing awareness that Earth, too, is a planet. We can use the techniques and theories developed for planetary exploration to understand and preserve our own—so far as we know—unique home world. Taken from orbit, this Landsat false color image of the abandoned delta of the Ganges and Brahmaputra Rivers shows a confluence of elements seen nowhere else in our solar system: land, liquid water and life. The dark red regions are mangrove forests; the bright blue areas are mudflats; some dark green areas have been claimed by certain lifeforms for agriculture.

Image courtesy MacDonald Dettwiler Corp., Vancouver, Canada

FROM THE EDITOR

With this special issue, The Planetary Society inaugurates a new theme: the study of Earth as a planet. For millennia astronomers and everyone else regarded Earth as the center of the cosmos, the fixed point around which the universe moved. In this sometimes exalted, sometimes denigrated position, Earth was regarded as different from the planets that appeared to move around it. Our world was divorced from the study of planets.

This perspective began to change with the revolutionary solar system of Copernicus. As every schoolchild should know, this Polish curate postulated that Earth revolves around the Sun and is indeed just one of the planets. Although the Copernican heliocentric solar system is now beyond doubt, remnants of the perception of Earth as set apart from its neighboring worlds have colored studies of our planet, and the Earth sciences have often been pursued as disciplines distinct from planetary sciences.

But inevitably, as the planetary sciences matured, researchers from those fields began to make discoveries that profoundly influenced Earth sciences. The greenhouse effect, the ozone hole, the extinction of the dinosaurs—these are among the hottest topics in science today, and without the work of planetary scientists, these Earth-changing effects might be unknown or misunderstood.

Science policy makers and scientists have now recognized the potential of comparative planetology for understanding our home world. As we continue to promote the exploration and discovery of other worlds and the search for extraterrestrial intelligence, The Planetary Society is now also directing resources toward Earth as a planet. We begin with this special issue of *The Planetary Report.*

Page 3—Members' Dialogue—Pluto, public access to spacecraft and recycling have drawn members' attention.

Page 4—Exploring Other Worlds and Protecting This One: The Connection—Society President Carl Sagan was one of the first to realize that Venus' runaway greenhouse effect and Mars' global dust storms hold lessons for Earth. Here he explains how understanding other worlds can help us protect our own.

Page 8—Earth, the Living Planet: How Life Regulates the Atmosphere—Earth's atmosphere is uniquely suited to the lifeforms that inhabit it, in part because they modify it in ways that favor their survival. Might we someday detect planets beyond our solar system with similar atmospheres?

Page 10—Earth in the Mind of Humankind—Ideas of Earth have changed through the ages, from a disc floating on water to a speck of debris in a vast galaxy.

Page 12—Earth as a Target for Planetary Research—Earth is only one planet among many in a busy solar system, where collisions have played a role in the origin of life and perhaps the extinction of the dinosaurs.

Page 16—Mission to Planet Earth—Earth is now a major focus for NASA as the agency turns the technology developed for space back toward Earth.

Page 20—Seeding Earth: Comets, Oceans and Life—Earth is often called the Water Planet or the Blue Planet for its distinctive planet-girdling ocean of liquid water. Standard wisdom says that this water came from within Earth itself, but recent studies suggest that it might have had an otherworldly source.

Page 25—Society Notes—Along with the Earth initiative, the Society continues to promote other areas of planetary research.

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—Charlene M. Anderson, Director of Publications

Members' Dialogue

As leaders of a membership organization, The Planetary Society's Directors and staff care about and are influenced by our members' opinions, suggestions and ideas about the future of the space program and of The Planetary Society. We encourage members to write us and create a dialogue with us on topics relating to the planetary program, such as the space station, the lunar outpost and the exploration of Mars.

Send your letters to: Members' Dialogue, The Planetary Society, 65 N. Catalina Avenue, Pasadena, CA 91106.

The ninth planet, Pluto, was included on the original Grand Tour proposed for *Voyager* but was dropped because of limited budgets. Since that time, the discovery of Pluto's large moon Charon and a once-per-century series of mutual eclipses between this pair have cast a new light on what was once considered a dark and dismal planet. Pluto has a bright icy surface similar to Triton's, and these bodies are likely close cousins as outer solar system planetesimals, one of which was captured by Neptune while the other remained in its own heliocentric orbit. Pluto may exhibit the most dramatic and complex surface-atmosphere interactions found in the solar system. Its recently discovered atmosphere probably only exists near perihelion [orbital point nearest the Sun] and freezes out onto the surface as it approaches aphelion.

It appears that Pluto-Charon may be dynamic worlds worthy of study in their own right, and some preparatory work towards developing a Pluto mission is under way [a "piggyback" mission aboard NASA's *Solar Explorer* has received recent attention]. So, although we should all be ecstatic over the accomplishments of *Voyager*, the preliminary reconnaissance of the outer solar system is not yet complete.
RICHARD P. BINZEL, *Massachusetts Institute of Technology*

To engage public interest in robotic rover missions to Mars, perhaps one of the rovers should be dedicated to public access. Books outlining Mars-rover programming could be sold in bookstores. Those so inclined could come to a NASA center to enroll in a course to refine programming skills. Those who pass the course would be allowed to buy time slots of, say, one hour in which to conduct their own exploration of the martian surface.

It is important that access be open to those who pass the course and pay the access fee, regardless of the value of their "mission"—perhaps just panning a camera or picking up a rock or just walking over that tantalizing little hill off to the right there.

Millions would think about this offer. Hundreds of thousands would buy the book. Many thousands would come to take the course. It is unlikely that reasonable access fees ($100 per hour?) could recover the cost of the rover, but millions of people would be set to thinking about space exploration as a personal thing, something they can do themselves. Can a manned mission to Mars, with its elite few astronauts, accomplish so much?
JON GIORGINI, *Austin, Texas*

About the *Voyager* photo showing the Earth and Moon in the same scene: Alas its distinction of being the first image of the home planet and its attendant is not correct.

The astronauts have been photographing the two for years, though neither the Earth nor the Moon were seen in their entirety. However, the GOES (Geostationary Operational Environmental Satellite) series of weather satellites has been capturing the two bodies since their first launch in 1971. The satellites are designed to photograph the Earth at half-hour intervals, and the Moon is frequently seen over one limb or the other.

Now that *Galileo* is on its way, we have the prospect of a much more dynamic set of Earth-Moon images in a few years.
JON ANDERSON, *Atmospheric Environment Service (Canada), Winnipeg*

I would like to support the suggestion in the September/October issue that the Planetary Society use recycled paper for its mailings. Each ton of recycled paper saves not only 17 trees (often from endangered tropical rain forests) but also 10,400 KWH of energy [source: Institute of Scrap Recycling Industries]; so it is important in dealing with the problems of acid rain and global warming.

One major reason for the limited demand is that people are not aware of the wide variety of high quality recycled paper products. I would hate to see *The Planetary Report* lose its excellent visual quality, but I think that it can be preserved as we help preserve the Earth.
FRANCES STEWART, *San Diego, California*

NEWS BRIEFS

The Cosmic Background Explorer (COBE), boosted into an Earth polar orbit aboard the last NASA-owned and -launched *Delta* rocket, is performing a year-long investigation of the explosion that started the expansion of the universe some 15 billion years ago.
—from Langley Research Center's *Researcher News*

In Math 496H, "Mathematics and the Search for Extraterrestrial Intelligence," University of Arizona students consider how to communicate across the far reaches of the galaxy.

The core of the course is a language developed by mathematician Carl L. DeVito and linguist Richard T. Oehrle; the language assumes extraterrestrial knowledge of the radio telescope and such physical concepts as the periodic table of elements, the critical temperature of a gas, absolute zero and volume.

Students get a good grounding in different kinds of mathematical reasoning, although some are frustrated at first by the homework problems. "Right away they sit down and want to do some manipulation," explains DeVito, "but there is no manipulation to do. It's just thinking about the problem. And they don't have another problem like it with the answer in the back of the book."
—from the University of Arizona

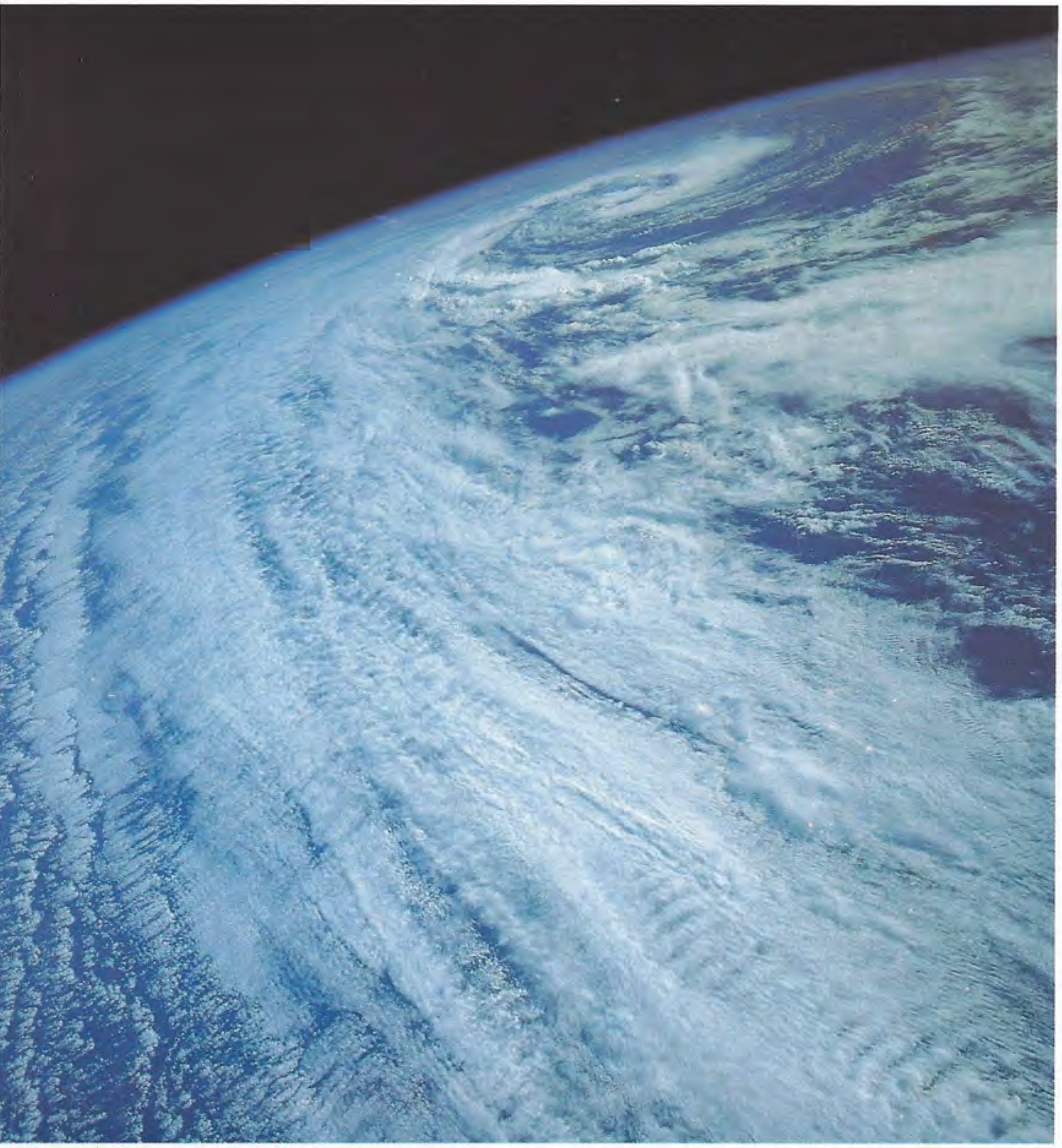
NASA has opened its data bases to stimulate "cottage industry" space research by professors and entice students into science.

The JOVE (for joint venture) program at Marshall Space Flight Center offers access to space data in exchange for analysis by faculty and students from seven participating colleges and universities. JOVE will add seven new schools in 1990.

Rick Chappell, Associate Director for Science at Marshall, calls the research side of JOVE important, "but in the long run, generating science interests in students will bring the most far-reaching benefits."
—from *NASA News*

Exploring Other Worlds and Protecting This One: The Connection

by Carl Sagan



Tropical storm Xina draws clouds into its vortex as it builds strength north of the Hawaiian Islands. Such cyclonic storms are common to planets with atmospheres.

Photograph: Johnson Space Center/NASA

> *For the first time in my life, I saw the horizon as a curved line. It was accentuated by a thin seam of dark blue light—our atmosphere. Obviously, this was not the "ocean" of air I had been told it was so many times in my life. I was terrified by its fragile appearance.*
> —Ulf Merbold, West German space shuttle astronaut

The *Apollo* images of Earth from space revealed plainly the fragility and vulnerability of our lovely little world, and powerfully assisted the coming of age of a global ecological consciousness. Such pictures by themselves may be worth the whole cost of the space program, because their meaning has reached so many. But what is not so widely understood is how much vital and urgent information we have gained about our own world from robotic exploration of other worlds.

If we are stuck on one world, we are limited to a single case; we do not know what else is possible. Then like a linguist who knows only English, or a physicist who knows about gravity only from falling bodies on Earth, our insights are narrow and our predictive abilities severely circumscribed. But when we explore other worlds, our perspective widens. We gain a new understanding of worlds in general, including our own.

Robotic exploration of other worlds has already opened our eyes in many fields of Earth science, including the study of volcanoes, earthquakes and weather. It may turn out to have profound implications for biology, because all life on Earth is built on a common biochemical master plan. The discovery of a single extraterrestrial organism—even something as humble as a bacterium—would revolutionize biology. But the connection between exploring other worlds and protecting our own is most evident in the study of Earth's climate and the burgeoning threat to the climate that our technology now represents. Other planets provide important insights about what dumb things not to do to Earth.

Three environmental catastrophes, or potential catastrophes, have been uncovered accidentally, mainly in the last two decades: ozonosphere depletion, greenhouse warming and nuclear winter. I want briefly to sketch some of the ways in which planetary exploration aided and deepened these findings.

Thinning Ozone Shield

It was disquieting to discover that an inert material with all sorts of practical functions—it serves as the working fluid in refrigerators and air conditioners, as propellant for deodorants and other products in aerosol cans and as lightweight foamy packaging for fast foods, to name only a few—can pose a danger to life on Earth. Who would have figured it?

