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Journeying to the Moon

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COVER: Remote sensing is possibly the most powerful scientific tool to mature during the Space Age. These false-color images of the Moon were compiled from data returned by Galileo during its 1990 Earth–Moon encounter and later superimposed over an airbrushed map. The ways surface materials, such as soils, reflect light can tell us about their composition. Here the different colors indicate different reflectivities and composition. For example, green and yellow indicate iron- and magnesium-rich minerals. ***Image: United States Geological Survey***

FROM THE EDITOR

The political and economic state of the world is in flux, making the future of planetary exploration uncertain. Still, the discoveries go on, as you'll read in this issue.

Page 3—Members' Dialogue—Clark Chapman's recent critique of exaggerated planetary images released by NASA hit home with a lot of our members, and many wrote to support his views. (One member, David Morrison, in a letter published in the American Geophysical Union's *Eos*, has even called for the creation of a "Flat Venus Society.")

Page 4—Titan's Greenhouse and Antigreenhouse Effects—A decade after it flew by Titan, *Voyager 1* still has something to teach us about this intriguing moon of Saturn's. Using *Voyager* data and computer models, a team of researchers has discovered an antigreenhouse effect operating in its atmosphere.

Page 8—Through the Fuzzy Boundary: A New Route to the Moon—"Innovation" is a word so casually used in the modern world that its meaning has been diluted. Really new concepts can be lost in a blizzard of buzzwords and half-baked ideas. One recent innovation in celestial mechanics, however, represents a true advance in space travel. The discoverer of fuzzy boundaries describes how this concept could make spacecraft missions more affordable.

Page 11—Keeping an Eye on Earth: Remote Sensing in Russia—The same technology that ushered in the Space Age and enabled spacecraft to explore the planets is also being used to study our home world. The former Soviet Union was a leader in remote sensing of Earth, and we report here on its satellite capabilities.

Page 16—Society Notes—The latest Society activities are detailed for you here.

Page 17—World Watch—Planetary exploration by the United States is seriously threatened: The *Cassini* mission to Saturn may be canceled by Congress. But France reaffirms its commitment to help the Russian Mars missions, and former President Reagan calls for the international exploration of space.

Page 18—News & Reviews—Triton, Neptune's largest satellite, is the topic of our faithful columnist.

Page 20—Questions & Answers—What would happen if a planet blew up? Could an asteroid be used as a spacecraft? What three planets rotate backwards? Read this column to find the answers.

—*Charlene M. Anderson*

SPECIAL ANNOUNCEMENT: *Cassini* Crisis Updates

As we go to press, the future of *Cassini*, the NASA/European Space Agency mission to investigate Saturn and its large moon, Titan, is in doubt. There is a possibility that the US Congress will cancel it, and so end the development of scientifically ambitious and mid-sized robotic missions for the foreseeable future.

The Planetary Society has taken a stand for *Cassini*, and, through the grassroots campaign of our members and the congressional testimony of our officers, we are trying to help save the mission.

As a bimonthly publication, it's impossible for *The Planetary Report* to keep you up to date on a political situation that can change day by day. To remedy this, the Society is instituting a new service for the duration of this crisis:

You can receive updates on the status of *Cassini* by calling our events calendar telephone line: (818) 793-4294.

As with anything involving a government program, things may change hourly or remain stable for weeks. We will update the recorded message as we receive news of developments.

We hope you will let your representatives and senators know that you support *Cassini*. If we lose this mission, the US planetary program may wither away.

Members' Dialogue

As administrators 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 our Society. We encourage members to write us and create a dialogue on topics such as a space station, a lunar outpost, the exploration of Mars and the search for extraterrestrial life.

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

Three cheers for Clark Chapman's critique of the false colors used in just about all publicly released NASA planet photos! [See the January/February 1992 issue of *The Planetary Report*.] It's about time someone pointed out that Io is not the same colors as a pizza with double cheese and pepperoni, that the distorted surface of Venus isn't Day-Glo orange and that even the Mars we've come to know and love is not a brilliant crimson and peach. Aside from a past issue of *Sky & Telescope* that had an article showing the "true" colors of the planets, I have seen no other refutations in the news media about all the fake colors that are passing for reality.

Would it be possible in some future issue of *The Planetary Report* to show us what all the planets (and at least some of the moons) in our solar system *really* look like, shorn of false ultraviolet purples (à la Venus and Saturn) and computer enhancement? Is Neptune as blue as *Newsweek* crowed in its 1989 cover story on *Voyager 2* and "The Blue Planet"? And what color *is* Mars, anyway?

—JOHN ROUNDS, *Hoboken, New Jersey*

In his News & Reviews column in the January/February 1992 *Planetary Report*, Clark R. Chapman is right on the mark in pointing out that the common use of exaggerated and false color in space probe images of other worlds, while useful for specific technical purposes, in the absence of proper labeling often misleads the public. It has sometimes even colored the impressions of scientists themselves as to how these worlds really look to the human eye. In his reference to "Saturn's nearly colorless rings," however, he is well off the mark.

In 1944 I was privileged to view Saturn through the 36-inch refractor at Lick Observatory. The image of Saturn I saw then, with its rings tilted at a good angle from Earth and extending across the entire field of view, has never left me. Especially awe-inspiring was the softly glowing deep violet of the inner, dark C-ring, contrasting dramatically with the brilliant yellow of the adjacent B-ring region and the duskier, orangy outer A-ring. To me the C-ring, sometimes called the crepe ring, was the crowning glory of the entire ring system. Yet no telescopic photos and no *Voyager* images I have seen (except, naturally, the false-color images) show the crepe ring as anything other than a dark gray color.

Some may suggest that the intensity of color I describe is a result of memory enhancement, but it was so vivid that I think no such enhancement is possible. It was very much like the deeply glowing violet seen at the shortwave end of a solar spectrum thrown by a prism against the white wall of a darkened room. It is conceivable too that the yellows and oranges might have been enhanced somewhat by Earth's atmosphere, but as noted in Chapman's article, our ground-based view of the Moon when high in the sky shows little discernible difference from the hue our astronauts have seen from space or on the Moon itself. I believe that truly deep colors like the C-ring's violet would be even less altered in viewing through Earth's atmosphere.

While there are certainly many examples of unlabeled color exaggeration and the use of false colors in the published images we have been treated to, in at least some cases there is a problem in the other direction, in which vividness of color in space objects has been grossly understated or even entirely uncaptured.

—LEE G. MADLAND, *Ridgecrest, California*

I wish to express my appreciation to the Society for the diversity of relevant information provided through *The Planetary Report*, while maintaining the integrity of basic goals. This publication is the only one that I study from cover to cover upon receipt and then wish there were more.

After noting the various references in the November/December 1991 issue to the potential availability of the "Soviet" space program equipment, I wondered if there might not be an opportunity to try a different approach. Let us consider the possibility of having the United

(continued on page 19)

NEWS BRIEFS

Michael Griffin, NASA's associate administrator for exploration, told Congress recently that the space agency could send humans back to the Moon and on to Mars for about one-fifth of the huge cost it estimated less than three years ago.

During testimony before the House Science, Space and Technology space subcommittee, the top exploration official rejected the old $500 billion price tag for the 30-year project that came out of a 1989 NASA study, and agreed to place the effort under tight funding caps.

NASA can do the projects for "on the order of $100 billion," but detailed numbers will not be ready for at least two years, Griffin said. The hearing marked the start of a contentious battle in Congress over boosting space agency funding for lunar and Mars missions.

—from *Space News*

In February, after hearing of new evidence that Earth's ozone layer may be weakening over parts of the United States, President Bush directed American manufacturers to stop virtually all production of ozone-destroying chemicals by the end of 1995, rather than by 2000.

—from Keith Schneider in *The New York Times*

James G. Anderson, Harvard chemistry professor and mission scientist for NASA's Airborne Arctic Stratospheric Experiment-2, an aerial assault on the ozone problem, says that the greatest restraint on science in studying ozone loss "is the inability to get deep into the higher altitudes of the atmosphere where the chemistry is happening, particularly over polar regions."

This zone, too high for most aircraft to reach and too low for thorough satellite observations from space, is prompting the development of a new class of robot airplanes to monitor ozone depletion and global warming.

Now six companies are proposing aircraft designed to work at

(continued on page 19)

Titan's Greenhouse and Antigreenhouse Effects

by Christopher P. McKay, James B. Pollack and Régis Courtin

Those of us engaged in comparative planetary science have traditionally focused on the three "terrestrial" planets: Venus, Earth and Mars. The outer solar system, dominated as it is by the giant planets, Jupiter, Saturn, Uranus and Neptune, seemed to hold nothing Earth-like at all.

But when *Voyager 1* flew by Titan, the largest natural satellite of the planet Saturn, more than a decade ago, we learned a lot about this distant world. We discovered this moon to be, in some unexpected ways, similar to Earth.

Titan is the only known moon in the solar system that has a significant atmosphere, as Earth has. We have been studying this atmosphere, using a computer program that can simulate it. Because we wanted to know what the temperature of Titan would be under conditions different from those of today, we began to perform a series of "what-if" experiments. It is one of the joys of computer modeling that such "experiments" can be carried out on an entire planet. A vexation is that sometimes the results can be surprising—just as they can be in regular experiments.

In our results, we found that under some conditions—pressures about half the present value—Titan was surprisingly cold. Colder, in fact, than it would be without any atmosphere at all. To understand this we had to delve deeply into the greenhouse effect. As we did, we discovered that Titan had an antigreenhouse effect as well.

We knew about Titan's atmosphere from early ground-based spectrographic studies, which detected methane (CH_4), a molecule that may have played a crucial role in the origin of life on Earth. From *Voyager,* we got a detailed look. We learned that Titan's atmosphere, like Earth's, is predominantly nitrogen (N_2). No other known objects in the solar system have such an atmosphere.

Moreover, Titan's surface pressure is only 50 percent greater than that of Earth. By contrast, our nearest celestial neighbors, Venus and Mars, have atmospheric pressures that are about a hundred times higher and a hundred times lower, respectively, than Earth's. It would be much easier to pressurize a space suit for an explorer on Titan than to outfit a human to survive on Venus or Mars.

The second most abundant gas on Titan is methane, and here the similarity with the present-day Earth breaks down. The nitrogen and methane in Titan's atmosphere react under the influence of sunlight and high-energy particles to form hydrogen (H_2), which escapes to space, and complex organic molecules. This process leads ultimately to solid organic material that forms a high-altitude haze layer. Like the smog that obscures the Los Angeles skyline on a hot

On November 12, 1980, Voyager 1 *flew close by Titan and from a range of 22,000 kilometers (13,700 miles) took this image of the organic haze layer surrounding the moon. The colors in this image are false and are used to show details that are not readily apparent in true colors.*

Image: JPL/NASA

summer day, this haze layer effectively hides Titan's surface. Since we can't see that surface, we can only speculate as to its nature.

This satellite's surface is intensely cold—minus 178 degrees Celsius (minus 288 degrees Fahrenheit), compared to the more salubrious 15 degrees Celsius (59 degrees Fahrenheit) average for Earth. Because of this cold, methane and other light organic molecules (primarily ethane, C_2H_6), which would be gases on Earth, exist on Titan's surface as liquids. However, at these cold temperatures, water is as hard as rock—a serious problem for life (see box on page 6).

Over the more than 4.5 billion years since Titan formed, we would have expected that simple hydrocarbons like methane would be continuously recombining into heavier organic molecules, which would collect on the surface as solids and liquids; this process would deplete the atmosphere of methane. But some source is resupplying the atmospheric methane. A large reservoir—an ocean— of methane has been suggested as this source by Jonathan Lunine and his colleagues. If the methane is not abundant enough, there may not be an ocean but many lakes: Titan, land of 10,000 lakes.