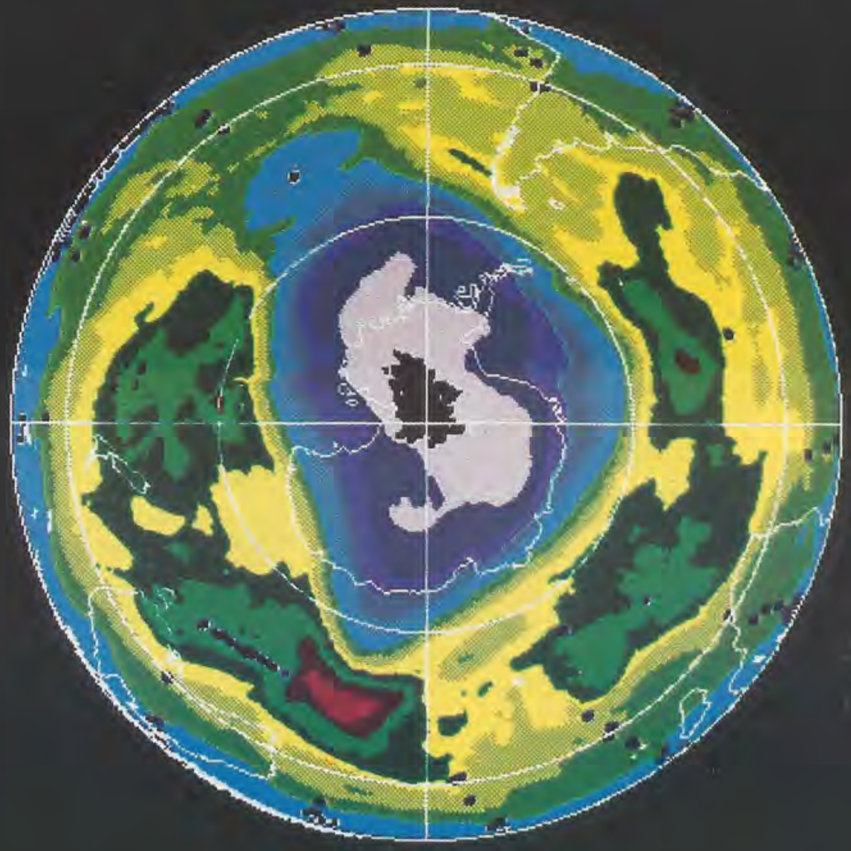
The molecules in question are called chlorofluorocarbons (CFCs). They are extremely chemically inert, which means they are invulnerable—until they find themselves up in the ozone layer, where they are dissociated by sunlight. The chlorine atoms thus liberated deplete the ozone and let more ultraviolet light from the Sun reach the ground.

This increased ultraviolet intensity ushers in a ghastly procession of potential consequences involving not just skin cancer but the weakening of the human immune system and, most dangerous of all, the destruction of agriculture and of photosynthetic microorganisms at the base of the food chain on which most life on Earth depends.

The principal manufacturer of this material, the Dupont company (which gave it the brand name Freon)—after years of pooh-poohing the concern of environmentalists, after taking out full-page ads in newspapers and scientific magazines claiming that the uproar all came from wild extrapolations from inadequate data, that nobody had actually demonstrated any peril—that company has now announced that it will rapidly phase out all its CFC production. The precipitating event seems to have been the discovery in 1986 by British scientists of a hole in the Antarctic ozone layer. There is now good evidence of thinning of the ozone layer at other latitudes as well.

Who discovered that CFCs posed a threat to the ozone layer? Was it Dupont exercising corporate responsibility? Nope. Was it the Environmental Protection Agency protecting us? Nope. Was it the Department of Defense defending us? Nope. It was two ivory-tower, white-coated university scientists working in 1974 on something else—Sherwood Rowland and Mario Molina of the University of California, Irvine.

Their work used reaction rate constants of chemical reactions involving chlorine and other halogens, determined in part with NASA support. Why NASA? Because Venus has chlorine and fluorine molecules in its atmosphere—as discovered by US spacecraft and groundbased observations—and planetary aeronomers wanted to understand what's happening there.



The ozone hole over Antarctica, caused by human-made chemicals released into the atmosphere, is only one of several threats to Earth's environment discovered, in part, through planetary studies. This image, made from data taken by the Nimbus 7 *satellite, shows the extent of the hole (dark purple) on October 5, 1989.*

Image: Goddard Space Flight Center/NASA

Thank You, Venus

Confirming theoretical work on ozone depletion was done with a big computer model by a group led by Michael McElroy at Harvard. How is it they had all these branching networks of halogen chemical kinetics in their computer ready to go? Because they were working on the halogen chemistry of the atmosphere of Venus. Venus helped make the discovery that the Earth's ozone layer is in danger. (Such serendipity, by the way, is found in many discoveries in science.)

There is an absolutely unexpected connection between the atmospheric photochemistries of two planets, and suddenly a very practical result emerges from the most blue-sky, abstract kind of work, understanding the upper atmosphere of Venus.

There is also a Mars connection to ozone depletion on Earth. *Viking* found the surface of Mars to be lifeless and remarkably deficient even in simple organic molecules. This deficiency is widely understood as due to the lack of ozone in the martian atmosphere. Ultraviolet light from the Sun strikes the surface of Mars unimpeded; if any organic matter were there, it would be quickly destroyed by solar ultraviolet light or the oxidation products of solar ultraviolet light. Thus part of the reason that the topmost layers of Mars are antiseptic is that Mars has an ozone hole of planetary dimensions—a possibly useful cautionary tale for us, who are busily making holes in our ozone layer.

CO_2 and the Greenhouse Effect

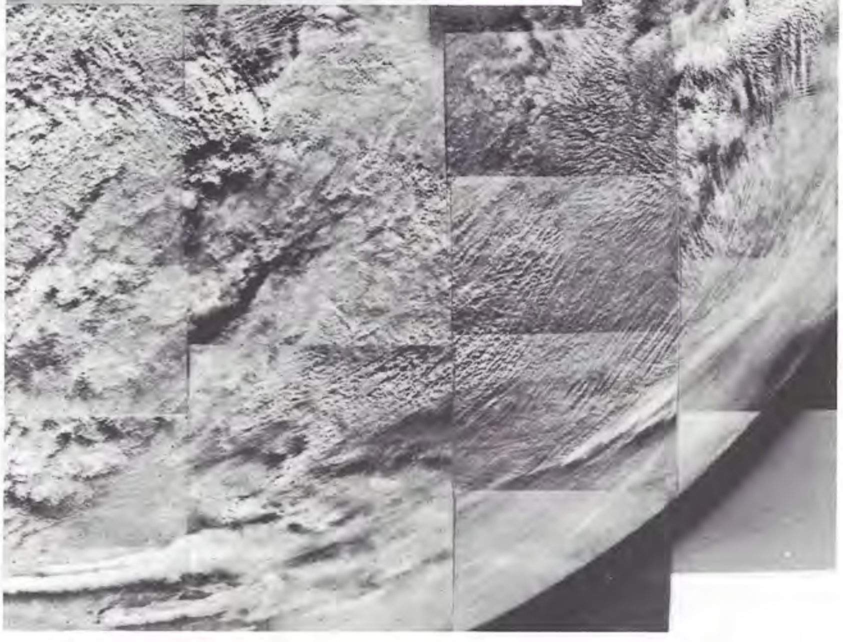
Now let's look at global warming from the increasing greenhouse effect, which derives largely from carbon dioxide generated by the burning of fossil fuels —but also from the buildup of other infrared-absorbing gases (oxides of nitrogen, methane, those same CFCs and some other molecules). Some of the important recent work on global warming has been done by James Hansen and his colleagues at the Goddard Institute for Space Sciences, a NASA facility in New York City.

Hansen and his colleagues point out that over the last hundred years the five warmest years in terms of average global temperature have been in the 1980s. If their current projections prove correct, and world temperatures continue to be driven up by the increasing levels of carbon dioxide and other gases in Earth's atmosphere, then 1990 will be the warmest year in the last 120,000.

LEFT: Venus' clouds enshroud a world of broiling surface temperatures. The greenhouse effect on Venus helped alert us to the dangers of the increasing greenhouse on Earth.

Image: Ames Research Center/NASA

BELOW LEFT: Cyclonic storms form on Mars as well as on Earth. By studying weather patterns on other planets, we gain insight into similar processes on our own planet.



BOTTOM: Scientists attempting to understand Mars' global dust storms realized that a nuclear war might produce similar effects on Earth, and so helped to develop the concept of "nuclear winter."

Images: JPL/NASA

Some of the consequences projected by various climatologists to the middle and end of the next century include the conversion of the Soviet Ukraine and the American Midwest, the breadbasket of the world, to something approaching scrub deserts. The slow volume expansion of sea water, the melting of glacial and polar ice and later the collapse of the West Antarctic ice sheet would cause the inundation of every coastal city on the planet. Now that's serious. Mitigating this warming will be very expensive.

Hansen has played a major role before committees of the House and Senate, convincing them to take the threat of global warming seriously. How did Hansen get involved with the issue of Earth's climatic future in the first place? As a graduate student at the University of Iowa he wrote a doctoral thesis that attempted (mistakenly, we now know) to disprove the contention that Venus was hot because of a massive greenhouse effect there. Venus got Hansen thinking about the greenhouse effect.

Those who are skeptical about carbon dioxide greenhouse warming might profitably note the massive greenhouse on Venus, where the atmosphere is primarily carbon dioxide, the surface pressure is about 90 times that on Earth, and the surface temperature is about 900 degrees Fahrenheit (480 degrees Celsius). No one proposes that Venus' runaway greenhouse effect was caused by Venusians who burned too much coal, drove fuel-inefficient autos or cut down their forests. That's not the point. But the climatological history of our planetary neighbor, an otherwise Earthlike planet on which the surface became hot enough to melt tin or lead, is worth considering—especially by those who say that the increasing greenhouse effect on Earth will be self-correcting, that we don't really have to worry about it.

In stable air over a calm ocean, cellular clouds such as these grow through slow, convective motion. This image was taken from the shuttle* Discovery *over Ascension Island in the Atlantic Ocean. The intricate, changing patterns of Earth's weather can be affected by human activities. Image: Johnson Space Center/NASA

Nuclear Winter

Nuclear winter is the darkening and cooling of the Earth, mainly from fine smoke particles injected into the atmosphere from the burning of cities and petroleum facilities that would follow even a "small" nuclear war.

There has been a vigorous scientific debate on just how serious nuclear winter is likely to be. The debate has now largely converged. Most three-dimensional general circulation models now get nearly the same answer provided they use the same starting conditions. That answer is close to the results first announced in 1982/1983 by a team of five scientists, to which I'm proud to belong, called TTAPS (for Richard P. Turco, Owen B. Toon, Thomas Ackerman, James Pollack and myself). Of the five TTAPS scientists, three are nearly full-time planetary scientists, and the other two have published many papers in planetary science.

The earliest intimation of nuclear winter came during the *Mariner 9* mission to Mars, when there was a global dust storm and we were unable to see the surface of the planet; the infrared spectrometer on *Mariner 9* found the high atmosphere to be warmer and the surface colder than it ought to have been. We sat down and tried to calculate how that could come about. Eventually this line of inquiry led us from dust storms on Mars to nuclear winter on Earth.

Planetary Perspective

Planetary science provides a global perspective, a big interdisciplinary picture that turns out to be very helpful in finding and attempting to define these looming climate catastrophes. When you cut your teeth studying other worlds, you develop a point of view—one very useful in understanding this world. There are probably other such catastrophes still to be uncovered. When they emerge, I think it likely that planetary science will play an important role in discovering and assessing them.

When I look at the evidence, I find that planetary exploration is of the most practical and urgent utility for us here on Earth. Even if we were not concerned about exploration, even if we did not have a nanogram of adventuresome spirit in us, even if we were only concerned for ourselves in the narrowest sense, planetary exploration would be a superb investment. NASA ought to make this case.

Carl Sagan, President of The Planetary Society, is coauthor with Richard Turco of a forthcoming book on nuclear winter and its implications for strategic policy and doctrine, force structures and arms control treaties, A Path Where No Man Thought: Nuclear Winter and the End of the Arms Race *(Random House, 1990). Dr. Sagan has just been awarded the Oersted Medal of the American Society of Physics Teachers.*

Earth, the Living Planet: How Life Regulates the Atmosphere

by James F. Kasting

Earth—is it alive? The straightforward, if somewhat stuffy, answer to this question is no. The bulk of our planet consists of obviously inanimate rock and metal. This ball of nonliving material is, however, surrounded by an envelope of water, gas and carbon-rich soil, collectively termed the biosphere, which supports a thriving network of organisms.

James Lovelock, author of *The Ages of Gaia*, borrows the metaphor of Earth as a giant redwood tree: The tree is undoubtedly alive even though some 99 percent is dead wood. The analogy is not perfect—unlike the tree, Earth cannot reproduce—however, it is close enough to justify a degree of poetic license.

Lovelock sees more than poetry in Gaia. According to his theory the biota of Earth (all its plant and animal life) control both the climate, by regulating atmospheric carbon dioxide (CO_2), and the bulk composition of the atmosphere, by controlling molecular nitrogen (N_2) and molecular oxygen (O_2). The Gaia hypothesis thus addresses a fundamental issue in the study of long-term climate: We know that solar luminosity has increased by approximately 40 percent over geologic time. Why then has Earth's surface temperature remained relatively constant?

A MOUNTAIN BROOK—Sunlight filtering through trees, a small bird searching for lunch, the flow of life-giving water, these are common things on Earth. Our planet is coated with a thin veneer of life that makes it unique in our solar system.
Painting: Arthur Parton, courtesy Museum of Fine Arts, Springfield, Massachusetts

The easiest explanation is that as the Sun's brightness increased, there was a corresponding decrease in atmospheric CO_2 and, as a result, a decrease in the greenhouse effect. Lovelock suggests that organisms may have caused such a CO_2 decrease; others, including me, have argued that the CO_2 decrease was primarily caused by physical factors.

While the overall importance of the biota in regulating climate remains a topic for further study, we can learn a great deal by focusing on the effects of the biota on the N_2 and O_2 content of Earth's atmosphere.

An Appetite for Nitrogen

Thermodynamically, Earth's nitrogen would prefer to be locked up in the ocean as nitrate ion (NO_3^-). The abundance of N_2 in the atmosphere is attributable, according to Lovelock, to bacteria that consume fixed nitrogen, including nitrate, and transform it into nitrous oxide (N_2O) and N_2. The nitrous oxide is converted to N_2 by photolysis (the breakdown of molecules by ultraviolet light) in the stratosphere.

The abundance of N_2 in Earth's atmosphere is indeed partly attributable to the presence of life, although the argument is not as straightforward as Lovelock suggests. The thermodynamic preference for nitrate, which is Lovelock's starting point, applies only if O_2 is present, and atmospheric O_2 levels would be much lower if we assumed an abiotic Earth. On a lifeless Earth nitrate could still be formed by such processes as the absorption of ultraviolet radiation from the Sun and shock heating by lightning. During the course of solar system history, lightning discharges alone would have converted most of Earth's N_2 into nitrate.

However, only a biological mechanism can account for the conversion of nitrate back into N_2. Thus a free-nitrogen atmosphere is characteristic of an inhabited planet. (This argument, too, requires some qualification: It would not apply, for example, to a planet such as Venus, which has no ocean in which to store nitrate.)

Steady-State Forest

The atmospheric constituent most obviously influenced by life is molecular oxygen, O_2. Molecular oxygen is a byproduct of photosynthesis, by which green plants create organic compounds from CO_2 and water.

Although the mechanism of photosynthesis is well understood, the process by which the biota actually regulate atmospheric O_2 is not. The most common misconception among nonscientists (and some scientists as well) is that green plants directly control the O_2 level simply by producing it in photosynthesis. To see the flaw in this idea, consider a forest that is not changing in size or internal structure. Most of the O_2 produced by trees within this forest is not released to the atmosphere but rather is taken up by respiration. Green plants, as well as animals, "breathe" to produce energy.

Some O_2 is released by each tree as it is growing, but exactly the same amount is consumed when the tree dies and decays completely on the forest floor.

A portion of the decaying tree's carbon may go into the soil. The resulting decrease in the amount of carbon available to the atmosphere would mean a relative increase in atmospheric O_2—except that the decrease in carbon is generally balanced by a decrease in oxygen, as the soil carbon is oxidized by O_2 dissolved in groundwater. If the total organic carbon content of the forest plus the soil remains constant, oxygen is neither produced nor consumed. Thus, such a steady-state forest has no effect whatsoever on the concentration of O_2 in the atmosphere.

One comforting corollary to this observation is that the current loss of tropical rain forests in the Amazon Basin and elsewhere around the world poses no immediate threat to our supply of oxygen. Although such forests produce massive quantities of O_2 by photosynthesis, they consume nearly equal amounts of O_2 during respiration and decay. Tropical deforestation contributes to the greenhouse effect and is a disaster for tropical ecosystems in general, but its short-term effect on atmospheric oxygen is negligible.

It's All in the Ocean

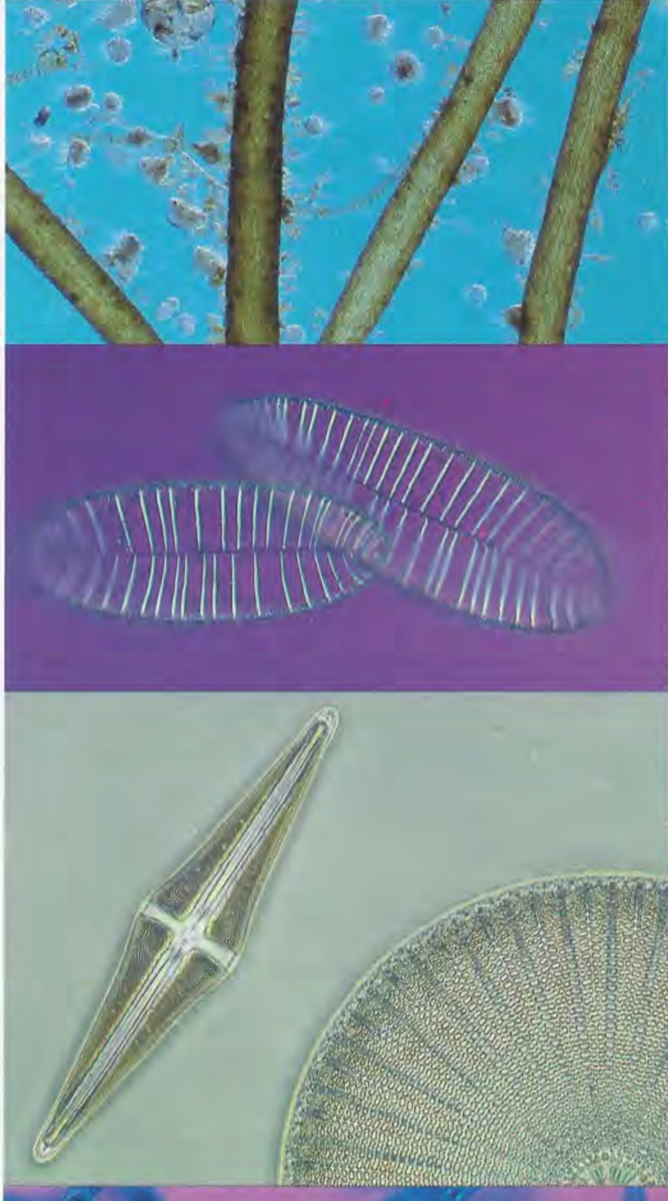
What, then, does control the atmospheric O_2 concentration? In the generally accepted view, the O_2 level is regulated by the burial of organic carbon in marine sediments.

The process begins near the ocean surface, where small (mostly microscopic) plants called phytoplankton release O_2 as they photosynthesize and grow. Some of the phytoplankton are consumed by zooplankton (microscopic animal life) and larger organisms, and all of these organisms eventually die and settle downwards toward the ocean floor, bringing their carbon with them. Fecal pellets from larger organisms such as fish provide an additional source of sinking organic-carbon particles.

Most of this organic material decays or is eaten either during its descent or shortly after it reaches the bottom. However, a small fraction (roughly 0.5 percent) is preserved in sediments on the ocean floor. Since this organic carbon originated as CO_2 an equivalent amount of free O_2 must have been released to the atmosphere. This excess O_2 is ultimately consumed by oxidation of minerals in the weathering of rocks.

To see how the feedback process controls the atmospheric O_2 level, suppose that for some reason too much organic carbon were buried over a period of time. All other things being equal, atmospheric O_2

(continued on page 24)



The oxygen cycle begins with microscopic phytoplankton—tiny "processors" powered by sunlight that turn water and carbon dioxide into free oxygen, which sustains life. If we were to find strangely high concentrations of molecular oxygen on another world, we might well suspect the presence of life. *Photos: Brian Parker, Paulette Brunner, Tom Stack & Assoc.*

Earth in the Mind of Humankind

by Richard Berendzen

What is Earth? To our earliest ancestors, the answer to this basic question—where do we live?—seemed simple: on a solid, flat object at the center of everything. In their world, astronomy and religion blended. The Egyptian universe was a large, rectangular box with Egypt at the center. The Hindu Earth rested on the backs of four elephants standing on a tortoise.

Less mystical concepts of Earth came from Greek philosophers, who tried to explain phenomena in a more scientific spirit and predict events such as eclipses and planetary motions. They distinguished between fixed stars (real stars) and wandering stars (planets, the Sun and Moon). Although the Greeks were astute observers of the sky, they lacked two technical tools: good time measuring devices and a notation system for large numbers. They devised remarkable models for the Earth and cosmos, but it would take another 2,000 years before we came to understand the true nature of Earth as a planet.

Earthbound Studies of Earth

Thales (circa 660 B.C.) said the Earth was a disc floating on water. He held that the universe could be explained through reasoning. Thus began science.

Pythagoras (circa 530 B.C.) taught that the Earth was spherical, defying the notion that people would "fall off." He said it was surrounded by concentric transparent spheres, each carrying a heavenly body around Earth.

Philolaus (circa 440 B.C.), a disciple of Pythagoras, was the first, as far as we know, to state that the Earth moved. Mixing shrewd insights with mystical numerology, he and other Pythagoreans counted nine circular motions in the sky: the fixed stars, the five known planets, the Sun, Moon and Earth. Ten was a "perfect" number, so Philolaus invented a tenth object, the Counter Earth. All ten bodies circled an unseen central fire. Despite this scheme's absurdity, it was an early example of a cosmology with a moving, non-central Earth.

Aristotle (circa 340 B.C.), whose influence lasted 2,000 years, argued compellingly that the Sun, Moon, planets and Earth were all spherical. By observation, the Earth's shadow was round as it moved across the Moon, and only a sphere could cast a moving round shadow. Also, north- and south-bound travelers saw stars that were otherwise hidden from view; thus, the travelers must have moved on a curved surface. To these rational and perceptive arguments, Aristotle added dogma: Circular orbits were perfect; the sphere was the perfect solid shape; the heavens were perfect.

> *The Earth is a round body in the center of the heavens.*
> *— Plato, Phaedo, circa 360 B.C.*

Aristotle recognized that the apparent daily motion of the sky could be explained in either of two ways: by rotation of the celestial sphere or by rotation of the Earth. He rejected the latter. He also considered a heliocentric model of the cosmos, with the Earth orbiting the Sun. He noted that if the Earth circled the Sun, then our vantage point would change as we moved along our orbit and the stars would seem to shift direction in the sky. But Aristotle could not detect this parallax, so he rejected the heliocentric model. The Greeks knew that stellar parallax would be minute and hard to detect if the stars were extremely far away. They did not realize how distant stars were.

Aristarchus (circa 240 B.C.) devised an ingenious way to compute the relative distances of the Moon and Sun from Earth. He also suggested that the Earth rotates, thereby accounting for the stars' diurnal motions. Most important, he argued that the Earth and other planets revolve around the Sun. Unfortunately, tradition (including Aristotle's influence) was against him, and, in the surviving fragment of his work, he failed to support his hypothesis with calculations or predictions of planetary motions. To the parallax argument, he could only reply that stars must be very remote, but he could not prove it. If he had been able to, ensuing centuries of confusion might have been avoided.

Eratosthenes (circa 235 B.C.) compared noon sightings of the Sun at the summer solstice from points 500 miles apart and calculated the Earth's circumference. His reckoning may have come within 1 percent of the correct value.

Ptolemy (circa 140) developed an elaborate geocentric cosmology. His model, buttressed by Aristotle's teaching and later Church doctrine, held sway for 1,500 years. It seemed logical, it fitted traditions and no available data disproved it.

The End of Ptolemy

Copernicus (circa 1530), two and a half centuries after Roger Bacon helped begin the Scientific Renaissance by urging people to experiment and think for themselves, reappraised the prevailing cosmological models. By then the Ptolemaic scheme was known to mispredict some motions; it needed modification. Copernicus did not prove the heliocentric model; rather he claimed that it was simpler and more elegant than the geocentric. He had no more supporting data than Aristarchus, and his model was no more reliable than Ptolemy's.

Tycho Brahe (circa 1580) made the most accurate astronomical observations to date, yet he rejected the heliocentric model because it seemed to conflict with the Bible. He did not believe the "sluggish" Earth could move, and even he could not detect stellar parallax. Instead, he proposed his own hybrid system with the Earth in the center, the Sun orbiting it, and the other planets orbiting the Sun.

New Spirit of Inquiry

Galileo (circa 1610) took the unconventional view that science should be grounded in observation and tested by experiment. He discarded the distinction —made by the Pythagoreans, Plato and Aristotle—between terrestrial science and heavenly matters, and he rejected the philosophy-based concept of perfect spheres, which Copernicus had still accepted. Galileo began to devise a new physics, much of which dealt with mechanics. As Leonardo da Vinci put it, "To understand motion is to understand nature."

If the Earth rotates around its axis, does air travel with it? When a bird dives for a worm, why does the Earth not turn and move the worm far away before the bird reaches the ground? After all, if the Earth rotates, its 24,000 mile circumference must turn 360 degrees in 24 hours; therefore, the equator must move at 1,000 miles per hour. Why do we not feel this motion?

What is Earth but a lump of clay surrounded by water?
— Bhartrihari,
Vairagya Sataka,
circa 625

And Galileo considered the Earth's purported motion around the Sun. In 365 1/4 days we must travel a circle of roughly 93 million miles' radius; hence, the Earth's orbital speed must be 19 miles per second. If you drop a weight from a tree, why would not the Earth and the tree move many miles before the weight hit the ground? Galileo solved these riddles, which had perplexed Aristotle, and he laid the groundwork for Newton's mechanics.

Galileo's observational work eventually changed the way humankind thought about the world. Through his crude telescope, he saw a "Copernican" system of moons around Jupiter, mountains on the Moon and spots on the Sun's "perfect" surface—in short, he saw truth. A few nights of observation, enhanced by the new technology of the telescope, cut down centuries of metaphysics. He disproved Aristotelian physics and Ptolemaic astronomy, and he incontrovertibly established the Earth as a planet in motion.

Newton (circa 1687) gave us the fundamental laws of motion and the concept that the laws of nature apply everywhere. He took it as given that Earth was a planet (as did most scientists after Galileo); thus Newton did not attempt to prove what was already settled. Rather, he explained in detail Earth's motion, its gravity at different altitudes and its tides; he conjectured about its oblateness. But even Newton had no data to answer the parallax problem; telescopes in his day could not detect it.

Throughout the 18th century, astronomers attempted to measure stellar parallax, and in one such attempt James Bradley discovered the aberration of starlight (the apparent displacement of a star's direction caused by Earth's rotation). However, astronomical instruments were still not adequate to capture stellar parallax, the change in position resulting from Earth's revolution around the Sun.

In 1837 Friedrich Wilhelm Bessel used a Fraunhofer heliometer, an instrument intended mainly to measure the angular diameters of the Sun and planets, to study the star 61 Cygni. He found a parallax for 61 Cygni of 0.314 seconds (one second of arc equals 1/3600 of a degree), which compares well with the currently accepted value. When Bessel published his finding in 1838, the parallax problem that had stumped Aristarchus at last was answered.

The Earth is round, and is inhabited on all sides . . . it is insignificantly small.
— Johannes Kepler,
Astronomia Nova, 1609

Journey to Self-Recognition

To the ancients—because of ego, dogma, common sense and everyday observation—the Earth was the immobile cosmic center. Even during Tycho's time, observations had not yet reached the precision needed to distinguish among cosmological models; one fitted the data as well as another. Slowly, over centuries, with brilliant bursts forward, mixed with intellectual retreats, humankind finally came to see the Earth for what it is: piece of debris number three orbiting a typical star on the periphery of a not-special galaxy at an unexceptional point in space and time.

A planet, yes; ordinary, no. Even in this universe, with more astronomical objects than grains of sand on all the terrestrial beaches, our planet remains special, beautiful, unique. Life may exist elsewhere; ineffably it exists on this fragile, precious place, our cradle and our grave. After millennia of wondering and exploring, we have come to understand what Earth truly is: home. In the words of T. S. Eliot:

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.

Richard Berendzen, a member of The Planetary Society's Board of Advisors, is President and Professor of Astronomy at The American University in Washington, DC. He is a member of NASA's Exploration Advisory Task Force.

Earth as a Target for Planetary Research

by William K. Hartmann

Over the eons, Earth has been a target floating through space, struck over and over by asteroids, comets and, perhaps, planet-sized bodies. Earth's Moon, whose reflection shines here on the Pacific Ocean, may have been created by a collision of Earth with another planetary body. Painting: William K. Hartmann

In NASA circles and the planetary science community these days there is much talk of a new emphasis in space exploration, sometimes called "Mission to Planet Earth." Usually this term connotes, above and beyond the sequence of missions described in the article by John Dutton (see page 16), a trend toward more space launches that would aim instruments at Earth.

The new emphasis on the study of Earth from space comes from two motives, one of which has a positive effect on long-term space exploration and one of which has a negative effect. The positive motivation is to direct our energies toward environmental problems and scientific questions about Earth—such as the greenhouse effect, ozone depletion, origins of life and the role of impacts in the Earth-Moon system.

The other motivation is a surrender to critics who say that there are not enough immediate economic benefits of planetary exploration.

After the failure of the *Challenger* mission, and the partial failure of *Phobos*, such criticism rose in intensity. The massively ambitious Soviet space program may have fallen victim to such criticism. Only last March their program seemed to be expanding dramatically as Soviet scientists in Houston publicly discussed a series of future missions, including balloons and rovers on Mars, a possible *Phobos* rerun, flybys of asteroids and comets, and even a rover on Mercury, not to mention piloted lunar missions around the year 2000.

A few weeks later, after the *Phobos 2* approach maneuvers failed, a subtle shift seemed to occur, with Soviet editorial pages carrying many letters from citizens who, in a spirit of *glasnost,* argued for solving problems on Earth before venturing to the planets. "Mars can wait" was a catchphrase for this movement.

One result of this line of thinking is that we lose our vision of the long-term importance of space science, and we see a shift in mission emphasis to relatively short-term practical applications, such as mapping mineral resources or improving weather surveillance, so that program managers can point to immediate economic benefits.