Seen from 2.3 million kilometers (1.4 million miles) away, Titan looks like a fuzzy orange tennis ball. Its thick, mostly nitrogen atmosphere, tinted orange by organic compounds, completely obscures the surface. It looks to be a dull place. But if you look closely at this image, taken by Voyager 2 *in August 1981, you can see some faint atmospheric features. A band of dark clouds circles its north polar region. Near the equator is a band that divides the atmosphere into hemispheres; the southern hemisphere appears lighter than the northern one. Faintly visible near the limb (apparent edge) of the moon is a haze layer of organic particles—the source of the antigreenhouse effect on Titan.*

Image: JPL/NASA

Titan and the Prebiotic Earth

The production of organics on Titan—by processes that don't involve life-forms—naturally suggests a comparison to Earth before life began. The study of Titan may help us refine theories that life on Earth began with a similar production of organic molecules.

These theories are based on the classic Miller–Urey experiment in which gases such as methane (CH_4), water vapor (H_2O) and ammonia (NH_3) were sparked with simulated lightning, producing a variety of organic molecules—including many key biomolecules. Stanley Miller first performed these experiments in the early 1950s, while he was a graduate student at the University of Chicago with Harold C. Urey.

At the time Miller did his experiments it was thought that Earth's early atmosphere was rich in hydrogen (H_2) and its compounds, such as methane and ammonia, but very poor in the oxygen so necessary for present-day life. This atmosphere would have been similar to the one we find on Titan today. Over billions of years, some of these simple molecules would have slowly evolved into more complex molecules, including amino acids. At some point, these large chemical compounds formed self-replicating units, which we would classify as life.

However, recent evidence suggests that Earth's early atmosphere was instead rich in carbon dioxide (CO_2), water and nitrogen (N_2), and poor in methane and ammonia. In this sort of atmosphere, the chemical pathways leading to life would have been very different from those explored by Stanley Miller and his colleagues.

This new view of the early Earth suggests that the organic compounds necessary for life were not made on Earth but were imported by comets and meteorites. Investigations of comets have shown them to be rich in organic molecules, and researchers have even found amino acids within meteorites.

Scientists are still hotly disputing these two competing views of the evolution of life. At the 1991 meeting of the Division for Planetary Sciences of the American Astronomical Society, Stanley Miller and Chris Chyba, a young proponent of the new view, debated before a packed house of scientists. However this debate is resolved, Titan's chemistry may still provide clues to the origin of life.

Since Miller's initial work, researchers have repeated organic synthesis experiments many times, including simulations in which the gas has been a Titan-like mix: 90 percent nitrogen and 10 percent methane. The solid organic material produced in these simulations has properties very similar to the organic haze observed on Titan.

Titan's upper atmosphere may be a natural Miller–Urey experiment. Although there may be copious organic production on Titan, its great distance from the Sun means that water cannot exist as a liquid at the low temperatures on its surface. This lack of liquid water is a serious obstacle on the road to life and limits the analogy between prebiological Earth and present-day Titan. —*CPM*

In these oceans or lakes would also be the accumulation of billions of years worth of complex organics produced in the atmosphere. The major product, ethane, would mix with the methane, making a clear liquid. Most of the other organic products would sink to the ocean floor or collect on the continents.

Examining the Greenhouse Effect

Titan's thick atmosphere produces a strong greenhouse effect. The atmospheric greenhouse effect, long known on our own planet, was discovered on Venus in the early 1960s by Carl Sagan, and it was subsequently found to affect other planets in the solar system.

In a horticultural greenhouse, from which the planetary greenhouse derives its name, the panes of glass allow solar energy to enter but prevent hot air or infrared heat energy (emitted by objects when heated) from leaving. The glass barrier keeps the heated air inside from mixing with cooler air outside. This one-way energy flow heats the greenhouse, keeping the inside warmer than the outside.

In a planetary atmosphere, the greenhouse effect operates on the same basic principle. The greenhouse gases on Earth, Venus and Mars—water vapor (H_2O) and carbon dioxide (CO_2)—allow solar energy in ordinary visible light to reach the planet's surface, but they block some of the infrared heat energy radiated away by the surface. Titan's greenhouse gases—methane, nitrogen and hydrogen—do the same thing. The atmospheric gases then radiate some of this energy back to the surface, thereby warming it.

The magnitude of this greenhouse warming compared to the direct heat from the Sun is an indication of the strength of the greenhouse effect. By this measure Titan has the second strongest greenhouse effect in the solar system—after Venus, of course.

Of the main greenhouse gases on Titan, hydrogen plays a key role. Even though it is present in only small amounts, it absorbs radiation in parts of the spectrum that the more abundant gases methane and nitrogen do not.

Methane Rain

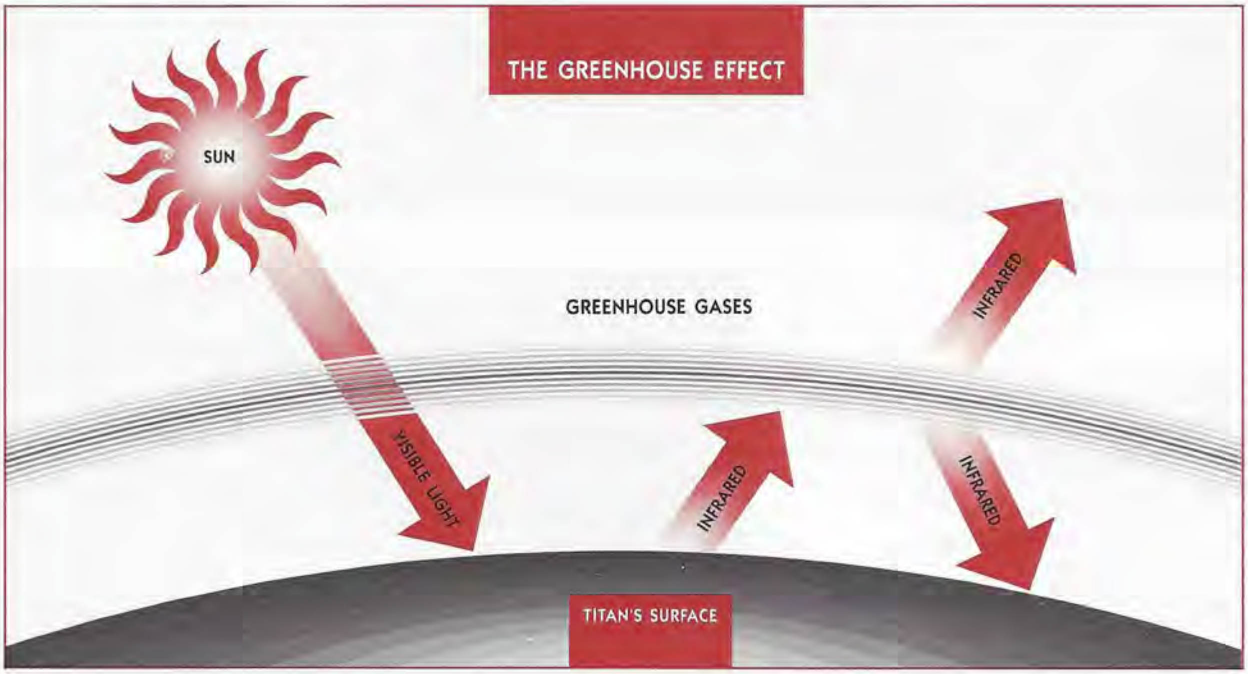
There are some interesting similarities between the roles played by the greenhouse gases methane and hydrogen on Titan and water vapor and carbon dioxide on Earth. As you know from reading the newspapers, it is the rise in carbon dioxide in Earth's atmosphere resulting from our industrialized life-style that has triggered the alarm about greenhouse warming.

Hydrogen on Titan and carbon dioxide on Earth are present in lower concentrations and play smaller roles in the greenhouse effect than do methane and water vapor. On Earth, the atmosphere can only hold a limited amount of water vapor; when the atmosphere becomes saturated, the water vapor condenses to a liquid and falls as rain. The same may happen to methane on Titan.

The amount of a gas like water vapor or methane that an atmosphere can hold is determined by its temperature. For example, on a hot summer's day Earth's atmosphere can hold much more water vapor than on a cold day, resulting in the high humidity that produces discomfort.

By contrast, the concentrations of hydrogen on Titan and carbon dioxide on Earth are not limited by saturation, so these gases will not rain out of an atmosphere. If their concentrations were to change, then the temperature of the surface would change. This temperature change would be amplified by corresponding, and much larger, changes in the concentrations of methane on Titan and water vapor on Earth.

Thus hydrogen on Titan, like carbon dioxide on Earth, plays a key role in climate evolution. Understanding the processes that control its concentration is critical to develop-



A planet's surface is warmed by energy that it receives from the Sun, which shines brightest in light from the portion of the electromagnetic spectrum visible to human eyes. The planet cools by emitting infrared radiation, which we could sense as warmth. A greenhouse effect arises when certain gases block the escape of the infrared radiation and radiate it back to the surface. This raises the surface temperature even more.

Illustration: R. G. Smith

ing our understanding of the history of Titan's atmosphere.

An Opposing Force

The picture on Titan is even more complicated. In addition to a greenhouse effect, it has an antigreenhouse effect. This effect was the key to explaining the surprisingly cold temperatures we encountered in our computer simulations. The upper atmospheric haze layer blocks incoming solar energy but allows the surface radiation to escape freely. Hence, we call this layer an antigreenhouse layer.

The organic substances that compose the haze are dark brown and orange and are very opaque to visible light, the region of the electromagnetic spectrum in which our Sun shines most brightly. But these same organic substances are virtually transparent to the infrared radiation that comes from the surface of Titan. It's like being in the shade with no clothes on. You are cooled (by convection and radiation), but you are not being warmed by the Sun. So, in opposition to the greenhouse effect, which warms a planet's surface, the antigreenhouse effect cools a planet's surface.

Once we realized the difference between the greenhouse and antigreenhouse in Titan's atmosphere, we used our computer simulations to investigate the relative roles of these two effects. We began by modeling the simplest case for Titan, as if it were a body with no atmosphere at all. In this case, sunlight would warm its surface to minus 191 degrees Celsius (minus 312 degrees Fahrenheit). This is called the effective temperature.

Carrying our calculations further, we saw that the greenhouse effect on today's Titan warms the surface above this effective temperature by 21 degrees Celsius (38 degrees Fahrenheit). But at the same time, the antigreenhouse effect cools the surface by 9 degrees Celsius (16 degrees Fahrenheit).

The net result, since the greenhouse effect is the stronger of the two, is that the surface is currently 12 degrees Celsius (22 degrees Fahrenheit) warmer than the effective temperature. If the antigreenhouse haze layer were somehow removed, then the surface temperature would be 23 degrees Celsius (41 degrees Fahrenheit) warmer than the effective temperature.

We also learned the reason for the cold temperatures in our simulations. If the pressure on Titan is reduced, the greenhouse effect is diminished, since it is mostly due to gases in the very lower parts of the atmosphere. The antigreenhouse haze, by contrast, is high in the atmosphere. If the pressure gets low enough, the greenhouse effect becomes small and the antigreenhouse effect dominates. Then, with only the antigreenhouse effect, Titan becomes cold.

Toward Understanding Earth

Expending all this effort to understand the behavior of gases surrounding a moon over a billion kilometers away may seem like debating how many scientists can dance on the head of a pin. But the behavior of similar gases on Earth may have determined if life could arise here. And the increase in greenhouse gases, triggered by one of the more highly evolved life-forms, may be changing the environment on our home world. In trying to understand greenhouse warming more fully, it helps to have examples from more than one planet. As we found out, the study of other worlds often holds surprises that can be lessons in how planets work.

The *Voyager 1* flyby of Titan allowed us to explore first the greenhouse effect induced by atmospheric gases other than carbon dioxide and water vapor, and now the antigreenhouse effect due to organic haze particles. We can carry our research only so far with the data we have available to us. To deepen our understanding of Titan, a world tantalizingly similar to our own, we need to go back.