Had Darwin Stayed Home

Mission to Planet Earth, as an orientation for the space program, can have many benefits but only if it is accompanied by a vigorous program of planetary exploration. The simple reason is that other planets are nature's experiments in world-building, and the analysis of those "experimental results" has been one of the major stimulants to our understanding of Earth.

If Charles Darwin had stayed in England studying, let us say, English cows and badgers, he would likely have developed only a limited understanding of natural selection, if any at all. Through his voyage on the *Beagle* to South America, the Galapagos and other "worlds," Darwin greatly expanded the variety of his hard data and, more important, he fired his scientist's imagination. In simple human terms, the "alien" data were more stimulating in directing his thoughts and research.

Similarly, data from planetary exploration—on chemical reactions high in Mars' and Venus' atmospheres, on organic molecules in Titan's atmosphere, on the role of water in asteroid soils, on giant impacts in Earth's ancient history, and on the rate and environmental effects of impacts by interplanetary bodies—have stimulated our ideas about the processes that shaped the atmosphere, biology and surface of Earth.

TOP: In its cratered face, Earth's Moon records the history of bombardment in the inner solar system. *Painting: William K. Hartmann*

MIDDLE: The dark mare regions of the Moon formed as flows of dark basaltic lava. Mare Crisium is the large arc to the upper left; crater Tsiolkovsky lies at far right. *Photo: NASA*

BOTTOM: Where did our Moon come from? Only since the Space Age have we had samples to begin to answer that question. The leading theory at the moment is that it formed when a Mars-sized body struck the Earth.

Painting: William K. Hartmann

Crud Becomes Biochemistry

The most striking examples of planetary science hitting home on Earth come from planetary scientists studying atmospheric chemistry and physics. Their work led to our awareness of global warming, ozone depletion and nuclear winter. These examples are described at more length by Carl Sagan (see page 4), who played an important role in their development. Also of fundamental importance, though not as widely known, is the work of scientists who have analyzed the black and very dark brown organic compounds that cover comets and asteroids.

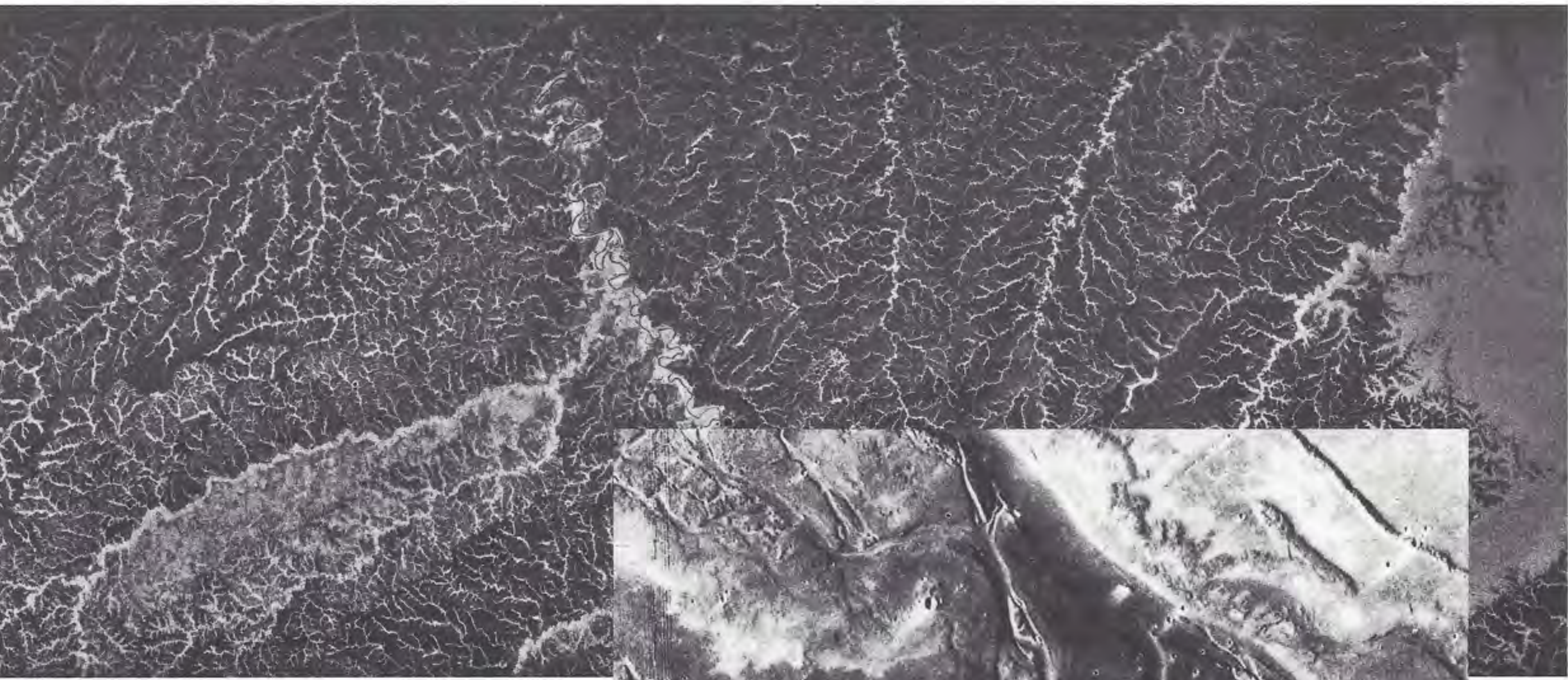
In attempting to decipher the chemistry of the solar system, experimenters in several laboratories have revealed the ease with which complex organic compounds synthesize in nature. University of Chicago chemist Clifford Mathews, for example, has shown that dark brown hydrogen-carbon-nitrogen compounds form readily and may be much more widespread in the cosmos than previously recognized. The organic compounds studied by planetary scientists—in research on carbonaceous meteorites, comets, the saturnian moon Titan, and Jupiter's clouds—involve the chemical building blocks of life. Therefore, such studies give us not only a new understanding of the chemistry of the cold cosmic environment but are a keystone in the continuing attempt to understand how biochemical processes —life—got started on Earth, and whether they started anywhere else.

Chip off the Old Earth

Studies of impact processes are also having a radical effect on our understanding of Earth's history. We learned by collecting lunar rocks that the Moon was formed out of material much like Earth's mantle, yet strangely depleted in water and other volatiles (materials that can readily be turned into vapor). It was as if the Moon were made of Earth-mantle material that had been strongly heated, with the water being driven out.

Pre-*Apollo* theories of the Moon's origin thus gave way to the current view, first proposed in my work with Donald Davis and also in independent additional work by A. G. W. Cameron and William Ward. The new theory holds that the early Earth was struck by a Mars-size body, which blew some of Earth's mantle into orbit, where it aggregated to form the Moon.

The larger importance of this work, aside from explaining the Moon, was that it led to greater appreciation of the role that catastrophic impacts have played in planet formation and evolution. In the early history of the solar system, planets formed by relatively smooth, slow, evolutionary processes—grain-by-grain aggregation, slow mountain-building and innumerable small impacts. These kinds of processes produced regularities, such as prograde orbits (only Neptune's Triton and a handful of much smaller moons have retrograde, or "wrong way," orbits), low axial tilts and uniform cratering of the oldest surfaces.



TOP:* *The intricate patterns on Earth's surface can be hard to perceive from the ground—or from space, if we look only with our eyes. Through space exploration we have developed tools to help us see our planet better. This image from the Shuttle Imaging Radar A (SIR-A) reveals the complex dendritic drainage pattern in east-central Colombia. *Image: JPL/NASA*

RIGHT:* *We found similar dendritic patterns on one other world: Mars. These channels strongly suggest that liquid water once flowed on this neighboring planet, although flowing lava, mud or ice are possible alternatives. These channels lie on the Plains of Elysium on Mars. The image is about 170 kilometers (100 miles) across.

Image: JPL/NASA

But we now recognize that for every thousand small impacts, there is one big impact. Therefore, even as the planets evolved slowly and gained their "regular" properties by accreting small particles, occasional catastrophic impacts altered, and individualized, their development. Thus, Earth gained one large moon. Uranus had its axis of rotation tipped by a giant impact, so that the axis now lies almost in the plane of Uranus' orbit.

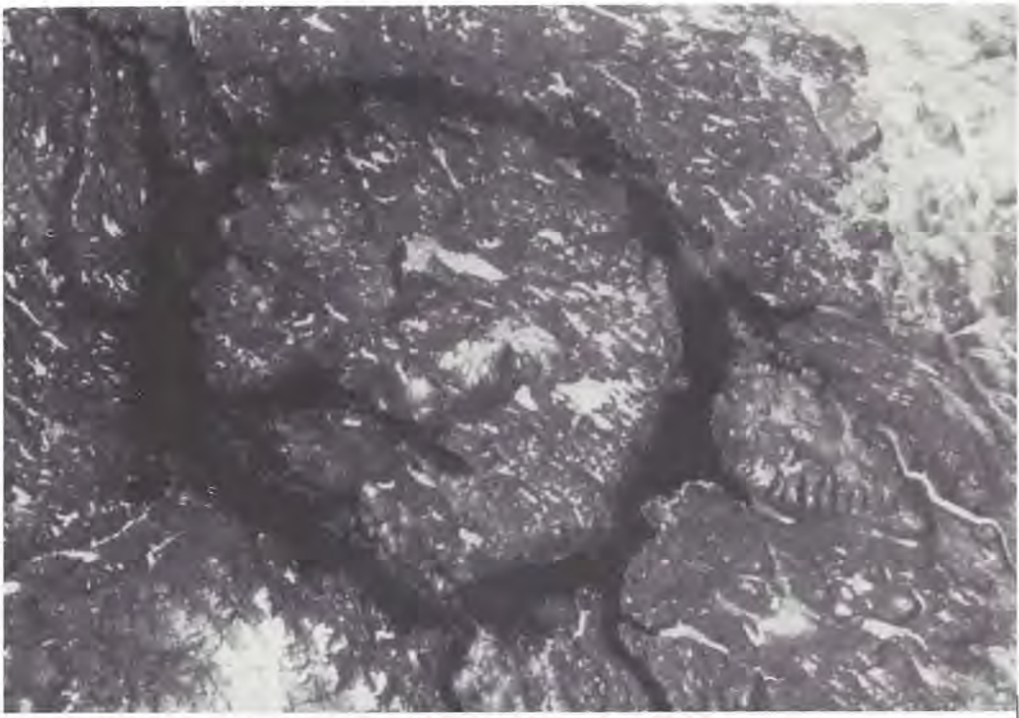
Collisions: Part of the Process

These realizations about impacts that occurred 4.5 billion years ago set the stage for acceptance of evidence that a much more recent impact—65 million years ago—had a decisive effect on the evolution of life on Earth.

About a decade ago, scientists discovered meteoritic remains and other signs of impact in the soil layer that divides the dinosaur-rich Cretaceous period from the Tertiary period, when mammals emerged. After much controversy, there is a growing consensus that Earth was hit 65 million years ago by an asteroid 10 kilometers (6 miles) wide and that the resulting explosion hurled enough dust and smoke into the atmosphere to alter Earth's climate temporarily, wiping out the dinosaurs and many other species of that period.

This exciting discovery, which could only have come after planetary scientists studied meteorites and asteroids, stimulated many calculations on the climatic effects of such an impact. Recent studies indicate that there would have been a sudden heating of the atmosphere as the meteoritic debris rose into space and then fell back. Jay Melosh of the University of Arizona calculates this heating could have broiled above-ground animals, except those protected by dense rainstorms or snowstorms. Afterward, the dust deposited in the stratosphere would have blocked sunlight for months, creating a super "nuclear winter."

These new theories, derived from asteroid and meteorite studies, force scientists to recognize that planets are not passive, stable environments for unending biological evolution. Rather, we are beginning to realize, the Earth's geological and biological histories have been profoundly affected by collisions with small and large interplanetary debris. Such knowledge of Earth could not have come about without the background data supplied by studies of lunar rocks, meteorites and asteroids. Research that was focused on Earth alone would not have done the job.



Erosion and recycling of Earth's crust have erased most impact craters from its surface. One of the largest remaining is Lake Manicouagan in Quebec, which measures 65 kilometers (40 miles) across. This photograph, taken from Earth orbit, shows that water and air are already modifying the crater's features. In a few million years, Manicouagan will disappear. Photo: NASA

A Balanced Approach

A Mission to Planet Earth coordinated with planetary exploration offers many continuing opportunities. For example, a lunar outpost research program to collect datable rock samples from 1,000 lunar craters would enable astronomers to work with paleontologists to construct a detailed chronology of the cratering record of the Earth-Moon system over the last billion years, thus resolving the current controversy about whether the Cretaceous boundary event that killed the dinosaurs was a fluke or part of an exceptional bombardment of comets or asteroids 65 million years ago.

To take another application, we now realize that accurate tracking of Earth-approaching asteroids might allow our grandchildren to predict any potentially dangerous impacts (such as the A-bomb-scale impact in 1908 in Tunguska, Siberia) and even prevent them by slightly altering the offending asteroid's orbit.

An important principle here is that for every big asteroid there are many middle-size and myriads of little ones. Therefore, we need to know more about the exact numbers of the smaller ones, and how often they hit Earth and other planets.

What we need for a truly successful Mission to Planet Earth is not simply a lot of cameras and spectrometers pointed at Earth from space but a vigorous, balanced program that includes exploration of the planets, moons and interplanetary bodies. Such a mix will do far more to enhance our understanding and appreciation of Earth than an Earth-chauvinistic program alone.

William K. Hartmann is a planetary scientist, writer and astronomical painter. The topics in this article receive fuller treatment in Hartmann's book Out of the Cradle *and in his forthcoming book on the history of Earth.*

Mission to Planet Earth

by John A. Dutton

Access to space has created astounding possibilities for the residents of planet Earth: the ability to survey nearby planets and perhaps someday walk upon them, as we have already on the Moon; the ability to look back through time toward the origin of the universe; and the ability to observe our planet holistically, learn how it works and perhaps control its future.

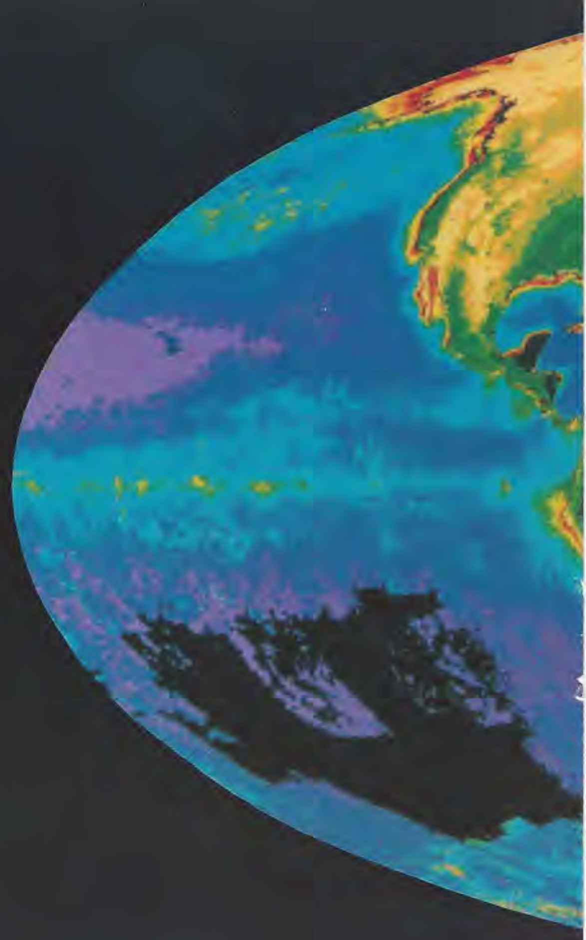
The missions to explore other planets and the mysteries of the universe are among our greatest achievements, stimulating our intellectual and technological capabilities. And the many missions we have launched to observe Earth have taught us much. But we have not yet learned enough to really understand how our planet works and what its future might be. That future may be in doubt, as a result of human activities that are altering natural balances. We need to understand this planet and the changes now in progress. We need to take another giant step for humankind—a Mission to Planet Earth.