NASA and the European Space Agency have plans for a mission to Titan that will send a probe through the atmosphere to the surface and a Saturn orbiter whose radar will "see" through the clouds of Titan. Known as the *Cassini* orbiter and *Huygens* probe mission, this ambitious project should help us unlock more of the secrets of this strange world that may be able to tell us so much about our own.

Christopher P. McKay and James B. Pollack are planetary scientists at NASA Ames Research Center in California. Régis Courtin is a planetary scientist at the Paris Observatory in Meudon, France.

Through the Fuzzy Boundary

by **Edward Belbruno**

Author Ed Belbruno is an artist as well as a celestial mechanician. In this painting he visualizes an Earth–Moon transfer orbit through a fuzzy boundary.
Painting: Edward Belbruno

I have always been mesmerized by the Moon, that body that lights the night sky and tantalizes us with its closeness. As a mathematician, I study ways to reach it. As an artist, I paint it. My fascination with Earth's beckoning satellite led me, in 1985, to the Jet Propulsion Laboratory (JPL).

My field is celestial mechanics, which means that I apply equations derived from Isaac Newton's law of universal gravitation to the motions of objects as they travel through space. One of the milestones in this field was Edmund Halley's prediction that the comet he saw in 1682 would return to Earth's vicinity in 1758. It showed up right on time, and posterity honored Halley by naming the comet after him.

Another milestone was reached in the 1920s, when W. Hohmann discovered a pathway to the Moon. During the 1960s and 1970s, the glory days of lunar exploration, every spacecraft that traveled to the Moon, including the *Apollo* spacecraft, followed Hohmann's classic, three-day route.

But, in 1985, some new findings in celestial mechanics indicated that there just might be more efficient routes. My curiosity piqued, I asked some aerospace engineers if a better way to travel from Earth to the Moon was a possibility. Every one of them gave me the same answer: a resounding no. After all, I was told, the space programs of both the United States and the Soviet Union had used this route for every one of their missions. Certainly, someone in the generations of rocket scientists since the 1920s would have found a better way if it existed.

That sounded reasonable—but the quickness of their responses bothered me. I decided to see for myself.

Introducing Fuzzy Boundaries

After two years of work, I developed a theory that enabled me to produce the first proof showing that there is a substantially better way to get to the Moon. This theory introduced the notion of "fuzzy boundaries." (I'll detail this somewhat fuzzy concept later.)

Mission designers at JPL applied the theory to the Lunar Get-Away Special mission—a mission unfortunately destined never to fly. (The Get-Away Specials were small, self-contained experiments that could be easily carried in the cargo bay of the space shuttle.) Not until 1991 did someone find a way to apply fuzzy boundaries to a spaceflight project—in a most spectacular fashion. Moreover, the spacecraft, *Hiten*, was flown not by NASA, but by the Japanese Institute of Space and Astronautical Science (ISAS). It reached the Moon on October 2, 1991, using a radically new route. James K. Miller of JPL and I worked out the trajectory that Japan followed to become the third nation in history to reach the Moon.

Starting Point: The Classic Route

How did this unlikely story come to pass? Many people and events had to come together for this new approach to space travel to be proved. Let's back up a bit and see how the search for a better route to the Moon evolved.

The classic, three-day route to the Moon had been discovered by Hohmann in his efforts to find a trajectory that minimized the energy needed; that is, one that would require the least amount of fuel to reach the Moon and enter orbit. His solution is called the Hohmann transfer.

The general idea is that a spacecraft fires its rocket engines to leave a parking orbit about Earth. It then coasts for about a quarter of a million miles to the Moon. Next, it fires its engines again to slow down, just enough to permit the Moon's gravity to capture it into orbit. If the spacecraft does not slow down, it will zoom past the Moon into interplanetary space.

The Hohmann transfer is essentially an ellipse with Earth at one focus, as Figure 1 (page 10) shows. All spacecraft trajectories are segments of hyperbolas or ellipses, and the planets all follow elliptical orbits about the Sun. (Newton used Kepler's laws of planetary motion, which describe these elliptical orbits, to derive his law of universal gravitation, but that is another story.)

This transfer requires some very restrictive assumptions. That is, when calculating the transfer, a celestial mechanician allows the spacecraft to interact gravitationally with either Earth or the Moon, but never with both at the same time. This is called a two-body interaction—the two bodies being the planetary object and the spacecraft.

Moving Forward: *Ballistic Capture*

When the spacecraft is allowed to interact with *both* Earth and the Moon at the same time throughout its motion, the range of possible transfers becomes more complex. These are called three-body interactions, and they are so complex they are almost impossible to calculate without the help of a high-powered computer.

Three-body interactions allow us to work out a transfer in which the spacecraft is captured by the Moon without using rocket engines, thus expending no precious fuel to accomplish this maneuver. This is called a ballistic capture, and it represents a substantial improvement over the Hohmann transfer to the Moon. Fuzzy boundaries are what allow ballistic capture to happen.

So what are these fuzzy boundaries? The Moon's fuzzy boundary can be thought of as a region surrounding the Moon where a spacecraft, as it moves, feels the gravitational effects of both Earth and the Moon nearly equally. As a spacecraft travels in this region, it will not know whether to move toward Earth or the Moon. Its motion will appear chaotic. Only a slight nudge is needed to allow the spacecraft to be captured by the Moon's gravity.

A spacecraft can be captured by the Moon without using rocket fuel if the celestial mechanician can find a transfer trajectory from Earth to the fuzzy boundary. The search must be done on a computer. Although the boundary is a complicated, higher-dimensional mathematical construct, we can say the spacecraft is in the boundary if it is at a specified distance from the Moon and moving at the correct velocity.

A Temporary Setback

In 1987, I had demonstrated that the Lunar Get-Away Special could use ballistic capture to conduct its mission. Although this work enabled the LGAS study to progress, the concept was not accepted by some of my colleagues at JPL. This was, of course, disappointing.

There were several obvious reasons for the skepticism. Ballistic capture was a new concept in mission design, as were fuzzy boundaries. Furthermore, the LGAS spacecraft would have used an unconventional form of propulsion, tapping electricity for power. So I then set out to extend my results to include the standard chemical rockets used in practice.

I thought this would be easy, but I was wrong. A spacecraft using electric propulsion moves in an entirely different way than does a spacecraft powered by chemical rockets. With electric propulsion, ionized atoms—atoms having an electrical charge—shoot out the back of the spacecraft, giving it a very small push. So it can take one to two years for such a craft to reach the Moon. This would leave plenty of time to make careful adjustments to reach the fuzzy boundary.

However, a spacecraft using chemical rockets can reach the Moon in three days. It seemed from my work that it would be impossible to reach the lunar fuzzy boundary from Earth at these speeds. For three more years I examined this problem. My colleague Jaume Llibre, from the mathematics department at the Autonomous University of Barcelona, worked with me on this difficulty while researching another problem. We had no luck.

In January 1990, JPL lost confidence in my line of research, and I pursued work elsewhere. By the end of May, I had accepted a position at Pomona College of the Claremont Colleges as a Visiting Associate Professor of Mathematics.

Back on Course

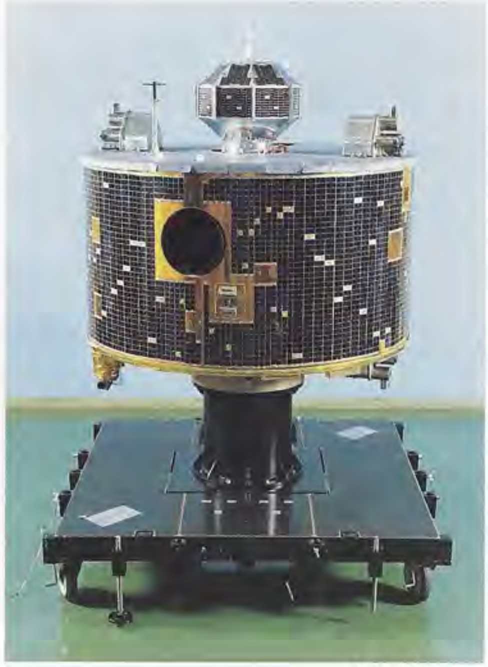
I tried to put the years of fuzzy boundary work behind me. My mind was on the future. Then, on the day I resigned myself to the idea that my work was not going to bear fruit, at least in my lifetime, there came a chance to apply fuzzy boundaries to chemical propulsion.

James K. Miller, an engineer at JPL, walked into my office and told me that he was working on a problem with a Japanese spacecraft called *Muses-A*. In January, it had been launched into Earth orbit carrying a daughter spacecraft designed to fly on to the Moon. The second spacecraft had not performed as planned, and the first Japanese lunar mission seemed doomed to failure.

Then, someone had the idea that the mother ship, *Muses-A*, might be able to complete the mission. But it would not be able to reach lunar orbit using the standard Hohmann transfer; slowing it down would take too much fuel. Miller asked me if my fuzzy boundary theory might be applicable.

I looked at the ceiling and silently said, "Thank you."

I explained to him that a way to solve the problem would be to start at the desired endpoint—at the Moon. Assume that the spacecraft was already at the fuzzy boundary in a captured state. Then work the problem back in time to find out where the spacecraft had to be to get there.



Called* Muses-A *at its launch in January 1990 and later renamed* Hiten, *this spacecraft carried the small subsatellite* Hagoromo *to the Moon, where the smaller craft's transmitter failed.* Hiten *executed a series of lunar swing-bys in 1990 and Earth aerobraking demonstrations in 1991. Then, following a path discovered by the author and James Miller, the spacecraft undertook a new mission to orbit the Moon.

Photograph: Institute of Space and Astronautical Science

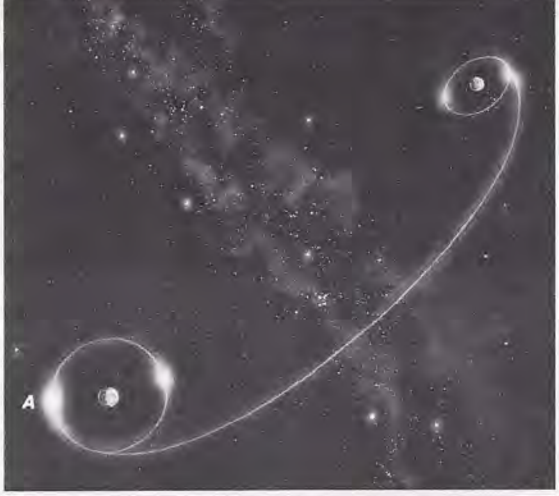


Figure 1—This is the classic Hohmann transfer trajectory from Earth to the Moon. At point A, the spacecraft fires its engines and leaves its parking orbit about Earth. After traveling three days, it fires its engines again to slow down so that the Moon's gravity can capture it into lunar orbit.

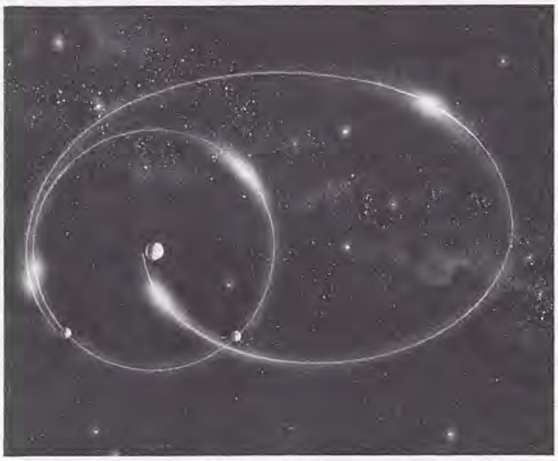


Figure 2—This is the path to the Moon through the Earth–Sun fuzzy boundary. The spacecraft leaves Earth and flies by the Moon, where it picks up an extra push from the Moon's gravity. It then travels to the fuzzy boundary, where it feels the effects of the Sun's gravity and Earth's nearly equally. The spacecraft's trajectory then carries it back toward the Moon. When it reaches its target, the lunar gravity captures the spacecraft into orbit without the use of braking engines.

Illustrations: Michael Carroll

Then hope that this position is accessible, with little modification, from *Muses-A*'s orbit about Earth.

Curiouser and Curiouser

Miller verified that it was possible, and he found the starting point for ballistic capture at about 1.5 million kilometers (930,000 miles) from Earth at a very special place: the Earth–Sun fuzzy boundary. Thus, to our surprise, the Sun played a crucial role on the way to the Moon, representing a fourth-body interaction.

So, to get to the lunar fuzzy boundary, the spacecraft had to start from a position well beyond the Moon. Miller was able to modify *Muses-A*'s orbit about Earth to have it fly past the Moon and use the Moon's gravity to slingshot out to the special position at the Earth–Sun boundary.

Thus we found a path to the Moon for *Muses-A*, a trajectory that required no fuel for lunar capture. The total flight time was estimated to be about five months.

At the end of June 1990, after refining and documenting our work, we faxed a report off to ISAS. They verified our findings in three days. In late April 1991, *Muses-A*, renamed *Hiten* after a Buddhist angel who plays music in heaven, was diverted to this route. It reached the Moon on October 2, 1991 (Figure 2).

Although *Hiten* could have fired its engines and gone into lunar capture on October 2, the fuel saved by taking this new route allowed the spacecraft to travel beyond the Moon and perform other experiments in the Earth–Moon system. *Hiten* returned to the Moon on February 15, 1992, and was finally inserted into lunar orbit.

Extending the Concept

After this demonstration, Miller and I showed that our methods would work for any spacecraft leaving a parking orbit about Earth, including the now-defunct *Lunar Observer* mission, a casualty of cuts in the NASA budget. We found that our methods could save about 25 percent of the fuel needed for a Hohmann transfer.

Using this new transfer, we can send scientific instruments to the Moon using a small, inexpensive rocket; a *Pegasus* rocket dropped from a jet plane can deliver a significant payload to lunar orbit, as Rex Ridenoure of JPL and I have recently shown.

Ronald Hellings of JPL is studying another potential application of the fuzzy boundary transfer. This could deliver the components of a space-based interferometer to special locations in the Earth–Moon system. Such an array of widely spaced instruments might be able to detect gravity waves from the universe. Gravity waves are predicted by Einstein's theory of relativity, but no one has yet detected one.

With imagination and hard work, celestial mechanicians may find even more ways to use fuzzy boundaries to send spacecraft and scientific instruments out to gather information and teach us more about our universe.

In closing, I'd like to note that, in 1988, Thomas R. McDonough, coordinator of The Planetary Society's program in the Search for Extraterrestrial Intelligence, predicted the outcome of our work on fuzzy boundaries. In his book, *Space: The Next 25 Years*, he wrote, "Research is taking place that will profoundly reduce the cost of getting into space. For example, mathematicians Edward Belbruno and Jaume Llibre have made breakthroughs in the calculation of orbits and trajectories that could greatly reduce the amount of fuel needed to get to the other planets. This may bring the cost of interplanetary exploration down to the level at which Japan and other countries could compete with the superpowers."

It looks as if McDonough had a crystal ball.

Edward Belbruno is a consulting orbital analyst with the Jet Propulsion Laboratory, and an artist with paintings on display in Los Angeles and Paris.

The Moon tantalizes us with its seemingly eternal, yet always changing face. In this photo, that familiar face appears illuminated by earthshine, or light reflected off Earth's surface. The bright arc of light is the region lit by sunshine, with its features burned out in this exposure.

Photograph: Kerry Hurd, courtesy of Dennis Milon

Keeping an Eye on Earth:

Remote Sensing in Russia

Ancient watchers of the skies knew that they lived on a spherical planet, and they even knew its approximate size, but their conception of what Earth looked like was limited by their rather parochial perspectives. Eventually, bold explorers crossed oceans, discovered new lands and began filling in the map of our globe. At some point, people must have begun to wonder what that globe would look like from the outside, but only in this century have we been able to see it for ourselves—first with cameras carried by balloons, airplanes and rockets and, finally, with scientific instruments and the eyes of human beings carried by spacecraft.

Every day, pictures from weather satellites are flashed across television screens and printed in newspapers. Coffee-table books are resplendent with images from the American Landsat, and the French high-resolution SPOT images dazzle us with their details. But pictures of Earth taken by Soviet spacecraft have rarely been published outside Russia. During the Cold War this was understandable (even though military observation systems were unlike those described here) in view of the general Soviet bent for secrecy. Indeed, both contestants in the great geopolitical match race of the 1960s and 1970s were sensitive about pictures of the Sun's third planet.

With their usual élan and disdain for rules made up by others, the French built SPOT, a system with higher resolution than existing civil systems. With *glasnost* and the breakup of the Soviet Union, plus wide distribution of beautiful pictures from SPOT, we can expect to learn more and more about our lovely planet and what we are doing to it.

This article is contributed by Arnold S. Selivanov, who is a founder of the art of space imagery, having designed camera systems for spacecraft since 1960. Dr. Selivanov is a department head at the Institute of Space Device Engineering in Moscow, where some 6,000 people are employed in various aspects of observation from air and space.
—James D. Burke

by Arnold S. Selivanov

Russia began observing Earth with the launch of its first meteorological satellite, Meteor, in 1967. This was designed primarily to observe cloud cover, but geologists and other scientists soon realized that the images would be useful tools for investigating the planet's surface, as well as its mineral resources.

The appearance of the American Landsat in 1972 stimulated further remote sensing activities by Russia, and the 1970s saw the launch of such satellites as the Kosmos, Meteor-Priroda and Ocean series. Cosmonauts aboard the *Salyut* orbiting space station also systematically imaged Earth, as those aboard *Mir* do today. The approach taken by Russian scientists and engineers paralleled the United States efforts, but they employed somewhat different technical means to watch Earth from space.

Remote sensing consists primarily of the acquisition of images using radiation in visible, infrared and radio wavelengths (see box on page 14), but other observing systems using various instruments are also possible.

By 1980, Russia had developed a system called Resource that combined several different remote sensing methods in three complementary systems: Resource-F for photography, two Resource-O's designed to observe land masses, and Ocean-O to monitor the oceans. Resource has been operating under the direction of the commercial space agency Glavkosmos.

Resource-F

Satellites of the Resource-F system (*F* here stands for the Cyrillic letter that carries the same sound in English and begins the Russian word for photography) provide photographic images of specific surface areas. A Resource-F satellite carries film into orbit, takes pictures and returns the exposed film to Earth.

There is an obvious drawback to this system: It takes a long time to fill the customers' orders. Moreover, the film is sensitive to only a narrow range of wavelengths, and the data are recorded in analog form, not as digital data easily processed by computers. These limitations are compensated by the unsurpassed quality of the images, with great surface detail.

Resource-O

The letter *O* is the first letter in the Russian word for fast—an appropriate designation for a

BELOW: Imagine yourself orbiting high above California, looking down on the state with satellite eyes. You start at a point off the coast and fly to the north. If you turn this magazine 90 degrees and let your eye follow this long strip of images, you can simulate such an experience. Professor Selivanov presented these images from the Resource-O satellite to Planetary Society Vice President Bruce Murray, who hosted Professor Selivanov during his visit to the California Institute of Technology.

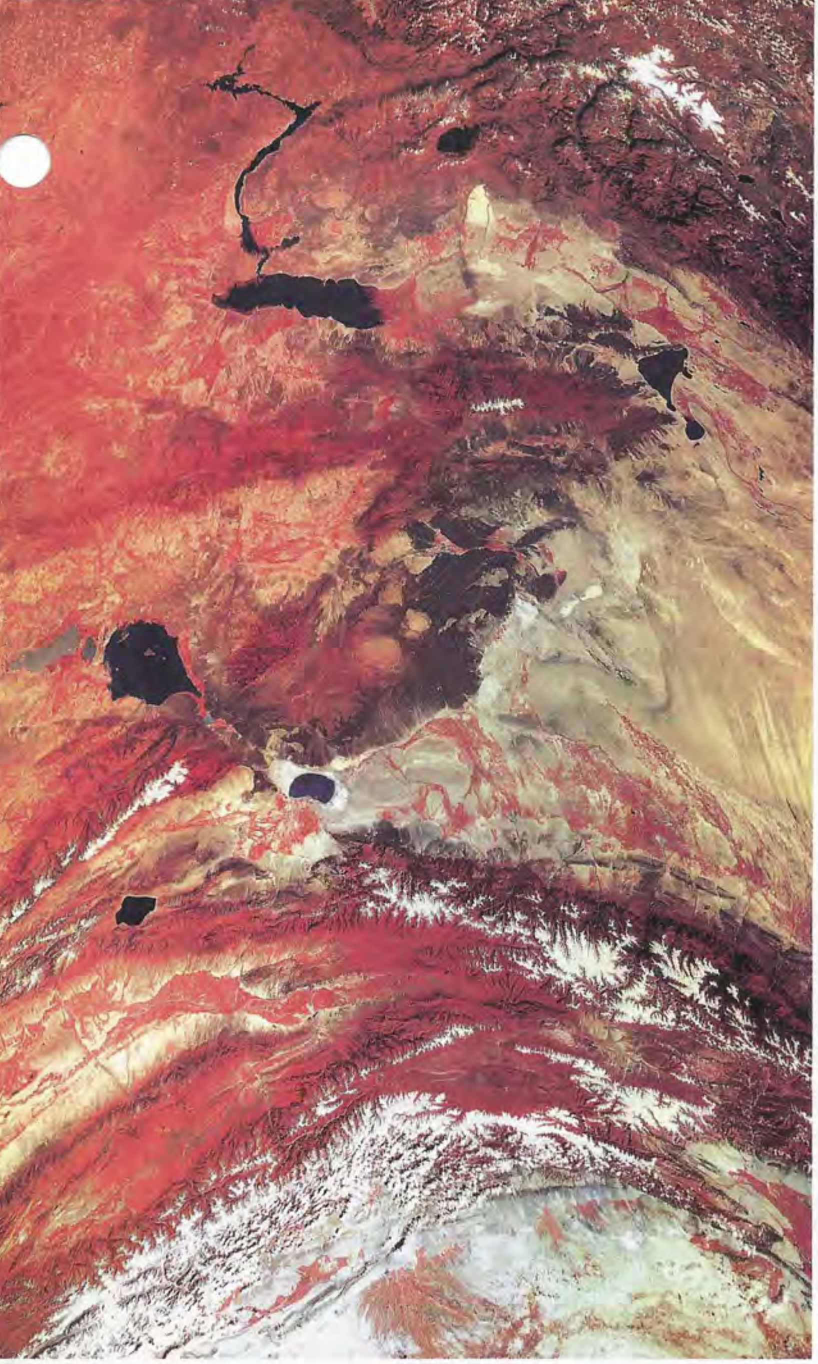
All images courtesy of Glavkosmos

ABOVE: At the same time Resource-O took the image at right, the satellite's high-resolution camera, MSU-E, obtained this false-color image. This is an enlarged view of the piece of land that now divides the Aral Sea into two separate reservoirs. The area shown is about 30 kilometers (19 miles) wide, with details visible down to 45 meters (150 feet).

RIGHT: The Aral Sea in Russia is rapidly drying out, triggering an ecological disaster for the region. Changes to this large lake can be monitored from space. This false-color image was obtained by the moderate-resolution camera MSU-SK on the Resource-O satellite. The area covered is 600 kilometers (370 miles) wide, with details visible down to 170 meters (560 feet).

system of data transmission using radio and television. Resource-O is the second generation of a multispectral television system designed to observe Earth from space, following the pioneering Meteor-Priroda.