Plans for such a mission, which will soon be presented to Congress for fiscal authorization, have been developed by NASA in cooperation with other nations over the past five years. The first mission phase will create the Earth Observing System (*Eos*), consisting initially of five polar-orbiting platforms with instruments to observe Earth's surface and atmosphere. The first platform will be launched in 1997, according to present plans. In the second phase of Mission to Planet Earth, the polar orbiters will be complemented by equator-orbiting platforms; these will be in geosynchronous orbit, matching Earth's rotation and thus providing a continuous view of an entire hemisphere.

These satellite systems will yield an unprecedented flow of information about the planet and the interactive processes that control its evolution. But obtaining these data from space is only the first step.

Earth System Science

Doubling in number every 50 years, the human species is changing the delicate physical, chemical and biological balances that shape the climate of the planet. The ozone layer, which absorbs ultraviolet radiation and thereby permits life to exist on land, is being depleted, most dramatically at the South Pole, by human use of chlorofluorocarbons in refrigeration and industrial processes. Use of fossil fuels and tropical deforestation are increasing the carbon dioxide content of the atmosphere. If this process continues, the greenhouse effect may lead to global warming,



The technology that investigates Earth from space brings new ways of seeing our planet. Most readers readily understand common political or relief maps, but this image shows something vastly different: the productive potential of plant life on Earth. Data from the Nimbus *7 satellite is processed so that high concentrations of marine phytoplankton, the basis of our food chain and oxygen cycle, appear in red and orange. Lesser concentrations show as yellow and green. (Black areas indicate no data.) Colors on the land indicate chlorophyll and leaf mass, with dark green areas having the highest potential. Colors taper through light green to yellow, with barren areas shown in brown.*

Image: Goddard Space Flight Center/NASA melting polar ice and rising seas; resulting changes in local climatic conditions would alter the distribution of vegetation and agricultural productivity.

First of all, we need to document the changes that are occurring and ascertain the rate of change. We'll have to learn to recognize which changes are driven by human activities and which are results of natural variations. The only way to obtain this level of understanding is to observe the entire Earth from space for several decades.

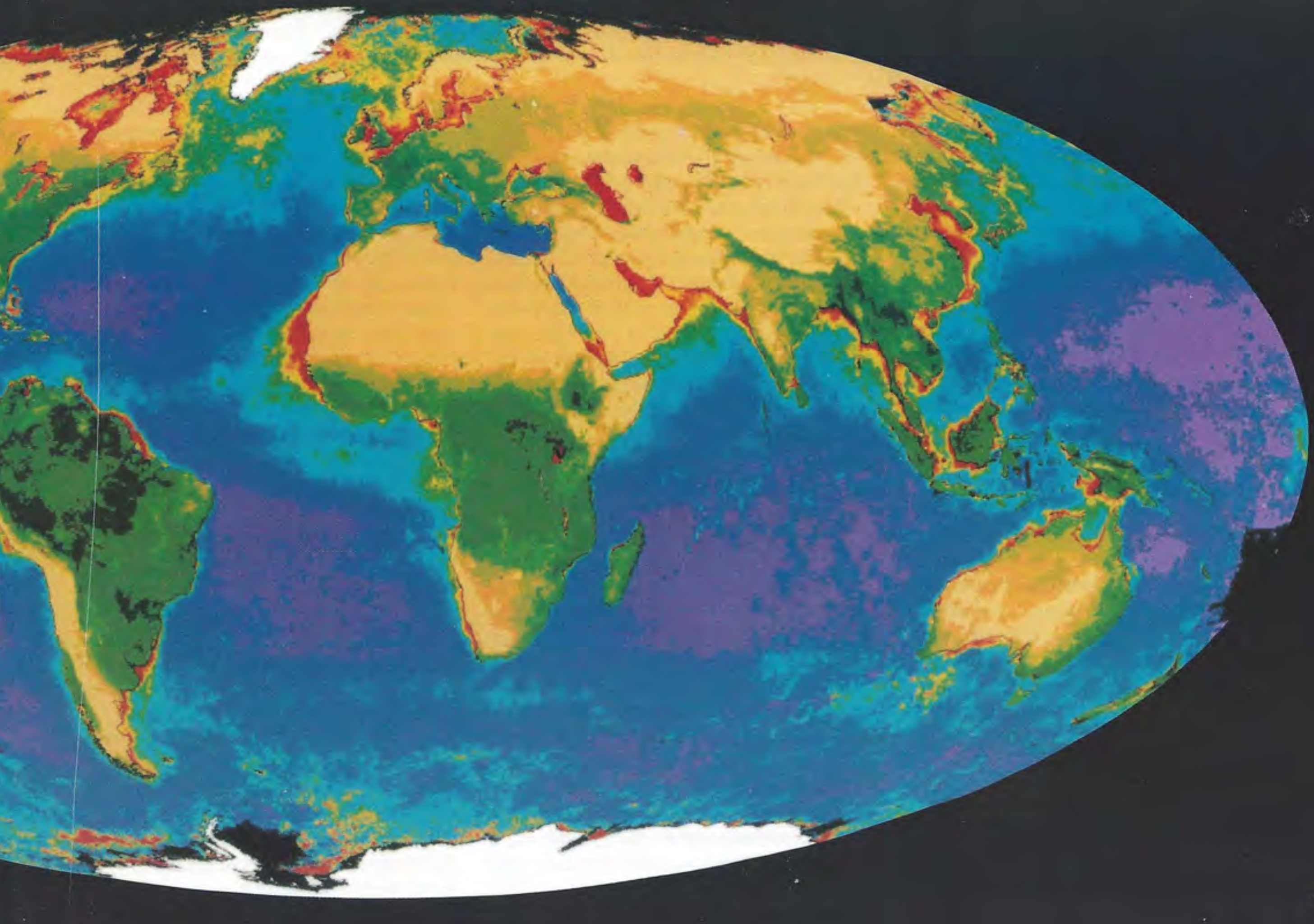
To understand how the whole Earth works as an integrated system, we must transcend the present specialization of disciplines to create a new science—an Earth system science—that can identify and comprehend the interactions among the atmosphere, oceans, land surface, life on land and in the sea, and the sheets of ice on land and sea. We know today that the chains of cause and effect are wondrously delicate and complex. The physical environment affects biological processes and in turn biological processes, interacting with the chemistry of the atmosphere and sea, modify the physical environment, most notably the radiation balances of the planet.

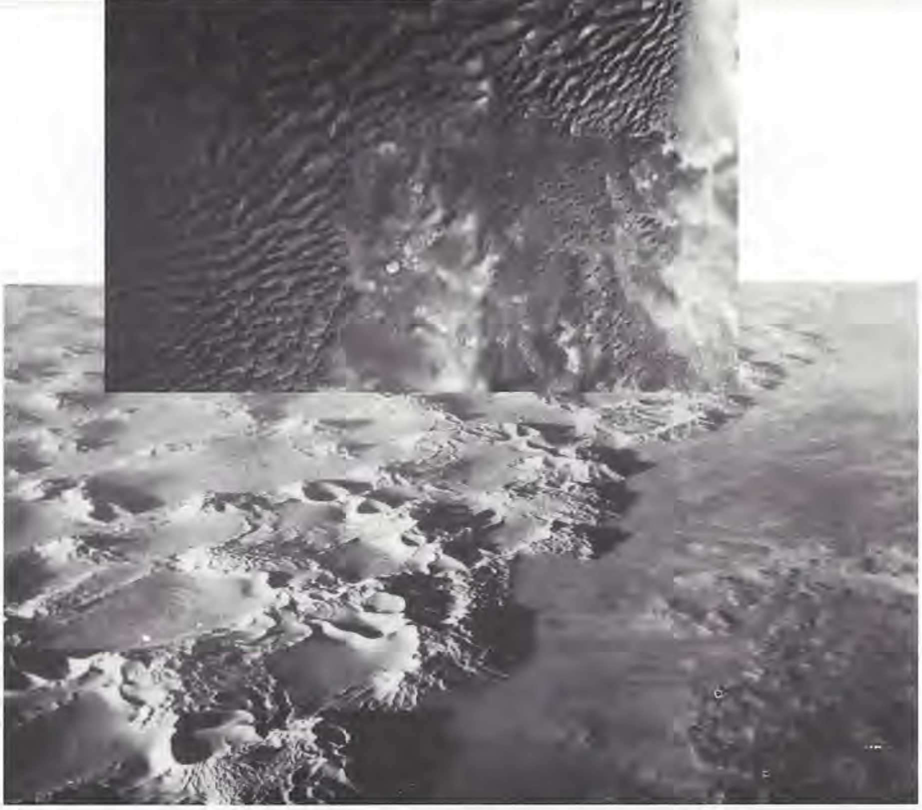
Long-Range Forecasting

Finally, we must learn to predict reliably what conditions on planet Earth will be like decades and centuries in the future. To preserve Earth, and ourselves, we must foresee what will happen if we continue on our present course and, in contrast, what would happen as a result of specific measures in the areas of energy, pollution, reforestation and human population growth.

Such predictions, taking into account the interactive complexity of the entire Earth system, can only be made with computer models that simulate the behavior of Earth. Today computer models that combine the known physics of the atmosphere with data on current conditions can predict weather conditions a few days or a week ahead. Tomorrow we'll have models that resolve the interactions of the Earth system—including physical, chemical and biological subsystems—and these models will enable scientists to predict, at least on a statistical basis, what global and regional environments will be decades, and maybe centuries, into the future.

To develop models that will accurately simulate the workings of the Earth system, we must learn the details of how its many processes interact, from local *and* global perspectives. Mission to Planet Earth, beginning with *Eos*, is designed to produce that information—the magic mirror, if you will, to let us foresee the future of planet Earth.





TOP: On terrestrial planets such as Mars, and even on moons such as Triton, winds sculpt shapes familiar to Earth-dwellers. These dunes in Mars' southern hemisphere, seen from the* Viking *orbiter, look as though they might have been formed in an earthly desert. ***Image: JPL/NASA***

BOTTOM: The great dune fields of Earth, such as the Grand Erg Oriental in the Sahara, would be familiar landforms to a Martian.
Photo: Nicholas Short, Bloomsburg State College, Pennsylvania

The Plan for Eos

Eos will be the largest single scientific initiative ever undertaken by NASA, or for that matter by the peoples of the world. The project will have three components: the instruments in space, an information system to distribute the results of observations and a program of interdisciplinary research focusing on application of the data to key issues in Earth system science (including the global water cycle, controls on biological productivity and atmospheric chemical cycles).

The five *Eos* polar-orbiting platforms—two each to be built by NASA and the European Space Agency and one by Japan—will carry 8 to 12 instruments per platform. The instruments, each with unique and advanced capabilities, are being designed by separate groups. Another 28 interdisciplinary research groups have already been funded to begin planning for the effective use of the data. Today, scientists and engineers from 168 institutions, universities and national laboratories in the US and 12 other countries are creating the *Eos* instruments and interdisciplinary centers. The *Eos* program will cost more than $1 billion per year over its lifetime. By way of comparison, this cost is only a little more than the Department of Defense spends each day of the year.

The NASA *Eos* polar-orbiting platforms will be large spacecraft, each approximately 12 by 4.3 meters (36 by 13 feet), weighing 12,000 kilograms (30,000 pounds). NASA will launch them from Vandenberg Air Force Base aboard *Titan IV* rockets into Sun-synchronous orbits (for continuous lighting). At an altitude of 705 kilometers (441 miles), the *Eos* satellites will obtain nearly global coverage every two days.

EosDIS

The design of *Eos* instruments reflects an emphasis on long-term continuity of observations and on simultaneity of observations by different instruments on the same platform. Simultaneity lends depth to our "picture" with extra wavelengths and increases accuracy since the data from one instrument will often be used to correct or adjust data from another.

The *Eos* instruments in space will produce a veritable flood of information about Earth. The two NASA platforms will send data at an average rate of 70 megabits per second, but at peak mode will produce data at the rate of some 300 megabits per second. To accommodate these unprecedented flows of information, NASA is designing the *Eos* Data and Information System (EosDIS), which will make results available to scientists throughout the world. The successful design and operation of EosDIS is an even greater challenge than creating the instruments to fly in space. Nevertheless, scientific planners and NASA are committed to *Eos* as an information system about Earth and its processes, above and beyond the space mission component.

Recognizing Patterns

Observations from space reveal patterns that sweep across the face of Earth. Most familiar are the cloud patterns seen by weather satellites, but there are other intermingling patterns —in the distribution of temperature and wind at the sea surface, vegetation and vegetative stress, biological productivity in the ocean, varieties of surface minerals and the ridging of polar ice.

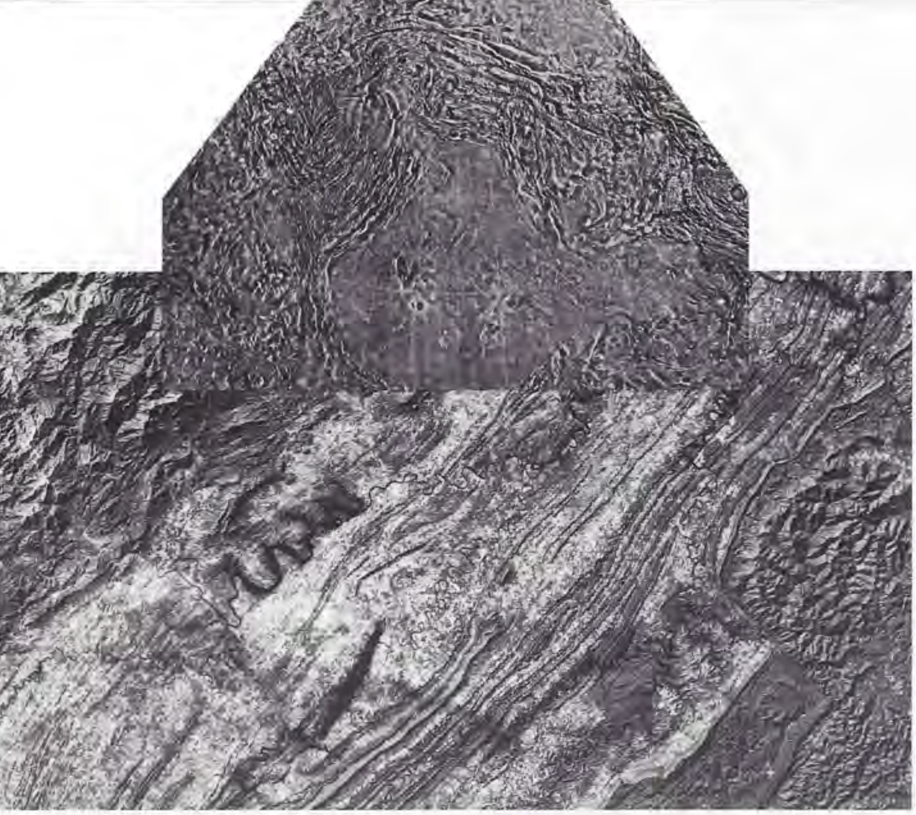
These tantalizing patterns, in their variety, reflect the complexity of the Earth system. They are our key to unlocking the secrets of change. We need to convert these patterns into quantitative information on processes and their rates.