Covering the enormous area of the former Soviet Union was a particular concern in the design of Resource-O. The country stretched across 11,000 kilometers (over 6,800 miles). Observations over several days were needed to monitor the hydrological situation, to study the vegetation, to look for forest fires and to investigate the distribu-



With its moderate-resolution scanner, the satellite Resource-O is able to record data for broad swaths of Earth's surface. This image, covering an area 600 kilometers (370 miles) wide, shows regions of Kazakhstan, northern China and the Tien Shan Mountains.

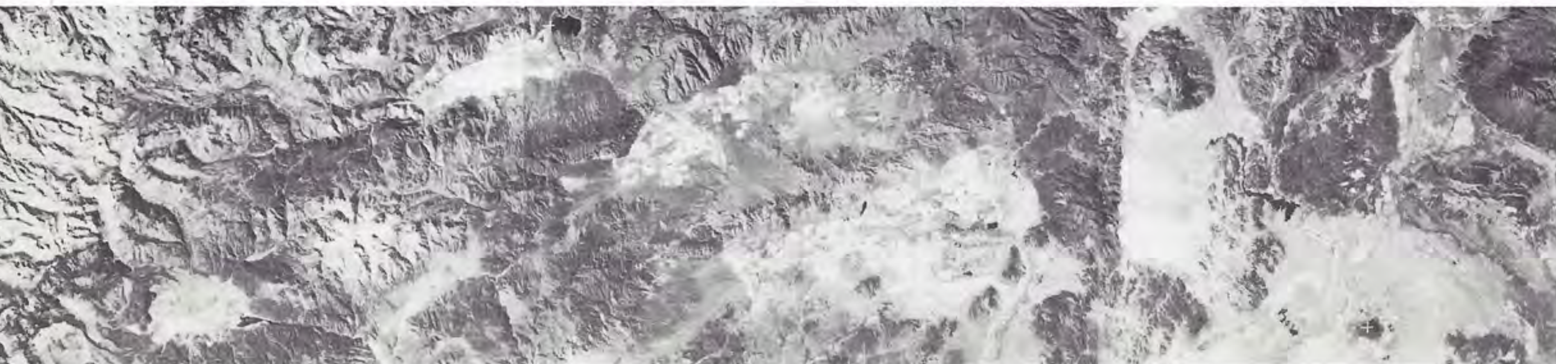
tion of various types of pollution.

For these purposes, a multispectral television system with moderate surface resolution (it can pick out details from 100 to 250 meters across) proved to be the best solution. Such systems provide data swaths 600 to 1,200 kilometers wide. They use multichannel radiometers that cover a wide range of the optical spectrum while scanning across the satellite's ground track. With this capability, we have obtained panoramic surface images in false color that are several thousand kilometers long.

The best unit of this type is MSU-SK, which is mounted on Resource-O and orbits at an altitude of 650 kilometers (400 miles). This camera can see an area 600 kilometers (370 miles) across with details visible down to 170 meters (560 feet). The camera sees four channels in the visible and near-infrared part of the spectrum, with a special channel that can measure surface temperature. The data from Resource-O satellites are recorded on board and then delivered to receiving stations in Moscow, Novosibirsk and Khabarovsk. MSU-SK can observe any area on Earth. The two center images on these pages are examples of its work.

However, there are certain problems that MSU-SK cannot solve alone. The satellite also carries two high-resolution MSU-E cameras with overlapping fields of view. Each covers a ground swath 45 kilometers (28 miles) wide, so the two cameras together cover about 80 kilometers (50 miles). They can see details down to 45 meters (150 feet) in three spectral channels, two in the visible and one in the near-infrared. The cameras use charge-coupled devices as detectors, and we have the ability to point these cameras with commands from the ground. They act as magnifying glasses within the field of view of MSU-SK.

The Resource-O combination of a survey camera with high-resolution, pointable cameras is one of the differences between Resource-O and the American Landsat and the French SPOT. This combination is very advantageous. The inset on the preceding page is an image of a piece of land that now divides the drying Aral Sea (larger image) into two sections. MSU-E obtained this image simul-



What Is Remote Sensing?

"Remote sensing" is a piece of engineering jargon that recurs frequently in accounts of spacecraft studies of the planets, including our own Earth. The phrase gives the process of investigation a distant sound, as if it were some arcane technique practiced only by the scientifically initiated. But, actually, remote sensing is something nearly everyone does every day.

The act of seeing is a type of remote sensing. Eyes do not make actual physical contact with the objects they perceive. Instead, they collect information from a distance —remotely—as light bounces off an object and is reflected into them.

Human eyes are sensitive to a narrow section of the electromagnetic spectrum, which extends from radio waves thousands of kilometers long to gamma rays smaller than individual atoms. The visible portion of the spectrum consists of waves ranging from about 16 to 32 millionths of an inch long (0.4 to 0.8 micron). But the universe shines across the entire spectrum, and we can construct instruments—artificial senses—to see in the many different types of light.

The way an object absorbs, radiates, reflects or transmits electromagnetic radiation betrays much about its nature. By building remote sensing instruments sensitive to particular portions of the spectrum, we can determine composition, texture, temperature, altitude and many other types of information.

Since space is an environment hostile to human beings, we have sent robotic surrogates to investigate the planets for us. We equip them with remote sensing devices, which collect data and relay them back to us using radio waves (a very useful part of the spectrum).

For example, the *Magellan* spacecraft is equipped with radar to map the surface of Venus, seeing in a portion of the electromagnetic spectrum very similar to the one used by the Ocean-O system described on these pages. These spacecraft, orbiting high above their respective planets, direct microwaves (high-frequency radio waves) at the planet surface. It is the nature of microwaves that they pass through clouds, so surface features that would be hidden to human eyes are visible to the spacecraft. Thus, by capturing the reflected microwaves, *Magellan* can see through the clouds that envelop Venus, and Ocean-O can track ice even through a thick cloud cover.

Another useful part of the electromagnetic spectrum is the infrared, which ranges in wavelength from about 1/30,000 to 1/100 of an inch (1 to 300 microns). Everything in the universe at a temperature above absolute zero (minus 273.15 degrees Celsius or minus 459.67 degrees Fahrenheit, the lowest temperature possible in any natural system) emits infrared radiation. Our bodies detect such radiation as heat. But the heat sensors in our skin are limited in the amount of information they can convey. (If you touch the fire, you will be burned; if you stay out in the snow, you will freeze.)

We can equip our spacecraft with sensors sensitive to infrared radiation that will tell us quite a bit about the objects they study. For example, the *Voyager*s carried an infrared system that determined the surface temperatures of the outer planets' moons as well as identifying some of the elements in the gaseous planets' atmospheres.

Earth-orbiting satellites carry infrared detectors that can map the distribution of minerals, track algae blooms in the oceans and monitor the health of crops. As Professor Selivanov describes, the Resource-O satellites, equipped with instruments sensitive to infrared, are closely watching the decline of the Aral Sea, which is being decimated by pollution and the loss of water to irrigation.

Of course, since human beings are so closely attuned to the sense of sight, we give our spacecraft remote sensors sensitive to wavelengths in the visible spectrum—the robotic equivalents of our eyes. We create images that show us what distant planets would look like if we could see them in person. We also take the data gathered in invisible wavelengths and convert them into pictures so that our highly evolved eye/brain combination can more easily appreciate their significance.

So, remote sensing is not such an arcane thing after all. It is a tool used in everyday life and in one of the most fantastic adventures yet dreamed of by humanity, the exploration of the planets. —*Charlene M. Anderson*

taneously with the image of the larger region taken with MSU-SK. This area is suffering an ecological disaster and is under constant surveillance by the Resource system.

Ocean-O

Optical images from satellites are important in the study of land masses, but they play a secondary role in the surveillance of the oceans. For this purpose, the microwave region of the spectrum is preferable. We use both active techniques—radars—and passive ones—radiometers. In microwave "light," clouds are transparent and the instruments can "see" in either day or night. These are important advantages in studying regions with bad climates, and in observing during the long polar nights.

Russia actually began to study the oceans from orbit in 1968 with the launch of Kosmos-243, which was equipped with radiometers working at radio frequencies. Other satellites in the Kosmos series followed, as did the

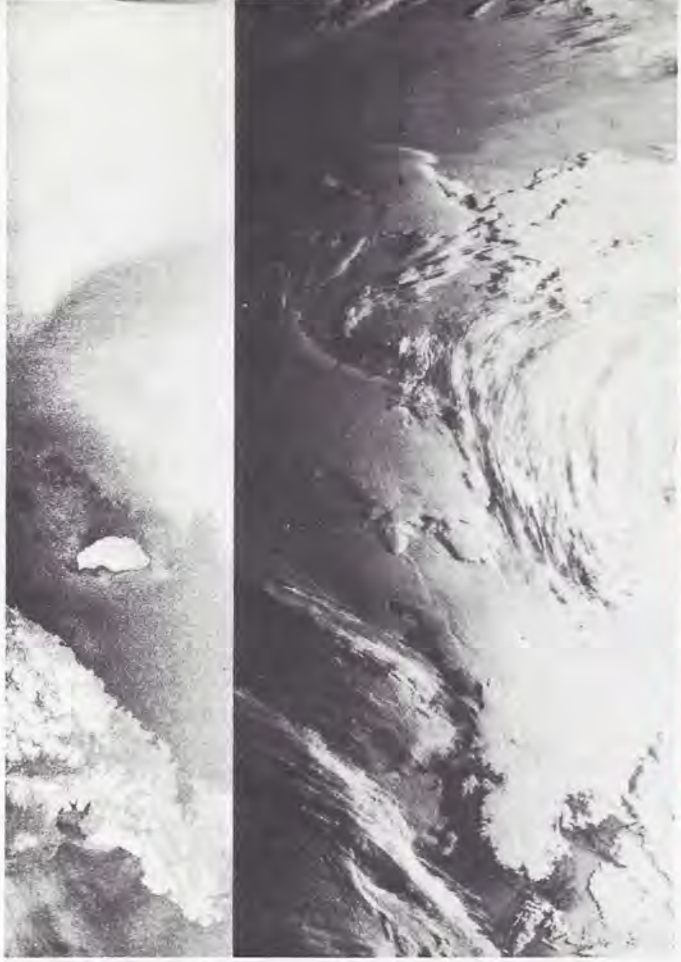
satellite Ocean-E, allowing us to develop a variety of observing techniques. The short-lived US Seasat, launched in 1978, and the Russian Almaz satellite, which launched at about the same time and operated until 1987, scanned oceans using radars with resolutions of tens of meters per pixel. (A pixel, or picture element, is one dot in an image.)

The Ocean-O satellites are based on a different concept, driven by a particular need of Russia: the systematic survey of polar ice in the Arctic and, occasionally, in the Antarctic to support expeditions to the area. Russia has a long coastline along a northern sea route. Lately, thanks to nuclear-powered icebreakers and the continuous stream of information about the polar ice provided by satellites, it has been possible to keep this route open for the entire year.

The Kosmos-1500 satellite was the first in the Ocean-O series. It carried a radar that covered 460 kilometers (285 miles) with a resolution of 2 kilometers (about 1.2 miles). Ocean-O enables us to produce, in just three days, a small-scale map we can use to evaluate the ice situation. Although guiding the ships through the ice requires other means of reconnaissance, such as airplanes and helicopters, there have been cases in which ice-trapped ships were rescued solely through the use of data from Ocean-O.

The radar images from this satellite are transmitted along with a video signal taken simultaneously by a high-resolution sensor, MSU-M, operating in the visible spectrum. A partial MSU-M image 895 kilometers (550 miles) wide is transmitted in the same frame as the radar image. An example is seen at upper right. It illustrates the efficiency of radar observations of the northern regions.

A great advantage of Ocean-O is its ability to "dump" data to many small stations that receive transmissions from meteorological satellites. Most of its information is also received by the same ground-based means as the Resource-O system.



The Ocean-O satellite sees in both visible light and radar. This figure combines information received simultaneously from the satellite's radar (left) and data from one of the channels in the optical range of the MSU-M scanner (right). The radar band covers a region 460 kilometers (285 miles) wide. The island easily visible in the radar image is Wrangel Island in the Arctic Ocean off the coast of Russia. In the visible light image, the island's features are obscured by clouds.

Ecological Surveillance

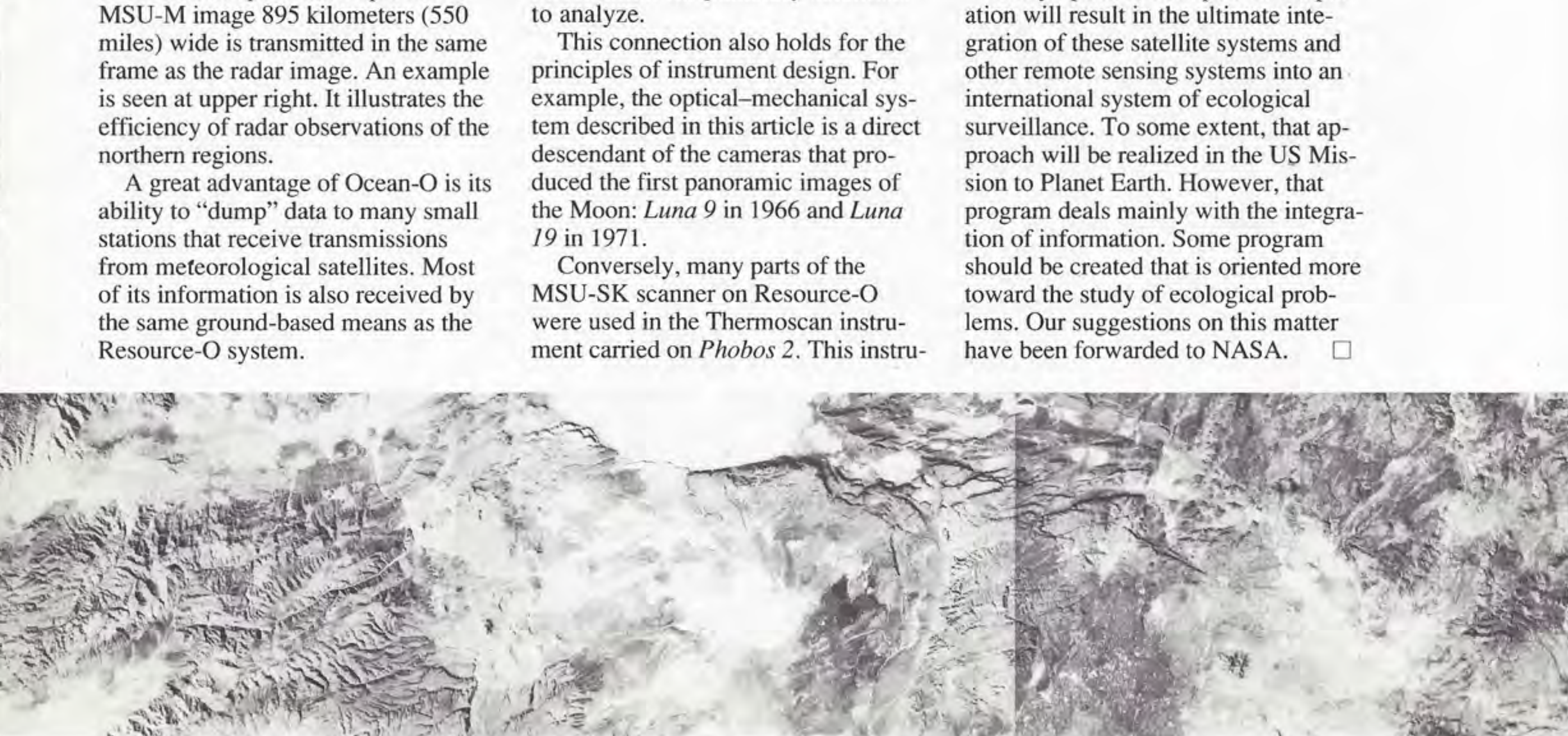
As readers of *The Planetary Report* know, there is a strong connection between programs for observing Earth from space and the study of other planets, and not solely because Earth is one of many planets in the solar system. There is also a methodological connection: Remote sensing is still the primary means of gathering information for planetary scientists to analyze.

This connection also holds for the principles of instrument design. For example, the optical–mechanical system described in this article is a direct descendant of the cameras that produced the first panoramic images of the Moon: *Luna 9* in 1966 and *Luna 19* in 1971.

Conversely, many parts of the MSU-SK scanner on Resource-O were used in the Thermoscan instrument carried on *Phobos 2*. This instrument obtained the first high-resolution thermal images of Mars.

That recent planetary investigation brought together many Russian and American scientists and engineers in the new climate of *perestroika*. Before that, we were competitors. Now we have the opportunity to cooperate in the scientific study of Earth and the other planets in our solar system.

In my opinion, this spirit of cooperation will result in the ultimate integration of these satellite systems and other remote sensing systems into an international system of ecological surveillance. To some extent, that approach will be realized in the US Mission to Planet Earth. However, that program deals mainly with the integration of information. Some program should be created that is oriented more toward the study of ecological problems. Our suggestions on this matter have been forwarded to NASA. □



SOCIETY *Notes*

UNITED NATIONS ADDRESSED

In February, Executive Director Louis Friedman spoke at the United Nations' special International Space Year session of the Committee on the Peaceful Uses of Outer Space (COPUOS). Substituting for Society President Carl Sagan, who was felled by the flu, Dr. Friedman addressed international delegates, leaders of space agencies, and a full gallery on the subject of spaceflight and global unification.

In addition to describing results and opportunities in planetary exploration, Dr. Friedman spoke of the international educational programs in which the Society is involved. The H. Dudley Wright International Student Contest, Latin American educational workshops and international team participation in the Mars Balloon and Rover projects were cited.

The participation at the COPUOS meeting was the first by The Planetary Society since receiving its nongovernmental organization (NGO) special consultative status with the UN Economic and Social Council.
—Louis D. Friedman, Executive Director

NEW CONFERENCES IN NOVEMBER

Two space science educators' conferences are planned for November 1992, under cosponsorship of the UN, the European Space Agency and The Planetary Society. The first conference is in Costa Rica, the second in Colombia. These build on the successful Mexico City workshop the Society held in 1987 and the one conducted in Bangalore, India, last year.
—LDF

INDEX UPDATE

An updated index for *The Planetary Report* is now available. For a copy, send $3.00 to TPR Index, c/o the Society. *—Mitchell Bird, Production Editor*

ROVERS ROAMING THE MALL

On September 1 and 2, the International Space Year Exhibition of Robots and Telepresence for Exploring New Worlds, or "Rover Expo," will be held adjacent to the Smithsonian National Air and Space Museum in Washington, DC.

In addition to The Planetary Society and the Smithsonian National Air and Space Museum, the following organizations are cosponsors of the Rover Expo: the NASA Offices of Exploration, of Aeronautics and Space Technology, and Space Science and Applications; the Space Automation and Robotics Technical Committee of the American Institute of Aeronautics and Astronautics; the French space agency, Centre National d'Études Spatiales; and the Russian Mobile Vehicle Engineering Institute.

Working demonstrations of rovers from government and private industry will be given in open-air enclosures. All the rovers will feature abilities applicable to planetary exploration, such as navigation, grasping and remote sensing. When not in use, the rovers will be on display near the demonstration area.

The Rover Expo is free and open to the public. It will coincide with the World Space Congress, also being held in Washington, DC.
—Susan Lendroth, Manager of Events and Communications

CONTEST WINNERS SELECTED

Congratulations to the winners of the H. Dudley Wright International Student Contest, "Together to Mars."

To enter the competition, students had to write about a specific aspect of a human mission to Mars. About 900 entries were received from more than 30 countries, representing every populated continent on Earth. Topics ranged from life-support systems for Mars missions to detailed analyses of materials needed to withstand the radiation of interplanetary space.

Winning entries were from the following countries: Argentina, Colombia, France, Germany, Great Britain, Hungary, India, Ireland, Israel, the Netherlands, Poland, Portugal, Spain, Ukraine and the United States.
—Barbara Bruning-LaBelle, Program Coordinator, H. Dudley Wright International Student Contest

SPACE EXPLORERS JOIN FORCES WITH THE SOCIETY

The Planetary Society will join forces with the Association of Space Explorers (ASE) to host an exciting public event in Washington, DC, on August 28.

ASE is an organization with an unusual requirement for membership—only individuals who have flown in space are permitted to join.

Hundreds of astronauts and cosmonauts from around the world will gather at the association's annual convention in Washington during the last week of August. The theme of this year's convention is "To Mars, Together."

The public event will be the final session of ASE's convention, and it will honor the 20 winners in the Society's H. Dudley Wright International Student "Together to Mars" Contest.

For information on tickets, write to ASE Event, c/o the Society. *—SL*

INTERNATIONAL SPACE YEAR

International Space Year, 1992, is under way. The Planetary Society, the National Space Society and *Final Frontier: The Magazine of Space Exploration* have joined together to publish a free directory of special events. The directory is available to all our members. Write for your copy of the ISY Directory c/o the Society. *—SL*

KEEP IN TOUCH

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

Call for an events calendar and Cassini *update:*
(818) 793-4294

General calls:
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World Watch

by Louis D. Friedman

WASHINGTON, DC—Responding to the threat to planetary exploration contained in the administration's fiscal year 1993 budget, as detailed in the March/April 1992 issue of *The Planetary Report,* The Planetary Society urgently requested that Congress hold hearings on the issue.

The Senate Subcommittee on Science, Technology and Space, chaired by Sen. Albert Gore, Jr., and the House Subcommittee on VA, HUD and Independent Agencies, chaired by Rep. Bob Traxler, agreed to hold hearings. Society Vice President Bruce Murray testified before the Senate, and Executive Director Louis Friedman testified before the House of Representatives.

In constructing our testimony, we had to balance the issues carefully. With the economic problems facing Congress, it would have been neither right nor effective simply to argue for more money for NASA. Indeed, to meet other budget constraints, it is likely that Congress will have to make additional cuts in the space agency budget.

This is an excerpt from our opening statement:

NASA was born in 1958, a positive side effect of the deadly serious Cold War. Now, three decades later, the Cold War is over. Suddenly, the geopolitical and economic situation in the world is vastly different.

To meet the challenges of this new world, NASA must refocus its energy and find a new raison d'être. Its planetary program is no exception. Our fleet of exploratory spacecraft needs to be reevaluated and revamped. We argue in favor of such changes, but we also caution not to let these changes become an excuse to scuttle the fleet itself. Specifically, we call to the attention of Congress:

• *the importance of maintaining the American/European* Cassini *mission, even as it is scaled down;*

• *the shortsightedness of ending operations for* Magellan *while it is still sending important new data from Venus;*

• *the need for small missions, such as the proposed Space Exploration Initiative lunar precursor, to supplement, but not to displace, mid-sized planetary missions.*

There is still a need for mid-sized planetary missions, such as *Mariner, Pioneer, Voyager, Magellan,* and *Mars Observer*. In our testimony, we focused on the *Cassini* mission now under development, since after the cancellation of its sister mission, the Comet Rendezvous Asteroid Flyby, this mission is seriously threatened.

Cassini would orbit Saturn to study the planet, its rings and moons. The spacecraft would carry a probe, called *Huygens* and built by the European Space Agency (ESA), that would investigate the atmosphere of Titan.

As originally planned, *Cassini* was an expensive mission, with an estimated cost of over $1.6 billion. A reduction in cost is justified, and without it the project will never survive the budget process. We supported the cuts but strongly stated the need to preserve the basic mission plan, with a launch in 1997.

We are asking all Planetary Society members in the United States to write their senators and representatives in support of the *Cassini* mission. The cancellation of this mission would end the development of planetary missions in both NASA and the European Space Agency.