For example, in cloud patterns we can recognize atmospheric processes on two scales. On the larger scale, cloud patterns reveal wind direction and speed, they indicate where convection is intense and they provide information about the distribution of water vapor. From cloud patterns we can discern and predict the regular behavior of frontal systems. On the smaller scale, cloud patterns reveal internal processes that involve vertical motion, condensation of water vapor, and absorption and emission of radiation. Thus with clouds we have some experience in relating patterns to dynamics. The same conversion from pattern to process must be effected for all the elements of the Earth system.

Soil, Water and Air

Even what we call the *solid* Earth is dynamic. The location of mountain chains and rifts in the sea floor, along with variations in Earth's gravitational and magnetic fields, combine to reveal the effects of convection in the mantle and the resulting motion of the tectonic plates that make up the crust. From these patterns we can infer processes at work deep within Earth.

Paradoxically, we don't know quite



TOP: The Venera orbiters revealed mountain chains on Venus that resemble the compressed and folded Appalachians on Earth. In this map, the ridges ring the upland region Ishtar Terra. *Image: Space Research Institute, USSR*

BOTTOM: What forces could crumple rock and thrust it miles into the sky? By studying mountains on other planets, comparing them with ranges such as the Appalachians, we unravel the secrets of geologic processes.

Photo: Nicholas Short, Bloomsburg State College, Pennsylvania

as much about certain processes taking place at the land surface—specifically, in the interactions of soil, vegetation and atmosphere. Observing the radiation emitted or reflected from the land surface, we can learn about its "heat budget," the sum of all transfers of energy between the atmosphere and the land and vegetation. While radiative components of this budget can be measured directly from space, other components, such as the evaporation rate, will have to be inferred, perhaps from remote observations of surface temperature and soil moisture content.

Much more difficult to ascertain are the processes involved in the balance and evolution of vegetative cover. Vegetation interacts with both the soil and the atmosphere, using nutrients from above and below the surface, and in the process alters the chemical composition of both land and air. However, we don't as yet know how to resolve that vast and complicated exchange of elements and energy.

It's critical that we learn to put together local records with sufficient detail *and* global records over the long term in order to get the whole picture of the chemistry occurring at Earth's surface. The vegetation on land and the flora and fauna of the oceans exchange chemical constituents with the atmosphere, soil and oceans, creating biogeochemical cycles. These biogeochemical cycles are important to us because they control the concentration of gases in the atmosphere that in turn control the flow of radiation in the atmosphere and hence determine the climate of the planet.

Even more than the land surface, the oceans control Earth's climate and the chemistry of its atmosphere. Their huge heat capacity regulates temperatures. Oceans also absorb carbon dioxide from the air, and their marine life absorbs and emits important components of Earth's chemical cycles. Satellite observations—of water colors due to suspended organisms (plankton), of ocean surface temperatures and of the winds that drive ocean currents—are critical to understanding our planet's evolution.

The atmosphere ties all of the processes together, providing pathways through which living systems can interact and exchange matter and energy. Some atmospheric patterns and processes are now readily observed from space; others, such as detailed wind fields and precipitation patterns, will become measurable in the *Eos* era.

Building Models of Earth

For some subsystems of Earth our understanding is good enough to identify critical processes and encapsulate them in computer models. However, for most cases we need to develop equations for computer models that are more comprehensive and more sensitive to the complexity of Earth's patterns and processes.

In all cases our knowledge is scale dependent. With vegetation and soil physics, we understand the processes better on the molecular scale than on the scale of a forest or savanna. With the atmosphere and ocean, we know well the equations that describe the gross features and motions, but optimum descriptions of turbulence, air-sea interactions and eddy motions still elude us. In the geological realm, we have theories of mantle convection and crustal motion but are not confident that we can describe the evolution of the land surface quantitatively.

Transformation of patterns into knowledge of processes and their interactions is the crucial step. That done, we can feed data into computer models that will simulate the evolution of the Earth system and perhaps foretell its future. That is the hope and the goal of *Eos*.

Legacy of Eos

Future generations, rather than we, will benefit from the knowledge gained through *Eos* and the Mission to Planet Earth. They will know vastly more about the threats of ozone depletion and greenhouse warming, and more about their planet. They will have a science of the entire Earth system. As benefits of space observations and technology, there will be greatly improved weather prediction with benefits to public safety as well as agriculture and commerce. Increased knowledge about the dynamics of the crust will improve understanding of earthquakes and how to predict them. Future generations will manage energy resources better and will manage, or at least be more aware of, the vagaries of the global water cycle. They will be more sensitive to the potential for human activities in one area having important consequences for all humans, for the entire planet.

If we attain the goals of *Eos* and Mission to Planet Earth, then future generations will know that we, as the 20th century came to a close, accepted our responsibility for the future.

John A. Dutton is Dean of the College of Earth and Mineral Sciences at The Pennsylvania State University.

Seeding Earth: Comets, Oceans and Life

by Christopher Chyba

Liquid water flowing over the surface of Earth makes our planet unique in the solar system. But where did the water come from? Did Earth process it herself, or did other solar system objects contribute to water—and so to life—on Earth?
Photo: Johnson Space Center/NASA

Giotto, the European spacecraft sent to encounter Halley's Comet in March 1986, pierced the cloud of gas and dust surrounding the comet's core and flew within 600 kilometers (400 miles) of its frozen nucleus. *Giotto*'s very close approach had been made possible by the "pathfinding" mission of two other probes only a few days earlier; these Soviet *Vega* spacecraft plotted the position and trajectory of Halley's nucleus for engineers at the European Space Agency, who then refined *Giotto*'s aim at the comet's gas-shrouded core. Two Japanese spacecraft made more distant approaches to Halley. (Of the major spacefaring nations, only the United States sent no representative to comet Halley. However, NASA's Deep Space Network of radio telescopes did make an essential contribution to the precise tracking required for the Soviet pathfinding mission.)

Observations by the spacecraft, complemented by observations made with instruments on the ground, in sounding rockets and in high-altitude aircraft, verified the long-standing hypothesis that comets consist largely of frozen water: Halley is about half water ice.

The suspicion that comets are loaded with organic molecules, the kinds of molecules needed for the earliest stages in the evolution of life on Earth, was also dramatically confirmed: The *Giotto* and *Vega* spacecraft sampled the comet's dust as they flew through its gaseous envelope and found organic-rich microscopic grains. (In the language of chemistry, saying a molecule is "organic" means only that it is a carbon compound, often with hydrogen, nitrogen or other atoms—the term carries no biological connotation.)

Some of the cometary grains, altogether free of rock, seemed to be purely organic in composition. But Halley's solid center held the big surprise: It was much larger, and much blacker, than many investigators had expected. We now think that the carbon-black exterior of the nucleus may be a kind of webbed crust of organic molecules and rock fragments.

If Halley Hit a Planet

Ground-based observations suggest that other comets are like Halley in gross respects; for the time being the best we can do is to assume that they are like Halley in detail as well. Suppose, then, that most comets are 50 percent water ice. Suppose that most comets are full of organic molecules. What would be the result of a cometary collision with a planet?

Comets course through the solar system in elongated orbits. Halley, for example, hurtles out past the orbit of Neptune and then, on its return, reaches the orbit of Venus, crossing the path of every planet in between. Sooner or later it will have a close encounter with one of these planets. Such an encounter might deflect the comet to a new orbit, perhaps ejecting it from the solar system altogether. But if the encounter is close enough, the planet's gravity will pull the comet into a collision.

Striking the surface of the planet, the comet would excavate a crater and vaporize almost entirely in the ensuing explosion. The comet's steam might form a tenuous atmosphere of water vapor, or perhaps clouds if the planet already has an atmosphere. Some of the comet's organic molecules might survive the explosion. In sum, the impact of a Halley-type comet would deliver to the surface of the target world a certain amount of organics and a great deal of water—around 250 cubic kilometers' worth.

The most recent cometary collision with Earth probably took place in 1908 when a huge explosion over Tunguska, Siberia caused widespread devastation in what was fortunately an extremely remote area. Throughout its history, Earth must have experienced many such collisions. But how many? How much cometary water might Earth have collected in this way?

Different theoretical models give different answers, but we can place empirical limits on these answers by using knowledge gained from the *Apollo* missions to the Moon and probes to other planets.

HALLEY'S COMET OVER ANTARCTICA—The water that covers Earth today may have originated in comets that condensed in the outer regions of our solar system. *Painting: Kim Poor*

Early Bombardment

When *Apollo 11* astronauts returned to Earth in July 1969, the first lunar samples quickly established two facts of enormous importance for the Moon's history: Most of the surface of the Moon is very ancient, and most of this surface has been geologically inactive for the past 3 billion years. Over the following three years of *Apollo* landings, it became clear that the oldest lunar terrain shows the cratering record from a period of intense bombardment that ended about 3.8 billion years ago.

What projectiles collided with the Moon to excavate these craters, and did the same family of objects also batter Earth? No terrestrial evidence can answer these questions. The oldest known rocks on Earth, from the Isua formation in Greenland, are no more than 3.8 billion years old. (However, in October 1989 Samuel Bowring at Washington University in St. Louis announced finding two rocks 3.96 billion years old in remote northern Canada.) Earth is such a geologically active planet that whatever terrestrial surface existed that long ago has since been completely eroded away or drawn back inside Earth's hot interior to be melted and forever lost as geological evidence. However, *Mariner* photographs of Mars and Mercury from the early 1970s demonstrate that the family of objects responsible for the lunar cratering bombarded these planets as well.

"Size/frequency" graphs, reflecting the number of craters as a function of crater size for each body, show definitive similarities in the impact history of Mercury, the most ancient terrain on Mars and the most heavily cratered terrain on the Moon. All these worlds, and by implication every planet in the inner solar system, were bombarded by the same family of projectiles, identifiable by their characteristic size/frequency distribution. Although direct evidence has been removed from its surface, Earth must have experienced this intense bombardment as well, as objects with diameters up to hundreds of kilometers repeatedly traversed the region of the

THE ICEBERGS—Only on Earth are temperatures near water's triple point, where it can exist simultaneously as vapor, liquid and ice, as seen in this dramatic rendering inspired by the artist's expedition to Labrador. *Painting: Frederick E. Church, courtesy Dallas Museum of Art* inner planets. Mercury, Venus, the Earth-Moon system and Mars gradually "swept up" these rogue bodies in collision after collision.

Comet-Delivered Oceans

In a recent study, I used the cratering record on the Moon to estimate how many of these bodies struck the lunar surface during the period of intense bombardment. From that number, taking into account Earth's larger diameter and higher gravity, I calculated the total mass of impactors collected by Earth during that time. Between 4.5 and 3.8 billion years ago, it appears that Earth swept up a total mass as great as a third of the mass of the Moon.

It is not certain how many of these wayward bodies were comets. Even if only a small fraction were comets, the implications for the early Earth are profound. A cometary fraction of about 10 percent would have been sufficient to deliver an ocean's worth of water to Earth's surface.

We don't have clear evidence to determine whether comets comprised 10 percent of the impacting bodies during the intense bombardment. In current cratering in the inner solar system, comets appear to account for between one tenth and one third of the total, although some investigators believe the fraction may actually be as high as one half. But cometary cratering in the present tells us little about its importance in the past.

Dating the Early Bombardment

Our knowledge of the early heavy bombardment of the inner solar system derives almost entirely from examination of the samples brought back from the Moon by the *Apollo* astronauts and by Soviet *Luna* robotic missions. From these samples we discovered that lunar cratering was not uniformly distributed through time; rather it decreased exponentially until about 3.8 billion years ago, when the frequency of cratering leveled off to its present low rate. Thus the ancient environment of all the planets of the inner solar system—including Earth's at the time of the origin of life—was impact-dominated, with cratering thousands of times more intense than today.

This was indeed a great deal to learn from the painstaking research lavished on the 380 kilograms (840 pounds) of rocks returned from the Moon. How was it accomplished?

The first step was to determine the age of the samples. While a number of radioactive dating methods are in use, the fundamental idea is well illustrated by a simplified version of the potassium-argon method.

Argon is a "noble" atom, one that does not chemically combine with other atoms. Thus when a rock "contains" argon it literally encloses this gaseous element: The argon is physically prevented from leaving the sample by the layers of rock surrounding it. If the rock is liquefied, the argon will bubble out and escape.

The Sea of Tranquillity, where *Apollo 11* landed, is a vast lunar lava flow, and when this flow was molten, it must have lost whatever argon it contained. But the rock samples returned by the astronauts contained traces of the isotope argon 40. This isotope is produced in the radioactive decay of an unstable isotope, potassium 40, whose decay rate can be precisely measured in the laboratory.

We add the amount of potassium 40 now remaining plus the amount of argon 40 decay product, and this gives us the initial amount of potassium present when the lava solidified. The decay rate then tells us how long it must have taken this much initial potassium 40 to transform into that much final argon 40. That length of time is the age of the rock.

Once we know the age of a particular locale, we can use "crater counts" to determine the relative age of other sites (more heavily cratered locales are older than less cratered ones). A knowledge of the ages of many different sites then allows us to determine the number of lunar craters formed in any given interval of time.

Thus we owe our understanding of the early bombardment of the inner solar system to a few Moon rocks, made available for study by sample-return missions. Similar missions to Mars will test these conclusions and undoubtedly provide new surprises. —*CC*

If comets brought a significant quantity of water to Earth, we would expect to find that they delivered water to the other planets as well. But again the evidence is indecisive. Mercury and the Moon appear to have no water, but water would not last long on either of these bodies, except perhaps in rare permanently shadowed regions. On the other hand there is indirect (though controversial) evidence for much water on Venus in the distant past (see the November/December 1988 *Planetary Report*). As for Mars, *Mariner* and *Viking* photographs show a variety of now-dry water channels and traces of ancient lakes. Early Mars may have been warmer than at present, with water flowing on its surface. So far there is no way to test whether this water was delivered by comets.

Closer to home, we can readily test Earth's ocean water, the isotopic composition of which hints at an extraterrestrial origin. In typical ocean water only about one water molecule in ten thousand contains deuterium (D), a hydrogen isotope that carries a neutron and is thus heavier than normal hydrogen (H). The D/H ratio in Earth's oceans is higher than the "cosmic" D/H ratio typical in our solar system and elsewhere in the galaxy by a factor of about ten.

Observations of Halley indicate that the D/H ratio of cometary ice is about equal to that of Earth's oceans—elevated above the cosmic D/H value by about the same factor of ten. Moreover, volcanic water from deep within Earth's interior appears to be closer to the cosmic D/H ratio; this evidence does not confirm but is consistent with an explanation of Earth's surface water as a late-arriving cometary veneer.

An important theoretical objection calls into question a cometary origin for Earth's oceans. Recent work by Jay Melosh and Ann Vickery of the University of Arizona shows that some impacts of comets and asteroids may erode planetary atmospheres by blasting atmospheric gases off into space.

If this view is correct, then cometary impacts would not simply have delivered water to Earth but would also have eroded it away. Research I have recently completed, however, seems to show that for the larger worlds of the inner solar system the competition between these two processes strongly favored the net accumulation of planetary oceans. This same work also points to the possibly important role of water-rich carbonaceous asteroids. If Earth's water arrived as a late veneer, it is likely that asteroids and comets both were important in its delivery.

Seeding Earth with Organics

If comets made a significant contribution to the oceans of primitive Earth —the conclusion remains tentative— then they played a major role in shaping the environment in which life evolved. Comets may also have contributed to the terrestrial inventory of organic molecules necessary for the origins of life.

In 1953 Stanley Miller, a University of Chicago graduate student working with the Nobel Prize-winning chemist Harold Urey, showed that amino acids and other organic molecules would form easily and naturally in what was then believed to have been the atmosphere of the early Earth. Simulating this primitive atmosphere with a gas mixture of methane, ammonia and water, Miller introduced an electrical spark (representing, for example, lightning) and obtained a high yield of amino acids.

It has since been shown that in such an atmosphere virtually any energy input (for example, ultraviolet light from the Sun, or shock energy from meteoritic impacts) will lead to the creation not only of amino acids but to the precursors of other important biological molecules. In the traditional view of primitive Earth, these precursor molecules collected in the oceans, forming a warm, dilute "organic soup," on the surface or shorelines of which life evolved.

More recently consensus among geochemists has been shifting to the view that the early terrestrial atmosphere may not have been so biologically accommodating. In this picture, the early atmosphere consisted not of methane and ammonia but mainly of nitrogen and great quantities of carbon dioxide. Under these conditions production of organic molecules is more difficult, and thus environments suitable for the origin of life on primitive Earth would have been more rare. Whichever scenario is correct, comets may have provided an important extraterrestrial link for the origins of terrestrial life.

Giotto and *Vega* showed that comets are full of organic molecules. It now appears that such molecules form inevitably in comets by a process analogous to the Miller/Urey experiment. Miller and Urey used a gaseous mixture, but the experiment will also produce organics when methane, ammonia and water are present in solid form, as ices.

(continued on page 30)

TOP: From Earth orbit we gain a perspective on water molecules cycling through their phases that is impossible from Earth. In this photograph taken by* Apollo 9 *astronauts, we look almost directly down on a thunderhead forming over South America.

MIDDLE: The perspective from Earth orbit also enables us to see the extent of humanity's effect on our planet. Here* Challenger *astronauts looked down on growing cumulonimbus clouds over Zaire, but haze created by fires set to clear ground for agriculture completely obscured the surface.

BOTTOM: Icebergs large enough to be seen from space break from an ice floe and drift off the coast of Labrador.

Photographs: Johnson Space Center/NASA

Living Planet/*continued from page 9*

would increase as a result. Since nearly all available minerals in rocks are already fully oxidized, weathering would be able to take up only a slight fraction of the extra O_2.

However, some of it would dissolve in the ocean, causing an increase in the decay rate of organic material. (The microorganisms responsible for most of the decay use O_2 to oxidize dead organic matter.) Accelerated decay would then cause a decrease in the amount of organic carbon being buried on the ocean floor. Eventually atmospheric O_2 would rebound toward normal levels.

Suppose the opposite case: a drastic decrease in the carbon burial rate over a period of time. There would be a decrease in atmospheric and dissolved O_2 and a corresponding decrease in the rate of decay of organic material and, hence, an increase in carbon burial. The self-correcting feedback built into this cycle makes atmospheric O_2 always want to return to its original level.

Although Saturn's large moon Titan is rich in the organic compounds that make up life, there is no evidence that anything living has been processing its atmosphere, as life does on Earth. *Image: JPL/NASA*

Where's the Fire?

One problem with the oxygen-control model described here is that it might leave terrestrial ecosystems very susceptible to fire. A number of years ago Lovelock and his student Andrew Watson pointed out that forests would burn much more readily if the atmosphere contained more oxygen. The exact point at which forest fires would become rampant is uncertain, but Watson's laboratory experiments (in which he ignited wet matches) indicate that the critical O_2 level may be only 20 to 30 percent higher than today's value.

Looking back in the history of Earth and its atmosphere, we are faced with this problem: If the controls on atmospheric O_2 are strictly marine, as the above theory suggests, what has prevented O_2 levels from having occasionally climbed well above the flammability limit? Shouldn't the world's forests have all burned down from time to time, and wouldn't this be apparent in the geologic record? It isn't (except possibly during one brief interval some 65 million years ago, when the asteroid or comet that is thought to have killed off the dinosaurs may have touched off a global conflagration).

The answer may lie in the fact that not all of the organic carbon that gets buried in the oceans is produced locally. A significant quantity of organic matter is produced on land and carried by streams and rivers to be deposited in near-shore sediments. Marshlands, too, bury some organic carbon. Forests may therefore play a role in a second negative feedback loop that keeps O_2 below the critical level at which they would burn down. A colleague of mine at Penn State, Lee Kump, has proposed a rather complicated mechanism involving phosphorus transfer from the land to the ocean that might produce such a feedback. Further research will tell the full story. From the standpoint of our discussion, it doesn't matter whether such a linkage exists; atmospheric O_2 is clearly under biological control, regardless of which particular ecosystem is controlling it.

Sampling Air on Other Worlds

The mainly semantic question of whether Earth is alive bears on a more interesting question: Are there planets besides Earth that harbor life? According to Richard Terrile of the Jet Propulsion Laboratory, a specially designed 10- to 15-meter diameter telescope in space ought to be able to resolve an Earth-size planet, if one exists, around a number of nearby stars. It could also be used to examine spectroscopically the composition of that planet's atmosphere.

Suppose we found a planet with a predominantly nitrogen/oxygen atmosphere like our own. Knowing what we do about how such an atmospheric balance is maintained, we would have a pretty good indication that the planet was inhabited.

In practice, detecting nitrogen would be difficult since it lacks absorption lines in the visible and infrared. However, suppose we found an abundance of molecular oxygen along with a significant concentration of some highly reduced gas like methane. Lovelock suggested years ago that this particular disequilibrium combination of gases could be used to test for the presence of life on Mars. Methane and oxygen react readily with each other in the presence of ultraviolet radiation; hence, their coexistence requires that both gases have a continuous source. The only source that could plausibly generate both gases simultaneously is a biological one.

Building a 10-meter space telescope today would be impractical, or at least very expensive, but I see no reason why we shouldn't be able to do so eventually. Thus, we may someday be able to determine whether life exists elsewhere by searching for its characteristic signature in the atmospheres of planets around other stars. In the meantime, by studying the interaction of the biota with our own atmosphere, we can learn more about how our planetary ecosystem operates.

James F. Kasting is Associate Professor of Geosciences at The Pennsylvania State University.

SOCIETY Notes

RE-NAME THAT MISSION

The Comet Rendezvous Asteroid Flyby (CRAF) mission is sorely in need of a new name. Why should CRAF suffer with numb nomenclature while its companion mission, *Cassini,* is so well named?

Another mission that could use a new moniker is the Soviets' innovative but unimaginatively named *Mars '94.*

Send us your suggestions, and we'll forward the ten best to NASA and Glavkosmos. First prize, for each mission, will be $50 in merchandise (your choice) from our sales department. Second through fifth prizes will be $25 in merchandise.

Entries must be submitted by March 31 on a postcard, one mission per postcard. Send as many entries as you like; include your member number and return address. *—Louis D. Friedman, Executive Director*

EXTRASOLAR PLANET SEARCH

The Society is supporting a productive search for planets beyond the solar system. Bruce Campbell and others at the University of Victoria have been observing stars for the subtle counter-orbit that might indicate a planetary companion. (See May/June 1988 *Planetary Report.*)

Of 18 stars under study, 9 have exhibited variations in velocity that could be due to planets with one to ten times the mass of Jupiter. *—LDF*

META II ASSEMBLED

Preparations to expand SETI to the Southern Hemisphere have reached a milestone with final soldering of memory boards for the second Megachannel Extraterrestrial Assay supercomputer (META II). Juan Carlos Olalde and Eduardo Hurrel have been working at Harvard, MA, with Paul Horowitz, designer and director of META I, which has been operating since 1985 with Society support as the world's most powerful SETI signal analyzer.

Olalde and Hurrel will return to Argentina to hook up META II to the antennas of the Argentine Institute of Radioastronomy. SETI research, backed by substantial grants from the Society, will proceed under the direction of Raul Colomb. *—Adriana Ocampo, Senior Consultant*

1990 SCHOLARSHIP COMPETITIONS BEGIN

The Planetary Society underwrites scholarship competitions to encourage high school and college students planning careers in or related to planetary science. You may qualify, or know someone who qualifies, for these awards.

New Millennium Committee High School Scholarships To be eligible, a student must be in the final year of secondary school and a member of the Society, or the nominee of a member. The amount of each award (up to $2,000) depends on the applicant's qualifications, which are evaluated on the basis of scholastic achievement, SAT or ACT scores, letters of recommendation, accomplishments and a typewritten 500-word essay on an assigned topic. Write to the Society for this year's topic.

National Merit Scholarship The Society sponsors a four-year college scholarship through the National Merit Scholarship program for an outstanding high school student planning to major in a subject related to planetary science. The National Merit Scholarship Corporation administers this scholarship; inquire at your school for details.

Mars Institute Contest High school and college students are eligible for the $1,000 prize plus an all-expense-paid trip to a major Mars conference. Write an essay in the form of a detailed proposal, typically 10 to 15 typewritten pages. Write to the Society for this year's topic.

College Fellowship Awards Undergraduates majoring in science or engineering who are Society members or nominees of Society members may apply for one of five $1,000 grants. The fellowships will be awarded on the basis of scholastic achievement and a typed 2,500-word essay on a relevant topic of your choice.

ALL SCHOLARSHIP ENTRIES MUST BE RECEIVED BY APRIL 16, 1990. FOR APPLICATION FORMS AND INFORMATION, WRITE TO THE SOCIETY, ATTN: SCHOLARSHIP DEPT.

Dudley Wright International Student Contest This project design competition for high school students will open in July 1990. Write to the Society for details.

SISTER WORLDS

The greenhouse effect and ozone depletion are making headlines, yet few people know how planetary science alerted us to these dangers. A free information packet, available this spring, launches a new Society program, "Sister Worlds: Earth and Venus." Write to Sister Worlds, c/o the Society. (Teachers, request the educator's packet.)
—Susan Lendroth, Manager of Events/Communications

BIOSPHERE II SEMINAR

For details on a Society-sponsored Biosphere II seminar in Arizona, March 24, write to Biosphere II , c/o the Society. *—SL*

GET YOUR TPR INDEX

The new index of *The Planetary Report,* from the first issue up to Nov/Dec 1989, is a handy guide for research or ordering back issues. Send $3.00 to TPR Index, c/o the Society.
—Karl Stull, Copy Editor

KEEP IN TOUCH

Our mailing address:
The Planetary Society
65 N. Catalina Avenue
Pasadena, CA 91106

General calls:
(818) 793-5100

Sales calls ONLY:
(818) 793-1675

News & Reviews

by Clark R. Chapman

One of the more interesting magazines about science is *Nature*. Subtitled "International Weekly Journal of Science," it is the British equivalent of *Science* magazine. Like its American counterpart, *Nature* publishes short technical reports on a wide variety of scientific topics, emphasizing the biological sciences. And it prints letters, book reviews and analyses of political events in the world of science.

Yet it goes beyond *Science* in its commentaries, which are generally written at a level accessible to nontechnical readers. Within the journal's covers are article summaries and perspectives by thoughtful scientists and nonscientists on current controversies. The far-ranging, combative flavor of *Nature* is refreshing, though at times it may cross boundaries of prudence and objectivity.

Since *Nature* is often available in city and college libraries, *Planetary Report* readers might want to delve into it from time to time, even though many of the articles are technical and most have nothing to do with the cosmos.

Phobos *Reports*

The cover of the October 9 issue bears a full-color Soviet *Phobos* mission picture of the dark, pockmarked moon Phobos silhouetted against the orange plains of Mars. Within the issue are the first official reports of scientific results from the *Phobos* mission. Although the *Phobos 1* spacecraft failed en route to Mars and *Phobos 2* failed just before lowering itself to hover close to the surface of the martian moon, nevertheless a lot of data was returned concerning the magnetic field and surface of Mars, in addition to useful observations of Phobos. Some of the Soviet instruments were unlike any flown to Mars before, so there is a wealth of information to study.

Nature's 38 pages of detailed Soviet reports about *Phobos 2* are a bit disappointing. Mainly they describe how the spacecraft and instruments worked and what kinds of data were taken. There is not very much about the actual data, and there is still less in the way of interpretation. However, two commentaries in this issue by scientists Mark Saunders and William McKinnon offer discussions of interest, for lay readers as well as specialists, on hints of a martian magnetic field and its interactions with the solar wind and on the new data on the density and mineralogy of Phobos. Evidently Phobos is even less dense than we had thought, which implies that part of its interior may consist of ice or even hollow spaces.

Journey into Space

In the October 26 issue of *Nature* there is a review, by *New York Times* science writer John Noble Wilford, of Bruce Murray's new book *Journey into Space: The First Thirty Years of Space Exploration*. Murray's brisk style propels the reader through the exhilarating, then depressing, days that have marked the rise and fall of planetary exploration.

Murray's recommendations should come as no surprise to Planetary Society members familiar with the Society Vice President's role in promoting an international push to explore Mars, which may or may not be implemented through President Bush's space initiative. Wilford's book review provides a nice synopsis of the history of the US planetary exploration program.

Meteorite Mystery

The October 26 issue also summarizes a meeting held last summer in Vienna about reported differences between the meteorites being collected in Antarctica and meteorites collected elsewhere around the world. Some scientists believe that the differences reflect changes over tens of thousands of years in what kinds of stones are raining down on Earth; that time scale conflicts with the prevailing view that such changes need millions of years to occur. Other scientists point to various processes that bias the Antarctic sample; for instance, many of the smaller stones may be broken up pieces of the same meteorite rather than separate falls. *Nature*'s report presents a balanced perspective on the controversy.

Early Earth Impacts

The November 9 issue contains a lengthy article (four pages is lengthy for *Nature*) by four American scientists, led by Norman Sleep, who have proposed that giant asteroid impacts with Earth were a prohibitive obstacle to the early beginnings of life on our planet. Not until the heavy bombardment had ended, half a billion years after our planet's birth, were the numbers of large asteroids in the inner solar system depleted to the point that life could really get under way.

Although not entirely new, this idea was widely reported in the press when it appeared in *Nature*. The article gives initial, if somewhat simplistic, calculations of how the early ocean might have been boiled away by some of the early impacts. If you missed the news reports or want more "meat," you might try plowing through the original article. A commentary by Caltech's Tom Ahrens elsewhere in the issue addresses how Earth first acquired its ocean and water budget. Both of these *Nature* articles are but harbingers of a deepening interest in the role of impacts in the development of the early Earth.