If you would like the full text of our statement, please write to: Congressional Statement, The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106.

PARIS—The French space agency, the Centre National d'Études Spatiales (CNES), has set up a hard currency reserve fund to help ensure the survival of the Russian *Mars '94/'96* project. (See the March/April 1992 *Planetary Report.*) Because of The Planetary Society's special nongovernmental role on the project, we sent a letter of appreciation to CNES' Director General, J.D. Levi.

He replied: "France is strongly supportive of these multinational Mars missions and is very willing to see them succeed. We believe, at CNES, in such cooperative projects, which are essential to make active use of the unique opportunities afforded by space to conduct research in fields such as planetary exploration. I can assure you that CNES, for its part, will continue its best efforts to help such programs."

WASHINGTON, DC—Sen. Barbara Mikulski, Chairman of the Senate Subcommittee on VA, HUD and Independent Agencies, held hearings on how the US could use the capabilities of the Russian space program. She then wrote President Bush and Secretary of State Baker asking them to take action on the issue.

Rep. Ralph Hall of the House Science, Space and Technology Committee also held hearings on the topic. Former President Reagan submitted some remarkable written testimony. He suggested that the US could save taxpayers' money by working with the Russians in space.

In his testimony, Reagan asked: "Are there ways America can save time and money building [space station] *Freedom* by using CIS [Commonwealth of Independent States] equipment and experience? Could we one day travel with the Russians to the planet Mars, as some have suggested? That wasn't my kind of thinking 10 years ago, but ironically, it may not be worth thinking about 10 years from now if the CIS space program shuts down for lack of funds."

The Defense Department is buying some space technology components from Russia, including the Topaz nuclear reactor. This appears to be a new direction for the White House, and indicates a loosening of the restrictions on trade. Whether this will apply to NASA is unknown.

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

News & Reviews

by Clark R. Chapman

Since William Lassell's mid-19th-century discovery of Triton, the giant neptunian moon has been the subject of much speculation but little concrete knowledge. Then, on August 25, 1989, human technology brought us 100,000 times closer to this mysterious world. Triton was the star of the show during *Voyager*'s final planetary encounter. Scientists have been poring over the data ever since.

An issue of *Science* magazine published in October 1990 discussed implications of *Voyager*'s Triton pictures, particularly the wholly unexpected geyser-like plumes. But there was little consensus, with explanations ranging from dust devils to something called a solid-state greenhouse, in which sunlight is trapped in an extensive, porous, translucent surface layer of nitrogen ice.

By January 1992, when a scientific conference on Neptune and Triton was held in Tucson, Arizona, ideas about Triton's geysers continued to multiply. But other aspects of Triton's unusual nature proved even more fascinating and controversial. Just one example: Why is Triton's sunlit pole so icy? A book about Neptune and Triton is being written by the scientists who attended the meeting. Since it is hoped that this latest project in the University of Arizona Space Science Series will stand the test of time, the scientist-authors are trying to reach some definitive conclusions in the wake of the debates at the January meeting.

As often happens, *Voyager*'s approach toward Neptune in the 1980s spurred ground-based astronomers' interest in Triton: It seemed like a fantasy world, whirling around its parent planet in a backward direction and covered—so it was thought—with oceans of liquid nitrogen. There was particular interest in Triton's seasons, with *Voyager*'s encounter nearly coinciding with the warmest south-polar temperatures on Triton in centuries. It had been predicted that all of its south-polar ices would have sublimated and been transferred to the colder northern hemisphere. But *Voyager*'s cameras found Triton to be a gleamingly bright world, with a large and especially bright south-polar cap, while its northern hemisphere appears darker and frost-free. Could Triton have *dark* frost?

Ices and Gases

In the first hours after *Voyager*'s encounter, all attention was riveted on Triton's weird geology. Its would-be oceans turned out to be frozen solid, and its atmosphere was measured to be so thin that it is practically a vacuum. Yet the atmospheric transport of Triton's gases, and calculations concerning its reservoirs of ices, are what have continued to perplex researchers. Triton's geology would seem to require the presence of water ice, but none has been found. Telescopic measurements over the last dozen years have revealed enormous global color changes on Triton, which some scientists attribute to "the snowfall of '83"; others demur.

The plumes provide clues about what's going on. Several active plumes were seen in stereo, and there are pictures of other atmospheric features that blend into a prominent haze layer. In addition, there is a whole family of dark surface features that bear an uncanny resemblance to the dark wind streaks on Mars. Imagine: wind streaks being deposited on the surface of a body with an atmospheric pressure just a few millionths of the sea level pressure on Earth! But there they are. Their directions hint at the wind flow, but differ from the orientations of the active plumes. Maps of where they are and where they're not across Triton's surface should tell us more about what is going on. Unfortunately, *Voyager*'s fleeting portraits of Triton don't show all parts of that world to equal advantage, so it is difficult to be sure we've mapped all the streaks. And we won't get another spacecraft back to Triton to double-check for a long, long time.

Origins

One of the most intriguing things about Triton concerns its origins. The idea that it is a Pluto-like body that somehow got captured into orbit around Neptune early in that planet's history was gaining favor long before *Voyager*'s flyby. Dynamical capture of a body orbiting the Sun into a moon-like orbit around a planet is a physicist's nightmare of a problem, but proto-Triton could have been unlucky. It may simply have crashed into a neptunian moon and been captured that way.

Once in orbit around Neptune, in an initially very elongated orbit, Triton may have "cleaned out" many preexisting neptunian satellites, which would explain Neptune's lack of a regular satellite system like those of other outer planets. Although Triton is big enough and rocky enough to have melted spontaneously early in its history, it would have been heated even more by great tides. Such tidal heating could have equaled that responsible for the sulfur volcanoes on Jupiter's moon Io, and raised Triton's surface temperature to a comparatively balmy 150 degrees Kelvin —more than 100 degrees Kelvin warmer than its current frigid state. The resulting early chemical, physical and geological evolution of Triton could well have been remarkable. It remains to be seen if Triton has yielded enough clues to *Voyager* to shed further light on that history.

Regardless of Triton's history, however, it is a stunning surprise that this world in the deep freeze of the outer solar system should sport currently active geysers and sudden changes in global color, and continue to mystify us with its seasonal behavior. It makes us yearn for a closer look at its possible twin, the planet Pluto. Though NASA has the rocket power to launch a fast-track stunt flight to Pluto, it will remain for another generation to reconnoiter Pluto with a full complement of instruments, or return for in-depth, follow-up studies of Triton.

Clark R. Chapman served on the 1991 NASA International Near-Earth-Object Detection Workshop.

Members' Dialogue

(continued from page 3)

Nations purchase the hardware or operating rights on behalf of member nations, [providing] urgently needed economic support. This could be a truly international opportunity.
—THOMAS S.W. LANGFORD, *Phoenix, Arizona*

Thank you for awarding me the College Fellowship. As I've continued my college education, I have become more excited about pursuing a career in a planetary science-related field. The current outlook for engineering has become somewhat pessimistic due to defense cutbacks and the recession. However, we are at a great crossroads.

In the past, a great deal of our technological efforts have gone for either preparing for war or trying to defend against the possibility of war. In fact, some of the greatest developments have come as a direct result of these times of crisis. Due to the collapse of the Soviet threat, it is no longer a national security requirement to spend so much on improving our technology. However, in order to remain a leader, the United States needs to continue to develop new technology by refocusing those energies previously focused on defense.

As The Planetary Society has promoted since its beginning, exploration of the solar system is where our focus needs to be. No longer do we need to concern ourselves with the destruction of peoples on Earth, but instead, we need to aim for new horizons. I hope that the United States as a country realizes that we need to make a real commitment to planetary exploration. In my future career, I plan to do everything that I can to make this idea come to fruition. If there is anything that I can do to help The Planetary Society further these goals, please let me know.
—PAUL KILLPACK, *Provo, Utah*

Educators are concerned that many of the students in the United States are not interested in the sciences, and they wonder what the future will be like if this lack of interest persists. To help counteract this, even in a small way, may I suggest the following to members: When a new issue of *The Planetary Report* arrives, donate the previous issue to your local high school science department. I'm sure that the teachers and students will find it interesting and challenging. Who knows? Perhaps one student will become more interested in space and the space program.

Even though The Planetary Society is encouraging work in SETI, the Mars program and other ventures, not that many people know about this work. Here's a chance to spread the word.
—ANN ZAWISTOWSKI, *Walpole, Massachusetts*

I found the News Brief in the January/February issue on NASA's long-term study of the establishment of a lunar outpost and other sites for astronomical telescopes to be quite exciting. I've always felt that the primary objective of any space program should be to obtain knowledge. An observatory on the Moon would increase our knowledge of the universe a hundredfold.

Perhaps it is time to cut our losses with the space station and redirect some of the savings to more robotic planetary missions. The data we would obtain far outweigh the heavy expenditures of a space laboratory.

Hopefully, with Daniel Goldin appointed as NASA's new administrator, the United States' space priorities will follow a more exploratory and scientific course.
—PETER SQUARINI, *Lauderhill, Florida*

Recent issues of *The Planetary Report* have reported on a series of serious budget setbacks for planetary exploration. Retreating from such exploration would be a disaster for the United States space program, but I worry about senior officers of The Planetary Society responding to this deplorable situation by targeting space station *Freedom* as the cause of the current crisis in planetary science.

The real cause of the Comet Rendezvous Asteroid Flyby's cancellation and *Magellan*'s death warrant is the constrained budget situation facing NASA as a whole. The space station is costly compared to planetary missions, but if it were canceled outright most of its $2 billion would be diverted out of NASA to social programs or to reducing the national debt. Some funds might go toward space science, but how long would that keep programs on track in an era of flat budgets?

When budgets were increasing a few years ago, a lack of consensus in the space community was merely an annoyance. Now it is a serious threat to the United States' future as a spacefaring nation. Is it too late for everyone to work together to build public support for continued growth in the overall NASA budget?
—JON R. WELTE, *Chicago, Illinois*

NEWS BRIEFS

(continued from page 3)

these altitudes, go thousands of miles without refueling or stay high in the sky for days, or weeks, at a time. All the designs resemble futuristic gliders that are pushed through the scant upper air by giant propellers.
—from Warren E. Leary in *The New York Times*

Ideally, the next NASA administrator will finish the shake-up of the bureaucracy begun by Mr. Bush. In the utopian NASA, problems will be confronted directly, and never glossed over. A new standard of accountability will enable outsiders to distinguish between those who succeeded on a NASA project and those whose management mistakes produced a failure. New ideas will not be frozen out by an entrenched team of big aerospace contractors and lifelong civil servants. NASA missions will be dissected by experts not because of the embarrassing political and technical mistakes they embody, but because they represent the finest work the country can do. NASA will give the American public something to cheer for, not something to shake their heads over and wonder, what are we doing up there?
—from *Space News*

At a time when many question America's ability to do quality work and make competitive products, the spacecraft *Pioneer 10* has just completed two decades of solid exploration of the solar system. Scientists involved in a long and complicated argument over "big science" versus "small science" have observed that *Pioneer 10*'s relatively simple, straightforward design is a key to its success.