(See also Christopher Chyba's "Seeding Earth: Comets, Oceans and Life" in this issue of *The Planetary Report*, page 20.)

Clark R. Chapman, coauthor with David Morrison of Cosmic Catastrophes, *is working on a new book about* Voyager 2*'s historic encounter with Neptune.*

World Watch

by Louis D. Friedman

WASHINGTON, DC—The NASA report on options and requirements for the presidential Moon-Mars initiative (now officially known as the Human Exploration Initiative) is under review by the National Space Council, headed by Vice President Dan Quayle.

The study, led by Johnson Space Center Director Aaron Cohen, outlines five options, each with its own timescale, for piloted missions to the Moon and Mars. The options were all based on space station deployment in 1999 and an approximately 30 year program of robotic and piloted missions. Such missions would require new developments in NASA's plans for the early 1990s, in technology areas such as launch vehicles, closed-loop life support and radiation protection, and in redesign of the space station to emphasize testing for long-duration human spaceflight.

The space station changes are controversial since they affect international partners in the project. Europe and Japan became involved in the US space station on the basis of hypothetical commercial benefits from microgravity research and materials processing (this approach is not well supported in the scientific community or among advocates of planetary exploration). The pressures on NASA are enormous because of budgetary restraints, international commitments and disparate congressional interests and also because of those of us advancing the Human Exploration Initiative as an international space goal.

In addition to the NASA study, the National Space Council has prepared three other Human Exploration Initiative studies, on international options, on overall rationale and on institutional/organizational considerations.

The NASA study was criticized by a Space Council review panel (which included two Planetary Society directors: Carl Sagan and Thomas O. Paine) for what was described as an unimaginative "business as usual" approach. Conversely, a highly innovative study by the Lawrence Livermore Laboratory, proposing that humans could be on Mars by 2001 at a cost under $15 billion, was characterized by some members of the panel as "brilliant but glib."

NASA officials responded that they had not been given any direction and thus had prepared a technical evaluation, rather than a broader study, to establish mission feasibility. The review panel recommended that the Space Council ask NASA to do the broader study. This request has now been made.

NOORDWIJK, THE NETHERLANDS—The Mars Exploration Study Team (MEST) of the European Space Agency (ESA) has outlined three major prospects for European involvement in international missions to Mars. The criteria guiding the MEST study were: scientific return, available technology and compatibility with American and Soviet mission planning.

Leading the MEST list is a network of small surface stations (including two penetrators and three semi-hard-landing probes) to perform seismological and compositional studies. Another possibility is a robot arm (to be put aboard a rover from another space agency) capable of stereovision and analyzing samples. In addition to these surface exploration options, MEST recommends a microwave radar aboard an orbiter for altimetry, subsurface sounding, radar imaging and atmospheric studies.

Publication of a glossy 140-page report on the MEST study, with Agustin Chicarro of ESA's Planetary and Space Science Division as principal author, reflects a strong European interest in defining a full partnership role for ESA in the solar-system exploration of the 1990s and beyond.

MOSCOW—In November the US/USSR planetary exploration working group held its annual meeting, as provided in a 1987 agreement between the two nations for cooperation in planetary exploration (emphasizing Mars), astronomy and astrophysics, and life sciences.

Not much happened at this year's meeting, except for some minor additions to US participation in experiments aboard the Soviet *Mars '94* mission, and ratification of a previous plan to transfer an infrared mapping experiment from *Mars Observer* to *Mars '94*. There were no new joint mission plans on the table, and, for the foreseeable future, the prohibition on studies for joint Mars missions remains in effect. Under a 1988 protocol to the basic agreement, the US and USSR may separately study Mars surface exploration missions and then compare findings at the annual meeting.

A lunar orbiter study was approved.

WASHINGTON, DC—NASA's project for SETI (Search for Extraterrestrial Intelligence) has won congressional approval. The exact amount of funding will depend on the Gramm-Rudman balanced-budget process: NASA requested $6.8 million; the allocation will likely not go below $4 million.

An easy target for congressional cost-cutters in the past, NASA SETI came very close to being sacrificed again. Last minute efforts to bring it back from the brink included a letter of appeal from Society President Carl Sagan to each member of the House-Senate Conference Committee.

The Microwave Observing Project, or MOP as it is known in NASA, can become operational as scheduled in 1992 if congressional funding continues, according to John Billingham, Chief of the SETI Office.

NOORDWIJK, THE NETHERLANDS—The *Giotto* spacecraft, launched in August 1985 to encounter Halley's Comet, will come close to Earth in mid-1990. If attempts in February to re-activate the probe are successful, ESA will fund a *Giotto* Extended Mission, sending the veteran craft on to an encounter with comet Grigg-Skjellerup in mid-1992.

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

Questions & Answers

A planet with two suns (in this case, red and yellow stars) might experience a double sunset like this.

Painting: William K. Hartmann

In a binary star system that has planets, would the planets revolve around both stars or would they move somehow between the two stars? Is it possible in the latter system to have around the clock sunlight?
—Kevin DeWitt, Odessa, Texas

It turns out that planets could maintain stable orbits over fairly extensive regions within binary systems, a fact that was not obvious until the advent of modern high-speed computers. The motion of a planet around a single star is easy to calculate, as Kepler demonstrated centuries ago. However, there are no simple equations to precisely describe the orbit of a planet in a binary system. Astronomers must turn to numerical techniques in such cases, which means that they must simulate the motions in a computer. In effect, they follow all of the bodies around in their orbits and calculate the motions and forces after each of many tiny steps. Such calculations show that planets can remain in stable orbits of two general varieties depending on the type of binary star.

If the binary is a close pair, then a planet could revolve around both stars at once in a relatively large orbit. The two stars will behave essentially like one large object, as far as the pull on the planet is concerned. However, the appearance of this "double sun" in the daytime sky would still be spectacular to our eyes.

On the other hand, if the binary is a wide pair, then a planet could revolve around one of the stars in a comparatively small orbit. But in this case the planet would revolve around its parent star much faster than the two stars would orbit each other, just as the inner planets of the solar system orbit the Sun more rapidly than the outer planets. So for part of this hypothetical planet's "year" its orbit would be close to a line between the two stars. (Here we must assume that the planet and distant star have orbits in the same plane). At these times from the surface of the planet one of the two stars would be up in the sky virtually all of the time and there would be around the clock sunlight.

The astute reader will recognize that we have so far avoided the very important question of whether planets could actually form in binary star systems. This is a question to which no one yet knows the answer; perhaps in the "mixmaster" of a nascent binary system planets cannot form at all. And we should not forget that we do not know for sure if planetary systems are common even for single stars. There is not yet even one generally accepted case of a planet known to orbit any star besides the Sun.

—BRUCE CAMPBELL, *University of Victoria*

During the* Apollo 11 *mission to the Moon, astronauts Buzz Aldrin and Neil Armstrong reported seeing little flashes of light both en route to the Moon and back. These were later called "flicker-flashes" and were believed to penetrate the spacecraft and

the astronauts' bodies, endangering their heatlh.

What has been learned about these flashes since then and what effects will they have on future long-duration spaceflights?
—John F. Godl, Sydney, Australia

The "flicker-flashes" are a real phenomenon known as Çerenkov radiation. When a particle is traveling at nearly the speed of light in vacuum and it enters a transparent medium (such as a crystal, a pool of water or the fluid in your eye) in which light travels more slowly than it does in vacuum, a "light cone" is produced, somewhat like the conical shock wave produced by a supersonic projectile in air. While the light flashes themselves are not harmful, the tissue ionization caused by the intruding particle near the end of its track is indeed deadly to some affected cells.

Future space dwellers will have to be shielded to keep these ionizing dose rates down to safe levels; what is meant here by "safe" is a complicated question. While authorities differ as to cosmic ray exposure limits under quiet Sun conditions, all agree that humans in space must seek heavily shielded shelter during large solar flares.
—JAMES D. BURKE, *Jet Propulsion Laboratory*

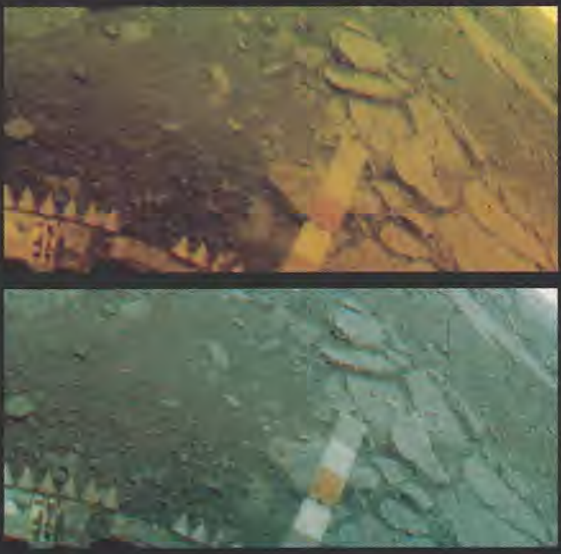
Everyone knows that Mars is red, but what color is the surface of Venus?
—Alexandra Lieben-Dougherty, Los Angeles, California

From Earth, Venus is a pearl glimmering in the morning and evening skies because we see only the permanent layer of thick clouds that hides the surface from our view. The answer to your question about the surface depends on what you mean by color, whether it is a property of a surface, or a sensory perception you would have if you were looking at it.

Soviet and American scientists have analyzed spectral information at visible wavelengths from Soviet *Venera* landers partly in an effort to see if the surface of Venus is an oxidized (rusted) red like the surface of Mars which we *can* see from Earth. They find that at least at the handful of sites for which we have any information, the surface is a uniform dark gray. That is, it reflects short wavelength (blue) light about as strongly as it reflects longer wavelength (red) light.

However, the light at the surface of Venus has a strong red tint to it. This is caused by the same phenomenon, known as Rayleigh scattering, that gives our sky here on Earth the blue we know and love. Atmospheric molecules scatter blue light much more strongly than red light, so on Earth the light that gets scattered out of the incoming beam of sunlight and lights up the sky is tinted blue.

On Venus, however, any light that makes it to the surface has come through the planetwide cloud cover and an atmosphere 90 times as thick as Earth's. Thus Rayleigh scattering effectively removes all the blue light, creating a planetwide red light district. So if you were standing on the surface of Venus in a protective suit that kept you from the noxious atmosphere, crushing pressure and searing heat, the surface would look red.
—DAVID GRINSPOON, *NASA Ames Research Center*



The upper panel of this Venera 13 color panorama of Venus shows how the planet's surface would look to us at visible wavelengths. In the lower image, the same panorama data was reprocessed to reveal how Venus' surface would appear in white light illumination, that is, without the interference of an atmosphere.

Image: Stephen F. Pratt, Brown University

FACTINOS

Water vapor from the oceans can amplify the global warming being caused primarily by human-generated carbon dioxide. Using temperature and radiation measurements from satellites, buoys and ships, University of Chicago geophysicists have confirmed computer models indicating that as more water vapor accumulates, more energy is trapped on Earth.

The trapping increases at a much higher rate than predicted in areas where ocean temperatures exceed a threshold of about 82 degrees Fahrenheit. Only 5 percent of the world's oceans are that warm, but if global warming continues as predicted, three times as much of the world's oceans would exceed the threshold temperature in 50 years, raising the possibility of a supergreenhouse in those areas.

Veorabhadran Ramanathan, whose study represents the most extensive testing yet of computer models, calls water vapor "the most powerful greenhouse gas."
—from the *Los Angeles Times*

Lightning is as common on Venus as it is on Earth, according to new analyses of data from the *Pioneer* Venus orbiter. Although *Pioneer* was not equipped to detect lightning, its Very Low Frequency receiver has picked up broadband radio emissions, "bursts of noise covering a wide range of frequencies." Christopher Russell of UCLA explains, "It is as if you are driving in the Midwest and you hear loud static on your car radio. Even if you could not see a thunderstorm or clouds, you could infer the storm from the radio interference."

It appears that "all planets with significant cloud cover have lightning activity," Russell adds. The only planet that clearly does not have lightning is Mercury.
—from the University of California, Los Angeles

A natural process may work to remove chlorofluorocarbons (CFCs) from the atmosphere, if preliminary indications from a study in the remote Boola Boola Forest of Australia prove correct. Researchers from the Oregon Graduate Center's Institute of Atmospheric Sciences, while measuring emissions from termite mounds, noticed that CFC levels were significantly lower inside the mounds.

Oregon researcher M. Aslam Khalil speculates that something in the 10-inch layer of soil is removing CFCs from the air as it filters through to fill the mounds. Such a process, if it can be identified, might be used in efforts against depletion of the ozone layer by industrial use of CFCs.
—from the *Los Angeles Times*

Seeding Earth *continued from page 23*

Both before and after cometary formation, the icy grains that make up comets are subjected to many kinds of radiation. Experimenters in North America and Europe have irradiated likely recipes of cometary ices in the laboratory, and the result is inevitably the formation of organic molecules. Recent work I have done in collaboration with Carl Sagan of Cornell University shows that certain spectral features observed in comet Halley, as well as in the lesser-known comets Wilson and Bradfield, are probably due to such irradiation-derived organics.

Cometary collisions with Earth would necessarily contribute some of these organics to Earth's prebiotic inventory. However, we don't know what fraction of cometary organics would survive the high temperatures and pressures associated with the resulting explosion and crater excavation. Cometary water ice would evaporate, enter the atmosphere as steam and eventually rain out, but the cometary organics might well be destroyed. The fact that some meteorite fragments contain intact organic molecules proves that some organics can survive such collisions. Many scientists are working to determine quantitatively the survival of comet-delivered organics under plausible early-Earth conditions.

Cometary Devastation

The intense bombardment of early Earth may have resulted in an "impact frustration" of the origins of life. Large impacts would have been catastrophic for local environments, and the extreme temperatures generated by the violent collisions may have effectively sterilized vast expanses. Moreover, the huge explosions would have vaulted enormous quantities of dust into the atmosphere. There may even have been enough debris to envelop Earth in a dust cloud, blocking sunlight and creating conditions like those envisioned in the "nuclear winter" hypothesis proposed by David Grinspoon and Carl Sagan. Such an era of inhospitable conditions would mean that the time available on the early Earth for the origin of life was even shorter than previously believed.

If the terrestrial evolution of life did occur very rapidly, then the possibility increases that life may have arisen on Mars during its apparently brief, comparatively Earthlike youth. Indeed, one of the objectives of Soviet and US missions to Mars in the next decade is to look for fossil evidence of extinct martian microorganisms. The new field of "exopaleontology" will begin in the 1990s.

The oceans have long inspired feelings of wonder. It is as though an inchoate understanding of our origins visited our minds even before the theory of evolution taught us that our beginnings lay in the sea. A special tinge of awe comes with the thought that oceans—this most terrestrial image, the cradle of life—may in fact have had an extraterrestrial origin. In this realization, scientific and aesthetic appreciation join in a single moment. Many more such moments await our continued exploration of space.

Christopher Chyba studied theoretical physics and the history and philosophy of science at the University of Cambridge; he is now a graduate student in space sciences at Cornell.

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