The whole *Pioneer* family, designed in the 1960s, is doing well: *Pioneer 6*, sent to orbit the Sun in 1965, is the world's oldest working space probe. *Pioneers 7* and *8* are still completing solar studies. *Pioneer 12* is circling Venus, and *Pioneer 11* is leaving the solar system after looping past Saturn.
—from the Baltimore *Sun*

Questions & Answers

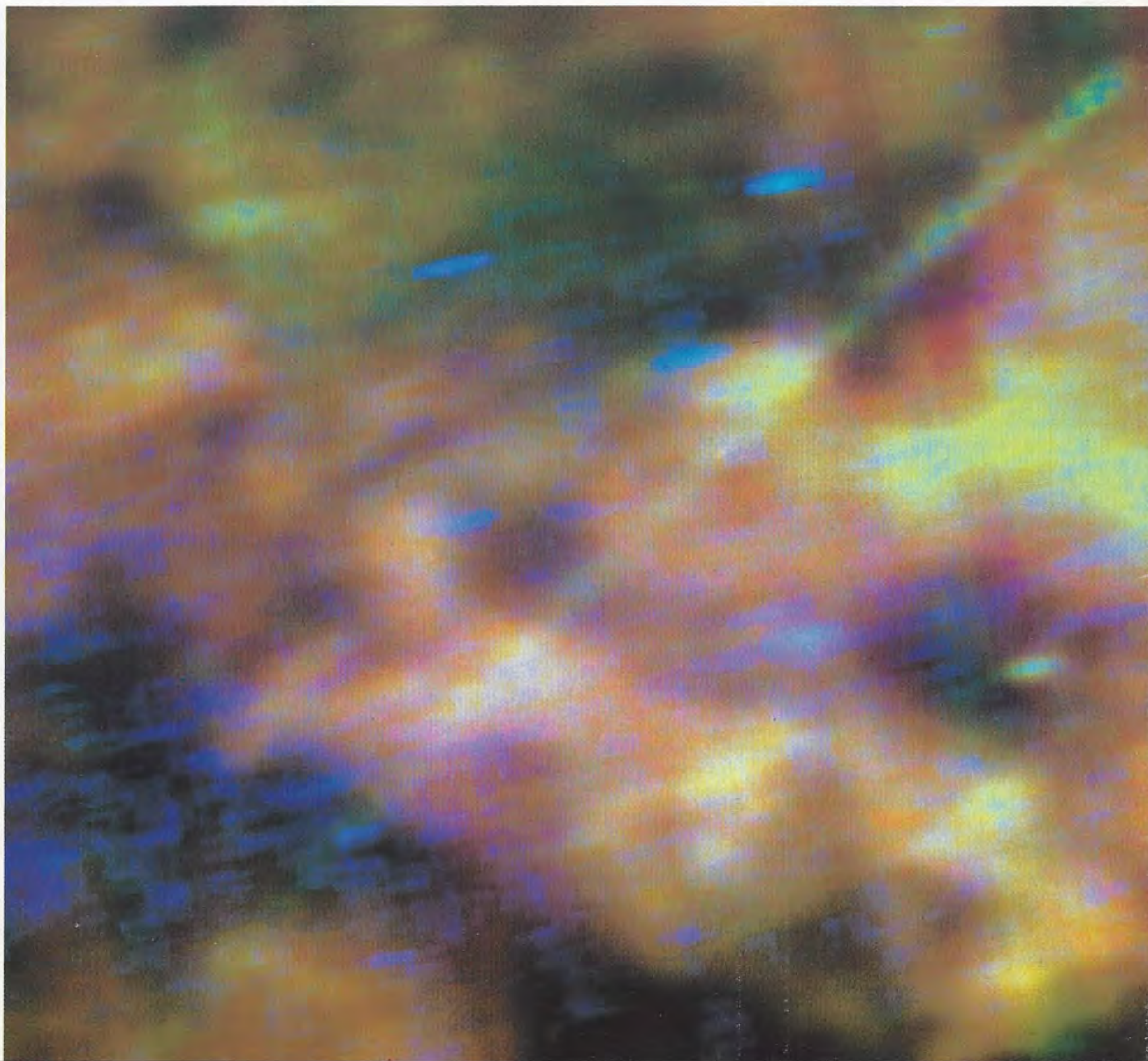
Could asteroids or comets be used as mock spacecraft to carry instruments throughout the solar system and, someday, the universe?
—Bill Merkes, Freeland, Washington

To use a comet or asteroid as a base for exploration, we would have to launch and navigate our spacecraft and instrument package to exactly match its orbit, just as the recently canceled Comet Rendezvous Asteroid Flyby mission was designed to rendezvous with comet Kopff. Once having expended the fuel to achieve a rendezvous, there is little advantage to landing except for the study of the comet or asteroid itself.

It is generally easier to control a spacecraft that is flying freely; for example, the communications antenna of a free-flyer can be kept constantly pointed at Earth, while on the surface of a rotating comet or asteroid Earth would be below the horizon half the time.

About the only possible advantage of riding along on a comet or asteroid would be to process the surface material to manufacture fuel for the spacecraft, but this is beyond current space technology.
—DAVID MORRISON, *NASA Ames Research Center*

If one of the planets blew up, or was destroyed by something, would a new planet take its place to keep a basic balance to the solar system?
—Tricia Kempton, age 11, Prescott, Arizona



The trail of a comet appears as a diagonal white streak across this infrared image of the sky. Comet trails were first recorded by the Infrared Astronomical Satellite (IRAS) in 1983, but they were not observed and characterized until 1986 when Mark Sykes found them in the IRAS data.

Comet trails are narrow, continuous streams of large debris particles (millimeters to centimeters in size) shed by cometary nuclei as they travel about the Sun. The debris particles travel at about the same speed as their parent bodies. They trace out a portion of the comet's orbital path, sometimes for tens of millions of kilometers. Sykes and Walker suggest that trails are probably common to all short-period comets.

Image: Mark V. Sykes

If a planet were destroyed, for example by a large impact, its material would continue to orbit the Sun and much of it would accumulate again into a new body. This may have happened during the formation of the solar system when millions of bodies were present in a cloud of gas and dust around the Sun.

Why don't the asteroids accumulate into a small planet between Mars and Jupiter? The answer is that the gravity of giant Jupiter continually perturbs their orbits, keeping them stirred up and colliding.
—JAMES D. BURKE, *Technical Editor*

What if an alien culture does not want us to know about its existence and is blocking our attempts to find it?
—Greg Myklegard, Ocala, Florida

In the Search for Extraterrestrial Intelligence (SETI), this is sometimes called the Zoo or Quarantine Hypothesis. Some scientists and science fiction writers have speculated that an advanced civilization would not want to contaminate a primitive one like ours with its culture.

This is inspired by those who advocate protecting isolated peoples in tropical rain forests from contact with modern civilization, on the grounds that they may lose their cultural heritage. Perhaps there are galactic preservationists who want to keep our unique culture from being disrupted by contact with the alien equivalent of hamburger stands, fax machines and TV commercials.

If so, they may not be successful. Any advanced technological civilization is likely to give itself away by stray electromagnetic emissions such as the radio, TV and radar signals that we inadvertently broadcast to the universe. And if they have huge structures in space, then these must emit infrared radiation that we may one day detect with an astronomical satellite—if the knowledge isn't already sitting in the data bank of the old Infrared Astronomical Satellite.

Most SETI programs have looked for radio waves, but some others have searched for other clues such as infrared or visible light pulses. The searches usually concentrate on beacons—signals deliberately meant to be detected. If we don't find any, we'll have to use more sensitive equipment to look for stray radio and infrared emissions.
—THOMAS R. McDONOUGH, *Planetary Society SETI Coordinator*

In answering Gerry Bogacz's question about the orbits of Uranus' moons (see Q&A in the January/February 1991* Planetary Report*), William McKinnon casts some doubt as to whether or not there is a "conventional alignment" for planetary spins because "three out of nine planets are retrograde rotators."

Which three planets are retrograde rotators?
—Nathan W. Cook, Sandwich, Illinois

The first and most famous case is Uranus, whose equator is nearly perpendicular to its orbit plane. The angle between the equator and the orbit plane is called *obliquity*, and in Uranus' case is listed at 98 degrees (with any angle over 90 degrees indicating retrograde rotation).

The second case is Venus, whose equator is nearly in its orbit plane, but which spins "backward" very slowly. The obliquity is listed as 177 degrees, or only 3 degrees off the "vertical" perpendicular to the orbit. With a day that lasts 243 Earth-days, Venus is hardly spinning at all. The spins of Uranus and Venus may have been altered by giant impacts, and it may be apt to picture Venus' spin as having been nearly stopped in its tracks.

The third case is Pluto. Its obliquity is listed as 122 degrees, indicating, as for Uranus, that its equator is at a steep angle to its orbit plane. The equatorial plane is also the plane of the satellite Charon's orbit around Pluto. In the case of Pluto, we have a twin mini-planet, whose axial tilt and rotation have probably been influenced by tidal interactions between the "planet" and satellite. I use quotes because, in my own view, Pluto may better be regarded as a large asteroid or cometary body than as a true planet, since it is even smaller than our Moon. Spins and axial tilts of asteroids and comets have been somewhat randomized by collisions, gas jet emissions and, perhaps, other effects.
—WILLIAM K. HARTMANN, *Planetary Science Institute*

FACTINOS

Comets are actually frozen mudballs rather than dirty snowballs, say Mark V. Sykes of the University of Arizona in Tucson and Russell G. Walker of Jamieson Science and Engineering, Inc., in Scotts Valley, California. The two scientists have spent years studying cometary dust trails (see photo on previous page) and have published their findings in a recent issue of *Icarus*.

Comet *trails* (not to be confused with comet *tails*) are the principal means by which comets lose mass. These trails indicate that comets are 75 percent dust or dirt. This would make their nuclei far dustier and less icy than previously believed, they say.

The mudball model is consistent with the idea that comets formed in the Uranus-Neptune region of the outer solar system rather than in icy molecular clouds far out in space. As they shift into the inner solar system, comets may evolve faster than previously believed, becoming inactive, asteroid-like bodies, says Sykes.
—from Lori Stiles at the University of Arizona

The European Space Agency's *Ulysses* spacecraft has found marked differences in Jupiter's magnetic field from what the last *Voyager* spacecraft uncovered there 12 years ago. In mid-February, *Ulysses* scientists reported that Jupiter's magnetosphere pulsates in and out and is now almost twice as extensive as it was when the *Voyagers* surveyed the region in 1979 and 1980.

Scientific instruments on the probe also observed less debris in the surrounding area, suggesting that volcanic eruptions on Jupiter's moon Io have slowed down since the *Voyagers*' visit.
—from John Noble Wilford in *The New York Times*

A team of planetary scientists has concluded that water contained in several meteorites found on Earth came from Mars, bolstering theories that free-flowing water once existed on the now-parched planet.

Everett Gibson of NASA's Johnson Space Center (JSC) in Houston and Haraldur Karlsson of Texas Tech University in Lubbock extracted tiny water droplets less than 1/64 of an inch in diameter from six meteorites using a small vacuum chamber at JSC.

The samples were then analyzed by Robert Clayton and Toshiko Mayeda of the University of Chicago, who determined that the water's oxygen isotopes were different from those in the rocky silicate portion of the meteorites. This suggests that the source of the water could have been the martian atmosphere, an ancient martian ocean or even a comet that hit the planet, according to Gibson.

The lack of homogeneous oxygen isotopes on Mars also supports the theory that the planet does not have plate tectonics like those on Earth, because this process would have mixed the different isotopes together.
—from *Space News*

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Saturn's largest moon, Titan, is a world rich in methane—a gas that may have played an important role in the origin of life on Earth. Some scientists believe that a giant ocean of liquid hydrocarbons lies on the surface of this smog-shrouded moon. Others think it is divided into myriad lakes and pools. Whatever the case, these bodies of liquid hydrocarbons could harbor billions of years worth of complex organic molecules produced in the satellite's thick atmosphere.

In "Titan Floating Probe," a tiny, robotic, paddle-wheeled steamship explores the seas of Titan. Native hydrocarbons and an onboard supply of oxygen make up its fuel.

Titan and Earth have enough chemistry in common that it is essential that we go back for a better look.

Ron Miller is a Fellow of the British Interplanetary Society and a member of the International Academy of Astronautics. He is illustrator and author or coauthor of more than a dozen books, including The Grand Tour, In the Stream of Stars *and the recent* History of Earth, *as well as the forthcoming* Dream Machines: A Pictorial History of the Spaceship in Art, Science and Literature.

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